The 3rd
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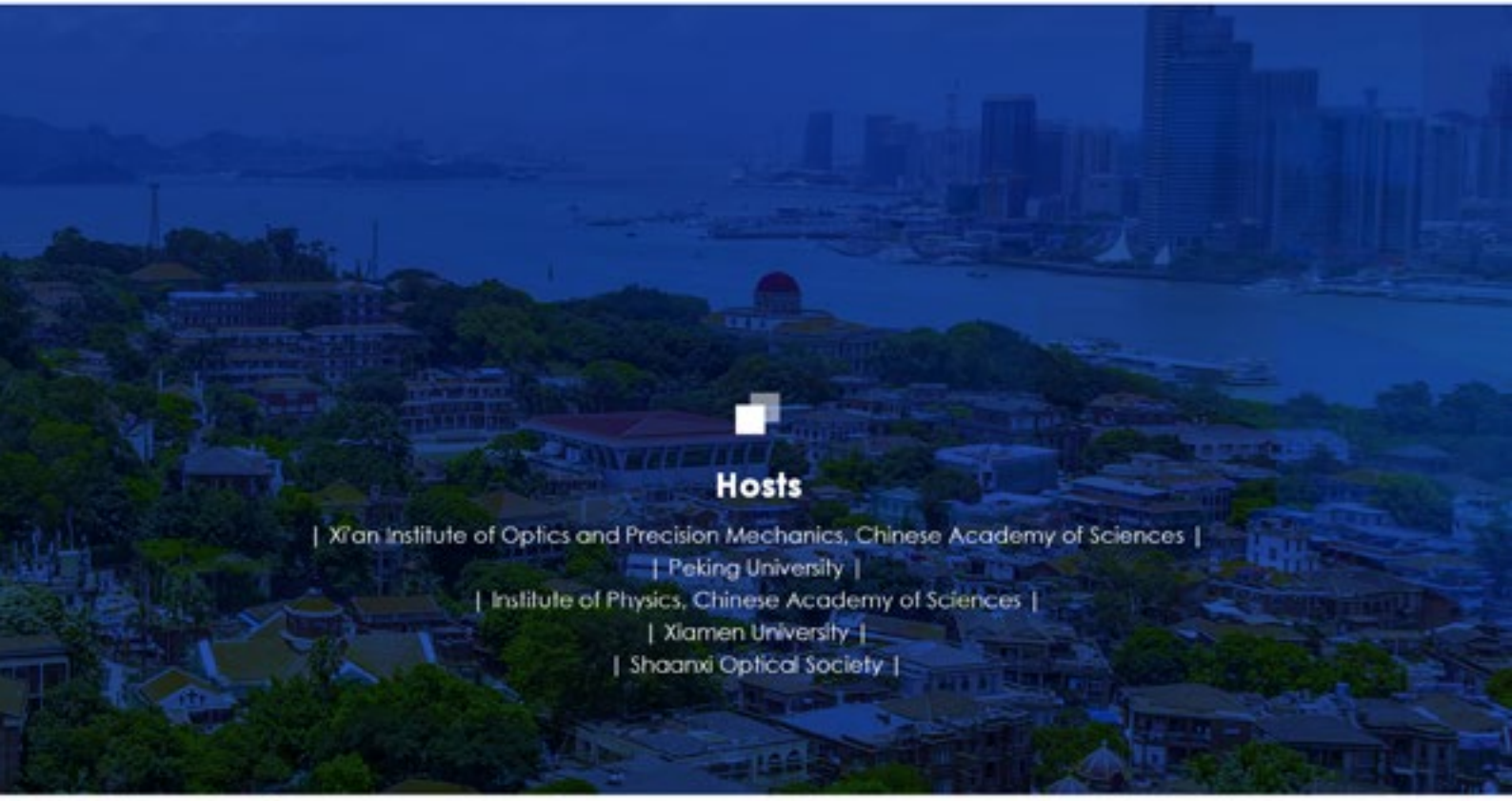

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ABSTRACTS

Plenary Talk

Sensors-Driven Innovation in Fluorescent Materials

Yu Fang
Institute of New Concept Sensors and Molecular Materials, School of Chemistry and Chemical Engineering, Shaanxi Normal University, China

Abstract: Film-based Fluorescent Sensors (FFSs) are a critical solution for developing high-performance sensors capable of detecting hazardous, toxic, and harmful chemicals, biological substances, radioactive materials, as well as strain, stress, humidity, and other parameters. By examining key factors such as mass transfer, energy transfer, microenvironment effects, sensing unit utilization efficiency, the photochemical stability of sensing materials, and moisture/dust barrier materials—all of which significantly influence FFS performance—we highlight the essential role of innovation in sensing and barrier materials. This includes advancements in sensing unit design and synthesis, modulation of excited-state processes, optimization of ad-layer structures, and internal structural tuning of barrier materials. Additionally, we explore innovations in sensor hardware architecture and improvements in detection equipment. Based on these insights, we assess the future development prospects and major challenges for FFSs.

For details, see our review papers published recently: (1) Yan Luo, Xiaoyan Liu, Yu Fang. Acc. Mater. Res. 2025, 6, 5, 600; (2) Rongrong Huang, Taihong Liu, Haonan Peng, Jing Liu, Xiaogang Liu, Liping Ding, Yu Fang. Chem. Soc. Rev. 2024, 53, 6960.

Biography: Yu Fang is a Professor at Shaanxi Normal University, a Joint Professor at Xi'an Jiaotong University, and an Academician of the Chinese Academy of Sciences. His current research focuses on: (1) Film-based fluorescent sensors—designing novel sensing fluorophores, modulating excited-state processes, and regulating aggregated structures in films.(2) Functional molecular materials—developing diverse structures for applications in future technologies such as millimeter-wave communication and terahertz technology with an emphasis on surface and interface physical chemistry.

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Control of Attosecond Entanglement and Coherence

Marc Vrakking
Max-Born Institute, Berlin

Abstract: Attosecond pulses produced using high-harmonic generation (HHG) have photon energies in the extreme-ultraviolet (XUV) and soft x-ray regime. As such, these pulses are ionizing radiation for any sample (atomic, molecular, liquid, solid) placed in their path. In attosecond pump-probe experiments, the time-resolved dynamics under investigation is commonly associated with either the photoelectrons (e.g. in measurements of photoionization time delays) or located within the ions (e.g. in observations of so-called "charge migration"). However, the observable dynamics may be compromised by quantum entanglement between the ions and photoelectrons.

We have investigated, both experimentally and theoretically, the role of ion-photoelectron entanglement in attosecond pump-probe probe scenarios relying on the creation of vibrational, respectively electronic coherence in H_2^+ ions that are produced via attosecond ionization of H_2. In the former experiments, we could show that the degree of vibrational coherence in H_2^+ ions produced by a few-femtosecond long attosecond pulse train (APT) can be controlled by using a pair of APTs and varying their relative time-delay [1-3]. In the latter experiments, we could show that the degree of electronic coherence in H_2^+ ions produced by a pair of isolated attosecond pulses (IAPs), could similarly be controlled by varying their relative delay [4]. Demonstrating the sensitivity of electronic coherences to quantum entanglement is particularly significant, since electronic coherences underlie the observation of time-dependent electron motion, the raison d'être of attosecond science.

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Biography: Prof. Marc Vrakking completed his Phd at the University of California at Berkeley in 1992. After postdoc positions at the National Research Council (Ottawa) and the Vrije Universiteit Amsterdam, he led a scientific group at the FOM Institute for Atomic and Molecular Physics (AMOLF) in Amsterdam from 1997 to 2011. While at AMOLF, he initiated a research program focusing on the use of ultrashort (femtosecond and attosecond) extreme-ultra-violet (XUV) and X-ray laser pulses in studies of time-resolved atomic and molecular dynamics. In March 2010 he was appointed as director at the Max-Born Institute (MBI) in Berlin, and as a professor of physics at the Freie Universität Berlin. At MBI, Marc Vrakking is the head of Division A ("Attosecond Science"), and leads a team of researchers that are both further developing and applying techniques to study electron dynamics on attosecond timescales as well as nuclear dynamics on femtosecond timescales.

Photoacoustic, Light-Speed, and Quantum Imaging

Lihong Wang
California Institute of Technology

Abstract: We developed photoacoustic tomography (PAT) for deep-tissue imaging, offering in vivo functional, metabolic, molecular, and histologic imaging from organelles to entire organisms. PAT combines optical and ultrasonic waves, overcoming the optical diffusion limit (~1 mm) with centimeter-scale deep penetration, high ultrasonic resolution, and optical contrast. Applications include early cancer detection and brain imaging.

Additionally, we developed light-speed compressed ultrafast photography (CUP), capable of capturing the fastest phenomena, such as light propagation, in real time. CUP, with a single exposure, captures transient events on femtosecond scales. CUP can be paired with various front optics, from microscopes to telescopes, facilitating diverse applications in fundamental and applied sciences, including biology and cosmophysics.

Further, our research extends to quantum entanglement for imaging. Quantum imaging utilizing Heisenberg scaling enhances spatial resolution linearly with the number of quanta, outperforming the standard quantum scaling's square-root improvement.

Biography: Lihong Wang is Bren Professor of Medical and Electrical Engineering at Caltech. Published 615 journal articles (h-index = 165, citations = 117K, #1 most cited in optics according to Stanford/Elsevier). Delivered 630 keynote/plenary/invited talks. Published the first functional photoacoustic CT, 3D photoacoustic microscopy, and light-speed compressed ultrafast photography (the world's fastest camera). Served as Editor-in-Chief of the Journal of Biomedical Optics. Received Goodman Book Award; NIH Outstanding Investigator, NIH Director's Transformative Research, and NIH Director's Pioneer Awards; Optica Mees Medal and Feld Award; IEEE Technical Achievement and Biomedical Engineering Awards; SPIE Chance Award; IPPA Senior Prize; honorary doctorate from Lund University, Sweden. Inducted into the National Academy of Engineering.

Intense attosecond pulse generation from visible to soft x-rays

Yuxi Fu
State Key Laboratory of Ultrafast Optical Science and Technology,
Xi'an Institute of Optics and Precision Mechanics (XIOPM), Chinese Academy of Sciences.

Abstract: Since the first demonstration of attosecond pulse generation and characterization at the beginning of this century, attosecond science has attracted a lot of attention due to its significant potential applications in revealing dynamics of electrons. Up to now, isolated attosecond pulses can be generated by high-order harmonic generation (HHG), free electron laser (FEL) and laser driven plasma emission. Attosecond facilities have also been constructed or proposed in different countries. In this presentation, I will show our work on generating attosecond pulses in the soft x-ray, XUV and visible regions, with potential maximum peak power reaches GW and even TW-class, with a table-top scale. These high-energy isolated attosecond pulses will be significant for high resolution spatial-temporal imaging, ultrafast dynamics capturing of electrons, and strong attosecond laser field physics.

Biography: Yuxi FU got his Ph.D in State Key Laboratory of Strong Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences in 2010. From 2010 to 2019, he worked in attosecond science research team of RIKEN first as a postdoctor and then as a Research Scientist. Then, he joined Xi'an Institute of Optics and Precision Mechanics (XIOPM) as a professor. He is currently the deputy director of XIOPM and Director of state key laboratory of ultrafast optical science and technology. His research interest includes strong infrared femtosecond laser technology, high-order harmonic generation and attosecond science, and ultrafast dynamics.

Thin Film Lithium Niobate Electro-Optic Devices and Ultralarge-Scale Photonic Integration

Ya Cheng
School of Physics and Electronic Sciences, East China Normal University

Abstract: The recent advancement in thin film lithium niobate (TFLN) photonic integration technology has been rapid, driven by profound physical, material, and technological factors. Single crystal thin film lithium niobate is particularly noteworthy for offering the most comprehensive performance solution to date, addressing long-term challenges in low transmission loss, high-density integration, and low modulation power consumption within the realm of photonic integrated circuits (PICs). To realize large-scale PICs, we develop photolithography assisted chemo-mechanical etching (PLACE) and apply it for fabricating PICs on TFLN. We then demonstrate various kinds of PICs ranging from low-loss optical delay lines and photonic neural network to EO tunable lasers and high-power waveguide amplifiers. Significant improvements have been achieved with respect to the key parameters/performances of TFLN photonics devices, such as modulation bandwidth, power consumption, propagation loss, active and passive functionalities, and scale of integration.

Biography: Ya Cheng is now a Professor of East China Normal University. His research focuses on ultrafast nonlinear photonics and femtosecond laser micromachining. He has been granted more than 30 Chinese invention patents and 8 US patents, and published more than 300 peer-viewed papers. He has also published 5 books in English, and 1 book in Chinese. Additionally, he has given more than 150 invited talks at various international conferences. He is an Optica Fellow and a Fellow of Institute of Physics, UK.

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Ultrafast nanoprinting for precision manufacturing

Baohua Jia
Centre for Atomaterials and Nanomanufacturing (CAN), RMIT University, Melbourne, Australia

Abstract: This presentation mainly introduces the interaction between 3D nanoprinting and various materials at the atomic scale. Describe the precise and unparalleled manipulation of materials by nanoprinting at the spatial, temporal, and atomic scales. In particular, the application status and broad prospects of optical nanoprinting and two-dimensional photonic integrated devices are introduced in detail. The report will also share the future development directions of ultrafast optical nanoprinting and angstrom material devices, and the major challenges faced. The developed scalable graphene metamaterials show attractive optical and thermal properties. Through patterning with advanced laser nanoprinting technique, functional photonic devices with ultrathin, light weight and flexible nature have been demonstrated promising exciting opportunities for integrated photonics.

Biography: Distinguished Professor Baohua Jia is a Fellow of Australian Academy of Technological Sciences and Technologies (FTSE), and Future Fellow at RMIT University, Australia. Before joining RMIT University in 2022, Baohua was a tenured professor at Swinburne University of Technology and Founding Director of Centre for Translational Atomaterials. Professor Jia is a Fellow of Optica (previously known as the Optical Society of America), and a Fellow of the Institute of Materials, Minerals and Mining (IMO3). Since 2019, Prof. Jia has served as a Colleague of Expert for the Australian Research Council. Professor Jia's research focuses on the design and optical characterization of novel nanostructures and nanomaterials, fabrication, and efficient conversion and storage of light energy. As a leading Chief Investigator, Professor Jia received a total of more than $90 million in research funding support. Professor Jia has published more than 350 journal papers with an h-index of 84 (Google Scholar) and developed over 20 invention patents and patent applications. Based on Professor Jia's outstanding contributions in scientific research, she has won many awards, including the 2024 Vice Chancellor Research Award, 2017 finalist of the Australian Prime Minister's Science Award, the Vice Chancellor's Industrial Achievement Award in 2011, 2016, and 2018, 2013, Young Science Leader Award, 2012 UNESCO L'Oréal Australia New Zealand Women in Science Award.

Decoding the Earliest Moments of Charge Transfer in Molecules with Attosecond EUV and UV Pulses

Mauro Nisoli[1,2]
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[2]*Institute for Photonics and Nanotechnologies, IFN-CNR, Milano, 20133, Italy*

Abstract: Photoinduced charge transfer (CT) is a fundamental process underpinning a wide range of phenomena in both natural and engineered systems. Despite significant advancements in ultrafast spectroscopy, the elementary mechanisms governing the initial stages of CT remain incompletely understood. A major challenge lies in capturing the complex coupling between electronic and nuclear degrees of freedom that emerges immediately after photoexcitation. Elucidating these ultrafast dynamics is critical not only for advancing fundamental knowledge but also for enabling innovation in optoelectronic and molecular electronic technologies. Ultrafast CT can be initiated either by attosecond extreme ultraviolet (EUV) pulses, which induce photoionization and permit tracking of electronic motion in molecular ions, or by few-cycle ultraviolet (UV) pulses, which maintain the molecule in a neutral state. Achieving femtosecond or sub-femtosecond resolution in the latter case requires UV pulses confined to only a few optical cycles.

This work employs both approaches in a complementary fashion. Using attosecond EUV-IR photoion spectroscopy, we examine a model donor–acceptor system to resolve the structural dependence of charge dynamics. Our findings reveal that CT does not proceed via continuous electron flow but initiates with a prompt redistribution of electron density, characterized by oscillatory behavior linked to nuclear motion. Additionally, we present a cutting-edge beamline designed for time-resolved photoelectron spectroscopy, featuring sub-3 fs tunable UV pump pulses and attosecond probe pulses. This setup enables high-resolution studies of ultrafast electronic processes, including nonadiabatic transitions and vibronic coupling, providing unprecedented insight into the interplay between electronic structure and nuclear rearrangements.

Biography: Mauro Nisoli is Full Professor at Politecnico di Milano since 2011. He leads the Attosecond Research Center within the Department of Physics of Politecnico and serves as co-director of the international school The Frontiers of Attosecond and Ultrafast X-ray Science. He is the author of over 230 peer-reviewed publications in international journals and has delivered numerous invited talks and tutorials at leading international conferences and schools. He was awarded an ERC Advanced Grant in 2009 (Electron-scale dynamics in chemistry, ELYCHE) and an ERC Synergy Grant in 2020 (The Ultimate Time Scale in Organic Molecular Opto-Electronics, the Attosecond, TOMATTO). In 2019, he was named OSA Fellow for his innovative contributions to attosecond science and technology, particularly for pioneering applications of attosecond pulses to molecular systems.

He has made groundbreaking contributions to attosecond science, especially in ultrafast electron dynamics in molecules and condensed matter. He co-invented the hollow-fiber compression technique, which enables few-cycle laser pulses at millijoule energies, now a global standard for generating isolated attosecond pulses. In 2006, his group achieved the first complete temporal characterization of isolated attosecond pulses, and in 2010 he developed an advanced temporal gating technique to produce high-energy isolated attosecond pulses. A pioneer in attochemistry, Nisoli performed the first attosecond pump-probe experiment on H_2 and D_2 in 2010. In 2014, he extended these studies to amino acids, achieving the first experimental observation of charge migration in complex molecules. Most recently, in 2024, he investigated the earliest stages of charge transfer in donor–acceptor systems, uncovering the fundamental coupling between ultrafast electronic redistribution and structural dynamics.

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Ultrafast dynamics of complex systems in biology and materials

Dongping Zhong
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Abstract: The dynamics of complex system in biology and materials usually contain many elementary processes and deciphering their underlying mechanisms is difficult and challenging. To resolve their detailed dynamic evolution and determine their actual timescales, we need to combine various state-of-the-art methods to dissect those processes. Here, we use femtosecond spectroscopy, molecular biology and ultrafast electron microscopy to map out their entire dynamics. We report several complex systems in biology and materials such as DNA repair by photoenzyme, dimer dissociation of photoreceptor UVR8 and nanomaterial dynamics. These results reveal their significant complexity and strongly suggest that the high spatiotemporal resoliution is a necessity to completely reveal their dynamics and elucidate the molecular mechanisms at the most fundamental level.

Biography: Dongping Zhong received his B.S. in laser physics from Huazhong University of Science and Technology in China and his Ph.D. in chemical physics from California Institute of Technology in 1999 under the late Prof. Ahmed H. Zewail. For his Ph.D. work, Dr. Zhong received the Herbert Newby McCoy Award and the Milton and Francis Clauser Doctoral Prize from Caltech. He continued his postdoctoral research in the same group with focus on protein dynamics. In 2002, he joined The Ohio State University as an Assistant Professor and was promptly promoted as Robert Smith Professor of Physics and Professor of Chemistry and Biochemistry. He is the Packard Fellow, Sloan Fellow, Camille Dreyfus Teacher-Scholar, Guggenheim Fellow, APS Fellow, AAAS Fellow, as well as the recipient of the NSF CAREER award and the Outstanding Young Research award from the International Organization of Chinese Physicists and Astronomers. He was the international Jury member in physical science for the L'Oréal-UNESCO awards for"Women in Science."His early work on femtochemistry and recent work on the enzyme dynamics have been cited in the press release and Noble lecture of two Nobel Prizes (1999 and 2015). Recently, he moved to China and now is a chair professor in Shanghai Jiao Tong University. His research interests focus on protein and nanomaterials dynamics using ultrafast photons and electrons.

Track 1 Attosecond Science and Technology

Coherent emission and attosecond absorption of molecules driven by strong laser fields

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Abstract: Strong field ionization (SFI) of molecules prepares the ions in coherent yet exotic exaction states which manifest extraordinary emission and absorption properties. In this talk, we present theoretical and experimental explorations of the muliti-dimensional dynamics of atoms driven by strong laser fields, from SFI of the neutral, multiphoton excitation of the ion to coherent emission. We show that coherent supercontinuum can be generated in either the ultraviolet for molecules or EUV region for noble gas atoms. We identify the crucial role of quantum coherence built by the strong field ionization. With the state-of-art attosecond transient absorption spectroscopy, we demonstrate that the subcycle dynamics and the quantum coherence can be probed in attoseconds. It is shown that the modulation of the absorbance provides importance clue of the electronic and vibronic coherence as well as the time-delay of resonant absorption of the ions.

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Spatial and Spectral characters of high harmonic generation in liquids

Wanchen Tao[1], Zhuang-Wei Ding[2,3], Lixin He[1], Changlong Xia [4], Xingdong Guan[1], Xue-Bin Bian[2], Pengfei Lan[1], and Peixiang Lu[1]

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Abstract: High-order harmonic generation (HHG) has been widely explored in gaseous media and crystalline solids with well-established mechanisms such as the three-step model and Bloch electron dynamics. HHG not only can produce attosecond pulse but also can be used to probe the ultrafast dynamics in gas and solids. In contrast, the study of HHG in liquids-even though liquids are the most prevalent and functionally important phase of matter at the molecular scale-remains in its early stages.

In this talk, I will report our recent works about the high-harmonic generation from bulk liquid driven by intense femtosecond laser fields. Through comparative measurements in water, ethanol, and gaseous argon, we identify universal intensity-dependent spectral redshifts and broadening in the liquid phase. These spectral features are consistently observed across different liquids but absent in the gas, indicating a phenomenon intrinsic to the liquid phase. The spectral modulations in liquid HHG can be attributed to scattering-dominated nonlocal electronic trajectories modulated by liquid-specific structural disorder. The interplay between delocalized-state electron motion in liquid and dynamic scattering emerges as the governing mechanism, contrasting sharply with Bloch oscillations in solids or recollision physics in gases.

Moreover, we have investigated the spatial characters of HHG in liquids. Similar to the HHG in gases, we observed that the spatial profiles of the generated high harmonics in liquids also depend on the focusing position of the driving laser pulse. On the other hand, we have shown that the HHG yields of D_2O/H_2O and propyl alcohol and its isomers are also different. These experiments indicate HHG as a potential tool for attosecond spectroscopy in liquids.

Keywords: High harmonic generation, liquids.

Attosecond Tunneling Dynamics in Atoms and Molecules

Weifeng Yang[1]

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Abstract: Attosecond dynamics represents a frontier research direction in the field of strong-field atomic and molecular physics, with its core aim being to unveil the microscopic mechanisms of tunneling ionization and the resulting attosecond electron dynamics in intense laser fields. Real-time tracking and imaging of ultrafast electron dynamics constitute essential approaches to understanding and exploring photophysical, photochemical, and photobiological processes. We propose an integrated self-referenced molecular attoclock theoretical–experimental scheme, through which we reveal transient resonance ionization radial patterns in $Ar–Kr^+$ dimers. By employing directly ionized electrons as self-referenced pointers of the molecular attoclock, we measure and extract a time delay of 3.5 ± 0.04 fs for electrons trapped in molecular resonance states. Furthermore, using the quantum-trajectory method, we investigate the photoionization dynamics of atoms and molecules driven by strong laser fields, thereby elucidating the role of sub-barrier interactions in attosecond angular streaking measurements as well as in resonance-enhanced molecular ionization.

Keywords: Attosecond dynamics; Strong-field physics; Molecular attoclock

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The Key Applications of Femtosecond/Attosecond High-Harmonic Generation Laser source in Advanced Semiconductor Manufacturing

Xiaoshi Zhang

Yunnan University

Abstract: Since the discovery of high-harmonic generation (HHG) based on pulsed lasers in the 1980s, it has undergone significant advancements, becoming one of the most efficient, compact, and cost-effective methods for producing short-wavelength lasers, ranging from deep ultraviolet to X-ray (1–200 nm). With the rapid progress of femtosecond laser technology, HHG has now reached the ability to generate milliwatt-level power and attosecond pulse durations. In fact, research on attosecond pulses was recognized with the 2023 Nobel Prize in Physics, marking a major milestone in the field.

A critical milestone in HHG technology's application to semiconductor manufacturing was the development of milliwatt-level extreme ultraviolet (EUV) lasers. In 2012, Intel, in collaboration with KMLabs and the University of Colorado Boulder, first applied HHG to EUV lithography, specifically for mask defect inspection and overlay calibration. This was followed by similar applications from Samsung, TSMC, and National Tsing Hua University, all of which explored EUV lithography applications in semiconductor manufacturing. By 2016, as HHG power improved significantly, ASML, in partnership with Delft University of Technology and TRUMPF, extended this technology to advanced (<3 nm) wafer defect inspection, further demonstrating its potential in semiconductor production.

In 2025, EUVtech in the United States began developing metrology and inspection equipment based on high-harmonic generation EUV lasers. Meanwhile, China has actively incorporated milliwatt-level HHG technology into its "14th Five-Year Plan," focusing on advancing its use in semiconductor defect inspection.

Looking ahead, as high-harmonic generation technology continues to mature with improvements in wavelength shortening, power scaling, pulse duration reduction, and engineering feasibility, its applications are expected to expand even further. It holds promise for transformative impact in areas such as advanced semiconductor manufacturing, large-scale quantum chip production, and biomedical diagnostics.

Photoelectron Spin Texture in Strong-field Ionization Induced by a Linearly Po- larized Laser Pulse

Pei-Lun He[1] *

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Synopsis We demonstrate that photoelectron spin texture exhibits a vortex structure relative to the laser polarization axis in the strong-field ionization of inert gas atoms. The momentum-resolved polarization originates from the emergence of spin-correlated quantum orbits in the continuum. For direct electrons in few-cycle pulses, the nonvanishing initial transverse velocity of the electron is responsible for the polarization. In long pulses, the spin texture is essentially shaped by recollisions. Furthermore, the interference between direct and rescattering ionization leads to spin-polarized electron holography, offering an alternative method for extracting atomic fine structure information.

Spin-orbit coupling in bound states can create a strong correlation between the electron's spin and orbital angular momentum due to degenerate atomic energy levels. This correlation, combined with significant angular momentum-dependent ionization probability, results in a nontrivial pho- toelectron polarization. When combined with circular dichroism in strong-field ionization, sig- nificant polarization along the laser polarization axis becomes possible.

In contrast to a circularly polarized pulse, the total polarization of the ionized electron vanishes when the laser pulse is linearly polarized. Never- theless, we demonstrate the emergence of signif- icant momentum-resolved spin polarization (spin texture). We trace the origin of the spin tex- ture to the correlation between spin and the initial transverse velocity of the photoelectron at the tunnel exit, which gives rise to spin-dependent quantum orbits. For direct electrons, using saddle point approximation in spin-resolved strong- field ionization, we demonstrate that the spin po- larization forms a vortex relative to the laser po- larization axis:

$$\langle \boldsymbol{\zeta}(\boldsymbol{p}) \rangle \sim \frac{\boldsymbol{p} \times \boldsymbol{E}(t_r)}{|\boldsymbol{E}(t_r)|},$$

where $\boldsymbol{p}$ is the photoelectron momentum and $\boldsymbol{E}(t_r)$ is the electric field at the instant of ioniza- tion. For rescattering electrons, the nontrivial momentum-resolved spin texture arises from for- ward rescattering of the spin-dependent quantum orbits and the associated quantum phase shift.

Moreover, the interference between direct and rescattered trajectories can lead to photoelectron

Fig. 1, the typical spider structure is not only vis- ible in the momentum distribution but also ap- pears with enhanced resolution in the spin polar- ization.

The photoelectron spin texture is generally nontrivial in strong-field ionization, providing complementary information to the photoelectron momentum distribution. The nontrivial spin tex- ture not only shows promise for enhancing the sensitivity of ultrafast electron spectroscopic techniques—such as photoelectron holography, attoclock, and streak camera measurements—but also may reveal novel methods for generating spin-polarized photoelectrons.

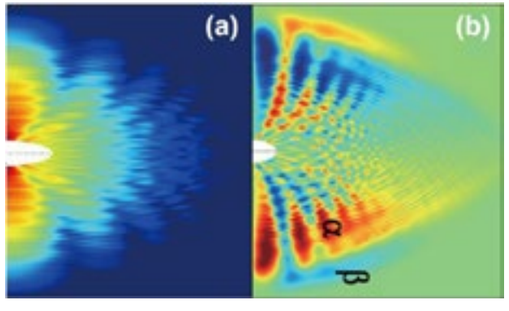

Figure 1. Photoelectron holography fringes observed in

(a) photoelectron momentum distribution and (b) spin tex- ture from a Xe atom.

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Few-cycle attosecond driver source at MHz repetition rates

Takuya Okamoto and Katsuya Oguri

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Abstract: Few-cycle intense pulse sources at high repetition rates are essential for photon-hungry applications such as isolated attosecond pulse (IAP) generation. Ytterbium (Yb)-doped amplifiers are emerging as next-generation attosecond driver sources, offering hundreds of watts to kilowatt-class average power at kHz–MHz repetition rates. Their narrower gain bandwidth, however, leads to longer pulse durations than conventional Ti:sapphire amplifiers. Thus, for IAP generation, two challenges must be addressed: post-compression with a high compression ratio into a few-cycle regime and carrier-envelope phase stabilization.

In this talk, we present our recent progress on MHz-repetition few-cycle attosecond driver source based on a Yb:KGW amplifier and its application to attosecond pulse generation. This source will further advance attosecond spectroscopies previously developed by NTT Basic Research Laboratories, including transient absorption spectroscopy, sub-10-fs time-resolved ARPES, and time-resolved Fourier-transform spectroscopy.

Keywords: Post compression; Yb-doped amplifier; Isolated attosecond pulse; CEP stabilization

Isolated attosecond pulses generated from plasma mirrors using non-collinear laser pulses

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Abstract: Relativistic high-harmonic generation (HHG) from plasma mirrors enables the production of intense attosecond pulse trains when an ultraintense laser is reflected from an overdense plasma surface. For many applications, such as pump–probe spectroscopy and attosecond-resolved studies of laser–plasma dynamics, it is essential to isolate a single attosecond pulse. Conventional isolation schemes demonstrated in gases—such as amplitude, polarization, or ionization gating—require ultrashort, few-cycle drivers that are difficult to realize at petawatt-class powers. Here, we introduce and numerically demonstrate a noncollinear temporal gating scheme that separates an isolated attosecond pulse from a relativistic plasma mirror. The method employs a long, intense driving pulse combined with a weak, single-cycle gating pulse incident at a small angle. Their superposition rotates the wavefront within a single optical cycle, deflecting a selected attosecond burst from the train. Particle-in-cell simulations confirm that this approach yields isolated attosecond pulses that can be readily separated by spatial filtering. Moreover, by varying the delay of the gating pulse, we selectively access individual bursts from the train, thereby reconstructing the temporal profile of the emission. This enables attosecond-scale diagnostics of plasma dynamics, such as surface denting and the reflection position shift caused by radiation pressure. Our results demonstrate that noncollinear gating provides a practical and scalable route to isolated attosecond pulses at relativistic intensities, overcoming the constraints of few-cycle driving fields. Beyond pulse generation, this method offers a new method for probing ultrafast laser–plasma interactions with attosecond temporal precision.

Keywords: Attosecond pulses, Relativistic high harmonic generation, Plasma mirror, Isolated attosecond pulses, noncollinear laser pulses

Intense isolated attosecond pulse generation and characterization through perturbed waveform synthesizer

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Abstract: We have demonstrated the stable generation of high-flux isolated attosecond pulses (IAPs) through a three-channel parallel waveform synthesizer operating at 10 Hz [1]. The generated sub-microjoule IAPs were characterized using the frequency-resolved optical gating for complete reconstruction of attosecond bursts (FROG-CRAB) technique, yielding a pulse duration of 226 as [2]. This achievement represented the first experimental characterization of gigawatt-scale IAPs at a low repetition rate. Nevertheless, the conventional FROG-CRAB method inherently requires a time-consuming data acquisition process, as the electron time-of-flight (eTOF) spectrometer must scan the delay over tens of femtoseconds with sub-femtosecond steps. Typically, it takes tens of minutes or even more to complete. To overcome this limitation, we employed an all-optical FROG scheme [3], enabling a substantially faster characterization of the IAP duration.

The all-optical FROG setup introduces a weak gating pulse (intensity ratio < 10^{-3}) as a perturbing waveform applied to the HHG process with a variable delay. The resulting HHG spectra trace exhibit modulation dependent on the perturbing field. By eliminating the eTOF spectrometer, the harmonic spectra are directly acquired using a CCD camera, thereby reducing the total measurement time to only a few minutes. From the experimentally recorded all-optical FROG trace, both the temporal profile of the IAP and the gating waveform can be reconstructed numerically. The retrieved temporal and spectral profiles reveal an IAP duration of 224 as, in excellent agreement with the result obtained using the conventional FROG-CRAB technique [2]. This proposed approach also helps us to achieve the temporal characterization of subgigawatt IAP (128 as, 107 eV) generated in neon gas with several tens of nanojoules [4].

Keywords: attosecond pulse, waveform synthesizer, pulse characterization, high intensity.

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Polarization and OAM control of laser-driven plasma high-harmonics and attosecond pulses

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Abstract: Plasma surface high-order harmonics (SHHG) generation is a nonlinear process on the solid target surface driven by a relativistically intense laser pulse. The SHHGs with wavelengths ranging from extreme ultraviolet to soft X-ray are characterized by perfect temporal coherence and a high conversion efficiency. Free control of their polarization and orbital angular momentum (OAM) is of great importance, which is motivated by the applications of dichroism, magnetization dynamics, and probing chiral molecules. We studied the ways to manipulate the SHHG polarization by employing an external magnetic field, a strong space-charge field or by controlling plasma profiles, thus are able to generate circularly polarized high-harmonics or attosecond pulses. We also introduced OAM to SHHG by spin-to-orbital conversion when a CP laser interacts with a dented solid target, and introduced time-varying OAM to SHHG when two time-delayed vortex laser pulses with different OAMs interact with a solid target. All these theoretical and numerical studies pay the way for the relevant SHHG experiments in the near future.

Keywords: plasma surface high-harmonics, circularly-polarized attosecond pulses, orbital angular momentum, relativistic laser plasma interactions

100 kHz Repetition Rate Extreme Ultraviolet Beamlines at the Artemis Facility

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Abstract: The Artemis laboratory at the UK's Central Laser Facility (CLF) is a user facility offering access to high average power femtosecond laser systems and HHG sources for a variety of ultrafast extreme ultraviolet (XUV) experiments. The XUV beamlines provide the capability for time-and angle- resolved photoemission spectroscopy (TR-ARPES) on solid samples, and photoelectron spectroscopy (PES) on gas-phase small molecules, with tunable optical pump pulses and XUV probe pulses. In the gas-phase, recent experiments include measurements of the full excited state dynamics of 1,2-Dicholoroethene [1].

TR-ARPES with high harmonic probe pulses has enabled studies of electron dynamics in 2D materials [2]. We use a 100 kHz optical parametric chirped pulse amplification system [3] to drive the HHG source. Our HHG beamline includes demagnification optics to give a sub-20 micron XUV focal spot and spatial mapping capability. We have also upgraded our TR-ARPES end-station with a new Fermi surface mapping analyser, enabling efficient acquisition of high-quality ARPES spectra of optically pumped excitations close to the Fermi surface level [4].

We have recently secured funding for a major upgrade of all the CLF's ultrafast facilities. The upgraded Artemis will offer a 100 kHz Yb-based laser system, with 1.5 mJ, <50 fs pulses at 1 micron for HHG, and tunable <50 fs pulses from 235 nm to 10 microns. A new gas-phase end-station will offer dual electron and ion coincidence spectrometers, with gas-jet and laser desorption sources. A new materials science end-station will offer a momentum microscope and a hemispherical analyser for time- and angle-resolved photoemission.

Finally, we aim to expand the facility's capabilities with the addition of a new beamline that will generate broadband XUV pulses for time-resolved XUV and soft-X-ray absorption spectroscopy in liquid- and gas-phase samples and perform XUV ptychographic imaging of microscopic samples.

The new capabilities will be available to access starting in 2026.

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Stabilization and Destabilization of Multimode Solitons in Nonlinear Degenerate Multi-Pass Cavities

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Abstract: Optical solitons in multimode nonlinear optical systems offer a unique platform for exploring the interplay of nonlinearity, dispersion, and spatial mode coupling, offering insights into complex nonlinear wave phenomena. Multi-pass cavities (MPCs) incorporating nonlinear Kerr media serve as prototypical systems, enabling high-efficiency supercontinuum generation and pulse compression. However, stabilizing femtosecond laser pulses in solid-medium-based MPCs (solid MPCs) under strong Kerr nonlinearity remains a significant challenge due to multimode coupling, which disrupts beam stability. In this work, we address this challenge by investigating the stability of laser pulses in MPCs using Floquet and perturbation model. We identify novel mode-coupling-suppression (MCS) medium lengths, where destructive interference among multimode wave components suppresses coupling and facilitates soliton stabilization. Under MCS conditions, our simulations demonstrate stable beam propagation in solid MPCs with nonlinear phases up to 1.5π per pass, achieving >13-fold pulse compression with excellent spatio-spectral homogeneity. Our findings offer valuable guidance for designing advanced MPCs with tailored Kerr media.

Keywords: Soliton, Nonlinear optics, Supercontinuum generation, Ultrashort pulse

Compact single-stage sub-TW Ti:Sa amplifier with high contrast，high repetition rate and CEP stabilization

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Abstract: Carrier-envelope phase (CEP) stabilized femtosecond lasers with high repetition rate and high temporal contrast are essential tools for attosecond science, strong-field physics, and laser–plasma interaction studies. Traditionally, achieving both sub-terawatt (sub-TW) peak power and high repetition rate requires complex multi-stage amplifier chains, which increase system complexity and implementation effort and limit system compactness and reliability. The objective of this work is to demonstrate a compact, single-stage Ti:Sapphire (Ti:Sa) chirped-pulse amplifier (CPA) delivering sub-terawatt (sub-TW) peak power that combines CEP stabilization, high temporal contrast at kilohertz repetition rate. The amplifier is seeded by a cross-polarized wave (XPW) generation pumped by CEP-stabilized sub-30fs pulses from a commercial laser. Seed pulses are temporally stretched in a bulk-material stretcher, spectrally shaped and phase-pre-compensated by a Dazzler(AOPDF) and injected into a single-stage 6-pass Ti:Sa amplifier pumped by two kHz frequency-doubled laser. Careful optimization of the multi-pass configuration and thermal management enables efficient energy extraction while minimizing amplified spontaneous emission (ASE), suppressing thermal lensing, and preventing optical damage.

The amplified pulses were subsequently recompressed in a high-efficiency transmission-grating compressor and two pairs of chirped mirrors. Slow CEP drifts in the system were stabilized by a feedback loop consisting of an f–2f interferometer and a PTC controlled material dispersion management.

Pulse duration and temporal contrast were characterized by TIPTOE and third-order cross-correlator SEQUOIA respectively. The single-stage Ti:Sa amplifier delivers sub-25fs pulses with energies exceeding 15 mJ at a repetition rate of 1 kHz, corresponding to peak powers approaching 0.65 TW after compression. Preliminary measurements demonstrate a temporal contrast exceeding 10^9 at as early as 10 ps prior to the main pulse. This performance is primarily due to a unique single-stage amplification architecture and the implementation of cross-polarized wave (XPW) filtering. The pulse peak-peak stability is better than 1.2% RMS.

Compared to conventional multi-stage Ti:Sa amplifier systems, the presented design reduces complexity, footprint, and cost while preserving key performance metrics such as energy, stability, and contrast. The compactness and reliability of this architecture make it highly suitable as a driver for attosecond pulse generation, high-harmonic generation (HHG), and strong-field experiments requiring both high repetition rate and CEP-stable sub-TW pulses. We demonstrate a compact, single-stage Ti:Sa CPA system that combines CEP stabilization, high temporal contrast, and sub-TW peak power at kHz repetition rate. This work highlights a route toward highly compact, robust ultrafast laser sources with state-of-the-art performance for attoscience and strong-field physics applications.

Keywords: Ultrafast amplifier, CEP stabilization, temporal contrast, high repetition rate

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Track 2 Ultrafast Lasers and Applications

Generation of two-cycle 5 µm pulses with high spatio-temporal homogeneity and multi-mJ energy via nonlinear compression in II-VI chalcogenides

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Abstract: Based on a midwave-IR OPCPA at 1-kHz repetition rate delivering performance parameters well beyond the state of the art for few-cycle sources at wavelength above 4 µm, temporal soliton self-compression with simultaneous formation of a radial Townes profile was demonstrated in ZnS. Two-cycle pulses at 4.9 µm with 2.0 mJ energy were generated, yielding a record peak power of 45 GW. The 37 fs self-compressed pulses exhibit an outstanding spatio-temporal homogeneity over the entire beam profile due to combined action of self-focusing and subsequent diffraction behind the ZnS sample, which distinguishes them from other bulk compression schemes.

Keywords: Mid-infrared lasers, nonlinear post-compression, few-cycle pulses

Frequency conversion of femtosecond spatiotemporal optical vortex

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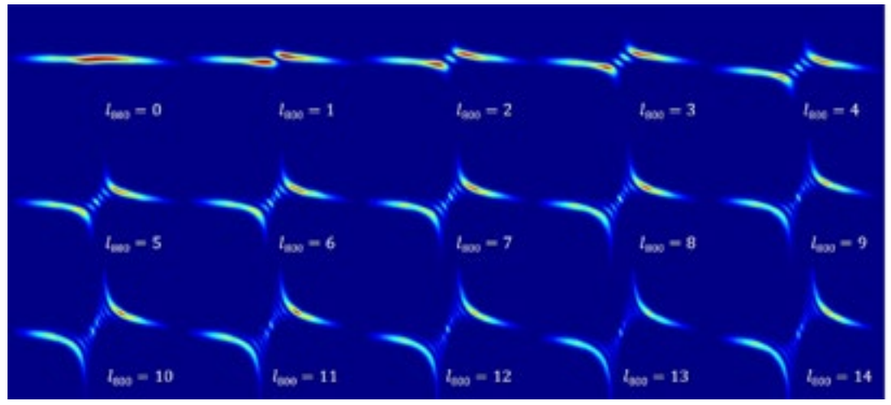

Abstract: The realization of spatiotemporal vortex structure of various physical fields with transverse orbital angular momenta (OAM) has attracted much attention and is expected to expand the research scope and open new opportunities in their respective fields[1]. Here we present frequency conversion of the femtosecond spatiotemporal optical vortex (STOV), extending its available frequency to the UV and XUV regime [2,3]. For the generation of STOV in the UV regime, we demonstrated a cascaded second harmonic generation (SHG) and third harmonic generation (THG) process, which enables the realization of highly charged STOV field [2], as shown for the SHG in Fig. 1. For the attosecond XUV pulse with STOV feature, we theoretically studied the high harmonic generation (HHG) by a two-color femtosecond light field, with each color carrying transverse OAM. Through careful optimization of relative phase and intensity ratio, we validate the efficient upconversion of the infrared pulse into its tens of order harmonics, showing that each harmonic preserves a corresponding intact topological charge [3]. This unique characteristic enables the synthesis of an extreme ultraviolet attosecond pulse train with transverse OAM.

Fig. 1. Generation and characterization of the second harmonic STOV field at 400nm with different topological charges, as indicated in each panel.

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Attosecond Metrology for Electron Dynamics Observation

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Abstract: Attosecond science exploits the extreme nonlinearity of strong-field interactions, driven by few-cycle laser pulses, to achieve attosecond temporal resolution, enabling real-time observation of electron dynamics in matter. Advances in this field, particularly the generation of extreme ultraviolet (XUV) attosecond pulses, have opened new opportunities for studying ultrafast electron behavior in matter. Here, we introduce a novel all-optical attosecond metrology technique to investigate light-field-induced electron dynamics. This methodology leverages phase transitions in dielectrics introduced by intense visible light fields. Such interactions trigger interband and intraband transitions, as well as their coherence effects, resulting in modifications to the electronic structure and optical response. Consequently, the dielectric experiences an adiabatic semimetal phase transition characterized by strong polarizability. This transition manifests as reflectivity changes that closely follow the shape of the driving optical field. Accordingly, the time-resolved reflectivity measurements provide direct access to the phase transition and the associated electronic dynamics in real-time. In addition, a new multimodal ultrafast electron imaging platform, integrating scanning electron microscopy (SEM), ultrafast electron diffraction (UED), and ultrafast electron energy-loss spectroscopy (Ultrafast-EELS), will be discussed. This approach offers unprecedented insight into microscopic structural and electronic dynamics, with wide-ranging implications for ultrafast science in quantum physics, chemistry, and biology.

Keywords : Attosecond science, Light-field-induced electron dynamics, Multimodal ultrafast electron imaging, Attosecond visible light

Mid-infrared pumped high-efficiency optical rectification in lithium niobate

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Abstract: Efficient terahertz (THz) wave generation is pivotal for advancing ultrafast optics and enabling diverse applications. This invited talk presents our recent works in achieving high-efficiency optical rectification (OR) through mid-infrared (MIR) pumping in lithium niobate (LN) crystals. Traditional OR systems utilizing near-infrared (NIR) pumping suffer from limited conversion efficiencies. Our studies demonstrate that MIR pumping, particularly at wavelengths around 2 μm, significantly enhances laser-to-THz conversion efficiency. By leveraging quasi-phase matching (QPM) in stacked LN wafer stacks and tilted-pulse-front (TPF) configurations in LN prisms, we have achieved substantial efficiency improvements. Experimental results show that QPM macro-crystals pumped at 2 μm reaching ~0.4% conversion efficiencies at room temperature. Further enhancement to a record-breaking 2.12% was achieved under cryogenic cooling conditions with 2-μm pumped TPF OR, generating single-cycle THz pulses centered at 0.4 THz. These findings establish MIR pumping as a potential approach for developing high-power, tunable THz sources, with significant implications for both fundamental research and technological innovation in ultrafast optics.

Keywords: Mid-infrared laser, optical rectification, terahertz pulses, lithium niobate, tilted-pulse-front.

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Stray Light Measurement for Space Optical Systems using the Time-Domain Method

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Abstract: Stray light significantly degrades the performance of space optical payloads. Ground-based calibration serves as a critical assurance measure to mitigate stray light risks for instruments in orbit. However, laboratory environments often introduce unwanted interference, limiting the accurate evaluation of stray light in instruments under test.

This report proposes a time-domain stray light measurement method utilizing a pulsed light source and a time-resolved detector. By analyzing the distinct characteristics of background noise and target light, filtering the temporal properties of optical signals, and enabling precise control, the method facilitates accurate identification and isolation of target stray light signals. Experimental results demonstrate that the point source transmittance (PST) achieved was below 10-10. This approach offers a cost-effective and straightforward solution for stray light measurement in space optical systems.

Few-cycle femtosecond pulse combination and optical parametric amplification of ultrabroad band chirped laser pulses

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Abstract: In this presentation we report a method in which synchronization of the time and carrier envelop phase (CEP) are realized simultaneously between the two few-cycle pulses. The technique gives a compact and simple solution to minimize the efficiency deterioration of few-cycle pulses coherent combining caused by the time jitter and CEP difference. Accuracy of the ΔCEP measurement is investigated and compared with the theoretical results. While set the theoretical value of ΔCEP difference 0.106 rad/μm at the center wavelength of 800 nm, the overall measurement gives a ΔCEP variation of 0.110 rad/μm, that matches the theoretical calculation quite well. By spectral interferometry, the two few-cycle femtosecond laser pulses are synchronized at the accuracy of 50 attoseconds. For ultrabroad-band chirped pulse amplification, we studied an optical parametric chirped pulse amplification (OPCPA) method based on mixed cascaded crystals, taking advantage of the unique phase-matching of LBO and YCOB crystals. OPCPA properties, of LBO at 880 nm, YCOB at both 750 nm and 1080nm are studied respectively. After the mixed crystals cascading amplification, a total gain of 10^8 and spectral bandwidth close to 400 nm are obtained. Pulse duration is measured 9.4 fs by a SHG-frequency-resolved optical grating (FROG).

Keywords: femtosecond pulse combination, carrier envelop phase, optical parametric chirped pulse amplification, broadband laser pulse.

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Ho:YLF composite thin disk laser at 2 μm

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Abstract: Lasers operating in the 2-μm spectral range have garnered significant interest due to their wide-ranging applications in science and industry. Their advantages include eye-safe operation, a higher water absorption coefficient, and low atmospheric attenuation, making them ideal for laser processing, surgery, remote sensing, and countermeasures. Recent advancements in 2-μm laser technology have also demonstrated their potential as efficient drivers for mid-infrared, terahertz, and attosecond light generation in the water window spectral range (284–530 eV).

Ho:YLF stands out as an ideal laser crystal, offering key advantages such as low multi-phonon relaxation, a long excited-state lifetime, and favorable thermo-optical properties, in particular its natural birefringence and negative thermal refractive index. When combined with in-band pumping—where the pump wavelength is closely matched to the absorption bands of the laser medium—Ho:YLF benefits from reduced quantum defect heating and enhanced overall efficiency. These attributes, combined with its intrinsic properties, make Ho:YLF particularly well-suited for thin-disk lasers, enabling high beam quality and efficient performance under demanding conditions.

However, the relatively low hardness of Ho:YLF presents challenges in crystal processing, especially in fabricating thin disks with thicknesses on the order of hundreds of micrometers. Moreover, amplified spontaneous emission (ASE) effects in thin-disk configurations hinder aperture scaling and degrade gain storage performance. To address these limitations, we introduced a composite thin-disk (CTD) design, where an undoped YLF cap layer is diffusion-bonded to the doped Ho:YLF disk. This innovative configuration enhances the mechanical strength of the crystal and suppresses ASE, thereby improving both power scaling and gain storage. Furthermore, this approach simplifies thin-disk fabrication and provides a viable pathway for achieving high-power operation under room-temperature conditions.

Here, we report, to the best of our knowledge, the first Ho:YLF-based composite thin-disk laser. Operating at room temperature and cryogenic conditions, it achieved output powers of 26 W and over 120 W, respectively, while maintaining near-diffraction-limited beam quality. These results demonstrate the significant potential of Ho:YLF composite thin disk laser to deliver high efficiency, high power, and excellent beam quality in the 2-μm wavelength regime.

Measuring electron dynamics in molecules, solids and layered systems on an attosecond timescale

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Abstract: The generation and measurement of single isolated attosecond pulses in the extreme ultraviolet (XUV) at the beginning of this century has recently been awarded with the Nobel Prize in Physics [1].

A pump/probe technique, “attosecond streaking” [2], was used to investigate electron dynamics on surfaces and layered systems with unprecedented resolution. Photoelectrons generated by laser based attosecond extreme ultraviolet pulses (XUV), are exposed to a dressing electric field from well synchronized few-cycle infrared (IR) laser pulses. The energy shift experienced by the photoelectrons by the dressing field is dependent on the delay between the XUV pulse and the dressing field and makes it possible to measure the respective delay in photoemission between electrons of different type (core electrons vs. conduction band electrons). The information gained in such experiments on tungsten [3] triggered many theoretical activities leading to different explanations on the physical reason of the delay. Attosecond streaking experiments have been performed on different solids [4,5], layered structures and liquids, resulting in different delays – also depending on the excitation photon energy. These measurements lead to a stepwise increase of the understanding of different physical effects contributing to the timing of photoemission. In this presentation, an overview on the different physical contributions to attosecond time delays in photoemission will be given. The “absolute” time delay, i.e. the delay between the instant of ionization and the emission of a photoelectron will be discussed and latest measurements on oriented molecules on surfaces and isosteric molecules in the gas-phase will be presented.

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High-power HHG driving source operating in the green wavelength range

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Abstract: High-order harmonic generation (HHG) in noble gases driven by femtosecond lasers is currently a feasible solution to obtain ultrafast pulses in the extreme ultraviolet (EUV) wavelength range. Implementation of high-flux EUV sources requires driving HHG using an ultrafast laser source at the visible wavelength range with MHz repetition-rate. In this paper, we employ a multi-pass cell followed by chirped mirrors to compress 1-MHz, 200-W, 300-fs pulses at 1.03 μm to a duration of 35 fs. The resulting 186-W compressed pulses are focused onto 0.5-mm thick BBO crystal to drive second harmonic generation and produce positively chirped pulses at 520 nm. These green pulses are dechirped to 26 fs in duration with an average power of 64 W, which, to the best of our knowledge, represents the highest average power of green pulses with the duration below 100 fs.

Keywords: ultrafast lasers, nonlinear compressor, second harmonic generation, ultrafast and attosecond optics

Progress on visible-wavelength mode-locked ultrafast fiber lasers

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Abstract: In this talk, I will focus on the recent progresses on visible-wavelength rare-earth-doped fluoride-glass fiber lasers, mainly including: 1) high-power all-fiber visible lasers at deep-red, red, green, yellow and blue wavelengths; 2) passively mode-locked visible fiber lasers from DSR, vortex, spatial-temporal to femotosecond mode-locking operations.

Keywords: Fiber laser, ultrafast, visible

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High performance femtosecond solid-state laser technology and its advanced applications

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Abstract: With the development of ultrafast laser interaction with matter, such as high harmonic generation, secondary optical source generation, laser micromaching, the femtosecond lasers feature high average power, high single pulse energy, ultrashort pulse duration, high repetition frequency and attainable wavelength. Among these high-performance femtosecond lasers, femtosecond solid-state laser has the comprehensive advantage of flexible output parameters, extremely good beam quality and very simple architecture. In this presentation, I will talk about the recent progress of 10 mJ/ 100 W average power femtosecond solid-state amplification and discuss my understanding on the beam quality concerning the cutting-edge demand of advanced applications.

High power ultrafast laser sources enabling efficient mid-infrared parametric conversion

Junqing Zhao

Shenzhen Technology University

Abstract: Our group's Recent progress on high power ultrafast laser sources as well as their further efficient mid-infrared parametric conversion will be presented. These in-lab developed sophisticated near infrared laser sources, some with all-fiber design and the other with fiber/bulky hybrid architecture, enable desired flexible parameters. By using them, we can more freely optimize the further parametric conversion, realizing some breakthroughs in both efficiency and power level.

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The applications of high-order multiphoton absorption-based optical and optoelectronic nonlinearities

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Abstract: Femtosecond lasers have long been recognized as revolutionary tools that have enabled numerous scientifical breakthroughs. In particular, multiphoton absorption (MPA)—a prototypical nonlinear optical effect in response to intense femtosecond laser excitation—facilitates sub-bandgap carrier excitation and has been widely exploited in advanced optical and optoelectronic technologies. Here, we demonstrate that our findings and results in this field, including the exciton-enhanced giant high-order MPA nonlinearities, the high harmonics generation in solids, and their diverse applications in broadband sub-bandgap photodetection, direct full-color upconversion in the NIR-III/IV spectral windows, and quantitative retrieval of electronic band structure. These results offer valuable insights into advancing high-order nonlinearity based on femtosecond lasers.

Keywords: femtosecond lasers; multiphoton absorption; high-order nonlinearity

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Efficient generation of Bessel-Gauss attosecond pulse trains via nonadiabatic phase-matched high-order harmonics

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Abstract: Generating Bessel-Gauss beams in the extreme ultraviolet (EUV) with attosecond pulse durations poses a significant challenge due to the limitations of conventional transmission optical components. Here, we propose a novel approach to produce such beams by inducing an annular EUV source through high-order harmonic generation (HHG) under nonadiabatic phase-matching conditions. The resulting light pulse maintains temporal coherence and manifests attosecond pulse trains as confirmed by the reconstruction of attosecond beating by interference of two-photon transitions (RABBIT) measurements. Macroscopic HHG calculations reproduce the measured spatiotemporal structures, demonstrating the plasma-induced spatial modulation on the formation of an annular source. Propagation simulations further confirm the feasibility of this approach for generating attosecond Bessel-Gauss beams, presenting exciting prospects for various applications in EUV photonics and attosecond science.

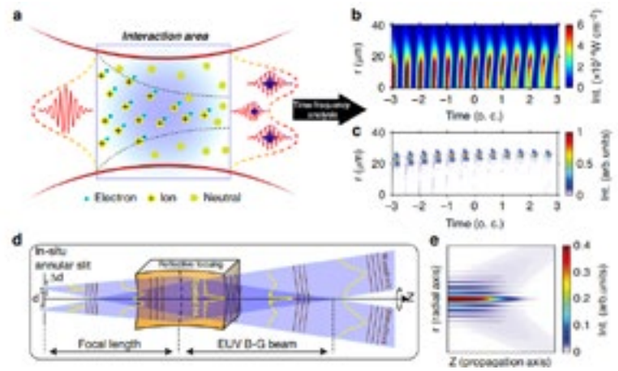

Figure1. Formation of an attosecond Bessel-Gauss beam. **a** Illustration of the annular EUV emissions resulting from the reshaping of the intense femtosecond NIR laser after propagation and harmonic generation in the nonadiabatic phase-matching regime. **b** Spatiotemporal structure of the NIR laser field at the exit plane. **c** Attosecond bursts observed at the exit plane of the interaction area. **d** The optical path for generating an attosecond EUV Bessel-Gauss beam using the annular EUV source. **e** Evolution of the Bessel-Gauss beam simulated for the annular source along the propagation axis.

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Track 3 Ultrafast Terahertz Science and Technology

Classical Electrodynamics in the Study of Dielectric Properties of Subwavelength Heterostructures Using Pulsed Terahertz Radiation.

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Abstract: For the terahertz frequency range, the possibility of studying the complex permittivity of heterostructures made of subwavelength planar layers of multilayer materials and metamaterials with a strong change in permittivity and conductivity using the TDS technique is considered. I consider a wide range of expert methods for pulsed probing of planar structures and various teleretic models based on both depolar re-emission and elementary current models. Using analytical estimates and numerical modeling, it is shown that the described approaches allow one to accurately and simply study the complex refractive index of planar elements of heterostructures for arbitrary polarization states (TE or TM) and angles of incidence of the terahertz beam on the sample.

An experimental setup based on simultaneous analysis of both reflected and transmitted THz waves for the sample under study (hereinafter referred to as a two-channel setup) is proposed and implemented. For a model containing a thin dielectric film, analytical and numerical solutions of Maxwell's equations are presented, which allow one to accurately and easily determine the complex refractive index of the film for arbitrary polarization states (TE or TM) and angles of incidence of the terahertz beam on the sample. A numerical verification of the model is performed, demonstrating the main advantages and limitations of the proposed model. The proposed method reduces the contribution of noise associated with laser radiation fluctuations, which improves the accuracy of determining the permittivity. An experimental verification of the approach is presented using the example of studying the dielectric properties of phase-change material GeTe films of different thicknesses. The focus of our study is a strong change in the permittivity and conductivity of a GeTe film during the transition of the film from a crystalline to an amorphous state upon heating with ultraviolet laser pulses.

Based on the reconstructed values of the complex permittivity of GeTe films, we developed, fabricated, and characterized a metastructure for the THz frequency range that demonstrates suppression of the resonant Fano mode by photoswitching. The phase state of GeTe films in the metamaterial was monitored using Raman spectroscopy.

Keywords: Terahertz spectroscopy, electrodynamics, phase changed materials

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Research on intense Terahertz Surface Wave Pulsed Source and Applications

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Abstract: High field ultrafast laser pulse can instantaneously generate intense electromagnetic fields at a very small scale of focus, in which microscale region it is expected to generate compact radiation sources. Here we present a principle of surface wave radiation amplification using laser pumping. When an ultrafast laser focus on a metal wire waveguide, the excited electron pulse pumps surface plasmon polaritons and achieves coherent amplification, which is observed by the ultrafast optical pump-probe method. Using this natural surface modes, we have demonstrated a new method of waveguide-coupled terahertz electron acceleration. Within an acceleration distance of 5 mm the electron energy gain exceeding MeV. This demonstrates a new type of fingertip-sized electron gun. Furthermore, using this intense-field surface wave to ionize gas, we achieved a ball-lightning-like soliton and enabled the nonlinear excitation of phonon polaritons, among other phenomena. Such intense-field terahertz surface waves hold significant scientific potential in research areas such as particle acceleration, control of material states, nonlinear optics, and spectroscopy.

Broadband THz pulse production with TW femtosecond laser in air and plasma

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Abstract: THz radiation has a wide variety of applications in material science, medicine, biology, non- destructive testing and other areas of fundamental research, applied science and engineering. Broadband THz sources are of particular importance here. High peak power femtosecond lasers provide different ways to generate such pulses. This paper describes two approaches based on TW high repetition rate Ti:Sa laser: DC field enhanced remote production from air filament and THz unipolar pulses from relativistic laser plasma interaction.

Femtosecond filamentation in air is known as a very promising source of THz pulses. Different schemes were developed to enhance efficiency, and among them the scheme with an external DC field looks especially interesting for the remote applications. Our experiments proved that maximum THz efficiency can be achieved if DC electrodes have the same length as the single-color filament and this scheme is efficient even at long distances from the laser source.

The main drawback of all the approached based on non linear conversion of femtosecond laser pulses into THz range is intensity limitations (filamentation in air, lithium niobate or organic molecular crystals, etc.). This limitation can be avoided if plasma is used instead. Here we report on our progress toward generation of sub cycle (quasi unipolar) THz pulses from relativistic laser interaction of laser pulse with thin plasma slab. Various approaches and optimization of the THz sources are presented.

Keywords: Femtosecond lasers, plasma, Terahertz radiation

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THz emission spectroscopy: probing and controlling ultrafast photocurrents in ferroelectric α−In_2Se_3

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Abstract: Nonvolatile control over the physical state of polar materials through all-optical methods and elucidating intricate photophysical processes has been a long-standing objective pursued in optoelectronics. Photoferroelectric semiconductors exhibit immense potential in capturing multimodal nonvolatile states, attributed to their spontaneous and reversible in-plane and out-of-plane polarizations, stemming from the versatility of their electronic degree of freedom. Herein, we uncover an unprecedented nonvolatile, zero-bias, ultrafast photocurrent hysteresis response with an innovative all-optical approach, discerned by analyzing in-plane and out-of-plane THz waves emitted from photoferroelectric α-In_2Se_3. The mechanism underlying such ultrafast photocurrent hysteresis arises from anomalous linear and circular photovoltaic effects synchronously fueled by a localized rearrangement of polarization. By harnessing the anisotropic photoferroelectric kinetics-induced relative phase between the in-plane and out-of-plane polarizations, we further demonstrate the flexible selection of chirality, tunable rotational angle, and optimizable ellipticity of THz waves. Our findings present a unique ultrafast and non-destructive strategy for investigating photoferroelectric hysteresis, empowering dynamic polarization manipulation of THz waves for a wide range of THz applications.

Keywords: Terahertz Emission Spectroscopy, Ultrafast Photocurrent, Photoferroelectric Semiconductor

Nonlinear Photonics in the Terahertz Regime

Liwei Song

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Abstract: Ultrashort pulse laser technology and its associated instrumentation have achieved remarkable progress in recent decades, establishing themselves as indispensable tools across frontier scientific research, precision industrial manufacturing, and advanced biomedical applications. Capitalizing on these advancements, the synergistic integration of ultrafast laser systems with nonlinear optical frequency conversion techniques has catalyzed a paradigm shift in high-field terahertz (THz) source development. Modern THz sources now deliver tunable spectral characteristics across multiple frequency bands, offering tailored excitation capabilities for probing non-equilibrium states in low-photon-energy condensed matter systems. The marriage of these intense THz sources with ultrafast pump-probe spectroscopy has opened unprecedented observational windows into THz-driven non-equilibrium dynamics. By leveraging both high peak fields (up to 10 MV/cm scale) and optimal photon energies (meV range), these THz excitations enable coherent manipulation of quantum states and lattice interactions with femtosecond precision. This talk will explore cutting-edge strategies for high-field THz generation and nonlinear photonics within the THz regime.

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Chiral Fermion Enantiomers Identification via Circular Photogalvanic Effect Related Ultrafast Terahertz Emission

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Abstract: Chirality is becoming one of the new cores of condensed matter physics, affecting multiple fields from quantum materials to topological quantum materials, and exotic properties in various quantum materials and promising future applications are emerging. Topological chiral semimetals are ideal material platforms for studies of chirality-related phenomena as well as topological properties. However, high-throughput identification of chiral enantiomers, which is the first and foremost characterization in chiral studies, is still lacking. Here, we show that terahertz (THz) emission from ultrafast excited circular photogalvanic effects of chiral fermions can be used to identify the chirality of topological chiral semimetal. The emitted THz electric fields induced by transient photogalvanic effect are reversed for the opposite enantiomers. This efficient and simple optical measurement and its intuitive results reveal that THz emission spectroscopy is very promising as a high-throughput, contactless and non-destructive method for identifying the chirality of chiral materials and therefore promotes studies of chiral physics and chiral materials.

Terahertz-driven Subcycle Electron Emission Dynamics and Multidimensional Control

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Abstract: Ultrafast laser fields enable coherent control of electron beams across energy, temporal, and quantum domains—key to advancing attosecond science and lightwave electronics. While free- space interactions face limitations in field strength and phase-matching, exploiting optical near- fields like surface plasmon polaritons (SPPs) unlocks efficient light-electron coupling. In our prior work, we demonstrated terahertz (THz) SPP amplification via free-electron pumping, achieving coherent energy transfer through superradiant growth of the SPPs. Building on this, SPP-driven acceleration in an integrated waveguide was implemented, where THz Sommerfeld waves delivered record 1.1 MeV gains (210 MV/m gradients) by synchronizing the electron phase with subcycle optical fields. Critically, these advances reveal THz's unique ability to bridge macroscopic energy control and microscopic subcycle dynamics via its long wavelength and single-cycle waveform.

Capitalizing on this feature of THz, we recently developed a direct reconstruction method resolving emission dynamics without pump-probe techniques. Driving a graphite nanotip with phase-stable THz pulses (191–290 kV/cm), spatially inhomogeneous near-fields established a monotonic energy-time map, which allows for extracting temporal emission profiles. We found that at near-zero carrier-envelope phase (CEP), spectral peaks scaled linearly with field strength, confirming Fowler-Nordheim emission. Temporal profiles extracted solely from energy spectra revealed pulse durations broadening from 97.3 to 114.3 fs with rising intensity—quantitatively validating tunneling theory. At opposite CEP (0.80π), however, deceleration fields anchored a stationary spectral peak, while simulations showed 71.2% cutoff-energy modulation and 99.7% current suppression, highlighting coherent phase control.

Further leveraging THz's subcycle control, we also proposed a design for generating isolated attosecond electron pulses: a bow-tie resonator enhanced THz fields to 13.9 GV/m, slicing 817- as pulses from 500-fs bunches via streaking and aperture gating. This scheme—extendable to

DC sources—enables compact temporal sculpting for ultrafast microscopy. Collectively, these advances establish THz-driven coherent control spanning energy transfer (SPP acceleration), temporal tailoring (attosecond chopping), and dynamics quantification (subcycle reconstruction), paving the way toward programmable electron wave packets.

Keywords: Terahertz; Electron dynamics; Attosecond pulses; Surface plasmon polaritons

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Terahertz Radiation Enhancement, Modulation, and Diagnostics via Near-Field Manipulation of Plasma Filaments

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University of Shanghai for Science and Technology

Abstract: Over the past three years, we have developed methods for manipulating the dielectric constant distribution in the near-field of laser-induced plasma filaments. By employing perturbations with polar materials, spatial shaping of filament density, and multi-filament interactions, we achieved precise control over the dielectric constant distribution at the peripheries of the filaments at sub-terahertz wavelength scales. This approach has not only enabled the diagnostics of terahertz bound modes in the near-field and enhanced far-field terahertz radiation but also facilitated all-optical calculus operations (first- and second-order) on broadband single-pulse terahertz signals. These advancements provide a theoretical foundation and key technological support for deepening the understanding of laser-plasma-terahertz wave interaction mechanisms and developing novel free-space all-optical terahertz modulation platforms, including radiation sources, waveguides, and modulators.

Systematic optimization of the THz yield from the dual-color air-based plasma

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Abstract: Among the terahertz (THz) sources, a two-color femtosecond filament in gases provides the coherent THz emission with the most broadband spectrum, which spans up to several tens of THz. Optical to terahertz conversion efficiency in the gas-based plasma reaches ~0.01% for the near infrared (800+400 nm) or up to 1% for the mid-infrared pump [1]. By positively chirping the initial pulse, one can increase the optical to THz conversion efficiency by an order of magnitude [2]. The THz yield depends strongly on the relative phase between the fundamental and the 2nd harmonic radiation. Recently it was found that the relationship between THz pulse energy and chirp changes with variations in the specific phase difference between the first and second harmonics, and that the maximum THz energy might be attained not only for positively, but also for the negatively chirped pulse [3].

In this work we find both experimentally and numerically that the initial duration of the chirped pulse in the two-color (800+400 nm) filament in air is the major factor that determines the THz energy yield. By scanning through the relative (ω–2ω) phase shift in the range (0–180°) for each chirped pulse duration between -200 and 200 fs, we found that the optimum pulse duration, responsible for the maximum THz energy, does not change essentially with the chirp sign. This scan presents systematic multiparameter optimization of optical pulse to terahertz radiation conversion.

In the experiment the fundamental 800 nm, 4.5 mJ, 37 fs FWHM pulse with 9 mm beam diameter was focused with f = 30 cm lens followed by the beta-BBO crystal into air, where it created a filament. The THz radiation, remained after the Teflon plate, was collected by the two parabolic mirrors with f = 15.4 cm followed by the Golay cell. In the simulations we used 3D+t axially symmetric carrier-resolved code based on unidirectional pulse propagation equation.

In conclusion, we demonstrate that the chirped pulse duration, but not the chirp sign, is the major factor determining the THz yield from a dual-color filament in air. In both the experiment and simulations, the THz energy reaches its maximum at approximately the same pulse duration but the opposite chirp signs, if the relative initial phase shift between the first and the second harmonics is gradually varied to attain the maximum THz yield.

The research was supported by Russian Science Foundation,project No. 25-49-00154 (https://rscf.ru/en/project/25-49-00154/), and National Natural Science Foundation of China (project No. W2412044)

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Nanoscale THz nonlinearity driven by femtosecond laser filamentation

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Abstract: Although THz scattering near-field optical microscopy (THz s-SNOM) with sub-diffraction limit spatial resolution and remarkable field enhancement can provide new insight into efficient Terahertz nonlinearity in nanoscale, exploring nanoscopic THz Nonlinear optics (NLO) still remains challenging due to the universally adopted low excitation power with the high repetition for near-field demodulation. Here we report an intense THz s-SNOM by combining high peak power THz pulse emitted from two-color femtosecond laser filaments with common THz s-SNOM for demonstrating the efficient THz third harmonic generation in 3D DSM Cd3As2 with nanoscale localized field enhancement. Additionally, the near-field third harmonic imaging with resolution of 200 nm, that is nanoscopic near field THz THG of 3D Dirac semimetal are demonstrated.

Keywords: THz, scattering near-field optical microscopy, nonlinear optics, nanometer resolution

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Enhancement of laser-induced single-cycle terahertz generation in a spintronic Pt/Co emitter with a composition-gradient interface

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Abstract: Generation of electromagnetic radiation in the terahertz (THz) frequency range is an interesting fundamental and technical problem, while sources of such radiation are in demand in several applications, from the study of biological objects to the development of security systems [1]. Spintronic emitters, in which THz radiation is generated as a result of the excitation of laser-induced spin dynamics in thin magnetic films, have proven to be promising sources of broadband pulses with frequencies from fractions of a terahertz up to 20 THz [2]. However, the radiation intensity of such sources is still inferior to alternatives, in particular, generators based on nonlinear optical effects in lithium niobate and organic crystals [3]. In this regard, an important fundamental and applied challenge is to find ways to optimize the structures employed as spintronic emitters.

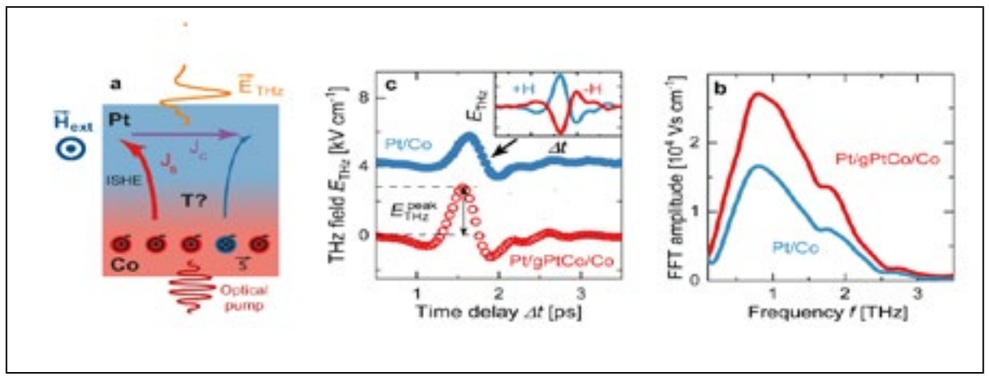

Figure 1. (a) Schematics of Pt/Co spintronic. Spin current J_s is generated via ultrafast laser-induced demagnetization in Co, injected through the interface with a transmittance T into Pt, and converted to the change current J_c conversion via inverse spin-Hall effect. J_c serves as a source of the single-cycle THz pulse. (b) Temporal waveforms of the THz pulses generated in the Co/Pt emitter with the gradient interface (red symbols) and with the abrupt interface (blue symbols). (c) FFT spectra of these THz pulses.

The aim of this work [4] is to determine the influence of the ferromagnet/heavy metal Pt/Co interface on the efficiency of converting optical femtosecond laser pulses into THz pulses in a spintronic emitter Co/Pt (Fig. 1(a)). For this purpose, we study experimentally single-cycle THz pulse generation from a laser-pulse excited Pt/Co emitter with a composition gradient interface between Pt and Co and compare it with the emission from a conventional Pt/Co structure with an abrupt interface. The two main structures under study were (numbers are layer thicknesses in nm):

Si/Ta(2)/Pt(3)/Co(1.2)/Ta(2) – a structure with the abrupt interface between Co and Pt layers;

Si/Ta(2)/Pt(3)/gPtCo(1.2)/Co(1,2)/Ta(2) – a structure with the interface between Co and Pt layers being a composition gradient layer gPtCo [5].

Femtosecond laser pulse with a central wavelength of 800 nm, duration of 50 ps and energy density up to 3 mJ cm^{-2} were used to excite the structures. Time-resolved THz spectroscopy was used to obtain the temporal waveforms of the generated THz pulses.

The main result is that the gradient interface enhances the efficiency of optics-to-THz conversion by a factor of two (Fig. 1(b,c)) in a wide range of optical fluences up to 3 mJ cm^{-2}. This enhancement is caused by a pronounced increase in transmittance T of the laser-driven spin-polarized current through the gradient interface compared to the abrupt one. Furthermore, such a transmission deteriorates with laser fluence due to the spin accumulation effect. We also note that the Pt/Co structure with the gradient interface supports in-plane magnetic anisotropy required for THz emitters in combination with a small Co layer thickness optimal for efficient spin current generation. This contrasts with Pt/Co structures typically characterized by an out-of-plane anisotropy.

This work is partly supported by the Russian Science Foundation grant No. 23-12-00251.

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Nonlinear terahertz dynamics of solid-state materials

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Abstract: In the talk I will present an overview of our recent experimental studies of nonlinear terahertz dynamics in several representative classes of solid-state materials, including Dirac semimetal, semiconductor, and strongly correlated metal. By using time-resolved ultrafast terahertz high-harmonic generation spectroscopy, we are able to reveal characteristic nonequilibrium nonlinear dynamics of Dirac fermions [1], may-body excitonic states [2], and quantum critical metal [3] in the terahertz frequencies. I will show that the ultrafast terahertz high-harmonic generation spectroscopy is very powerful for the investigation of the complex dynamic behaviors of Dirac fermions, many-body excitons, or strongly correlated electrons, and present our understanding of the physics responsible for the very intriguing nonlinear phenomena.

Keywords : Terahertz high-harmonic generation, ultrafast nonequilibrium dynamics, Dirac fermions, many-body excitons, strongly correlated electrons

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Anomalous third-order nonlinearity of disordered superconductors close to a superconductor-insulator transition

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Abstract: Disorder significantly influences the coupling between the terahertz (THz) photon and the Higgs mode, yet the effect of strong disorder on the nonlinear spectrum of superconductors remains largely unexplored. Here, we present a systematic THz third-harmonic generation (THG) study on NbN thin films with varying Ioffe-Regel parameters (kFl), as functions of temperature and magnetic field. In strongly disordered NbN (kFl≈2.5) near the superconductor-insulator transition (SIT), we observe an anomalous normal-state THG signal, absent in both clean superconducting (kFl≈7.2) and nonsuperconducting (kFl<1) films. This signal persists even when superconductivity is fully suppressed by a magnetic field, ruling out superconducting fluctuations as its origin. Below Tc, the THG intensity rises sharply, indicating a dominant contribution from the driven Higgs mode. Notably, the THG spectrum of the strongly disordered sample displays a characteristic multi-peak structure, attributed to path interference between distinct THG channels involving unpaired electrons and Cooper pairs confined in superconducting islands. This feature directly reflects how strong disorder modifies the nonlinear spectrum of the Higgs mode. Our results establish THz nonlinear spectroscopy as a bulk-sensitive, statistical probe of mesoscopic inhomogeneity in disordered superconductors through their collective modes.

Coherent SHG Modulation via THz-Driven Phonon-Polaritons in ZnO

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Abstract: The coherent control of phonon polaritons (PhPs) in holds transformative potential for nonlinear photonics. We demonstrate terahertz-driven excitation of low-frequency PhPs in zinc oxide (ZnO) crystals, with their nonlinear dynamics resolved via time-resolved second harmonic generation (SHG) spectroscopy. By achieving phase matching via nine sequential reflections within a millimeter-scale crystal, we observe sustained SHG oscillations with 3–4 THz modulation frequencies, achieving optimal extinction ratios of ~18 dB that persist for 90 picoseconds—a temporal span directly governed by polariton propagation dynamics. This work establishes a dual-functionality platform enabling spectral-temporal resolved mapping of quasiparticle interaction dynamics while simultaneously advancing polariton-engineered nonlinear optical modulators through symmetry-broken frequency conversion architectures.

Nonlinear Spin-Lattice Dynamics in A Layered Antiferromagnet Revealed by Terahertz 2D Coherent Spectroscopy

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Abstract: The response of quantum materials to external perturbations is largely governed by collective excitations, which dictate many correlated phenomena. Nonlinear dynamics of these collective modes offer rich insights into the underlying interactions between different degrees of freedom and provide pathways for manipulating quantum phases. Two-dimensional (2D) honeycomb lattice spin systems, with their diverse magnetic orders, present an ideal setting for studying the coupling between magnons and phonons in both linear and nonlinear regimes. In this presentation, we first report the observation of the magnon-phonon hybridization in 2D zigzag antiferromagnets. Using terahertz two-dimensional coherent spectroscopy, we further unveil the nonequilibrium and nonlinear dynamics of both magnons and phonons, shedding light on their intricate interactions in 2D antiferromagnetic materials.

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Track 4 Ultrafast Imaging and Spectroscopy

Two-dimensional fluorescence excitation spectroscopy (2D-FLEX): experimental approaches and first insights

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Abstract: Multidimensional time-resolved spectroscopy has emerged as the most comprehensive method in non-linear spectroscopy. Despite its advantages, the wealth of information in two-dimensional electronic spectroscopy (2D-ES) can turn into a downside, as several signal pathways such as stimulated emission and excited state absorption may overlap. In the recently proposed two-dimensional fluorescence excitation spectroscopy (2D-FLEX), we retain the advantages of excitation frequency resolved signal representation, but focus on a single signal pathway, namely fluorescence. In this way, 2D-FLEX reports exclusively on excited state processes and eliminates ambiguities in data interpretation.

The most straightforward way of implementing 2D-FLEX is by adding an interferometer to the pump arm of a fluorescence upconversion (FLUPS) experiment. We show how a collinear interferometer based on birefringence (TWINS) adds the desired excitation frequency resolution. First results on Stokes shift dynamics on a solvated dye molecule will be discussed. An alternative approach is given by time-resolving fluorescence in a non-collinear parametric amplification (NOPA) process. This approach has been shown to provide a large fluorescence amplification factor of up to six orders of magnitude, see e.g. Xiao-Feng Han, Xing-Hai Chen, Yu-Xiang Weng, and Jing-Yuan Zhang, “Ultrasensitive femtosecond time-resolved fluorescence spectroscopy for relaxation processes by using parametric amplification,” J. Opt. Soc. Am. B 24, 1633-1638 (2007). We compare both approaches to 2D-FLEX (FLUPS and NOPA-FL) and discuss a third variant based on two-photon excitation. The latter provides spectral separation of pump- and fluorescence wavelengths. We show how two-photon fluorescence excitation spectra are obtained with a TWINS interferometer. The spectral resolution of the experiment is more than sufficient to resolve vibronic progression peaks in the two-photon excitation spectrum of perylene dyes in solution. The latter serve as linkers in metal-organic frameworks (MOFs). We discuss how the architecture and inter-chromophore coupling in a MOF affects the two-photon response as compared to uncoupled linker molecules in solution.

Besides first results on the FLUPS-based implementation of 2D-FLEX, we will discuss theoretical aspects of 2D-FLEX, specifically the mutual dependence of frequency- and time-resolution on the detection axis, which is missing in 2D-ES. Based on simulations of time-resolved signals of a paradigmatic four-level system and the Fenna-Matthews-Olsen complex (FMO), we provide a direct comparison to 2D-ES and 2D-FLEX, underlining the simplicity and ease of data interpretation in the latter.

Keywords: Multidimensional spectroscopy, 2D-ES, 2D-FLEX, FLUPS, NOPA-FL

Fast Detector for High-Sensitivity Ultrafast Spectroscopy

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Abstract: Ultrafast spectroscopy has been widely employed to probe the excited-state dynamics underlying solar-to-electricity conversion in optoelectronic materials. However, because of limited detection sensitivity, experiments are often performed at excitation densities far above solar illumination. To overcome this challenge, we developed a high-speed, large-well-depth, low-noise spectroscopic detector that significantly enhances sensitivity. This advance enables precise characterization of excited states in photoactive materials under excitation densities equivalent to sunlight. Building on this foundation, we further developed methods including transient magneto-optical spectroscopy, two-dimensional electronic spectroscopy, and high-precision terahertz spectroscopy. These experimental breakthroughs have revealed intrinsic excited-state dynamics in molecular systems and provided important insights for optimizing the performance of optoelectronic devices.

Keywords: Ultrafast spectroscopy, Solar energy conversion

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Energy transfer and charge separation mechanisms initiated by antenna excitons in the Heliobacterial reaction center

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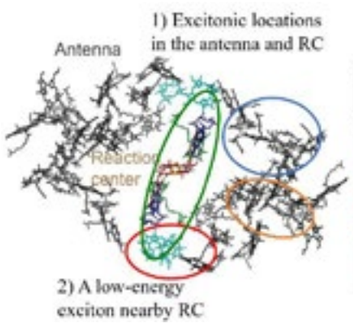
Abstract: The heliobacterial reaction center (HbRC) is widely regarded as the closest modern analog of the ancestral photosynthetic reaction center[1]. Although structurally similar to photosystem I (PSI), it features chemically distinct pigments—such as Chl a_F—as its primary electron acceptors. Investigating the mechanisms of energy transfer and charge separation in HbRC is therefore critical for understanding not only the mechanisms of excited-state processes in other photosynthetic reaction centers, but also their structural and functional evolution. Building on our previous work[2] that characterized the excitonic structure and charge separation dynamics within the core RC of HbRC, we now explore the photophysical processes initiated by antenna excitons using two-dimensional electronic spectroscopy (2DES) [3]. The high temporal and spectral resolution of 2DES enables us to disentangle overlapping pathways of energy transfer and charge separation arising from distinct excitons. Through lifetime density and global-target analyses, we construct a comprehensive kinetic map involving most energy transfer and charge separation pathways. Notably, we resolve and assign several key excitonic states to specific pigment domains within the HbRC. Among them, we identify a low-energy exciton located near the reaction center that acts as an energy funnel bridging the antenna and core RC. These results offer new insight into excitonic structure and photophysical mechanisms of HbRC, and shedding light on how early photosynthetic systems may have evolved to achieve efficient energy conversion.



Lifetime	peaks (nm)	Proposed assignment
0.80 ps	747	Excitonic relaxation
1.38 ps	768, 791	RC and near RC
4.13 ps	802-807	RC
16 ps	778	Antenna
250 ps	748, 765, 794, 807	Relax to low-energy exciton before charge separation

Fig. 1 Energy transfer and charge separation in the HbRC

Keywords Energy transfer, charge separation, photosynthesis, two-dimensional electronic spectroscopy

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Femtosecond Broadband Transient Fluorescence Spectroscopy

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Abstract: The femtosecond time-resolved transient fluorescence spectrometer, based on the principle of non-collinear optical parametric amplification (NOPA), possesses unique advantages including high temporal resolution, high gain, broad measurement bandwidth, and low detection limit. This makes it a crucial tool for investigating ultrafast photochemical and photophysical dynamics. However, parametric superfluorescence (PSF), originated from the intensity fluctuations of vacuum quantum noise introduced during the optical parametric amplification process, constitute the primary noise source, significantly limiting the instrument's ability to detect weak transient fluorescence signals. We propose and implement for the first time a femtosecond fluorescence conical optical parametric amplification spectroscopy (FCOPAS), aimed at effectively suppressing the noise fluctuation from the PSF background. In contrast to traditional NOPA configurations utilizing lateral fluorescence collection and dot-like parametric amplification, FCOPAS employs an innovative conical fluorescence collection and ring-like amplification setup. This design enables effective cancellation of noise fluctuation across the entire PSF ring, resulting in an approximate order of magnitude reduction in PSF noise compared to prior NOPA outcomes. This breakthrough enables the detection of previously undetectable weak transient signals. Utilizing this advanced technique, we have experimentally observed the transient fluorescence dynamics of chlorophyll molecular excited states and various photosynthetic protein systems. These observations have revealed key ultrafast dynamical processes within these systems, including energy transfer, charge separation, and vibrational cooling.

Keywords: Femtosecond transient fluorescence spectroscopy; Parametric superfluorescence; Vibronic coupling; Chlorophyll excited states; Photosynthetic protein systems

Ultrafast all-optical logic gates in quasi-2D perovskites

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Abstract: Optical logic gates are fundamental building blocks for all-optical computing and optical interconnects. Spin-based optical logic gates have the potential to enhance information capacity and processing speed, meeting the growing demand for information processing in next-generation optical networks. Owing to dielectric and quantum confinement effects, two-dimensional/quasi-two-dimensional perovskite materials exhibit high exciton binding energies. Meanwhile, the strong spin–orbit coupling of heavy atoms such as lead makes them promising candidates for spin-optoelectronic devices and provides a platform for studying the relaxation behavior of spin-polarized electrons. The use of chiral metasurfaces enables further control over the excitation and relaxation processes of spin-polarized electrons, laying the groundwork for ultrafast spin–photon devices.

We investigated the exciton dynamics of quasi-two-dimensional perovskite $PEA_2(FAPbBr_3)_2PbBr_4$ films under non-resonant excitation. Using a circularly polarized pump–probe technique, we observed a spin-selective optical Stark effect (OSE), achieving a Stark shift of 3.3 meV under 1.11 eV excitation. In spin-selective OSE, the OSE signal is strong when the pump and probe beams share the same circular polarization, and weak when they have opposite circular polarizations, enabling the realization of a spin-encoded all-optical XNOR gate with a response time of approximately 180 fs.

To enable more logic functions, we proposed further manipulation of spin-selective OSE using chiral metasurfaces. We fabricated two-dimensional perovskite (PEA_2PbI_4) metasurfaces with optical chirality near the optical communication wavelength of 1550 nm, where the local electric field intensities for left- and right-handed circularly polarized light differ significantly. When the pump and probe beams have the same circular polarization, pump pulses with the same energy density but opposite handedness produce OSE signals of different intensities. Using a pair of enantiomeric chiral metasurfaces, we realized AND, NOR, and NOT gates with response times reaching 122 fs. Our work offers a new approach for implementing spin-based all-optical logic devices with femtosecond response times using perovskite materials.

Keywords: Quasi 2D perovskite, optical Stark effect, chiral metasurfaces , optical logic gates

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Ultrafast photoelectron imaging of spatiotemporal plasmonic vortices

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Abstract: Optical vortices and their spatiotemporal extensions provide a powerful means to structure light in both space and time, enabling advances in ultrafast optics, quantum control, and topological photonics. Translating these concepts to surface plasmon polaritons unlocks new possibilities for nanometer–attosecond field engineering at metal–dielectric interfaces. In this talk, I will present the generation mechanism of spatiotemporal plasmonic vortices (STPVs), created by coherently interfering two plasmon vortex wave packets to sculpt spatiotemporal vortex singularities in joint space–time coordinates. Using interferometric time-resolved two-photon photoemission electron microscopy (ITR-2P-PEEM), we directly image their evolution with simultaneous nanometer spatial and attosecond phase resolution, revealing tunable vortex charge, position, and time-reversal symmetry breaking on deep-subwavelength scales. I will further discuss the generation and characterization of higher-order STPVs, supported by quantum pathway mapping and density-matrix modeling of the coherent nonlinear photoemission process. These STPVs offer promising routes toward ultrafast topological field control, coherent quasiparticle manipulation, and on-chip Petahertz optoelectronic functionalities.

A 4D Spectroscopic Diagnostic Method for Laser-induced Plasma aided by Femtosecond Filamentation probe

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Abstract: Understanding the spatiotemporal evolution of species in laser-induced plasma (LIP) is significant for LIP applications, such as laser fusion, extreme ultraviolet, laser processing, LIP spectroscopy, and so forth. However, common LIP diagnostics only allow for capturing two-dimensional (2D) characteristics of the LIPs and suffer from spatiotemporal integral effects. These effects obscure the large gradients in the physical and chemical properties of LIPs over time and space. Therefore, in this work, we introduce for the first time a four-dimensional (4D) ultrafast spectroscopic diagnostic, that is, a temporal dimension and three spatial dimensions, for the spatiotemporal evolution of species in LIP using femtosecond laser filamentation. The schematic diagram of the 4D spectroscopic diagnostic is shown in Figure 1. By virtue of the extremely high-power density in filamentation probe, species within the plasma are re-excited, and fs-laser induced breakdown spectroscopy (FIBS) for the local species is obtained, as shown in Figure 1(c). It follows from the FIBS that the spatiotemporal distributions of Fe, Al, and Mn in the vertical plane of plasmas with a thickness of about 100 μm are mapped, effectively avoiding the spatiotemporal integral effects. Moreover, the fractionation of the elements in LIP is obtained, showing that the Al elements mainly distributed in the outer shell and the tail of the plume. In contrast, the Mn element is mostly distributed in the inner shell of the plume. Additionally, the self-absorption effects on diagnosis through the FIBS in the horizontal direction are investigated. This study provides a novel and important avenue to diagnose the LIP with high spatiotemporal resolution in a 4D manner, exhibiting great potential in LIP applications.

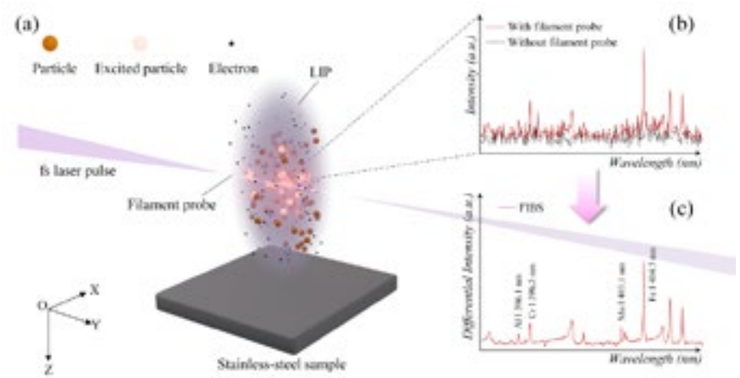

Figure 1. Schematic diagram of the laser-induced plasma 4D diagnosis using a femtosecond laser filamentation. (a) Interaction between a femtosecond laser filamentation probe and a laser-induced plasma. (b) Spectral signals of FIBS and ns-LIPS. (c) Differential FIBS spectra.

Keywords: Laser-induced plasma, 4D ultrafast spectroscopic diagnosis, femtosecond laser filamentation, fractionation effect.

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Unravelling photo-induced hot charge carrier dynamics in low-dimensional perovskites by ultrafast optical spectroscopy

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Abstract: Rapid cooling of photoinduced carriers with excess energy above the bandgap, or hot charge carriers (HCCs), is one of the major energy loss channels in current photovoltaics/photocatalysis applications. These processes are receiving intense interest following the triumph of the perovskite-based photoelectronic devices. In particular, the emergence of low-dimensional perovskite structures have again revived the HCC-based applications for their potential in control of HCC dynamics. For example, 2D organic-inorganic lead halide perovskites, in which interspersed organic spacers clamping the assembled Pb-X octahedra form typical periodic quantum well structures, provide tunable dimensional quantum confinement and subsequently possible control of energy flow of HCCs. Concurrently it has been revealed that the relaxation is mostly mediated by the carrier-phonon coupling (CPC) interaction. Although by suppressing CPC it is straightforward to slow the HCC cooling accordingly, so far the community still lacks an insightful investigation in direct control of the CPC. This is largely due to the challenges in reliably probing the coupling with diverse phonon modes in low-dimensional perovskties, as well as the lack of theoretical frameworks capable of quantifying their energy dissipation pathways.

In this talk, we raise the question in what ways low energy phonons or lattice oscillations in low-dimensional perovskties affect the CPC interaction and subsequently the HCC relaxation. By fitting to ultrafast transient absorption spectra using a fine model based on the Fermi-Dirac distribution with modulation effects on the bandgap, the HCC dynamics on short time scales can be reliably revealed. We then find a suppressed HCC cooling rate by reducing mechanical oscillation (MO) frequency of the 2D pervoskite film sample when an additional surface load layer is deposited. We further supplement a periodically forcing oscillation model and unravel the role of MOs in HCC energy dissipation. By this model, we elaborate the counterintuitive trend found herein of the HCC cooling in different 2D perovskite film samples with different organic cations that could result in different MOs. Our work complements the missing understanding of the role that MOs paly in HCC relaxation in 2D perovskites, and may provide a practical approach by stiffness engineering to manipulate the HCC behaviors in 2D perovskites towards to diverse applications.

Keywords: Hot charge carrier; ultrafast carrier dynamics; ultrafast optical spectroscopy; optoelectronic materials; low-dimensional perovskite.

Unveiling Solvation Dynamics of Excited and Ground States Via Ultrafast Pump-Dump-Probe Spectroscopy

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Abstract: The conventional ultrafast pump-probe spectroscopy has primarily focused on examining the formation and decay of the excited state intermediates, but it is very difficult to detect those intermediates while the formation is slow and dissipation is much fast, because of the limited concentration during the intrinsic photocycle. To address this issue, a multi-pulse ultrafast pump-dump-probe spectroscopy was employed to generate and probe the short-lived ground state intermediates (GSIs) in an electronic push−pull pyrene derivative (**EPP**). This particular derivative undergoes planarized intramolecular charge transfer (PICT) in the excited state upon initial femtosecond pulse excitation. After applying the dump pulse once the PICT was formed, the blue shifted transient absorption GSIs with the ground state dynamics of the structure recovery was directly observed. It is found that GSIs undergo slower reorganization than the PICT formation in the excited state of **EPP** due to solvation effect with different dipole moments of ground states and excited states. These findings provide a comprehensive understanding of the full photocycle dynamics of both the ground and excited states, shedding light on the presence of hidden ground state behaviors.

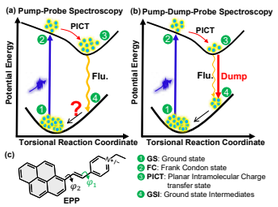

Figure 1. Schematic depiction of planar intramolecular charge excited-state relaxation via (a) pump-probe spectroscopy and (b) pump-dump-probe spectroscopy for correlating. (c) Molecular structure of the compound **EPP**.

Keywords: ultrafast pump-dump-probe spectroscopy, solvation, dipole moment

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Mid-IR Harmonic Generation from Liquid Water Jets under Extreme Conditions

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Abstract: We investigate harmonic generation in the visible spectral range from a flat liquid water jet driven by resonant mid-infrared (MIR) pulses. Intense MIR excitation induces strong vibrational absorption in water, producing high-temperature and high-pressure states, while strong-field excitation with intense 800 nm pulses creates high-density electron plasmas. Remarkably, harmonic generation is observed under both extreme conditions. In the first experiment, ~30 μJ, 70 fs pulses at 3100 nm were focused on an ~8 μm-thick water jet. With weak MIR prepulses, a gradual enhancement of the harmonic yield appears about 2 ps after pre-excitation and lasts for more than 120 ps. This enhancement becomes more pronounced near the 2940 nm resonance, suggesting ultrafast heating of liquid water to ~4200 K and the loss of hydrogen bonding [1]. In the second experiment, the rapid creation of plasmas leads to an electron density exceeding the critical density. Under such conditions, harmonics are still generated by intense evanescent fields confined at the air–water interface, and spectral narrowing is observed due to the absence of nonlinear propagation [2]. These results demonstrate a new regime of harmonic generation in liquids at intensities of 10^{14}–10^{15} W/cm², which may enable attosecond-scale control of electron motion in condensed matter.

Keywords: Liquid water jet; intense mid-infrared pulses; harmonic generation, strong-field interaction

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THz selective control of quantum materials at ATHOS/SwissFEL

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Abstract: The physics of quantum materials is enriched by the interplay between charge, orbital, spin, and lattice. This interplay can in principle be exploited to achieve ultrafast control of the material properties. High-temperature cuprates are one of the most studied classes of strongly correlated materials, however, the microscopic mechanism behind superconductivity in these materials has not been fully understood. Ultrafast laser pulses, especially strong-field THz pulses, can effectively manipulate the coupling between the co-existing and/or competing phases and enhance quantum properties. In this regard, further understanding of the ultrafast dynamics in light-driven cuprates might define a novel route toward the realization of superconductivity at even high-temperatures.

Taking advantage of the brilliant soft X-ray pulses from the ATHOS beamline at SwissFEL, we aim to discover the underlying physics of quantum materials with state-of-the-art ultrafast laser sources and complementary X-ray detection techniques at Furka, the condensed matter endstation at Athos. In this talk, I will give a short overview of the laser infrastructure and scientific capability of Furka endstation. Then, I will discuss the potential of THz quantum control with a special focus on our recent experiments of probing dynamics of competing charge orders (CO) in cuprate superconductor induced by mid-infrared and THz excitation with time-resolved resonant inelastic X-ray scattering (tr-RIXS). We study $YBa_2Cu_3O_{6.6}$ (YBCO), a bi-layer cuprate in which CO is established below T_{CO} = 103 K and superconductivity sets in below T_{SC} = 58 K. Experimentally, we set the X-ray photon energy to 932 eV and collect RIXS spectra with 150 meV energy resolution, near wave vector $\boldsymbol{q}_{//}$ = -0.31 to monitor the dynamics of CO after THz excitation. The sample was first pumped by 20-THz pulses with grazing incidence to resonantly excite the out-of-plane optical phonon, which previously showed the signature of enhancing superconducting correlations. A systematic measurement at different temperatures revealed that the CO was suppressed in both pseudogap and superconducting phases, which could potentially support the previous assumption of promoting incipient superconducting condensation. To compare, we also excite the system with strong-field pulses centered at 2 THz. The CO was enhanced with a higher intensity than the equilibrium value at T_{SC}, indicating the effect of quenching superconductivity, similar to applying magnetic field. Notably, a coherent oscillation of the CO intensity at 0.8 THz was observed at 80 K in the pseudogap phase, which could be associated with the amplitudon of the CO. It implies that, by perturbing the system with photon energy much lower than the corresponding energy scales, the order parameters of the competing phases started to largely oscillate around the equilibrium of the energy potential, inferring a corresponding fluctuation of the incipient superconducting correlation. We hope our result will shed new light on the understanding of light-induced phenomena in cuprate superconductors.

Keywords: THz quantum control, time-resolved RIXS, superconductivity, charge order

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Ultrafast electron microscopy: Instrument developments and scientific applications

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Abstract: In the past decade, four-dimensional electron microscopy (4D-EM), which enables the direct observation of transient structures, morphologies and even carrier transport of materials in real time and space, has attracted increasing interest to the research community due to its powerful capability in the interdisciplines of physics, chemistry, material science, and biology. In this presentation, I will firstly give a brief introduction of the development of 4D-EM and the state-of-the-art of its applications in scientific research. Then, I will present our recent progress in the development of a new generation 4D-EM based on a 200kV field emission transmission electron microscope at Nankai University and its application to the dynamics of topological magnetic structures. Following that, I will talk about our development of the development of a femtosecond electron-based versatile microscopy that combines scanning ultrafast electron microscopy (SUEM) imaging and time-resolved cathodoluminescence (TRCL) detection, which allows for visualizing and decoupling different dynamical processes of carriers involved in surface and bulk in semiconductors with unprecedented spatiotemporal and energetic resolutions. Using this technique, we directly tracked and distinguished the surface and bulk carrier dynamics involved in n-type GaAs and other semiconductors. We revealed, in real time and space, that hot carrier cooling, defect trapping, and inter-band-/defect-assisted radiative recombination in the energy domain result in ordinal super-diffusion, localization and sub-diffusion of carriers at surface, elucidating the crucial role of surface states on carrier dynamics. The high versatility and sensitivity of our method would allow capturing the magnetic domain and electronic dynamics of a wide range of materials with ultimate spatiotemporal resolution.

Keywords: Ultrafast electron microscopy, topological magnetic structures, scanning ultrafast electron microscopy, time-resolved cathodoluminescence, Photocarrier dynamics

Ultrafast Carrier Transport in Two-Dimensional Semiconductors

Long Yuan

University of Science and Technology of China

Abstract: Two-dimensional (2D) semiconductors have garnered significant attention due to their distinctive optical properties and electronic structures at the nanoscale. Gaining insight into charge carrier transport in these materials is essential for understanding their energy conversion mechanisms and advancing the development of next-generation, high-performance optoelectronic devices. In this work, we utilize an ultrafast optical imaging technique that integrates pump-probe and stroboscopic wide-field imaging, enabling high-throughput visualization of charge transport dynamics across various 2D semiconductors. Our study reveals a pronounced hot carrier diffusion process on the picosecond timescale in WS_2 and WSe_2—behavior that is absent in MoS_2 and $MoSe_2$. The hot carrier dynamics display strong thickness dependence and are markedly affected by substrate interfaces. Additionally, photocurrent imaging demonstrates that hot carriers possess significantly longer diffusion lengths than cold carriers. These results offer both experimental evidence and theoretical insights to guide the design of efficient 2D semiconductor-based optoelectronic devices.

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Photon Momentum Transfer and Partitioning: From One to Many

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Abstract:

Photoelectron Spin Texture in Strong-field Ionization Induced by a Linearly Polarized Laser Pulse

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Synopsis We demonstrate that photoelectron spin texture exhibits a vortex structure relative to the laser polarization axis in the strong-field ionization of inert gas atoms. The momentum-resolved polarization originates from the emergence of spin-correlated quantum orbits in the continuum. For direct electrons in few-cycle pulses, the nonvanishing initial transverse velocity of the electron is responsible for the polarization. In long pulses, the spin texture is essentially shaped by recollisions. Furthermore, the interference between direct and rescattering ionization leads to spin-polarized electron holography, offering an alternative method for extracting atomic fine structure information.

Spin-orbit coupling in bound states can create a strong correlation between the electron's spin and orbital angular momentum due to degenerate atomic energy levels. This correlation, combined with significant angular momentum-dependent ionization probability, results in a nontrivial photoelectron polarization. When combined with circular dichroism in strong-field ionization, significant polarization along the laser polarization axis becomes possible.

In contrast to a circularly polarized pulse, the total polarization of the ionized electron vanishes when the laser pulse is linearly polarized. Nevertheless, we demonstrate the emergence of significant momentum-resolved spin polarization (spin texture). We trace the origin of the spin texture to the correlation between spin and the initial transverse velocity of the photoelectron at the tunnel exit, which gives rise to spin-dependent quantum orbits. For direct electrons, using saddle point approximation in spin-resolved strong-field ionization, we demonstrate that the spin polarization forms a vortex relative to the laser polarization axis:

$$\langle \boldsymbol{\zeta}(\boldsymbol{p}) \rangle \sim \frac{\boldsymbol{p}\times\boldsymbol{E}(t_r)}{|\boldsymbol{E}(t_r)|},$$

where $\boldsymbol{p}$ is the photoelectron momentum and $\boldsymbol{E}(t_r)$ is the electric field at the instant of ionization. For rescattering electrons, the nontrivial momentum-resolved spin texture arises from forward rescattering of the spin-dependent quantum orbits and the associated quantum phase shift.

Moreover, the interference between direct and rescattered trajectories can lead to photoelectron Fig. 1, the typical spider structure is not only visible in the momentum distribution but also appears with enhanced resolution in the spin polarization.

The photoelectron spin texture is generally nontrivial in strong-field ionization, providing complementary information to the photoelectron momentum distribution. The nontrivial spin texture not only shows promise for enhancing the sensitivity of ultrafast electron spectroscopic techniques—such as photoelectron holography, attoclock, and streak camera measurements—but also may reveal novel methods for generating spin-polarized photoelectrons.

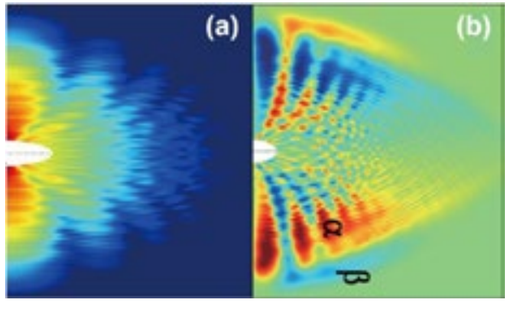

Figure 1. Photoelectron holography fringes observed in (a) photoelectron momentum distribution and (b) spin texture from a Xe atom.

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Track 5 Ultrafast Phenomena and Dynamics

Specific Structure and Ultrafast Vibrational Dynamics of Water Layers at the Interface of Fluorinated Polymers and Chiral Biomolecules

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Abstract: Water layers at polymer and biomolecular interfaces play a critical role in mediating the structure, dynamics, function, and stability of proteins and other biomolecules. Elucidating the structure and ultrafast dynamics of water molecules at these confined environments is essential for understanding the interaction mechanisms between biomolecules and water, which underpin many biological processes. This report highlights our recent advances in investigating the structure and ultrafast vibrational dynamics of water at the interface of fluorinated polymers and chiral biomolecules using femtosecond time-resolved sum frequency generation vibration spectroscopy. We identified a two-dimensional “hydrophobic water layer” on the Teflon surface at room temperature [1], isolated “H2O” monomers and chiral OH-(H_2O) species within Teflon matrices [2], and observed a structured “chiral water” arrangement at chiral biomolecular interfaces. By selectively exciting the N-H and C=O groups of protein amide bonds, we uncovered energy coupling between interface proteins and H_2O molecules, as well as the role of interfacial water in facilitating vibrational energy transfer within biomolecules [3]. Specifically, chiral water was found to couple strongly with the N-H vibrational mode while decoupling from nearby achiral interfacial water and bulk water [4], demonstrating distinct behavior relative to achiral water. These findings underscore the important role of chiral water in vibrational energy redistribution and propagation in biomolecular systems and provide new insights into the mechanism of chirality generation and transfer.

Keywords: hydrophobic water layer; water monomers; chiral water; ultrafast vibrational dynamics; sum frequency generation vibration spectroscopy

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Time-Domain Spectroscopy with Quantum-Correlated Light: Electron dynamics and interactions

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Abstract: Quantum-correlated light, e.g., entanglement and squeezing, open up a new avenue for molecular spectroscopy, by using parameters of the quantum-light correlations as new control knobs. With recent advancements of quantum optical technologies, imaging and controlling the electron and phonon motions in a variety of molecules are achievable, towards unprecedented time-energy scales and precision that are not attainable by classical light. Two essential problems emerge thereby: 1. quantum-light interactions with molecules containing much richer degrees of freedom than atoms; 2. Quantum fluctuations. The underlying physics still remains elusive for molecular spectroscopy and metrology.

In this talk, I will present an overview of our recent works on nonlinear optical spectroscopy for ultrafast electron dynamics, using quantum-correlated photons. The entangled twin photons and squeezed light will be of the most interest, with a focus on the time-resolved scheme. The transient absorption and Raman spectra with quantum-correlated light are studied, where the microscopic models are developed for a real-time monitoring of electron dynamics. Our results reveal an incredible time-frequency resolution beyond the classical Fourier's limitations, which therefore presents a quantum supremacy in the ultrafast spectroscopy.

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Enhancement effect of third-order transient optical nonlinearity under strong light-matter coupling

Kuidong Wang

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Abstract: Strong coupling of an optical mode with organic or inorganic materials paves the way for understanding the light-matter interactions. With the existence of this hybrid light-matter state, many properties of the material can be modified significantly[1]. Besides, recent studies also connected the hybrid light-matter states of specific organic materials with their nonlinear optical responses. For instance, the second harmonic generation[2] and the third harmonic generation[3], can be enhanced remarkably under strong coupling condition. However, the measurements in these works are only focused on some specific nonlinear optical phenomenons, this limits their generality in other nonlinear optical processes. In addition, the synthesis of those molecules is quite complicated, which precludes their practical application.

In our work, by means of electronic strong coupling (ESC) and optical strong coupling (OSC), here the ESC is obtained by strongly couple the Frenkel excitons of J-aggregate cyanine molecules (TDBC) to an optical mode in a Fabry-Perot cavity, and the OSC is realized by couple the Mie resonances of the dielectric nanocavity to the epsilon-near-zero mode of an ultrathin indium tin oxide layer. We achieve enhancement of both nonlinear refractive index (n_2) and nonlinear absorption coefficient (β) of the coupled systems for more than 2 orders of magnitude with respect to that of the uncoupled conditions. In addition, the temporal response of the coupled systems show a few hundreds of femtoseconds, which have promising applications in ultrafast optical switching and high speed data processing. These findings make them possible to study the effect of strong coupling on a series of n_2, β-related nonlinear optical phenomenons[4-6].

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Nonadiabatic Dynamics and Time-Resolved Spectra

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Abstract: Nonadiabatic dynamics widely exist in photophysics, photochemistry and photobiology. We tried to develop theoretical approaches to study the photoinduced nonadiabatic dynamics. Particularly, we developed the on-the-fly surface hopping dynamics to simulate the nonadiabatic dynamics of polyatomic systems.

We combined the doorway-window representation of the nonlinear response theories and ab initio nonadiabatic dynamics to simulate various time-resolved spectra, including both transient absorption spectra, time-resolved fluorescence spectra and two-dimensional electronic Spectra. A few interesting examples, including photoinduced energy transfer and photoisomerization, are discussed.

Keywords: Nonadiabatic Dynamics, Ultrafast Dynamics, Conical intersections, Ultrafast Spectra

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From Graphite to Diamond in a Flash — Playing with Carbon–Carbon Bonds

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Abstract: Understanding the ultrafast dynamics of carbon–carbon bond rearrangements during the graphite-to-diamond transition has been a longstanding challenge in condensed matter physics. Despite decades of study, the atomic pathways, transient intermediates, and potential novel diamond polymorphs have remained elusive. Here, using ultrafast electron-based characterization with atomic spatial and fs temporal resolution, we captured key transient states and revealed new metastable phases. Aberration-corrected electron microscopy and diffraction directly visualized the long-predicted orthorhombic graphite (AB′ stacking) intermediate, resolving the full pathway from hexagonal graphite (AB) to orthorhombic graphite and ultimately to hexagonal or cubic diamond, thereby providing direct evidence for a nucleation–growth mechanism. Furthermore, fs pump–probe ultrafast electron diffraction (UED) on twisted bilayer graphene uncovered the transient (~100 fs) formation of a novel 2D diamond phase in AA/AB′ stacked systems, highlighting the potential of ultrafast light fields for optically controlling phase transitions and suggesting a route to 2D diamond synthesis. In parallel, millimeter-scale, high-purity hexagonal diamond was synthesized under quasi-hydrostatic high-pressure–high-temperature conditions (20 GPa, 1400 °C). Atomic-resolution measurements confirmed its unique mixed sp^3 bonding with two distinct C–C bond lengths, and mechanical tests revealed a Vickers hardness up to 110 GPa, comparable to cubic diamond, thus definitively confirming hexagonal diamond as a distinct carbon phase. Finally, a next-generation UED system integrating jitter-free Ω-type magnetic compression, UHV tight-focusing optics, and MEMS-based multi-field excitation, was developed for a deeper understanding of these discoveries. Together, our results resolve enduring debates on graphite–diamond transition dynamics, demonstrate femtosecond optical control of sp^3 carbon phases, and establish a versatile methodology for probing ultrafast structural transformations in condensed matter.

Keywords: ultrafast electron diffraction; graphite–diamond transition; transient phases; femtosecond dynamics; sp^3 carbon materials; hexagonal diamond

Multistable soliton collisions in an optical microresonator

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Abstract: Microresonator-based optical frequency combs (microcombs) exhibit high repetition rate, broad bandwidth, compact footprint, high coherence, and compatibility with CMOS fabrication processes, playing an important role in spectroscopy, precision measurement, high-speed optical communications and basic physics researches. Multistable solitons generated via multicolor pumping in a microresonator constitute a novel class of high-performance on-chip single-cavity dual-comb sources. Multistable solitons exhibit dispersion-governed group velocity and repetition rate mismatch, which result in the transient collision dynamics of multistable solitons. However, limited by the high free spectral range (FSR) and large bandwidth of the microcombs, real-time full-field characterization of multistable soliton dynamics in microcombs remains highly challenging in experiments. Here, we apply an improved way named chirped coherent detection, completely capturing the real-time spectral and temporal evolution of solitons in microcombs firstly, as the dynamics pass through different multistable solitons states with complex collisions and fusions before the stable singlet soliton state. This could be helpful to understand multistable soliton interaction mechanisms.

In this work, based on coherent detection and optical Fourier transform, the real-time full-field spectral and temporal characterization of the complex soliton dynamics transition is realized firstly, with about ~25 nm bandwidth and ~28 pm spectral resolution, as well as a high measurement speed of ~20 MHz, which can provide a useful tool for developing new soliton applications and understanding the complex soliton physical processes much better in microcavites. For the signal under test (SUT) and local oscillator (LO), by using dispersive time stretch, their spectrums are mapped into the frequency-mapped waveform with the same wavelength-to-time relationship, which keeps the interference frequency of the SUT and the LO always at fundamental frequency. And by the digital signal processing (DSP), the real-time full-field characterization of soliton spectrums in microcombs is figured out unaffected by the signal aliasing. Meanwhile, by Fourier transform, the full-field temporal waveforms can also be obtained.

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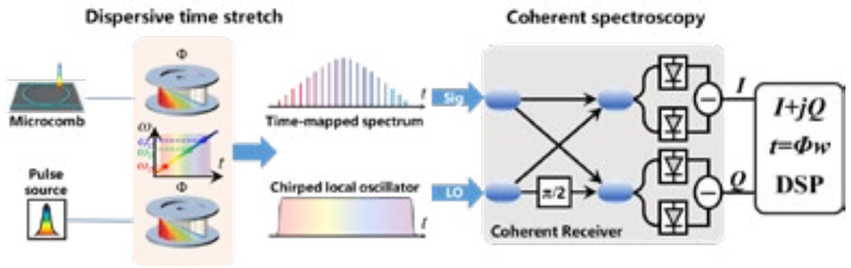

Figure 1. The principle of chirped coherent detection.

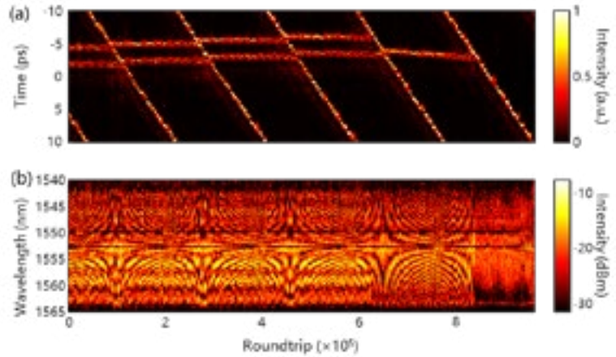

Figure 2. Experimental observations of multistable soliton collision dynamics. (a) 2D temporal evolution portrait. (b) spectral evolution portrait. The x-axis in both 2D portraits represents the slow time (in units of round-trip number). The y-axis of the temporal map corresponds to the fast time (full scale is one round-trip time), while the spectral portrait's y-axis spans the wavelength range.

Keywords: microcomb, multistable soliton dynamics, coherent detection, optical Fourier transform

Macroscopic Alignment-mimicking Effect Induced by Few-State Quantum Amplification in Dephased Rotational Wave packets

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Abstract: Achieving macroscopic observable measurements in dephased rotational wave packets presents persistent challenge. Here, we report a remarkable observation of macroscopic alignment-mimicking modulations in coherent emissions from N_2^+ within the non-revival delays spanning tens of picoseconds. These coherent modulations vanish as the gas pressure increases slightly from 3 mbar to 10 mbar, revealing its exquisite sensitivity to collisional processes. Through time-frequency analysis, we identify that only few rotational states J with beating frequencies near 100 cm^{-1} dominate the emission dynamics. This phenomenon arises from gain-driven amplification competition among spectrally indistinguishable transitions undergoing strong interference. Our simulations confirm that few-state quantum amplification in dephased rotational wave packets selectively enhances specific rotational pathways, generating measurable macroscopic signals despite vanishing ensemble alignment. This work uncovers a new regime of room-temperature quantum control beyond revival structures, with implications for molecular lasers and quantum-coherent photonics.

Keywords: N_2^+ lasing, coherent rotational wave packets, few-state quantum amplification, alignment-mimicking modulations

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Ultrafast magneto-optical phenomena in europium chalcogenides

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Abstract: The manipulation of magnetic materials with light has become a highly promising concept in developing innovative magneto-optical devices. In this lecture, we demonstrate a number of ultrafast photo-induced magneto-optical phenomena in europium chalcogenides EuX (X = O, S, Se, Te), which are intrinsic magnetic semiconductors with unique electronic, magnetic, optical and magneto-optical properties. The top of the valence band of the Eu^{2+} atom in these compounds is formed by 4f states, which contain seven strongly localized electrons with a total spin of 7/2. The first empty 5d state forms the conduction band. When the EuX sample is illuminated by light with photon energy exceeding the band gap, it significantly enhances the exchange interaction between excited 5d-electrons and surrounding lattice 4f spins compared to the ground state.

We report on an experimental study of ultrafast photo-induced phenomena in europium chalcogenides. The approach offers direct observation of spin dynamics in EuX on a broad timescale from hundreds femtoseconds up to hundreds microseconds, providing a deeper understanding of the light-induced manipulation of magnetism in these materials. Pump-probe measurements of EuO-based ferromagnets by a time-resolved two-color stroboscopic technique establish optical spin orientation by the electronic transition $4f^7 5d^0 \rightarrow 4f^6 5d^1$ as a mechanism triggering collective magnetization precession [1]. Acting on the lattice 4f spins, a photo excited $5d^1$ electrons lead to the formation of giant magnetic polarons with a large magnetic moment. It is shown that in the antiferromagnetic EuTe at temperature 5K light generates magnetic polarons with a magnetic moment larger than 600 Bohr magnetons [2]. Rather efficiently magnetic polarons are excited in metamagnetic EuSe [3]. In this material, the concentration of polarons is not saturated with an increase in the intensity of the pump light. Thus, EuSe can be completely transferred to a ferromagnetic state by the optical excitation. By time-resolved pump-probe technique the spin dynamics involving the growth of giant spin polarons in a EuSe is investigated. Photo-induced Faraday effect helps to unveil the excitation of magnetic polarons with an extra-large magnetic moment in the ferromagnetic europium oxide EuO. The temporal dynamics of magnetic polarons with a record high magnetic moment up to $175 \cdot 10^3$ μB is disclosed at temperatures slightly higher the Curie temperature [4]. A reversal of the magnetic hysteresis loops by the Photo-induced Faraday effect is detected, which is due to the relaxation of excited electron associated with a magnetic polaron from 5d minority spin state to 5d majority spin state. The decay times of 5 μs is determined revealing the polaron lifetime. The colossal magnetic moments of magnetic polarons and its temperature behavior are in good agreement with available theoretical predictions on EuO. This finding has a great impact on the efficient optical control of magnetic state in solids.

Support by the Russian Science Foundation (project No. 24-12-00348) is acknowledged.

Keywords: Europium Chalcogenides, Photo-Induced Magneto-Optical Effects, Magnetization Precession, Magnetic Polaron, Magnetic Semiconductor

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Ultrafast Excitonic Nonlinear Spectroscopy in Two-Dimensional Semiconductors

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Abstract: Strong light–matter interactions can provide opportunities for the development of novel optoelectronic devices and quantum technologies, such as inversionless optical gain, laser cooling, and optical quantum information processing. Transition metal dichalcogenides (TMDs) have emerged as a new platform for studying strong light–matter interactions due to their excitonic properties. Recently, we have observed exciton quantum interference behaviors in both monolayer [1] and bilayer [2] TMDs, and found that these mainly originate from a three-level excitonic system near the momentum-space K point in the material [3]. By constructing monolayer or bilayer WSe_2 transistor devices, we can effectively regulate this three-level excitonic system [4], thereby controlling exciton quantum interference behavior [5]. We developed time-resolved sum-frequency generation (SFG) and four-wave mixing (FWM) spectroscopy to probe the dynamics of exciton quantum interference in monolayer WSe_2 [6]. Through two-photon resonant pumping, high-energy excitons are populated, which then trigger a four-wave mixing radiation process via a non-resonant pulse. At the exciton resonance, the intensity of the nonlinear spectrum as a function of the time delay between the two pulses can help to understand Rabi oscillations during the exciton quantum interference process, providing insights into the dynamics of coherent excitons. This time-resolved nonlinear spectroscopic approach offers a new method for investigating condensed matter chemical systems.

Keywords: Ultrafast nonlinear optics, exciton, two-dimensional semiconductors

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Progress on ultrafast Kapitza-Dirac effect

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AbstractIn 2024, we report on the discovery of a principally new phenomenon, termed as ultrafast Kapitza- Dirac effect. Similar to the optical diffraction of light passing through a material grating, the Kapitza-Dirac effect occurs when an electron is diffracted by a standing light wave. In its original description, the effect is time independent. In the ultrafast case, we extended the Kapitza-Dirac effect to the time domain. By tracking the spatiotemporal evolution of a pulsed electron wave packet diffracted by a 60 fs standing wave pulse in a pump-probe scheme, we observed time-dependent diffraction patterns. The fringe spacing in the observed pattern differs from that generated by the conventional Kapitza-Dirac effect. By exploiting this time-resolved diffraction scheme, we can access the time evolution of the phase properties of a free electron and image the ionic potentials. Now, we have successfully applied it to the phase imaging of Coulomb-focused electrons in strong- field ionization by observing the distorted interference fringes. Moreover, we have successfully observed the diffraction pattern beyond two-photon recoil limit.

Keywords: Ultrafast Kapitza-Dirac effect; Coulomb focusing; Strong-field ionization

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Femtosecond dynamics of small molecules in helium nanodroplets

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Abstract: Superfluid helium nanodroplets cool embedded molecules to 0.37 K, making them ideal nanoreactors for light-induced interactions between cold molecules and the helium environment. To investigate the ultrafast dynamics of in-droplet molecules induced by femtosecond laser pulses, we developed helium-nanodroplet target recoil ion momentum spectroscopy (He_NTRIMS), a reaction microscopy technique in which electrons and ions ejected from a molecule within the droplet are measured in coincidence. Using femtosecond pump-probe experiments with He_NTRIMS, we observed laser-induced, field-free molecular alignment dynamics of D_2 inside He droplets [1]. Our measurements indicate that for at least 100 ps, equivalent to more than 500 rotational periods, D_2 molecules in He droplets rotate as if they were isolated gas-phase particles, a behavior strikingly different from that observed for larger molecules within droplets. Moreover, we captured in real time the collision-induced ultrafast dissipation of vibrational nuclear wave packet dynamics in D_2^+ ions embedded in helium nanodroplets [2]. Our results show that, unlike neutral in-droplet molecules, charged ions strongly couple to the helium solvent via ion-He collisional interactions, leading to rapid vibrational decoherence on the order of ~140 fs. We also examined how strong ion-He interactions affect light-induced molecular bond breaking. By analyzing the above-threshold multiphoton ionization of H_2 embedded in a superfluid helium nanodroplet [3], we found that low-vibrationally excited H_2^+ in droplets is more prone to dissociation, whereas in the gas phase only highly vibrationally excited H_2^+ dissociates. These findings are significant for understanding and steering light-induced molecular dynamics in helium nanodroplets. Additionally, by considering the molecule as a de Broglie wave interacting with the confining potential of the droplet, we explored the spatial scale of a cold molecule's matter wave relative to the nanodroplet by examining the angular nodal structures in the photoelectron momentum distributions (PMDs) [4]. The preserved nodal structures in the PMDs allowed us to distinguish between the delocalization of the lightest H_2 molecules and the localization of heavier D_2 and O_2 molecules, whose de Broglie wavelengths are comparable to or smaller than the droplet size.

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Light-induced structural phase transition in WTe_2

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Abstract: The rapid advancement of ultrafast technique enables optical control and transient probing of the structure and electronic properties of complex quantum materials. Layered transitionmetal dichalcogenide such as W/$MoTe_2$, can adopt several distinct crystal structures via interlayer sliding, each possessing distinct topological and electronic characteristics[1,2]. In our earlier work we demonstrated that femtosecondlaser excitation can be used to identify the stacking sequence of octahedral $MoTe_2$ by monitoring the response of optical or acoustic shear phonons[3]. Here we extend this approach to WTe_2 and further investigate the structural pathway of its photo-induced phase transition (PIPT) by ultrafast electron diffraction (UED). By analyzing the relative intensities of the (010) and (020) diffraction spots under three conditions—(i) in situ thermal heating the sample, (ii) continuous laser pumping, and (iii) ultrafast pulsed-laser excitation—we extracted a transition temperature of ≈570 K and identified a threshold fluence of 3.6 mJ/cm² (Fig. 1a,b). Tracking the intensity evolution of multiple diffraction spots (Fig. 1c,d) then allowed us to delineate the multistage pathway of this PIPT. Within the first 50 ps, the intensities of odd- and even- order diffraction spots oscillated and evolved in opposite directions, indicating a transformation from $TdWTe_2$ to the highersymmetry T_0 phase (Fig. 1e). After 50 ps, all the intensities except (200) spot decays and a pronounced oscillation appears whose period matches that of acoustic shear phonons, signifying a subsequent transformation of the T_0 phase into the T′ phase (Fig. 1f) through collective shear sliding. Approximately 50 μs later, the diffraction intensity have fully recovered, conforming the completion of structural relaxation (Fig. 1d). Thus, using ultrafast electron diffraction and microscopy, we report the systematic observation of PIPT in WTe_2 and elucidates the interlayersliding processes that unfold on multiple timescales.

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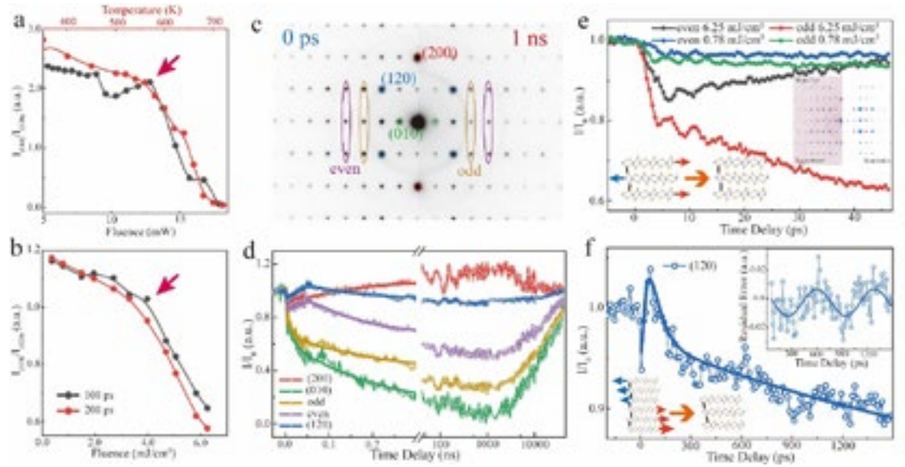

Figure 1. Structural pathway of photoinduced phase transition in WTe_2. (a, b) Determination of the transition temperature, T_c=570 K and threshold fluence, F_c=3.6 mJ/cm^2. (c) Comparison of the diffractionspot intensity before (0 ps) and after (1 ns) the laser excitation. (d) Intensity evolution of characteristic diffraction spots as a function of time delay. (e) Intensity changes of odd and evenorder diffractionspot within the first 50 ps, below and above F_c. The inset on the right shows the experimental and simulated changes of diffraction intensity, while the lowerleft inset illustrates the corresponding interlayersliding. (f) Temporal evolution of the (120) diffractionspot intensity showing the acoustic shear phonons. The lowerleft inset depicts the collective interlayersliding.

Keywords: Photo-induced phase transition; Ultrafast electron diffraction; WTe_2; Shear phonon; Interlayer sliding

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Track 6 Ultrafast Particle Science, Technology and Applications

Ultra-high fluxes of direct laser accelerated electrons, MeV photons and neutrons using overcritical-density foams

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Abstract: The aim of the presented research is to significantly improve the performance MeV particle and radiation sources powered by petawatt-kJ-class lasers in the context of ICF research and applications in laboratory astrophysics. Experiment was performed at the 200 TW, sub-picosecond PHELIX laser pulse at a moderately relativistic intensity of 10^{19} Wcm^{-2}, delivering ~50 J of energy into pre-ionized, overcritical-density foam targets. Interaction of relativistic laser pulse with long-scale plasma resulted in production of beams of direct laser accelerated (DLA) electrons.

The electron spectrum measured along the laser axis exhibited an effective temperature of ~ 30 MeV and energies beyond 100 MeV. A total charge of ~300 nC for electrons with energies E > 1.5 MeV, and ~80 nC with energies E > 7.5 MeV within 2π. The fraction of DLA electrons with energies exceeding 7.5 MeV, directed within a half-angle of ~13◦ along the laser axis, carries a charge of ~20 nC, corresponding to a flux of directed electrons of approximately 2 × 10^{24} sr^{-1} s^{-1}.This high-current, relativistic electron beam efficiently generates MeV X-rays by penetrating 3 mm-thick high-Z converter, enabling the subsequent production of isotopes and neutrons with exceptional yield and application potential. In laser shots employing overcritical-density foam placed in front of a high-Z converter, bremsstrahlung photons with energies up to 70 MeV were generated and analyzed via nuclear activation of tantalum and gold. The formation of the isotopes 176Ta and 190Au, with their photonuclear cross-section peaks at 50 MeV and 70 MeV, respectively, confirmed the presence of high-energy photons.

Nuclear diagnostics indicate an unprecedented photon flux of ~2×10^{22}sr^{-1}s^{-1}, corresponding to up to 10^{11} photons per shot propagating in a half-angle of 22° with energies exceeding 7.5 MeV. The conversion efficiency of focused laser energy into bremsstrahlung reached 1–2% (within the FWHM of the X-ray beam). More than 5×10^{9} photo-neutrons per shot are emitted isotropically, corresponding to a peak flux of 2×10^{20}cm^{-2}s^{-1} at the back of the converter (4×10^{18}cm^{-2}s^{-1}J^{-1} of laser energy on target).

This approach demonstrates a robust and scalable method for generating ultra-intense MeV photon beams at kilojoule, petawatt-class laser facilities operating at moderate relativistic intensities, with strong implications for high energy density physics and nuclear astrophysics research.

Key words: Laser-plasma interaction, over-dense foam, direct laser accelerated electrons, MeV bremsstrahlung, photo-nuclear reactions, isotopes, neutrons.

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Generation mechanism of high-energy polarized and vortex particle beams driven by strong fields

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Abstract: Recently, with the rapid developments of ultra-strong ultra-short laser technologies, strong laser field driven high-energy polarized and vortex particle beams (e.g., electrons, positrons and Gamma-photons) with spin and orbital angular momenta, which have significant applications in many fields, have attracted broad interests. However, their generation and measurement are still great challenges. In this talk, we would like to introduce the related progresses of our group [1-6].

Key words: Strong field QED; Nonlinear Compton scattering; Nonlinear Breit-Wheeler process; Spin polarization; Orbital angular momentum

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Control of laser-driven high-current relativistic electron beam and its application in generating compact radiation sources

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Abstract: The advent of short intense lasers has revolutionized the generation of relativistic electron beams (REBs), enabling unprecedented currents up to mega-amperes – surpassing any previously achievable in laboratory settings by several orders of magnitude. As these high-current REBs propagate through materials, the latter is immediately ionized into plasma, giving rise to various new phenomena. Transport of these high-current REBs in plasma is a fundamental issue relevant to high-energy-density space and laboratory plasmas, and has attracted much research interest. The problems involved include collisionless shocks, cosmic magnetic field generation, gamma-ray bursts, etc. It is also relevant to many applications, including inertial confinement fusion, compact particle and/or radiation sources. In this paper, I will introduce our recent research progress on the microscopic transport of REB in plasmas and its application in generating compact radiation sources. Some interesting new results are obtained, including the branching, super-channeling, and anomalous stopping of REB in porous materials. Based on these new phenomena, we have further extended the applications of REB in generating coherent radiation source and high-brilliance incoherent gamma-rays. In particular, we propose new approaches for producing coherent intense radiation pulses by simply directing a REB into a plasma with a density up-ramp or by interacting a laser pulse with an REB at a grazing angle. Super-channeling of high-current electron beam in disordered microstructures is also discovered and this phenomenon can lead to extremely high conversion efficiency gamma-rays. These results should be of much interest to researchers in many areas.

Key words: Relativistic electron beam, coherent radiation pulses, high-brilliance gamma-rays, porous materials

Toward the Realization of a Tabletop XUV Free-Electron Laser Driven by Laser Wakefield Acceleration

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Abstract: To develop a stable laser wakefield acceleration (LWFA)-based accelerator [1] and demonstrate free-electron laser (FEL) generation, a novel LWFA platform was constructed at the RIKEN SPring-8 Center. Systematic experiments were carried out under the support of the ImPACT (2013–2018) and JST MIRAI (2017–present) programs. Although undulator radiation in the XUV spectral range, driven by LWFA electron beams, was successfully demonstrated in 2019, reproducibility was hampered by poor electron pointing stability and large energy fluctuations. To overcome these challenges, the quality of the accelerated electron beam was enhanced through the development of a shock injection scheme, which allows precise injection control and ensures stable plasma conditions. This advancement significantly improved both the reproducibility and stability of the LWFA electron beam. This presentation will outline the LWFA platform, detail the setup of the proof-of-concept experiments with a focus on key improvements, and discuss the results obtained.

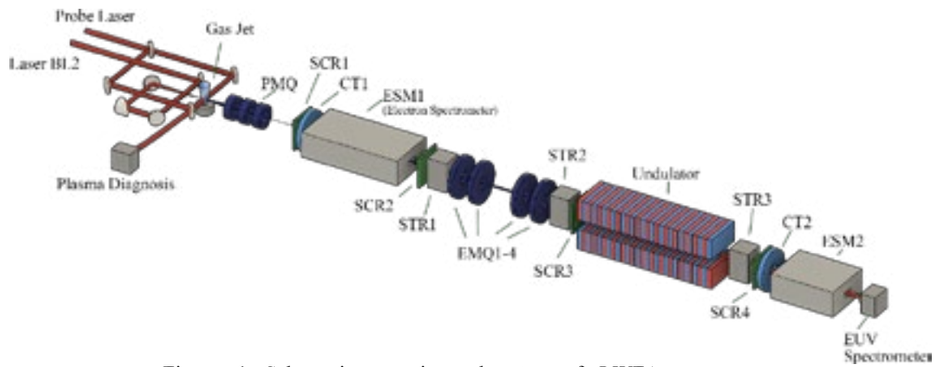

Figure 1 Schematic experimental setup of LWFA

The experiment was conducted at Laser Acceleration Platform LAPLACIAN (Laser Acceleration Platform as a Coordinated Innovative Anchor), a specialized facility designed for laser wakefield acceleration research (Fig. 1). This platform is located at the RIKEN SPring-8 Center. The laser system utilized in the platform is a custom-built Ti:Sapphire femtosecond laser system capable of delivering three laser beamlines with adjustable parameters, all synchronized with each other.

For the FEL experiment, beamline 2 was employed as the driver laser, providing a laser pulse energy of 0.8 J and a minimum pulse duration of 21 fs post-compression. A gold-coated off-axis parabola with a focal length of 1500 mm was used to focus the laser onto the gas target.

A stable laser wakefield accelerator relies on two key factors: a well-tailored, stable plasma (gas) density distribution and a stable drive laser with suitable parameters. Efforts have been made to enhance both plasma and laser stability [2, 3].

By ensuring precise injection control, stabilization of the laser wavefront, and optimal performance of the gas jet, as well as by optimizing phase rotation and beam loading, we can generate quasi-monoenergetic electron beams with an energy spread of less than 1%, energies approaching 400 MeV, pointing stability of less than 0.5 mrad, and energy stability of less than 6% (rms). Demonstration experiments by sending these beams into a mini-undulator have shown a FEL gain of 14 times in XUV range.

This work was funded by the JST-MIRAI program grant no. JPMJMI17A1. We are grateful to the technical teams of Spring-8 Center for their support to the Laser Acceleration Platform.

Key words: laser wakefield acceleration, free-electron laser

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Laser-driven ion acceleration and its applications

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Abstract: Laser-driven ion acceleration has attracted significant interest over the past decades owing to its potential towards the development of a new generation of compact and cost-effective accelerators. Ion beams accelerated by intense lasers exhibit unique properties such as ultrashort burst emission, high brilliance, and low emittance, which open opportunities for a wide range of applications in proton imaging, cancer therapy, warm density matter production, neutron sources, etc. Here I will present recent theoretical and experimental progress achieved by our group in optimizing ion acceleration mechanisms and exploring their applications in diverse fields.

Key words: Laser-driven ion acceleration, Intense lasers, Neutron sources

Tunable High-Field Terahertz Radiation from Plasma Channels

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Abstract: High-field terahertz radiation with highly tunability is essential for relative applications, i.e., terahertz communications, optical manipulations, and terahertz imaging. Here, we introduce methods for the generation and manipulation on high-field terahertz radiation, which is introduced by the laser wakefield excited by weakly relativistic laser pulses inside plasma channels. Firstly, we demonstrate that terahertz radiation with field strength up to sub GV/cm can be generated by off-axially injecting a laser pulse inside a parabolic plasma channel. Two-dimensional particle-in-cell simulations shows that such a terahertz radiation can be tuned between two modes, i.e., linearly polarized mode and radially polarized mode, by simply changing the injection condition or the channel length. Secondly, we present a way to generate intense terahertz vortex beams with continuously tunable topological charge by injecting a weakly-relativistic ultrashort laser pulse into a parabolic plasma channel. By adjusting the injection conditions of the laser pulse, the trajectory of the laser centroid can be twisted into a cylindrical spiral, along which laser wakefields are also excited. Due to the inhomogeneous transverse density profile of the plasma channel and laser wakefield excitation, intense terahertz radiation carrying orbital angular momentum is produced with field strength reaching sub GV/m, even though the drive laser energy is at a few tens of mJ. The topological charge of such a radiation is determined by the laser trajectories, which is continuously tunable as demonstrated by theoretical analysis as well as three-dimensional particle-in-cell simulations.

Key words: Terahertz radiation, laser-plasma interactions, laser wakefield, optical vortex.

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Generation and applications of strong terahertz bursts driven by high-intensity laser pulses

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Abstract: Recently Terahertz (THz) radiation from laser-produced plasmas has attracted much interest since plasmas can work at arbitrarily high laser intensity. We systematically investigate the generation of strong THz radiation from solid targets irradiated by ultraintense laser pulses with relativistic intensities exceeding 10^{18}W/cm^2.The experiments were performed with femtosecond and picosecond laser facilities respectively. The numerous energetic MeV fast electrons produced by the high-intensity laser pulses serve as the primary source of the THz radiation. When the forward fast electrons reach the target rear surface, THz radiation is induced via the mechanism of transition radiation. To enhance the THz radiation, a variety of techniques have been employed. These include increasing laser absorption through the use of a preplasma, fabricating nanostructures on the front surface of the target, optimizing the target thickness, applying a CH coating, and employing an additional laser pulse to ablate the target rear. The optimized energy of the terahertz pulses can reach the millijoule to hundreds of millijoules range, depending on the specific parameters of the driving laser pulses. Additionally, we have conducted preliminary studies exploring the new physics driven by the strong terahertz pulses, such as the excitation of biological protein dynamics, water dynamics, and THz-induced plasma.

Recent developments of a laser-driven ion acceleration beamline at SIOM

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Abstract: Laser driven ion acceleration provides a route to achieve high quality ion beams, which could be superior for specific applications. In this talk I will present recent development of a laser driven ion acceleration beam line based on a homemade table-top 200 TW laser system at Shanghai Institute of Optics and Fine Mechanics (SIOM). Our major motivation is the potential application of such pulsed ion sources.

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MeV Ultrafast Electron Diffraction Using a Laser Wakefield Accelerator with Double Bend Achromat Beamline

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Tsinghua University

Abstract: MeV ultrafast electron diffraction (UED) has emerged as a powerful tool for investigating structural dynamics across various scientific domains. The advent of laser wakefield accelerators (LWFAs) offers promising prospects for developing compact, all-optical electron sources for UED applications. In this work, we present an experimental demonstration of a tabletop UED system employing an LWFA coupled with a miniature permanent magnet beamline. Key to our approach is the implementation of a double bend achromat that compensates for temporal broadening induced by the beam's energy spread while maintaining isochronism. This design can effectively mitigate arrival time jitter caused by shot-to-shot energy fluctuations, preserving the inherent laser-beam synchronization advantage of LWFAs. Through energy filtering, we achieve a 3% (FWHM) energy spread while retaining sufficient bunch charge (11.9 fC) for diffraction measurements. Characterization using a laser-driven THz deflector reveals a bunch length of 49.6 fs (RMS) and an arrival time jitter of 4.7 fs (RMS) at the sample plane, yielding an overall temporal resolution of ~49.8 fs. Our simulations suggest the potential for reaching ~10 fs (RMS) temporal resolution with further optimization to 1.6% energy spread. The system's capability is validated through clear single-shot and multi-shot diffraction patterns from single-crystalline gold samples, with derived lattice constants showing excellent agreement with reference values. These proof-of-principle results establish LWFA-based electron sources as viable candidates for ultrafast structural dynamics studies and lay the foundation for future sub-10-fs UED applications.

Radiative spin-polarized plasmas driven by ultrafast laser or electron beams

Zheng Gong[1, *]

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Abstract: Radiative spin-polarized plasmas represent a novel frontier in high-energy-density plasma physics, where the intrinsic spin degrees of freedom of electrons become dynamically polarized through interaction with ultra-intense electromagnetic fields. In this talk, I will present recent theoretical and numerical advances in understanding how ultrafast laser pulses or relativistic electron beams can drive spin-polarized plasmas via spin-dependent radiation processes. When electrons undergo synchrotron-like emission in strong fields, spin-selective radiation losses lead to spontaneous spin polarization, analogous to the Sokolov-Ternov effect but occurring on femtosecond timescales. I will discuss key mechanisms underlying this phenomenon, including the role of radiation reaction, radiative spin flips, and plasma collective effects. Using spin-resolved particle-in-cell simulations coupled with Monte Carlo modules, we show how spin polarization evolves in various configurations, such as laser-plasma interactions, beam-plasma systems, and radiative magnetic reconnection layers. These findings indicate the potential for generating relativistic spin-polarized electron beams and exploring spin-informed plasma instabilities. The implications might offer alternative perspectives for laboratory astrophysics and high-brightness beam applications. This work highlights the interplay between quantum spin effects and classical plasma dynamics in extreme environments, marking a step toward the emerging discipline of spin plasma physics.

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Efficient Free-Electron Laser Modelling Using a Lorentz-Boosted Coordinate System

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Imperial College London

Abstract: Free Electron Lasers (FELs) are novel light sources capable of generating ultrashort, femtosecond-duration pulses via electron oscillations in electromagnetic fields. A defining advantage of FELs is that the radiation wavelength is inversely proportional to the square of the electron beam energy, allowing continuous and tunable access across the electromagnetic spectrum. At electron energies of 10 GeV, FELs can produce hard X-rays—wavelengths otherwise unattainable with conventional lasers. These X-rays, characterised by their high penetration and ultrashort wavelengths, are uniquely suited for applications such as imaging dense materials (e.g. bone tomography) and time-resolved probing of dynamic processes like shock wave propagation in metals.

Recent progress in compact free-electron laser (FEL) concepts, driven by laser and beam-plasma wakefield acceleration, has demonstrated exponential gain using electron beams with energies of a few hundred MeV. While wakefield acceleration offers a pathway to significantly more compact FEL systems, accurately modelling their performance remains computationally demanding. This challenge arises primarily from the vast scale disparity between the nanometre-scale radiation wavelength and the macroscopic length of the beamline. Moreover, at these relatively low electron energies, space-charge effects and beam emittance critically influence both the beam dynamics and overall FEL performance.

In this work, we employ boosted-frame particle-in-cell (PIC) simulations to perform efficient, start-to-end modelling of the SPARC FEL. The use of a Lorentz-boosted frame leverages the Doppler redshift and length contraction, yielding a substantial computational speed-up that scales as γ^2. Simulations that would require over a month in the laboratory frame can be completed within hours in the boosted frame. Importantly, PIC simulations inherently capture self-consistent space-charge and emittance effects, making them ideally suited for exploring the beam dynamics and lasing behaviour in compact FEL systems.

Photoinduced ultrafast phase transitions in strongly correlated materials

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Abstract: The charge, lattice, orbital, and spin degrees of freedom are strongly coupled together in strongly correlated materials, leading to a variety of insulator-metal transition pathways in strongly correlated materials [1-2]. Using real-time time-dependent density functional theory (rt-TDDFT) simulations, we found that 800 nm laser pulses can excite electrons at the valence band to the conduction band of M_1-VO_2 and triggers the ultrafast structural and electronic phase transitions in photoexcited M_1-VO_2 [3]. The structural and electronic phase transitions have the same threshold of laser intensities. The electronic phase transition is instantaneously generated, while the structural phase transitions have time constants of 100 to 300 fs, leading to the isostructural electronic phase transitions in M_1-VO_2 configuration. At the same time, THz-induced strong-field tunneling processes were also shown to induce the effective carrier generations. In contrast to conventional Zener tunneling for static electric fields, the slow-varing THz electric fields lead to the delayed carrier generation and the occupation of photocarriers restrains the subsquent photoexcitation.

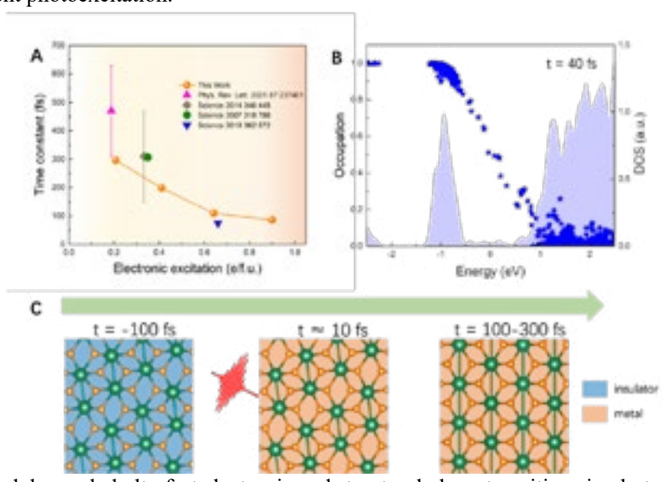

Figure. Photoinduced decoupled ultrafast electronic and structural phase transitions in photoexcited M_1-VO_2.

Keywords: Strongly correlated materials, photoexcitation, ultrafast phase transition, rt-TDDFT

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Track 7 Laser-Matter Interactions

Sub-picosecond topological phase transition in nonlinear exciton-polaritons

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Femtosecond Laser Spatiotemporal manipulation and Its Research

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Abstract: In this report, we demonstrated the recent progress made by Tianjin University's Ultrafast Laser Lan in the field of femtosecond laser spatiotemporal manipulation. This includes achieving higher-performance femtosecond laser output through spatial synthesis, analyzing and regulating ultrafast laser nonlinear dynamics with attosecond temporal resolution, and realizing precise control of femtosecond lasers by combining spatiotemporal manipulation. Systematic research has been conducted in areas such as precision machining and precision measurement.

Keywords: Femtosecond laser

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Design of 340 attoseconds long high-brightness 2GeV electron beams LWFA accelerator and preliminary Free Electron Laser optimization for water-window single/few-spikes X ray sources.

Paolo Tomassini[1], Federico Avella[2], Nasr A. M. Hafz[3], Luca Labate[2], Vojtech Horny[1], Szabolcs Toth[3], Domenico Doria[1], Leonida A. Gizzi[2], Luca Serafini[4] and Vittoria Petrillo[4]

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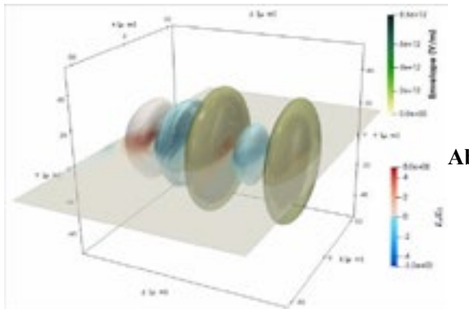

Abstract: Ultra-low emittance and length-tunable electron beams can be obtained with the Laser Wake Field Acceleration (LWFA) by employing advanced ionization injection techniques, such as the Two-Color and the Resonant Multi-Pulse Ionization injection (ReMPI) [1,2] schemes. There, a tightly focused, short wavelength (ionization) pulse extracts electrons from a selected inner shell of a dopant, allowing them to be longitudinally compressed and trapped in the wakefield excited by a different (driver) pulse.

We demonstrate [3], by means of analytical results and Particle In Cell simulations, that 340as long electron beams with 2.3GeV energy, 6.1 pC charge, 0.15% projected energy spread, 60nm normalised emittance, and projected 6D-Brightness in excess of $3x10^{18}A/m^2/0.1\%BW$ can be generated with a ~200TW Ti:Sa laser system. The beam slice analysis reveals its potential for driving single or few-spikes attosecond long X-ray Free Electron Laser (FEL).

We finally show preliminary results about the related FEL source optimization in in the SASE configuration. GENESIS simulations show that single-spike or few-spiles radiation in the water window, with about 10^{12} photons/shot, can be obtained with a 10-20m long undulators.

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Subcycle bandstructure videography of lightwave-driven currents

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Abstract: Lightwave ARPES, a recent development of time- and angle-resolved photoemission (APRES), makes it possible to explore light-matter interaction in the strong field regime with subcycle time resolution. Our first experiment employed electric fields of a few kV/cm from a THz wave to induce electrical currents at the topologically protected Dirac surface state of Bi_2Te_3 [1]. The electrons in these states move like relativistic particles and, since spin-momentum locking suppresses scattering, they travel ballistically over distances of several 100 nm. Subsequently, we demonstrated subcycle time-resolution at mid-infrared frequencies of 25-40 THz and electric fields in the MV/cm range. Under these conditions, the accelerated electrons in the Dirac cone give rise to strong high-harmonic generation [2]. Moreover, Floquet-Bloch sidebands build up. Starting with strong intraband currents, we observe how Floquet replicas emerge already in the second optical cycle of the driving field and how electrons in high-order sidebands scatter into bulk states [3].

In this work, we present the next generation of subcycle band-structure videography. Hemispherical photoelectron analyzers in combination with near-UV probe pulses (photon energy, 3 to 6 eV) can image electron dynamics along specific directions near the Brillouin zone center. In many quantum materials, however, critical phenomena occur at the Brillouin zone boundaries. Our new experiment combines atomically strong 1.5-cycle mid-infrared (MIR) driving fields with sub-10-fs EUV probe pulses (photon energy, 21.7 eV) and state-of-the-art photoemission momentum microscopy. It allows us to explore field-driven electron dynamics throughout the entire first Brillouin zone. To reach good measurement statistics within short acquisition times, we develop a laser system that operates at a high a repetition rate of 50 kHz while still reaching MIR peak electric fields above 200 MV/cm, corresponding to an average MIR power as high as 1 W. The new laboratory allows us to drive electrons in a monolayer of graphene with MIR pulses (center frequency, 27 THz) while EUV pulses probe the dynamics with subcycle time resolution. Observing the full 2D carrier distribution with sub-fs temporal resolution, we uncover the fundamental microscopic processes at play. In particular, the dynamics of intraband currents and interband transitions as well as the subsequent interplay between different scattering channels are revealed.

Our approach provides key insights into the conditions necessary for achieving fully coherent, field-driven electronic dynamics and opens new avenues for exploring rich phenomena in the strong-field regime, including Landau-Zener tunneling, dynamical Bloch oscillations, optical band-structure engineering and light-induced phase transitions.

Keywords: Strong-field light-matter interaction, subcycle time-resolved photoelectron spectroscopy, topological surface states, Dirac cone, graphene, lightwave electronics

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Ab Initio Strong-Field Physics

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Abstract: To theoretically study laser-matter interaction, in particular, attosecond and strong field processes from the first principles, we have developed various cost-effective wavefunction-based methods such as the time-dependent multiconfiguration self-consistent-field (TD-MCSCF) methods, the time-dependent optimized coupled-cluster (TD-OCC) methods using time-varying orbitals, and the gauge-invariant time-dependent configuration-interaction-singles (TDCIS) method (see Ref. [1] and references therein). In this talk, we report on their formulations, numerical implementations and results, and comparison with experimental results.

For example, we show that the Rabi coupling converts ion-photoelectron entanglement in two-color photoionization of Ne to coherent superposition. This creates coherence between the two, otherwise incoherent, photoelectron wave packets, leading to, e.g., coherent control of the photoelectron angular distribution through the relative phase between the fundamental and second-harmonic extreme-ultraviolet pulses [2,3].

In addition, we study laser-solid interaction, based on the time-dependent density functional theory (TDDFT) using the SALMON code [4]. For example, we investigate high-harmonic generation (HHG) from bilayer WTe_2 [5]. The HHG spectra under a strong field clearly exhibit a plateau and energy cutoffs, i.e., an unambiguous signature of nonperturbativeness. If we take a comprehensive *all-band* perspective, the anomalous Hall responses are attributed to the interband processes.

Keywords: First-principles calculation, attosecond science, entanglement, Nonlinear Hall effect

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Enhancing laser plasma accelerator for nuclear physics

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Abstract: Laser plasma acceleration is not only suitable for advanced accelerator, but also possess great potential for plasma nuclear exciter or collider. At present, most of research topics in this field focus on the quality improvement of accelerated particle beams. On the other hand, the laser plasma accelerator also has extremely high density which will produce high brightness gamma ray source and intense neutron source, resulting in powerful tool for nuclear physics research.

Recently, our team has carried out systematic studies on electron acceleration with large charge. For example, we used a solid target to realize relativistic electron acceleration of 100 nC [1] with very small divergence angle; And achieved stable acceleration of ~ 20 nC with electron energy tens MeV using high-density gas targets, through a novel efficient injection that the atom inner shell electrons are ionized and continuously injected into multiple plasma bubbles [2]. Micro-C level electron beam produced via combination of near critical density plasma and PW lasers [3].

Based on new experimental results of electron acceleration, we have carried out the research about „laser-plasma exciter/reactor“. Firstly, a high brightness neutron source [4] is obtained by driving a solid target with an electron beam. And, with optimized high charge electron beam driven (γ,n) reaction, the peak flux of neutron source reaches to 10^20 n/cm^2/s, which is comparable to Supernova [3]; Then, using the nonlinear resonance of Kr clusters excited by intense laser, the 83Kr isomeric state is achieved experimentally with peak efficiency 2x10^15 p/s [5]. After carefully measurement of the excitation cross section, the 83Kr excited from the ground state to the 3rd exciting state with cross section as small as 10^{-11} barn [6], which is usually have to measure them deep into ground to reduce the background; Using the enhanced electron accelerator, MeV-level ellectron beam has been introduced to excite high energy isomeric states such as In [2]. With the above novel method, a systematic nuclear excitation techniques have benn constructed covering low energy to high energy range, suitable for the study of BBN, steller and SuperNova nucleosysnesis.

In order to carry out the experimental verification of laser „laser-plasma exciter/reactor“ based on extremely strong field QED, we will finalizing the construction of the „laboratory astrophysics research platform“ (LAP) [7] in TsungDao Lee Institute, for the nuclear astrophysics research in relativistic.

Keywords: Laser wakefield acceleration, Isomeric state, nuclear excitation

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Optical second harmonic generation in antiferromagnets

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Abstract: Among the various optical phenomena associated with the frequency conversion of electromagnetic waves, the second harmonic generation (SHG) is the simplest nonlinear process of the second order [1]. Nonlinear spectroscopy using the method of SHG allows one to obtain fundamentally new information in the study of solids in comparison with studies using linear optical techniques. This is due to the difference in the selection rules for single-photon and multi-photon processes [2].

In this lecture, we will consider nonlinear magneto-optical phenomena associated with SHG in various classes of antiferromagnets. These materials not only make up the vast majority of magnetically ordered substances, but also possess many specific physical properties unique to them. Antiferromagnetic materials attract significant research interest due to their potential for modern technologies, including antiferromagnetic spintronics, opto-spintronics, and memory devices [3, 4].

Antiferromagnets can be divided into three classes – magnetoelectrics (well-known example is Cr_2O_3), ordinary antiferromagnets (like NiO) and altermagnets (for example, CoF_2). In the electric dipole (ED) approximation, SHG is allowed only in noncentrosymmetric materials. SHG is also allowed in centrosymmetric media in the magnetic dipole (MD) or electric quadrupole (EQ) approximations. In the classical magnetoelectric antiferromagnet Cr_2O_3, the spatial inversion is violated due to the spin order below the Néel temperature T_N, therefore ED SHG can be observed in the temperature range below T_N. A new magnetic-field-induced mechanism of SHG is associated with the magnetoelectric effect [5]. In centrosymmetric antiferromagnet NiO the SHG is due to the nonlinear optical susceptibility of the MD type. A novel nonlinear optical susceptibility of the EQ type is observed in altermagnetic CoF_2. Materials, that can have both ferroelectric and antiferromagnetic order parameters simultaneously, are multiferroics. Hexagonal manganites $RMnO_3$ (R = Sc, Y, Ho, Er, Tm, Yb, Lu) belong to this group of antiferromagnets. In $RMnO_3$ SHG is associated with a nonlinear optical polarization of the ED type, being a bilinear function of two order parameters. The interference of various SHG contributions can be used to visualize antiferromagnetic domains that are invisible in linear optics. SHG technique makes it possible to identify new nonlinear mechanisms related to the light-matter interaction.

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Keywords: optical second harmonic generation; nonlinear spectroscopy; antiferromagnets

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Ultrafast Dynamics of Strong-Field Ionization

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Abstract: Under strong laser fields, the ionization processes of atoms and molecules primarily involve three mechanisms: multiphoton ionization, tunneling ionization, and over-barrier ionization. This talk highlights our recent progress in the dynamics of these ionization mechanisms. In the context of multiphoton ionization, we have developed a universal framework for photon momentum transfer applicable to an arbitrary number of absorbed photons, revealing that on average, an electron acquires twice of the photon momentum per absorbed photon [1]. Regarding tunneling ionization, by exploiting dynamical symmetries in circularly polarized laser fields, we uncovered a new energy–angular momentum conservation law on the sub-cycle scale [2]. Furthermore, we demonstrated that the quantum tunneling process is primarily driven by the electric field, while the subsequent classical continuum motion is governed by the vector potential [3,4]. Additionally, we found that the presence or absence of a tunneling time delay is determined by the relative magnitudes of the intrinsic timescale of the system and the timescale of the probing pulse [5,6]. For over-barrier ionization, we generalized the backpropagation method to investigate, for the first time, the dynamical evolution of this process, leading to a new physical picture of over-barrier ionization [7].

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The ultrafast electronic response of small quantum systems, and modifying it by intense-laser interactions

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Abstract: Atoms are fundamentally well-defined quantum objects, found in a pure multi-particle correlated electronic ground state even at room temperature, yet providing an infinite number of internal quantum states.

In our experiments, we explore the controlled modification of small quantum systems, such as atoms, in their bound states, by intense and short-pulsed laser light. We observe characteristic changes of their spectra and thus learn from their response to intense ultrafast questions carried and encoded by near-visible laser pulses and attosecond extreme-ultraviolet (XUV) and x-ray bursts.

Some of our findings include the time-resolved observation of Rabi cycling between auto-ionizing states and recollision electron dynamics at extremely low intensities in circularly polarized laser fields [1]. We achieve the speeding up of molecular dynamics by strongly driving vibronic states in neutral hydrogen molecules [2]. The revival time of a molecular wavepacket can be shifted forward in time, observed solely by analyzing the absorption spectrum, without requiring a second (“probe”) pulse.

We also employ Free-Electron Lasers (FELs) to control electronic transitions of one and two valence electrons, and the combination of core- and valence electrons to achieve element specificity. Resonant nonlinear interactions are quantified by high-resolution XUV and x-ray-optical spectroscopy of photons transmitted through dilute and dense gas-phase samples.

An interesting recent development is the enhancement of weak (“forbidden”) transitions. Opening an additional “bridge” pathway to an excited state of interest by intense-laser coupling linearizes the otherwise unfavorable transition-matrix-squared scaling of linear absorption and thus can in principle enhance extremely weak transitions uby many orders of magnitude. As a first proof-of-principle, we enhance an XUV transition by a factor of ten [3]. Future applications could aim at the identification of clock transitions used in the search for new physics beyond the standard model, including low-energy nuclear transitions such as the one in metastable Thorium ^{229m}Th.

With all this controllability on the atomic level, we consider an opportunity for future development: Atomic-scale information processing at ultrafast clock speeds, programmed by intense laser light [4].

Keywords: Laser, Atom, Molecule, Optics, Photons, Ultrafast, Quantum, Electron, Dynamics

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In situ monitoring ultrafast laser-induced material modifications using high-harmonics generation

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Abstract: Femtosecond laser offers a means to confine energy beyond the diffraction limit. Triggered by pioneer works performed at the turn of the millennia and in the early 2000s, the use of femtosecond lasers to induce non-ablative transformation of transparent materials have emerged as a key technology for functional devices impacting numerous fields, from integrated photonics to complex micro-parts processing fluids or fulfilling mechanical functions (including actuators), and from high-density optical memories to solving complex packaging issues. The core of all these technological developments is the ability of ultrafast lasers, thanks to non-linear absorption processes and strong field interaction with high energy confinement, tailoring the intimate structure of the matter and inducing a variety of localized structural modifications, including densification, nano-crystallization, or phase separation. This broad diversity of laser-induced modifications enables a rich taxonomy of functional properties that can be selectively introduced in the bulk of materials, enabling novel types of integrated systems finding a broad range of applications, from photonics integrated circuits in quantum computing to lab-on-a-chip, and from miniaturized sensors to novel concepts of optical packaging. As a single laser can produce a variety of morphological transformations of the material structure, in situ monitoring how the material is transformed while being exposed to the laser is a key endeavor for achieving robust functional integration.

Towards this goal, the use of second and third harmonic light generation from the same laser (referred as ‘SHG’ and ‘THG’, respectively) used to transform materials is particularly interesting as it offers a direct means to retrieve morphological and/or crystallographic information from the exact same volume being exposed for processing by the laser.

In this talk, we will present results from both SHG and THG experiments performed on various transparent glass substrates, highlighting how these methods can be used to identify different types of laser-induced transformations, such as densified volumes, self-organized nanograting and nano-crystallites. As another example, we will show how polarimetry SHG can be used to retrieve rich information on the crystal nature and characteristics of nano-crystalline phases forming in tellurite substrates during ultrafast laser exposure.

Keywords: Ultrafast laser processing, higher-harmonics generation, in situ monitoring, laser-induced crystallization

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Spectroscopic detection and microscopic imaging via solid-state high-order sideband generation

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Abstract: Ultrafast control of electronic states in quantum materials is a key challenge in advancing quantum technologies. While strong-field-driven systems exhibit rich phenomena such as topological transitions and exciton dynamics, experimentally resolving quantum state evolution remains difficult. Here we present solid-state high-order sideband spectroscopy and microscopy techniques that enable frequency-, time-, polarization-, and spatially-resolved probing of quantum states and near fields under strong-field excitation. We applied this approach to study the decoherence of Autler–Townes excitons in monolayer MoS_2, and extended it to dielectric resonator tomography, super-resolution imaging, and plasmonic near-field mapping. These results highlight the technique’s potential for exploring ultrafast dynamics, controlling quantum states, and advancing nanoscale optical diagnostics.

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Track 8 Large Scale Scientific Facilities

Attosecond optics and attosecond research infrastructures

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Abstract: I'm going to review the development of attosecond optics, and explain how high-order harmonics and attosecond pulses in the extreme ultraviolet band are generated from a gas target. I will also introduce the structure of an attosecond streak camera and how to construct an attosecond light source and beamline. At the end I'll show the attosecond research infrastructures around the globe.

Keywords: attosecond optics, attosecond pulse, attosecond streak camera, attosecond research infrastructure

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Fe-Doped Mid-Infrared CPA Systems and Their Prospects for Strong-Field Physics

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Abstract: Fe-doped II–VI crystals, such as Fe:ZnSe and Fe-doped chalcogenides, have recently attracted attention as promising gain media for high-power, broadband mid-infrared (mid-IR) ultrafast lasers. Their gain spectrum centered near 4 μm, combined with long upper-state lifetimes at cryogenic temperatures, enables chirped-pulse amplification (CPA) of few-cycle pulses with high energy and excellent stability. Such laser systems are particularly attractive for strong-field physics, where the ponderomotive energy scales quadratically with wavelength, making mid-IR drivers uniquely suited for generating relativistic intensities at moderate pulse energies. In this work, we present our recent progress toward a terawatt-class Fe-doped mid-IR CPA system and discuss its potential for relativistic high-order harmonic generation (HHG).

Our approach is currently under development and combines a high-contrast optical parametric amplifier (OPA) based on potassium titanyl arsenate (KTA) with a planned multipass Fe:ZnSe CPA stage. The front end, which has already been constructed, consists of a nonlinear polarization rotation mode-locked Yb fiber oscillator, followed by a Yb:CaF_2 CPA delivering femtosecond pulses at 1040 nm. These pulses pump a three-stage KTA OPA to generate broadband seed pulses at 4 μm with ~100 fs duration and μJ-level energy. The next stage, a cryogenically cooled Fe:ZnSe amplifier, is being designed to boost these seeds to pulse energies exceeding 100 mJ at 10 Hz, corresponding to peak powers beyond 1 TW. The broad gain bandwidth of Fe:ZnSe supports less than 200 fs compressed pulse durations, enabling electric field strengths sufficient for driving relativistic plasma dynamics.

One of the key motivations for this development is the application of mid-IR drivers to relativistic HHG from solid-density plasmas. In this regime, the laser's long wavelength increases the quiver momentum of electrons, allowing coherent radiation to be emitted at much higher harmonic orders than with near-IR drivers. Moreover, the relativistic regime can produce bright, coherent extreme-ultraviolet (XUV) and soft X-ray with attosecond-scale duration, opening new possibilities for probing ultrafast electron dynamics in solids and dense plasmas. The high pulse energy and excellent beam quality achievable with Fe:ZnSe CPA systems are critical for maintaining the required intensity and contrast on target while minimizing preplasma formation.

In addition to relativistic HHG, such a laser platform is relevant to a broad range of strong-field phenomena, including laser-driven particle acceleration, nonlinear Compton scattering, and terahertz generation from plasma currents. The combination of high peak power, long wavelength, and excellent temporal contrast distinguishes Fe-doped mid-IR CPA systems from conventional near-IR and short-wavelength drivers, offering complementary capabilities for strong-field science.

We will present the current status of our Fe:ZnSe CPA development, including system design, amplifier modeling, and preliminary results from the OPA front end. The roadmap toward achieving multi-hundred-millijoule pulses at 4 μm will be outlined, together with strategies for optimizing gain extraction, managing thermal loading, and sup-

pressing amplified spontaneous emission and parasitic oscillations in the Fe:ZnSe crystal. Finally, we will discuss experimental plans for relativistic HHG, including target chamber design, diagnostics for XUV emission, and prospects for scaling toward multi-tens-of-terawatt mid-IR drivers.

Our work aims to establish Fe-doped mid-IR CPA technology as a robust, user-friendly platform for the next generation of strong-field experiments. By leveraging the advantages of long- wavelength drivers, we anticipate opening new frontiers in attosecond science and relativistic light– matter interaction studies.

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Development of High average Power direct-liquid-cooled Yb:YAG thin disk laser for pumping mid-infrared Optical Parametric Amplifiers

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Abstract: The amplification of high average power 1030 nm laser pulses based on direct-liquid-cooled Yb:YAG thin disk laser head was experimentally demonstrated. The 1 kHz pulse was amplified to >260 mJ by a regenerative amplifier. The pulse duration was measured to be around 1 ps after the compressor. The power stability was better than RMS 0.6% over 6 hours. The beam quality of M^2<1.3 was achieved. This technique provides a promising approach for pumping mid-infrared Optical Parametric Amplifiers, which will be used for Soft X-Ray High Harmonic Generation.

Research on Key Technologies and Development Prospects of the Laser Fusion Energy Drivers

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Abstract: Enhancing the laser repetition rate and bandwidth is critical for the development of laser fusion energy drivers. However, constrained by the thermal conductivity and gain-bandwidth of laser gain materials, mainstream operational laser drivers to date cannot meet the requirements of fusion energy research. This report focuses on laser technology-related considerations for fusion energy. A spectral broadening scheme at the final stage of laser system is proposed, which effectively decouples the challenges of achieving high repetition rate and broad bandwidth. To address the demand for broad-bandwidth ultraviolet lasers, a technical approach based on signal-excited stimulated rotational Raman scattering (SRRS) was developed and validated for achieving large bandwidth. As for the thermal depolarization introduced by high repetition rates, a mechanistic study was conducted with Nd:glass. Based on polarization control and conjugate reflection methods, a solution was proposed, showing promise for compensation thermal effects. A research platform for broad-bandwidth ultraviolet and high-repetition-rate lasers has been arranged. Furthermore, insights into the future of fusion energy are provided, regarding the recent progress in laser fusion energy driver research.

As the engine of laser fusion energy, the laser-target coupling efficiency and high-repetition-rate capability of the laser drivers are crucial for reducing the cost of electricity. Playing a decisive role, the broadening of the laser bandwidth and mitigating thermal depolarization must be addressed.

Broadband lasers can effectively suppress laser-plasma instability (LPI) and reduce scattered losses, serving as one of the viable pathways to enhance laser-target coupling efficiency. In response to the demand for large-bandwidth ultraviolet lasers, an innovative approach based on signal-excited stimulated rotational Raman scattering for spectral broadening has been proposed. Integrating the amplification of both signal and pump beams, a comprehensive design for a large-bandwidth UV laser system has been developed. Preliminary results demonstrate that the fraction of scattered light after the bandwidth boarding is significantly reduced from 63% to 80%.

Thermal deposition in optical components under high-repetition-rate operation induces thermal depolarization, which significantly degrades the output energy, beam quality and operational stability. To address the challenge of thermal depolarization, a mechanistic study was conducted with Nd:glass. By optimizing the laser polarization orientation, the average depolarization of a single amplifier was reduced by a factor of four. Furthermore, optical phase conjugation was employed to compensate the distortions between the two orthogonal polarization components. Through backward propagation, the phase distortion between these components was effectively mitigated, thereby achieving the depolarization compensation.

Based on the technical advancements, a research platform for large-bandwidth ultraviolet and high-repetition-rate lasers has been arranged. This facility is expected to significantly bolster innovation and breakthroughs in critical technologies for fusion energy drivers.

Keywords: Fusion Energy，Laser Driver System，Broad Bandwidth，Thermal Depolarization

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Current progress of SEL-100 PW laser facility

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Abstract: Development of ultra-intense and ultrafast lasers have promised scientists with unprecedented extreme physical conditions and new experimental techniques. The Station of Extreme Light (SEL) at Shanghai high repetition rate XFEL and Extreme Light Facility (SHINE) facility started at April-2018, will pioneer cutting-edge researches on strong field QED physics with the marriage of XFEL and the 100PW laser. The SEL project is the product of the marriage of the most two powerful lasers 100 PW optical laser and hard XFEL, for quantum electrodynamics (QED) physics and other high energy density physics researches, powered by the unprecedented capability first in the world. In SEL facility, a 100 PW laser facility based on all optical parametric chirped pulse amplification (OPCPA) will be developed, which can provide the focused intensity of more than 10^{23} W/cm^2. SEL-100PW is also based on OPCPA, which will deliver 1.5 kJ energy in 15 fs pulse width. According to the schedule, the facility will be completed in 2027 and then open to users. We will report the new progress of the latest progress of SEL-100PW laser.

Shanghai Soft X-ray Free-electron Laser Facility (SXFEL) is the first XFEL user facility in China, which is quite suitable for the generation of ultrashort, high intensity x-ray pulses with the typical pulse duration of 100 fs. In the past decade, many schemes have been proposed to generate fs/as level pulses, which may have potential application on ultrafast sciences. We could introduce the status of SXFEL facility including the performance of the radiation and the experiments. Prospects and the upgradation of the facility could be exhibit as well.

Dual-front-end high-contrast 1-Hz, 200-TW/1-PW femtosecond laser system

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Abstract: Ultra-intense and ultrafast lasers are becoming increasingly indispensable for exploring extreme states of matter under strong electromagnetic fields. This paper presents the development progress and current key performance metrics of a high-contrast petawatt (PW) femtosecond laser system independently developed at Peking University.

The laser system is a chirped pulse amplification (CPA) system based on a Ti: sapphire final amplifier, capable of outputting femtosecond laser pulses at a repetition rate of 1 Hz with peak powers of 200 TW and 1 PW, respectively. The laser system incorporates two independent front ends: a conventional front end composed of a regenerative amplifier Ti: sapphire CPA1 system combined with a cross-polarized wave (XPW) filter, and a high-contrast front end based on optical parametric chirped pulse amplification (OPCPA) self-seeded at a central wavelength of 1600 nm via white light supercontinuum generation (WLG) pumped by an ultrafast Yb: YAG solid-state laser, combined with second-harmonic generation (SHG) technology for the seed laser. Both front ends share the same CPA2 optical system, which contains an Öffner stretcher, a five-stage multi-pass amplifier, and a Treacy compressor. Within this chain, the first amplifier is a 1000-Hz booster amplifier, while the remaining amplifiers operate at 1 Hz.

Based on the first four amplifier stages, we have achieved output from both front ends at a repetition rate of 1 Hz with peak powers at the 200-TW level; the pulse duration after compression in vacuum is approximately 30 fs for both, the beam diameter is approximately 80 mm for both, and the temporal contrast at 100 ps is 10^{-9} (XPW front end) and 10^{-12} (OPCPA front end), respectively. Building on this foundation, we have further completed the design and construction of a 1-Hz, PW-level amplification system. The PW amplifier utilizes four pump lasers operating at a central wavelength of 532 nm and a repetition rate of 1 Hz, providing high-quality linearly polarized light with a maximum energy of 8 beams at 14 J each, energy stability (RMS over 8 hours) better than 1%, top-hat beam profile flatness better than 1.7, and pointing stability better than 10 μrad. By formulating a refractive index-matching fluid, designing a dual-circulation cooling system, and actively adjusting the pump laser timing, we successfully suppressed parasitic oscillations in the PW amplifier and stabilized the temperature rise of the crystal. Ultimately, using the XPW front end, the PW amplifier achieved amplified energy of approximately 48.7 J, energy stability (RMS over 600 consecutive shots) of approximately 0.93%, while compressing the pulse to 27.5 fs in air with a compression efficiency of approximately 77%.

These results indicate that this laser system has already achieved the capability to output laser pulses at a 1-Hz repetition rate with peak power exceeding 1 PW. Next, we will continue to complete tasks including PW-level commissioning of the OPCPA front end at the 1-Hz repetition rate, construction of the PW-level vacuum compressor, and comprehensive diagnostics and optimization of laser parameters.

Keywords ultra-intense and ultrafast laser; 1Hz; Ti: sapphire; dual-front-end, high-contrast

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Beyond 100 Petawatt Laser and Related Technology Developments

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Abstract: Many 20-100 Petawatt laser projects have been proposed worldwide, and some are under construction now. Considering the development of ultra-intense lasers in the post-10/100-Petawatt era, several technological developments have been presented by many groups. Here, I am going to introduce the technology of the wide-angle non-collinear optical parametric chirped pulse amplification (WNOPCPA) and, especially, the prototype facility construction in Shanghai, China. The goal of this technology is to realize near-octave ultra-broadband high-energy amplification for future near-single-cycle Exawatt-class lasers, and that of the prototype facility is to demonstrate the performance in experiments. In this talk, I will also introduce the near-octave ultra-broadband gratings for pulse stretching/compression and near-octave ultra-broadband mirrors for beam propagation those developed for our WNOPCPA laser.

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Addressing Key Challenges to Enhance Peak and Average Power in CPA Laser Systems

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Abstract: Chirped Pulse Amplification (CPA) laser systems have reached extremely high peak power levels—up to tens of petawatts [1]. However, two major challenges remain for their widespread adoption in scientific and industrial applications: increasing the pulse repetition rate and improving the overall energy efficiency of the systems.

There are two primary strategies to address these obstacles. One approach involves using laser gain media with a broad fluorescence spectrum and high thermal conductivity of the suitable laser crystals—to enable high-energy, broadband amplification. The second approach focuses on gaining media with a low quantum defect, such as Yb:YAG [2]. For overwhelming a narrower fluorescence spectrum of this crystals, the post-compression techniques are employed to broaden the spectrum after amplification, allowing for shorter pulse durations and thus higher peak power.

This report discusses both strategies in detail, comparing their advantages, limitations, and applicability to future high-power CPA laser systems.

Ti:Sapphire (Ti:Sa) is a typical laser crystal known for its broad fluorescence spectrum and high thermal conductivity, making it well-suited for ultrafast amplification. However, its relatively high quantum defect leads to significant heat generation. This report will examine various Ti:Sa crystal configurations used in final amplifier stages, tailored to specific CPA system parameters such as pulse repetition rate and pulse energy [3]. The example of design of a rectangular thin-plate Ti:Sa laser amplifier—capable of delivering over 3 J of output energy per pulse at a repetition rate of 1 kHz, corresponding to pulse powers exceeding 100 TW—will be presented.

In the context of Yb:YAG laser systems combined with post-compression techniques, existing methods are limited in their ability to scale both pulse energy and repetition rate [4]. This report introduces a novel approach for post-compressing high-energy laser pulses using gas-filled multipass cells.

To overcome the pulse energy limitation and reduce the footprint of the setup, the spectral broadening by free beam propagation at high intensities using flat mirrors to fold the beam similar to MPC optical scheme was proposed and demonstrated. Self-focusing compensation by initial wavefront and beam shape tailoring allows achieving long propagation distance while avoiding beam collapse for pulses exceeding the critical power for self-focusing. A spherical convex initial wavefront is a one example of this tailoring; elliptical beam shape is another. A numerical estimation shows that the critical power for self-focusing can be significantly mitigated by increase of the beam divergence, which was demonstrated in our experiments. In this scheme the intensity of Gaussian beam remains nearly constant along the length of propagation, allowing efficient light-gas interaction throughout the entire beam volume. Furthermore, this configuration simplifies the need for complicated optical schemes and optical elements.

Keywords: High peak power laser; High average power lasers; Ultrafast lasers; Thin disc amplifiers; Nonlinear optics; Self phase modulation; Post compression technique.

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Shanghai Soft X-ray Free-electron Laser Facility: Status and Prospects

zhen wang

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Abstract: Shanghai Soft X-ray Free-electron Laser Facility (SXFEL) is the first XFEL user facility in China, which is quite suitable for the generation of ultrashort, high intensity x-ray pulses with the typical pulse duration of 100 fs. In the past decade, many schemes have been proposed to generate fs/as level pulses, which may have potential application on ultrafast sciences. We could introduce the status of SXFEL facility including the performance of the radiation and the experiments. Prospects and the upgradation of the facility could be exhibit as well.

Attosecond Laser Station in Synergetic Extreme Condition User Facility

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Abstract: With the development of ultrafast laser technology, the attosecond laser based on high order harmonics generation has become one of the leading direction in ultrafast sciences. The generation and measurement of attosecond light pulses provided scientists to master a powerful tool to peek into ultrafast processes inside materials at unprecedented precision, and give birth to a new field and research direction: attosecond science.

In order to better realize the application of attosecond light pulses in multiple fields for more users, the Institute of Physics CAS has built a large ultrafast dynamic and image system as one of the four extreme conditions of the " Synergetic Extreme Conditions User Facility (SECUF)", with the support of National Major Basic Science Infrastructure Projects, in September 2017. The attosecond laser station is responsible for the generation and application of isolated attosecond pulse based on high harmonic generation with pulse duration of less than 100 as in XUV, and is equipped with time-resolved angular resolved photoelectron spectrometer (ARPES), photoelectron microscope (PEEM), cold target recoil-ion momentum spectrometer (COLTRIMS) and other end-stations. Thus, it provides users with the attosecond to femtosecond time resolution and momentum, energy resolution measurements for study on the ultrafast dynamics of physical, chemical and biological materials on atomic scale.

After 5 years of development of four XUV beamlines and end stations, the attosecond laser station can output extreme ultraviolet (XUV) coherent radiation with photon energy of nearly 100eV and isolated attosecond pulse (IAP) with duration of 86 as. The time-resolved ARPES beamline use a femtosecond laser with an average power of 280W in 57 fs at repetition rate of 500 kHz to produce high order harmonics of 20~50 eV. A narrow-band high-order harmonic light source was selected by a monochromator and combined with a femtosecond IR laser to form a pump-probe pulses, which was jointly focused on the ARPES sample. The photoelectrons generated were detected by an energy analyzer. By scanning the precise delay between the pump light and the detection light, the time resolution was demonstrated to be 125.75 fs, as well, the energy resolution is 43.9 meV. The minimum temperature of the sample is 3.8 K. As for the PEEM, the spatial resolution of PEEM with 21.6 eV high harmonic light source generated by few-cycle laser at 100kHz was demonstrated to be less than 100 nm. As for the COLTRIMS, the momentum resolution of electron was 0.03 a.u., and the momentum resolution of ion was 0.04 a.u.

After passing the national acceptance inspection, the facility has been fully open to users since 2023. The attosecond laser station has provided users with approximately 9,000 hours of beamline time, and achieved some results, such as the generation of sub-60-as light source, revealing light-induced charge density wave melting and carrier redistribution in 1T-TiSe2, etc.

Keywords attosecond pulse; few-cycle laser pulse; high harmonic generation; carrier envelope phase; attosecond streaking spectroscopy; PEEM; COLTRIMS; ARPES; TOF； XUV spectroscopy

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Generation and Application Prospects of Tabletop Muon Sources Driven by Laser Wakefield Electron Accelerators

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Abstract: Muons, which play a crucial role in both fundamental and applied physics, have traditionally been generated through proton accelerators or from cosmic rays. With the advent of ultra-short high-intensity lasers capable of accelerating electrons to GeV levels, it has become possible to generate muons in laser laboratories. In this work, we show the first proof of principle experiment for novel muon production with an ultra-short, high-intensity laser device through GeV electron beam bombardment on a lead converter target. The muon physical signal is confirmed by measuring its lifetime which is the first clear demonstration of laser-produced muons. Geant4 simulations were employed to investigate the photo-production, electro-production, and Bethe-Heitler processes response for muon generation and their subsequent detection. The results show that the dominant contributions of muons are attributed to the photo-production/electro-production and a significant yield of muons up to 0.01 μ/e-out of the converter target could be achieved. This laser muon source features compact, ultra-short pulse and high flux. Therefore, its implementation in a small laser laboratory is relatively straightforward, significantly reducing the barriers to entry for research in areas such as muonic X-ray elemental analysis, muon spin spectroscopy and so on.

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Track 9 Ultrafast Laser Processing and Manufacturing

High-repetition-rate Femtosecond Laser Micro/Nano-Processing Via Multiple Pulses Incubation

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Abstract: As a flexible and efficient non-contact processing strategy in ambient air, femtosecond laser precision engineering has become an advanced technology for micro/nano-structures' fabrication. Femtosecond laser can output ultrashort laser pulses at a very high repetition rate, ensuring higher machining accuracy and improving the machining efficiency. The femtosecond laser manufacturing is mostly processed under multiple pulses irradiation. At a high-repetition-rate, incubation effect based on the multiple pulses irradiation provides a new theoretical and technical support to realize precision manufacturing. This report summarizes the influence of femtosecond laser repetition rate on the mechanism of multiple pulses incubation. Based on the incubation effect of defects' accumulation at kHz, the thermal incubation effect at MHz is proposed. Our latest progress in high-repetition-rate femtosecond laser precision engineering based on multiple pulses incubation is emphatically introduced. At a repetition rate of kHz, the incubation effect manifests as a reduction in the ablation threshold due to the accumulation of surface defects inside materials. When the repetition rate reaches MHz, the thermal relaxation time of the materials and the pulse interval achieve a dynamic equilibrium, resulting in the heat accumulation. Through the precise control of this thermal incubation, various processes can be realized, such as oxidation structure patterning, nanostructure synthesis and flexible nanopatterning. These processing strategies based on multiple pulses incubation provide unique insights for femtosecond laser micro/nano-processing. Furthermore, the challenges and future prospects of high-repetition-rate femtosecond lasers in both fundamental research frontiers and industrial applications are discussed.

Keywords: high-repetition-rate femtosecond laser; incubation effect; defects' accumulation; heat accumulation; micro/nano-processing.

Uultrafast laser high-aspect-ratio extreme nanostructuring of optical materials

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Abstract: A capacity to substantially exceed optical limits and to structure below 100 nm is essential to advance ultrafast processing into the field of metamaterials. Using ultrafast nondiffractive Bessel beams, we demonstrate unprecedented feature sizes down to 7 nm, result from self-generated near-field light components initiated by cavities induced by far-field radiation in a back-surface illumination geometry. This sustains the generation of more confined near-field evanescent components along the laser scan with a nanometer pitch, perpendicular to the incident field direction, driving a super-resolved laser structuring process via local thermal ablation. The near-field pattern is replicated with high robustness, advancing toward a 10-nm nanoscribing tool with a millimeter-sized photolithography. The nondiffractive irradiation develops evanescent fields over the focusing length, resulting in high-aspect-ratio trenching with a nanometer section and a micrometer depth. A predictive multi-pulse simulation method validates the far-field-induced near-field electromagnetic scenario of void nanochannel growth and replication, indicating the processing range and resolution on the surface and in the depth. We conducted in situ reconstruction of thermodynamic states over the entire matter relaxation path in bulk fused silica irradiated by ultrafast nondiffractive laser beams using time-resolved optical phase microscopy. The dispersion and time design of the optical beam to picosecond durations increases the spatial confinement and triggers an extreme nanostructuring process based on nanocavitation. This allows for structural and morphological nanoscale material features under 3D confinement that can engineer optical materials.

Keywords: Ultrafast Laser, Nanoscribing, Transient Thermodynamic

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Ultrafast laser-induced modulation of structures and photonic functionalities in glass

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Abstract: Various functional structures have been created by ultrafast laser direct writing. A novel mechanism for controlling glass structure through ultrafast laser-induced nanophase separation and ion migration has been proposed. This innovation has led to the invention of three-dimensional micro-nano photonic structures with broadly and continuously tunable luminescence, and the development of the first glass-based micro-LEDs[1,2]. Additionally, a new method for rapid optical field modulation driven by deep learning has been developed to reduce focal spot and structural distortions, increasing the speed of holographic phase calculation by two orders of magnitude[3,4]. This enhancement improves the precision and efficiency of glass structure modulation, achieving the world's lowest loss in optical waveguides and significantly expanding their operational wavelength range. Furthermore, a butt-coupled optical chip architecture has been introduced, along with an ultra-broadband, low-energy nonlinear optical modulation method[5]. This method exhibits a ultrasmall threshold for nonlinear activation function that is an order of magnitude smaller than previously reported, enabling the construction of an optical neural network. The invention of the first glass optical chip capable of all-optical nonlinear operations has notably improved the accuracy of image recognition and classification in optical neural networks through its nonlinear activation functions.

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Burst-Mode Femtosecond Laser Coloring of Pure Titanium Products

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Xidian University

Abstract: Coloring on pure titanium without toxic chemicals or thermal distortion remain a key challenge for consumer products. Here, we introduce burst-mode femtosecond laser processing that tailor oxide growth on titanium surface by varying the number of sub-pulses within each 400 kHz burst. We observe a continuous transition from muted, low-saturation hues to vivid, uniform colors as the sub-pulse count gradually increases from 1 to 10. This evolution arises from the synergy between ultrafast non-thermal oxidation and gentle heat accumulation, which progressively smooths the oxide surface and suppresses iridescent microstructures. The resulting colors are free of electrolyte residues and the underlying titanium retains its original flatness. The technique thus offers an acid-free and mask-less route for high-resolution decoration of pure titanium products.

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Beam Shaping Empowered Ultrafast Laser Processing

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Abstract: Precision and efficiency are crucial metrics for evaluating laser processing performance. Beam shaping in temporal, spatial, and spectral domains provides a powerful toolkit for enhancing the accuracy and efficiency of laser processing. Ultrafast laser processing, known for its distinctive nonlinear optical effects, has become an effective approach for three-dimensional (3D) machining of transparent materials. However, the spatial resolution and processing throughput often remain limited with conventional Gaussian ultrafast laser pulses. Therefore, developing tailored beam-shaping strategies has become essential to meet the diverse needs of different applications. We present our recent advancements in beam-shaping-assisted high-precision and high-efficiency ultrafast laser 3D processing in glass materials, including: spatially shaped laser fabrication of multifunctional optofluidic waveguide devices, Bessel-beam-assisted fabrication of high-depth, high-aspect-ratio microstructures, 3D isotropic fabrication through spatiotemporal focusing using high-repetition-rate femtosecond laser pulses, and 3D isotropic processing aided by high-speed rotating slit beam shaping.

Keywords: Beam shaping; Ultrafast laser processing; Spatiotemporal focusing; Bessel beam; Glass

References

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Attosecond seeded intensity gating for second plateau generation in solid-state HHG via Landau–Zener inter-conduction-band transfer

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Abstract: This study presents a novel mechanism for generating the second plateau in solid-state high-harmonic generation (HHG): the combination of attosecond seeding and intensity gating under weak-field conditions. Through Landau–Zener inter-conduction-band transfer, we demonstrate how attosecond pulses enable stable generation of the second plateau under moderate MIR intensities without exceeding damage thresholds. Time–frequency analysis shows that the second plateau emits once per MIR cycle, exhibiting a 2ω_MIR delay modulation, and its envelope rigidly shifts by T/4 when the CEP of the MIR is changed, confirming the intensity gating nature of the second plateau. Furthermore, even harmonics in the first plateau exhibit a 2ω modulation out of phase with the second plateau, demonstrating the vector-potential/slope gating effect. Channel ablation and transient absorption spectroscopy (ATAS) confirm the critical role of attosecond injection and conduction-band handoff in second plateau generation.

This work provides a new pathway for programmable high-energy HHG in solids, offering a clear theoretical framework with experimentally verifiable mechanisms and tunable parameters (such as delay, CEP, and intensity) for future ultrafast light source design and applications.

Keywords: attosecond seeding; solid-state HHG; intensity gating; Landau–Zener transfer; intraband acceleration; time-delay modulation; CEP phase shift; TDSE; ATAS

Results

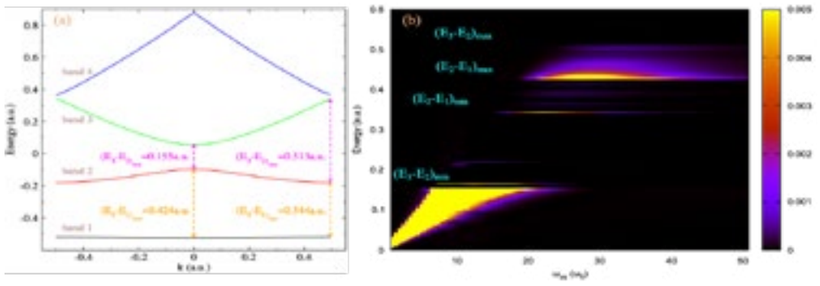

Figure 1. (a) Band structure used in the TDSE simulations. The lowest, upper valence bands and the first, second, third conduction bands are indicated. Dashed markers highlight the minimal and maximal band gaps among different bands. (b) Attosecond transient absorption (ATAS) with the attosecond pulse alone for different frequencies. Prominent absorption features are annotated and coincide with the extreme gaps in panel (a), providing band-structure fingerprints that will be used to identify emission channels and interpret the second-plateau formation in the combined as+MIR case.

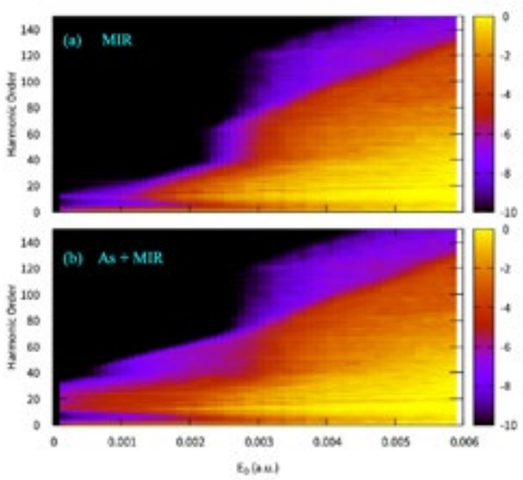

Figure 2. (a) High-harmonic spectra as a function of MIR field amplitude for MIR-only driving. Before E_{MIR}=0.003 a.u., a single first plateau is observed across the scan, no second plateau appears. (b) Same scan with an attosecond seed ($\omega_{as}=11\omega_{MIR}$) arriving before the MIR. A robust second plateau emerges at weak–moderate fields, while the first plateau remains.

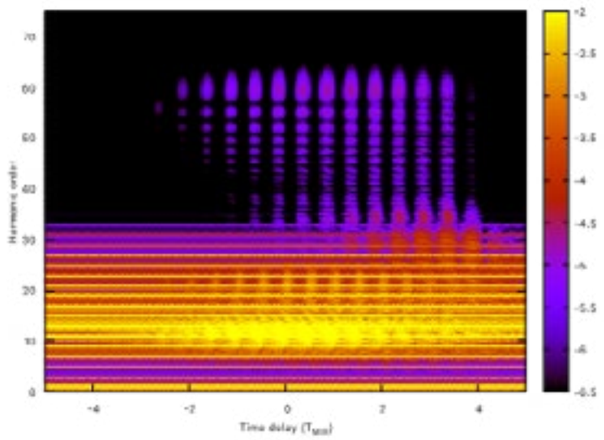

Figure 3. Delay-dependent HHG map (as+MIR). Horizontal axis: MIR–as time delay τ; vertical axis: harmonic order; color scale: spectral intensity (log). Two plateaus are clearly visible. Key features: (1) In the first plateau, the dominant odd orders are essentially delay-flat (no observable modulation). (2) The even orders interleaved between adjacent odd harmonics within the first plateau show a pronounced $2\omega_{MIR}$ modulation versus τ. (3) The second plateau exhibits a strong $2\omega_{MIR}$ delay modulation with two maxima per MIR cycle. The maxima of the second-plateau envelope are phase-shifted by π/2 relative to the even-harmonic maxima in the first plateau.

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Femtosecond laser atomic-scale processing for inherently superhydrophobic metal surfaces

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Abstract: Superhydrophobic metal surfaces are great significant for many applications in industry, aerospace, navigation and medical fields, because of having self-cleaning, high corrosive resistance, drag reduction and anti-icing behaviors. Currently, their realization is mostly based on a combination of micro/nanostructure with low-surface-energy organic coatings. This inevitably results in serious problems of aging instability and poor durability for superhydrophobic properties, which becomes a bottle-neck challenge hindering its pratical applications.

To solve the above issues, we recently proposed a new stratergy of femtosecond laser atomic-scale processing of aluminum alloys to achieve the coating-free inorganic superhydrophobic surface. The laser-induced modulations are manifested in three aspects: the surface morphology converting into topological anthill-tribe structures, the atomic composition transferring into silicate ceramics, the atomic arrangement changing into amorphous and paracrystalline phases. The subsequent low-temperature annealing endowed the surface with the evident superhydrophobic performance.

Remarkably, the availlable extreme water repellency was found to well remain within the simulated seawater immersion over 2000 hours. A series of additional tests, including rigorous electrochemical measurements, mechanical friction, ultraviolet exposure, freezing cycling, acidic/alkaline solutions, were also employed to validate the superhydrophobic property. Moreover, the measured corrosion current of the superhydrophobic sample exhibits a striking reduce by about 5 orders of magnitude when compared to the pristine material. Ab initio calculations revealed that the paracrystalline formation within the structures can facilitate the surface energy reduction and the chemical stability enhancement, thereby posing the extraordinary long-lasting superhydrophobic effects. These findings demonstrate a potential of femtosecond laser-driven atomic-level engineering of material surfaces for development of eco-friendly inorganic superhydrophobic surfaces to fulfill mutiple demonds.

Keywords: Femtosecond laser , Metal surface, Superhydrophobicity

Ultrafast Laser Multi-Scale Manufacturing of Inorganic Nanomaterials

Linhan Lin

Tsinghua University

Abstract: Laser 3D nanoprinting is a maskless manufacturing technique, which can achieve high-resolution fabrication of diverse 3D nanostructures. However, traditional laser printing techniques are limited by the photopolymerization process and are only applicable to some photoresists. In this talk, I will introduce several additive manufacturing techniques such as photoexcitation-induced chemical bonding (PEB) and optofluidic crystallithography, which allows the 3D printing of inorganic materials including semiconductors, metals, insulators, as well as the laser direct writing of single-crystal halide perovskites. These laser manufacturing techniques open new ways for the fabrication of functional nanodevices and will find many applications such as integrated chips and near-eye display.

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Laser Mode Manipulation in Both Solid-State and Fiber Lasers

Sha Wang

Sichuan University

Abstract: The modes of lasers include two types: transverse modes and longitudinal modes. This report mainly focuses on the regulation of transverse modes and longitudinal modes in lasers.

For the transverse mode manipulation of lasers, methods such as off-axis pumping, Sagnac interferometric structure, and polarization rotation technology are adopted to realize the generation of vortex beams, flat-top beams, and skyrmions in solid-state and fiber lasers.

For the longitudinal mode manipulation: in the single-frequency laser regime, high-stability single-frequency laser output is achieved through a composite cavity structure; in mode-locked lasers regime, stable mode-locked lasers and single-cavity dual optical comb lasers are obtained by combining multiple mode-locking mechanisms, and the intelligent control of mode locking in both solid-state and fiber lasers is explored.

Attosecond electron and gamma-ray sources by intense laser-plasma interactions

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Abstract: The rapid development of laser technologies promises substantial growth of peak laser intensities and thus has pushed laser–plasma interaction to the relativistic regime over the past several decades. This has provided opportunities for building tabletop particle accelerators and compact X/γ-ray radiation sources. High energy density electron beams and γ-rays with attosecond duration, high collimation and beam angular momentum (BAM) may find many potential applications in several fields like nuclear physics, astrophysics, laboratory astrophysics, etc. Especially, the generation of attosecond bunches of energetic electrons offers significant potential from ultrafast physics to novel radiation sources. A proper laser field structure in time and space potentially provides effective manipulation of atoms and charged particles, including the generation and acceleration of ultrashort electron bunches. In this talk, we propose a scheme to generate such electron and γ-ray beams by a few-cycle twisted laser pulse interacting with plasma targets. Our model clarifies the laser intensity threshold and carrier-envelope phase effect on the generation of the isolated electron sheet. Three-dimensional numerical simulations demonstrate the γ-ray emission with 320 attoseconds duration and peak brilliance of 9.3×10^{24} photons s^{-1} $mrad^{-2}$ mm^{-2} per 0.1% bandwidth at 4.3 MeV. The γ-ray beam carries a large BAM of $2.8\times10^{16}\hbar$, which arises from the efficient BAM transfer from the rotating electron sheet, subsequently leading to a unique angular distribution. This work should promote the experimental investigation of nonlinear Thomson scattering of rotating electron sheets in large laser facilities.

Keywords: Attoseond electron beams, LG laser pulse, Beam angular momentum.

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Femtosecond laser fabricated functional micro/nanostrucutres and applications

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Abstract: Compared to traditional laser processing technology, femtosecond laser offers higher precision, reduced thermal effect, and a broader range of material applicability. Here, we present the research progress on the fabrication of functional micro/nanostrucutres, such as waveguides, grating, based on femtosecond laser. Furthermore, we report applications in spectroscopy and nonlinear optics.

Femtosecond lasers possess the capability to readily process three-dimensional micro- and nano-structures inside transparent hard materials, enabling the fabrication of complex three-dimensional micro- and nano-structures inside the material. Among these, three-dimensional optical waveguides, as the most fundamental optical components in integrated optics, find extensive applications in waveguide lasers, frequency converters, and supercontinuum generation. We fabricated helical three-dimensional optical waveguides in YAG using femtosecond laser processing. By creating auxiliary etching dual lines and auxiliary etching pores at both ends, followed by wet etching to expose these positions to air, we successfully produced hollow channel waveguides in YAG. The results show that the waveguide exhibits excellent light-guiding properties and supercontinuum characteristics. Furthermore, calculations indicate that small-sized hollow-channel waveguides can achieve dispersion control, with smaller dimensions yielding stronger dispersion control capabilities. Combined with near-field enhancement effects, the fabrication of nanoscale three-dimensional hollow-channel waveguides can be easy, thereby achieving highly precise dispersion control.

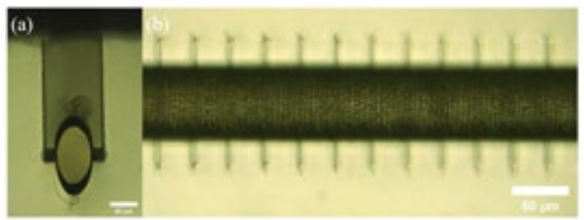

Fig.1 The microscopic images of the end-faces (a) and top-view patterns (b) of the helical hollow channel waveguide.

Keywords: femtosecond laser processing, waveguide, supercontinuum generation

Track 10 PhD Student Special

Generation of strong attosecond field in soft x-ray region: Toward attosecond nonlinear experiments

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Abstract: We developed a perturbed waveform synthesizer to generate and characterize intense, low-repetition-rate isolated attosecond pulses. Intense IAPs are characterized by an efficient and convenient all-optical frequency-resolved optical gating method, demonstrating pulse durations of ~227 as and ~128 as with central photon energies of 60 eV and 107 eV, respectively. Ultra-intense isolated attosecond fields were realized through sub-micrometer focusing with a high-precision ellipsoidal focusing mirror. The peak power intensity is expected to reach the Petawatt/cm^2 level, enabling access to attosecond nonlinear spectroscopy.

The generation of isolated attosecond pulses (IAPs) is vital to attosecond science, enabling ultrafast investigations of electronic dynamics in atoms, molecules, and condensed matter. In this study, we developed a perturbed three-channel waveform synthesizer for efficient IAP generation and characterization at low repetition rates (10 Hz)[1]. Intense IAPs centered at photon energies of 60 eV (227 as duration, as shown in Fig.1) in argon (Ar) and 107 eV (128 as duration) in neon (Ne) were generated by the driving field from an optimized three-channel waveform synthesizer and characterized using all-optical frequency-resolved optical gating (AO-FROG) by introducing a perturbed pulse to the waveform synthesizer, which proved to be an effective and precise method for analyzing IAPs, providing fast feedback and improved spectral flexibility for the tunability of the IAP source. We demonstrated the generation of gigawatt and subgigawatt-scale IAPs in the extreme ultraviolet (XUV) and soft X-ray region, respectively, achieving peak powers higher than previously reported values.

Furthermore, the proposed tabletop gigawatt-class IAP was tightly focused down to a sub-micrometer scale spot size by employing a custom-made ellipsoidal mirror, where the peak power intensity is expected to reach a Petawatt/cm² level. The surface of the ellipsoidal mirror was finely polished to meet the requirements of such extreme focusing and was coated with a multi-layer Mo/Si coating, which supports high reflectivity of up to 28% for the 60 eV regime. The focused spot size was evaluated using the knife-edge method, which employed the atomically flat edge of a silicon window and an X-ray CCD camera. A preliminary demonstration is presented in Fig.2, corresponding to the sub-micron focusing of attosecond pulse trains driven by a multi-cycle 800 nm femtosecond pulse, which validates the focusing capability of the system. Although sub-micrometer focusing of IAPs has been achieved, their repeatability and long-term stability require further improvement.

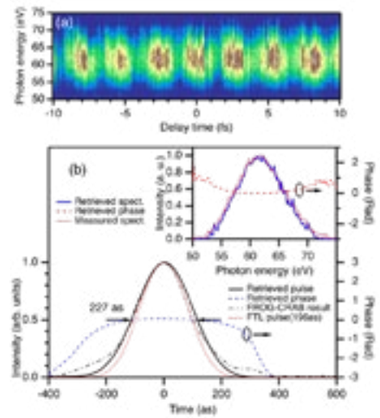

Fig. 1. Results of gigawatt-scale XUV IAPs in Ar gas. (a) Experimentally measured AO-FROG trace. (b) Retrieved IAP intensity and phase profiles, the experimentally measured spectrum, along with the retrieved spectrum from the IAP profile via Fourier-Transform, are shown in the inset.

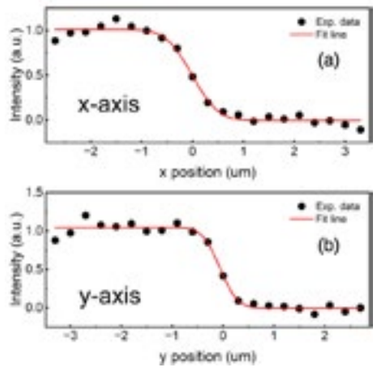

Fig. 2. Results of knife-edge measurement. (a) and (b): results for attosecond pulse trains with beam diameter (FWHM) of 0.95 micron along the X axis and 0.64 micron along the Y axis, respectively.

The ability to generate such powerful IAP fields opens the door to realizing and exploring attosecond nonlinear optics, such as nonlinear frequency conversion and four-wave mixing. This work will also help build a method for the application of IAP pump-IAP probe nonlinear spectroscopy, which has been considered a powerful tool for understanding ultrafast electron dynamics.

Keywords: isolated attosecond pulses, intense attosecond fields, attosecond nonlinear optics

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Ultrafast dynamics of charge ordered phases of $IrTe_2$

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Abstract: $IrTe_2$ exhibits several charge-ordered (CO) phases. The low temperature polarized Raman spectroscopy studies on single crystals have revealed distinct active phonon modes at various temperatures; however, these modes were not directly linked to a specific CO phase. Additionally, tunning the system through chemical doping or reducing its thickness induces superconductivity in the ground state and stabilizes a CO state in the normal state. Understanding of the intrinsic properties of each individual CO phase in $IrTe_2$ single crystal is essential for unraveling the fundamental mechanisms governing phase transitions.

We used near-infrared pump-probe technique to investigate various charge ordered phases of $IrTe_2$. Initiated by an ultrashort laser pulse, coherent lattice vibrations can be detected by measuring a transient reflectivity change. The Fourier transform spectra of the oscillations reveal three distinct low-temperature phases. Temperature-dependent measurements allowed us to identify each phase and correlate its unique oscillation characteristics with the underlying structural configuration. Furthermore, by analyzing the polarization dependence of the ultrafast dynamics, we determined that both the oscillation frequencies and polarization-dependent responses serve as key signatures for distinguishing between different CO phases of $IrTe_2$.

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Simulation of Quantum nature in High-Harmonic Generation

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Abstract: High Harmonic Generation (HHG) is an extremely nonlinear optical phenomenon that occurs when intense laser fields interact with matter, which leading to the emission of high harmonics of driving frequency that can extend to the X-ray spectral ranges and reduce to the attosecond timescale. This process has become a powerful tool in the generation of coherent X-ray resources, attosecond pulses, ultrafast spectroscopy and transient electron dynamics. For decades, three-step model within Strong Field Approximation(SFA) has provided a semi-classical theory for revealing its spectral features, such as the characteristic plateau and cutoff frequency. Classical descriptions of the driving and emission field is sufficient in most experimental environments. However, recent advances in HHG emission photon statistics constituted an experimental demonstration of the quantum-optical nature of the HHG process, opened a new avenue for extending HHG to a fully quantum optics regime. I. Kaminer, M. Lewenstein have introduced Quantum Optical-corrected Strong-field Approximation(QOSFA) model, revealing non-classical phenomena such as preservation of the quantum properties of the quantum driving field, and the squeezing of the initial coherent driving field. This model can reveal the primary quantum properties of the optical field in the high-harmonic generation process, yet its results remain dependent on semiclassical numerical calculations.

The QOSFA model partitions the driving field into the classical strong-field component and the quantum fluctuation component, thereby leveraging established outcomes from the semiclassical SFA. This approximation neglects quantum interactions between optical modes and the material system, leading to a loss of correlations between the system and field, which may consequently result in the absence of partially corresponding quantum properties. In this talk, we numerically investigate quantum effects in HHG by using the fully quantized model for the interaction between the intense laser field and a two-level system. In this model, we quantized both the driving mode and the harmonic modes, and directly solved the time-dependent schrodinger equation. Our model fully incorporates the quantum nature of both the driving field and the high harmonics. The precise numerical solution describes the dynamics of the two-level system and the photon distribution in each mode. Our results confirm the existence of squeezing in the driving field. Especially, we found that both the driving and harmonic fields exhibit more significant squeezing as the field intensity grows, demonstrating that the quantum nature of high harmonic generation is intensity-sensitive.

In summary, we have precisely calculated a fully quantum high-harmonic generation model. We anticipate that this approximation-free full quantum treatment will help exploring additional non-classical properties in high-harmonic generation.

Keywords: Ultrafast Lasers; Quantum Optics; Harmonic Generation; Nonlinear Optics

Intense 11 eV femtosecond beamline by third harmonic generation in Xe and Kr

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Abstract: Vacuum Ultraviolet (VUV) at 11 eV (114 nm) is suitable for Time- and angle-resolved photoemission spectroscopy (Tr-ARPES) beamlines [1-4], as it lies in the shortest wavelength range where transmission optics such as LiF and MgF_2 are still available. Starting from the 1030 nm Yb-based lasers and focusing its 3rd harmonic around 343 nm into an enclosed noble gas chamber, THG at 11 eV with high conversion efficiency have been demonstrated.

One difficulty in such a setup is the separation of 11 eV from the much stronger 343 nm driver beam; while spectral separation optics such as LiF prisms and dielectric beamsplitters exist, they offer limited throughput and often suffer from long-term degradation. Here, we propose an alternative approach: the 343 nm beam spatially filtered into a donut shape as the driver pulse. By carefully adjusting the pressure, it is shown that the emitted 11 eV beam can form a gaussian-like profile, filling the central part of the beam where the driver has little intensity, giving a good spatial separation.

A turnkey Yb:KGW laser with a central wavelength at 1030 nm and repetition rate up to 50 kHz is used to produce 3rd harmonic pulses at 343 nm with single pulse energy up to 51 μJ. The central part of the 343 nm beam is then clipped a metallic spatial filter with a diameter of 1.9 mm, turning the beam into a donut shape. The outer part of the beam is additionally clipped by an iris. The remaining intensity of 28 μJ is then focused into an enclosed gas chamber filled with Xe or Kr by a CaF_2 lens with a focal length of f=500mm. The generated 11 eV beam exits from a LiF window, is sent into a grating monochromator and then finally measured by an X-ray CCD camera, as shown in Figure 1.

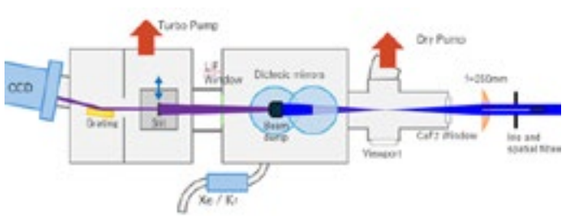

Figure 1. Vacuum system setup and light propagation

Figure 2 shows the Kr-pressure dependence of the beam profile of the emitted 11 eV pulse, measured along the vertical direction. As the pressure increases from zero, the total yield of the 11 eV rises, peaking around 6-8 kPa. At lower pressure range, the 11 eV beam shows two peaks, reflecting the original beam shape of the 343 nm driver. At higher pressures, the two peaks become less separated, gradually merging into a gaussian-like single peak. The conversion efficiency is estimated to reach 0.4% in Xe gas, and 0.1% in Kr. We indicate that the observed beam shaping effect can be explained by the geometrical phase matching conditions around the focus point.

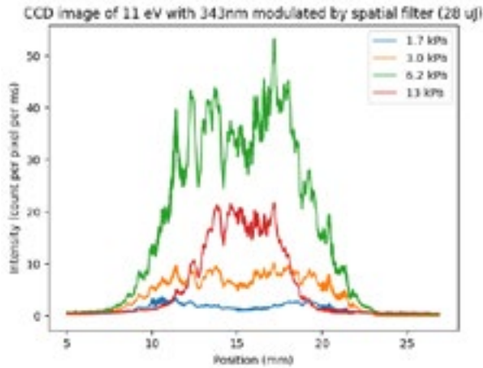

Fig. 2. Beam profile of the 11 eV emitted from a donut-shaped 343 nm driver pulse, measured under different pressures.

We demonstrated a bright femtosecond 11 eV generation from a commercial Yb:KGW laser system with the highly efficient THG process in Xe/Kr gases. By modulating the 343 nm driver beam profile into a donut shape, an excellent spatial separation of the 11 eV emission from the driver is achieved. This offers a simple and robust 11 eV light source, potentially suitable for a Tr-ARPES beamline in future.

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Continuum-continuum transition: the hydrogen model and beyond

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Abstract: Continuum-continuum (CC) transition plays an important role in the attosecond photoionization time-delay measurements using the two-photon scheme such as the RABBIT technique, where the two-photon transition amplitude is decomposed as the product of the bound-continuum transition and the CC transition. For a long time, the CC transition has been only available with asymptotic approximation [1], which is less accurate at low-kinetic energy and cannot correctly describe the angular dependence of the time delay [2]. We have derived the analytical formula for the CC transition amplitude for the hydrogen-like atoms using the exact Coulomb wavefunctions without asymptotic approximation [3], which overcomes the inaccuracy in the low-kinetic-energy region and agrees with the experimental and TDSE-simulated angle-dependent time delay [4]. This formula also reveals a Cooper-like minimum in the CC transition for high-angular-momentum states due to the centrifugal potential, which is confirmed by TDSE on the Ce 4f two-photon ionization [5]. More recently [6], we have extended the treatment of CC transition amplitude into the Coulomb potential accompanied with a short-range potential, hybridizing the numerical and analytical methods. This approach can be further extended to the case where the intermediate state of the absorption pathway lies under the ionization threshold. Results on He 1s, Ar 3p, and Xe 4d XUV-UV two-photon ionizations agree quantitatively with TDSE, showing the violation of Fano's propensity rule [7,8] at certain energies. Our new approach paves the way for calculating the CC transition amplitudes in molecular potentials with consideration beyond the central force field.

Keywords: Two-photon transition, continuum-continuum transition, Coulomb Green's function, Cooper minimum

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Generation of isolated white-light attosecond pulses in solids

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Abstract: Attosecond-pump attosceond–probe spectroscopy (APAP) is the key to understanding electronic-dominated dynamics in light-matter interactions. Although the feasibility of APAP has been demon-strated using isolated attosecond pulses (IAPs), the efforts are mainly confined to the ionization-induced dynamics triggered by the extreme ultraviolet (XUV) and soft X-ray lights. However, thegeneration of IAPs capable of exciting neutral electronic excited states, which are more prevalentin nature, is still in its infancy, significantly limiting a comprehensive insights into valence-electron wavepacket dynamics. Here, we theoretically demonstrate a novel scheme for the straightforward and compact generation of white-light IAPs covering the visible and ultraviolet regions, based on solid-state HHG. By analyzing the strong-field-induced electron-hole dynamics together with a saddle-point approximation, we unfold its microscopic generation mechanism. Furthermore, the feasibility and robustness of this approach are validated by the generation of IAPs from various ma-terials under the same mechanism. Our work paves the way for generation of tabletop white-light IAP sources, thereby harnessing the widespread applications of APAP.

Keywords: white-light isolated attosecond pulse; solid-state HHG; attosecond science

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2.7-octave supercontinuum generation spanning from ultraviolet to near-infrared in thin-film lithium niobate waveguides

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Abstract: Supercontinuum generation (SCG) with spectral coverage across the full visible and ultraviolet (UV) ranges is crucial for numorous quantum computing and atomic systems. Here, such ultrabroad-bandwidth SCG was demonstrated in thin-film lithium niobate (TFLN) nanophotonic waveguides fabricated by photolithography assisted chemo-mechanical etching method, without introducing complex periodic poling during process flow. The MgO doped waveguides were designed to exhibit anomalous-dispersion in the telecom band, simultaneously enabling dispersive wave emergence to broaden spectrum. Thanks to the utilization of the strong $\chi(2)$ and $\chi(3)$ nonlinear processes, 2.7-octave SCG spanning from 330 nm to 2250 nm was observed by pumping the waveguide with a 1550-nm femtosecond pulsed laser with 0.687 nJ, agreeing well with numerical simulation. This spectral coverage represents the state of the art in TFLN platforms without fine microdomains, and even close to the record in sophisticated chirped periodically poled TFLN waveguides. Meantime, photorefractive effect of lithium niobate (LN) was effectively suppressed by doping of MgO to support long time maintenance of spectra.

Keywords: Supercontinuum generation, thin film lithium niobate, nanophotonic waveguides

Exploringhigh Tcsuperconductorsat High Pressures using Ultrafast Spectroscopy

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Abstract: High pressure is a clean and efficient platform for studying high T_c superconductors. However, a major challenge is that most experimental probes are incompatible with high-pressure environments, hindering the direct observation of many intertwined orders. Ultrafast spectroscopy provides a powerful solution to this limitation. In this report I will present our findings on the nickelate superconductor $La_3Ni_2O_7$ and cuprate superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$, using a custom-built high-pressure ultrafast spectroscopy system. In $La_3Ni_2O_7$, we give the full evolution of density-wave-like phases for the first time at high pressures. In $Bi_2Sr_2CaCu_2O_{8+\delta}$, we observed a pressure-temperature phase diagram distinct from the hole concentration-temperature phase diagram, revealing different roles of charge and spin degree of freedom in the pseudogap phase.

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Terahertz third-harmonic generation of lightwave driven Weyl fermions far from equilibrium

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Abstract: While terahertz (THz) high-harmonic generation (HHG) has been studied in Dirac materials such as graphene, topological insulators, and three-dimensional Dirac semimetals, this nonlinear phenomenon has not yet been reported in Weyl semimetals. In this work, we report on room-temperature THz third-harmonic generation in the Weyl semimetal TaP [1]. We find that the third-harmonic signal exhibits a cubic power-law dependence on the incident THz field, confirming its perturbative origin. In addition, we observe a pronounced sensitivity of the harmonic efficiency to pump-pulse ellipticity [1,2], enabling control over the nonlinear response through polarization tuning. The qualitative features of the measured response are consistent with nonlinear kinetics of Weyl fermions, where the topologically protected band crossings – Weyl points – play a central role in mediating harmonic generation. Our results establish Weyl semimetals as a new material platform for THz nonlinear optics, providing insight into ultrafast carrier dynamics and offering opportunities for polarization-controlled photonic functionalities in the THz regime.

Keywords: Weyl semimetals, THz spectroscopy, High harmonic generation

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Supercontinuum generation assisted by 2.8 μm high repetition rate and high power mode-locked fluoride fiber lasers

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Abstract: This letter reports a mode-locked fluoride fiber laser (MLFFL) based on hybrid mode-locked technology, with a center wavelength of 2.8 μm, a repetition rate of 176 MHz, an average output power of 440 mW, and a pulse width of 285 fs. To the best of our knowledge, this is the highest repetition rate output from a MLFFL. Due to the low pulse peak power of high repetition rate MLFFL, the accumulation of nonlinear phase shift can be effectively suppressed during amplification to avoid pulse splitting. We employ the high repetition rate MLFFL as the seed source. The average output power of the pulse was increased to 5 W, and the pulse width was compressed to 135 fs, after two-stage amplification of pre amplification and main amplification. Subsequently, the amplified pulse was injected into an indium fluoride fiber to generate a supercontinuum spectrum. The influence of the length and dispersion characteristics of the indium fluoride fiber on the broadening of the supercontinuum spectrum was further simulated. The simulation results show that the spectral coverage range can reach 4.5 μm by using a 10 m long indium fluoride fiber.

Keywords: hybrid mode-locked, high repetition rate, high average power, supercontinuum spectrum

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Nonadiabatic Effect in High-Order Harmonic Generation Revealed by a Fully Analytical Method

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Abstract: We propose a fully analytical method for describing high-order harmonic generation (HHG). This method is based on the strong-field approximation (SFA) and utilizes the perturbation expansion method. Specifically, we expand the laser-induced dipole moment to third-order analytical expansion (TAE) and fifth-order expansion (FAE) with respect to the Keldysh parameter γ, presented the scaling law of HHG with respect to the wavelength and intensity of the driving laser. We show that higher-order perturbation terms usually capture the nonadiabatic effect, while the zero-order term always represents the adiabatic effect. Furthermore, we reveal how the nonadiabatic effect influences HHG intensity by impacting electron dynamics and apply it in HHG phase matching.

Enhanced terahertz emission signal in antiferromagnet-heavy metal heterostructures

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Abstract: Antiferromagnetic materials (AFMs), have potential to achieve spintronic applications due to their advantages, such as being insensitive to external magnetic fields, the resonance frequency of AFMs being in the terahertz (THz) region. In addition, the zero net magnetization in AFMs makes them easier to design some devices of high-density integration. On the other hand, the insensitivity of AFMs to external magnetic fields makes the manipulation and detection of spin currents or magnetic order in AFMs difficult. Since some available techniques has been set up for antiferromagnetic order, for instance by electromagnetic radiation we can probe the order of AFMs due to magneto-optical effect. Among the outstanding questions is how to generate, manipulate and detect the spin currents of an antiferromagnet effectively. It has been reported that the THz spin currents can be generated by a femtosecond laser pumping the AFM film. And the THz spin currents in AFM can be injected to the adjacent heavy metal (HM), as a spin current detector due to inverse spin Hall effect (ISHE), i.e. covert spin current into charge current. However, the injection of the THz spin currents is inefficient in such a process, sometimes we can even not distinguish observation signals from system noise. In this research, a significant improvement of the injection of THz spin currents will be accomplished by us. In order to raise the efficiency, two methods are adopted by us. It has been found that the signal of THz spin currents is bolstered, and ultimately could achieve a largely boost comparing to original state.The results from our research can be conducive to the understanding of the generation, transportation and detection of spin currents in both magnetism and spintronics, especially in antiferromagnetic spintronics. Besides, it can pave a road for the design of spintronic application based on AFMs as well.

Keywords: terahertz emission, antiferromagnets, spintronics, orbitronics

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High-Magnification Asynchronous Time Lens System

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Abstract: Time-lens systems exploit space-time duality to transform optical waveforms between temporal and spectral domains, enabling pulse compression, temporal broadening, and real-time analysis of single-shot ultrafast phenomena. Traditional electro-optic time lenses face inherent trade-offs between modulation bandwidth and temporal aperture, leading to waveform distortion, while conventional parametric designs struggle with limited figure-of-merit (FOM) and stability. Here, we present an asynchronous four-wave mixing (FWM) time lens with a record magnification factor of 445.97×, surpassing prior fiber-based systems by over 220%. This architecture eliminates strict repetition rate alignment requirements by employing two mode-locked fiber lasers (MLFLs) with different central wavelengths operating at 1531 nm (signal) and 1555 nm (pump) with a 26 Hz repetition rate difference. The system integrates soliton molecule generation, distributed Raman amplification, and cascaded dispersion compensation to achieve unprecedented temporal resolution and stability.

The experimental framework utilizes a signal arm with a carbon-nanotube mode-locked laser (10.559411 MHz) and a pump arm based on nonlinear polarization rotation (10.559385 MHz). A MachZehnder interferometer generates soliton pairs with 13.74 ps separation, verified via spectral modulation (0.569 nm periodicity). Dispersion pre-chirping is implemented using 50 m of dispersion-compensating fiber (DCF1: −160 ps/nm/km, $\varphi_s \approx 10.2$ ps²) and erbium-doped fiber amplification (EDFA), while the pump arm employs 100 m DCF2 ($\varphi_p \approx 20.4$ ps²) for linear chirp induction. Asynchronous FWM occurs in a 100 m highly nonlinear fiber (HNLF, $\gamma \approx 10$ W⁻¹ km⁻¹), producing idler pulses that undergo cascaded dispersion compensation ($\varphi_i \approx 4506.3$ ps²) to achieve temporal broadening. Theoretical magnification (M = 441.79×) aligns with experimental results (434.66×), with deviations attributed to third-order dispersion effects and detector response limitations.

Key innovations include distributed Raman amplification to mitigate idler pulse attenuation, enhancing signal-to-noise ratio (SNR) by 18 dB, and active polarization control to optimize FWM efficiency. Autocorrelation measurements confirm soliton separation (14.08 ps, 2.5% deviation from theory), while real-time oscilloscope data (20 Gsamples/s) reveal a 6.12 ns pulse interval, corresponding to a 434.66× magnification. Comparative analysis with low-magnification configurations (93.04×) demonstrates a 4.8fold resolution improvement, validating the system's capability to resolve sub-picosecond dynamics.

This advancement addresses critical limitations in ultrafast metrology by decoupling FOM from power-dependent parameters, achieving a 220% improvement over prior fiber-based systems. The asynchronous architecture eliminates synchronization constraints, enabling flexible temporal window adjustment (spanning thousands of cavity round trips) and robust operation under environmental perturbations. Applications span high-speed communications, nonlinear optics, and single-shot spectroscopy, where precise characterization of ultrafast phenomena is paramount. For instance, in optical time-domain reflectometry, this system could enhance fault detection resolution in

fiber networks by resolving sub-ps reflections.

Future work will focus on multi-wavelength scalability using wavelength-division multiplexing and adaptive feedback control for real-time imaging. Integration with machine learning algorithms could further optimize dispersion management and polarization alignment, reducing measurement uncertainties. By overcoming traditional bandwidth-aperture trade-offs, this technology establishes a new paradigm for ultrafast optical systems, with transformative potential in next-generation photonic networks and quantum coherence studies.

For FWM time lens, in 2020, Zhang et al. used time lens technology for pulse dynamics observation of passively mode-locked fiber lasers and achieved time magnification factors of 100 and 165 times [1,2].

In 2022, Joshi reported a picosecond resolution quantum signal all-optical time lens based on Bragg scattering four-wave mixing. The system achieved a time magnification factor of 158 times at singlephoton input [3]. In 2023, Li et al. proposed a time amplifier based on a synchronized time lens to characterize ultrafast pulses, achieving a time magnification factor of 200 times[4]. In 2024, Kilic et al. demonstrated Time Lens Photon Doppler Velocimetry for the first time, verifying the performance in the 74 km/s speed range with high accuracy using a time magnification factor of 7.6[5].

Prior studies indicate that conventional all-fiber time-lens amplification systems exhibit a maximum magnification factor of approximately 200×, while characterization of ultrashort optical pulses necessitates significantly greater magnification capabilities. To address this limitation, we developed an all-fiber asynchronous four-wave mixing (FWM) time-lens system. Through soliton molecule spacing analysis, this architecture achieves a magnification factor of 445.97×, surpassing current fiber-based implementations by over 220%.

The experimental architecture, illustrated in Fig. 1, employs two custom-built mode-locked fiber lasers (MLFLs) as dual-wavelength seed sources. The signal arm utilizes an MLFL operating at 10.559411 MHz repetition rate (central wavelength: 1531 nm) with carbon-nanotube-based mode-locking for stable traditional soliton generation. Synthetic soliton pairs are created via a Mach-Zehnder interferometer (upper branch, Fig. 1) incorporating a tunable time delay line (TDL) for precise pulse spacing control (50:50 optical coupler splitting ratio). Spectral characterization (Fig. 2a) reveals a 0.569 nm modulation periodicity, corresponding to a 13.74 ps soliton separation. Subsequent dispersion pre-chirping is achieved through 50 m dispersion-compensating fiber (DCF1: −160 ps/nm/km, $\varphi_s \approx 10.2$ ps²), followed by erbiumdoped fiber (EDF) and ASE suppression via a 1530 nm bandpass filter (BPF1).

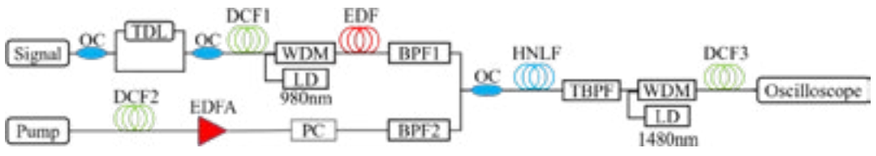

Fig. 1: Schematic diagram of the time lens system

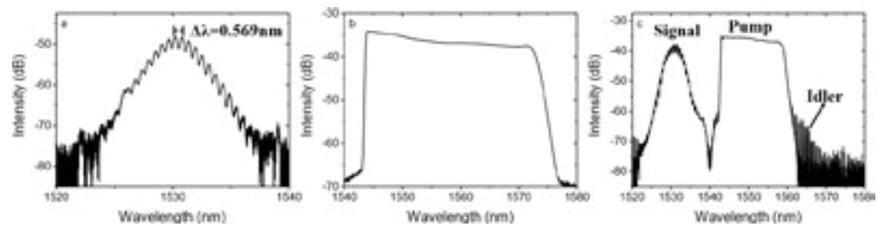

Fig. 2: Spectrum of the time lens system. (a) Spectrum of the signal pulse after the soliton molecule is formed. (b) Spectrum of the pump pulse. (c) Spectrum of the soliton molecule and the pump pulse after four-wave mixing.

The pump arm features an NPR-based MLFL (nonlinear polarization rotation) generating dissipative solitons at 10.559385 MHz repetition rate (central wavelength: 1555 nm; spectrum in Fig. 2b). The repetition frequencies of the signal pulse and the pump pulse only differ by 26 Hz. Pump pulses undergo dispersion tailoring via 100 m DCF2 ($\varphi_p \approx 20.4$ ps²) to induce linear chirp, followed by erbium-doped fiber amplification (EDFA) and ASE filtering (1550 nm BPF, 15 nm bandwidth).

Our time lens system leverages asynchronous four-wave mixing (FWM) between signal and pump pulses in a highly nonlinear fiber- based time lens, enabling a record temporal measurement window spanning thousands of cavity round trips. In synchronous FWM systems, stringent repetition rate matching between pump and signal pulses is required. To achieve this, we stabilize the repetition rates using a synchronization device, implemented by integrating a tunable delay line (TDL) into the signal modelocked fiber laser (MLFL) cavity. By contrast, the asynchronous FWM time lens eliminates the need for strict repetition rate alignment. Instead, its temporal measurement window is governed by the stable repetition rate difference between signal and pump pulses, significantly enhancing operational flexibility and scalability.

Four-wave mixing interaction occurs in a 100 m highly nonlinear fiber (HNLF: $\gamma \approx 10$ W^{-1} km^{-1}; output spectrum in Fig. 2c). The generated idler undergoes spectral isolation via a tunable bandpass filter (TBPF) and temporal broadening through cascaded dispersion compensation DCF3 (15 km DCF + dispersion compensation module, $\varphi_i \approx 4506.3$ ps²). The additional dispersion φ_s and φ_p introduced by the signal arm and the pump arm satisfy the following formula [6]:

$$\frac{1}{\varphi_s} - \frac{1}{\varphi_i} = \frac{2}{\varphi_p}$$

Therefore, the theoretical time magnification factor is $M = \varphi_i / \varphi_s \approx 441.79$. In practice, due to the distortion induced by third-order dispersion, the residual linear chirp of the pump pulse, and the response time of the detector, the actual magnification factor may be larger or smaller.

To enhance the temporal measurement range of our time lens system, we integrated distributed Raman amplification. This approach compensates for idler pulse attenuation, achieving a significantly improved signal-to-noise ra-

tio (SNR). Furthermore, we employed an extracavity polarization controller to actively align the pump and signal pulse polarization states, optimizing four-wave mixing (FWM) efficiency and ensuring robust nonlinear interactions.

The laser output was measured by a high-speed real-time oscilloscope (20Gsamples/s sampling rate) and a 25-GHz bandwidth photodetector (PD).

To validate measurement fidelity, autocorrelation characterization of the soliton molecule signal pulse was performed (Fig. 3a). Experimental data reveal a pulse separation of 14.08 ps, exhibiting a 2.5% deviation from theoretical predictions. This discrepancy arises primarily from pulse broadening during erbium-doped fiber (EDF) amplification, compounded by systematic measurement uncertainties inherent to autocorrelation trace interpretation. The observed temporal expansion underscores the importance of accounting for nonlinear propagation effects in high-magnification temporal imaging systems.

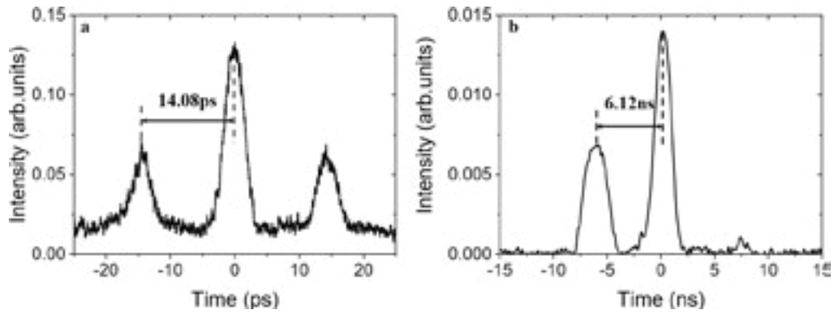

Fig. 3: (a) Autocorrelation curve of a soliton molecule. (b) 445.97× time lens measurement result.

As shown in Fig. 3b, measurements from the high-speed real-time oscilloscope and photodetector reveal a pulse interval of 6.12 ns. Combining this value with autocorrelation curve analysis, we calculate a system magnification of 434.66×. This aligns closely with the theoretical soliton molecular spacing prediction (445.97×), with deviations attributed to erbium-doped fiber (EDF) broadening effects. Both experimental and theoretical results are consistent with the dispersion-derived magnification of 441.79×, falling within the acceptable error margin.

To validate the fidelity of soliton molecules after undergoing a 434.66× temporal magnification via time-lens technology, we analyzed the peak height ratios of the triple-peak structure in their autocorrelation traces. The intrinsic soliton molecule exhibited a baseline peak height ratio of 1.01:2.68:1. Based on the measurement principle of autocorrelation, the derived peak height ratio of the original soliton molecule was calculated as 2.232:1. As demonstrated in Fig. 3b, experimental measurements revealed a post-time-lens peak height ratio of 2.0498:1. The discrepancy of 8% between the initial peak height ratio of molecular solitons and the Time-lens-measured ratio objectively demonstrates the measurement accuracy of our 434.66× time-lens system. This quantitative agreement between pre-compression and post-compression profiles rigorously validates the fidelity of temporal waveform characterization in our photonic time-lens architecture.

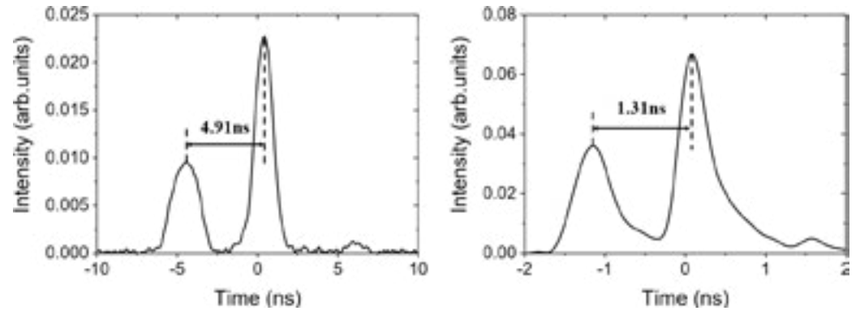

Fig. 4: (a) 357.35× time lens measurement result. (b) 95.34× time lens measurement result.

To further validate our findings, we replaced the post-stage dispersion with two dispersion compensation modules (results in Fig. 4). The first DCM implementation achieved a 357.35× temporal magnification factor, as shown in Fig. 4a. This result demonstrates close agreement with the 348.72× magnification derived from autocorrelation trace analysis. Quantitative evaluation of the soliton molecule's peak height ratio revealed a measured value of 2.374:1, deviating merely 6% from the initial configuration, confirming the system's accuracy at 348.72× magnification.

In contrast, the second DCM configuration yielded a reduced magnification factor of 93.04×. Here, the magnification factor measured via autocorrelation is 93.04×, closely aligning with the 95.34× predicted by soliton molecule spectral modulation theory. Analysis of Fig. 4b showed an altered peak height ratio of 1.86:1, corresponding to a 16.76% discrepancy from the original molecular configuration. This distortion phenomenon aligns with theoretical predictions from equation $1/\varphi_s - 1/\varphi_i = 2/\varphi_p$, which establishes that decreased post-dispersion compensation disrupts the critical quadratic phase relationship between φ_s and φ_p . The compromised phase matching not only induces defocusing effects in time-lens measurements but also directly reduces the achievable magnification factor. However, compared to the highmagnification time lens system (445.97×), the lower amplification factor induces partial soliton molecule overlap, as shown in Fig. 4b. This overlap obscures clear temporal distinction between soliton molecules— a limitation absents in the high-magnification configuration. Thus, the high-magnification time lens proves superior for resolving ultrafast dynamics with precision. These experimental results quantitatively demonstrate the sensitivity of time-lens performance to dispersion management, particularly emphasizing the importance of maintaining proper phase relationships for distortion-free temporal imaging applications.

Keywords: Time-lens, Real-time observation, Asynchronous four-wave mixing

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Ultrafast Laser Patterning of Topology and Phonons in WTe_2

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Abstract: Topological materials have fundamentally transformed the landscape of condensed matter physics, owing to their unique band structures and robust boundary states that enable applications in quantum information processing, spintronics, and low-power electronics. A major challenge in this field is achieving real-time, reversible control over topological phases with both high spatial and temporal resolution. While static approaches—such as strain engineering, doping, or layer stacking—have enabled access to topological states, they are inherently limited in speed and reconfigurability. Dynamic, spatiotemporal modulation of topological order remains an open frontier.

In this work, we demonstrate ultrafast, spatially patterned control of the topological phase transition in the layered semimetal WTe_2, achieving nanometer-scale spatial precision and picosecond temporal resolution using femtosecond laser excitation. We generate a transient optical grating (TOG) by interfering two femtosecond laser pulses, creating a spatially periodic excitation pattern. This patterned optical field selectively drives the structural phase transition from the topological Td phase to the topologically trivial 1T* phase in WTe_2.

To visualize the resulting phase patterns and dynamics, we employ ultrafast four-dimensional scanning transmission electron microscopy (U-4D-STEM). This technique reconstructs structural phase maps across multiple lattice planes, revealing nanoscale heterostructures between the two phases. Dark-field imaging using Ultrafast transmission electron microscopy (UEM) enables real-space tracking of the structural evolution over time.

Our measurements reveal that the structural transition is not only reversible but also strongly modulated by the spatial profile of the optical fluence, resulting in a transient striped domain structure of alternating Td and 1T* phases. U-4D-STEM reconstructions show well-defined interfaces between these phases, while UEM dark-field imaging captures their dynamic behavior. Notably, we observe strain-mediated diffusion of the excited 1T phase*, indicating that the transition is influenced not only by local excitation but also by mechanical coupling across the lattice. Furthermore, we investigate the generation of coherent interlayer shear phonons, particularly the $1A_1$ mode, under TOG excitation. We map the phonon amplitude distribution in real space from dark field image series. The results show that the phonon population is confined to the optical grating fringes, demonstrating spatial control of lattice vibrations in sub-micron regions and confirming that the optical field effectively shapes both structural and vibrational dynamics.

In conclusion, we present a new framework for ultrafast, light-driven patterning of topological phases in layered quantum materials. This approach offers reversible, high-resolution control over both phase transitions and phonon populations. Our findings pave the way for optically reconfigurable topological circuits, ultrafast logic devices, and dynamic quantum-state engineering in van der Waals materials.

Keywords: Topology phase transition, WTe_2, Phonons, Transient optical grating, Ultrafast electron microscopy

Generation of Ultrafast Drill-Like Laser Fields with Shot-to-Shot Intensity Rotation

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Abstract: Thermal and stress effects play key roles in the interaction of light with solid materials. Prior studies proposed employing intensity-rotating optical fields to mitigate the impact of these factors. Conventional rotating optical fields exhibit intra-pulse rotation. To achieve a sufficiently large rotation number, the rotation period must be much shorter than the pulse duration. This requirement limits the applicability of intra-pulse rotating optical fields in the ultrashort-pulse regime. This work presents an alternative based on shot-to-shot control that homogenizes the multi-pulse accumulation of the thermal and stress effects, which circumvents the above constraint. Superposing the vortex pulses allows to generate a structured light field with azimuthal-dependent petal-like intensity, which can be rotated by the manipulation of phase differences. Here, we demonstrate inter-pulse rotating optical fields with two complementary designs, all-optical control and electro-optic modulation. These drill-like optical field hold many potential applications, e.g. precision laser machining and manufacturing.

Light field manipulation; Carrier-envelope phase; Drill-like optical field; Optical parametric amplification;

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Ultrafast laser nanostructuring and its application in electrochemical deposition of metal microstructures with high density and robust bonding strength

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Abstract: Ultrafast laser direct writing technology, with its capacity to efficiently and conveniently induce micro-nano structures on material surfaces, has opened up new avenues for precision material processing and the preparation of functional devices. In this study, we investigate the potential application of laser nanostructuring for surface functionalization and therefore localized electrochemical deposition. The surface skin-layer nanorelief structures induced by ultrafast laser are demonstrated to provide localized field enhancement and create attachment sites for electrochemical reactions, thereby enabling equivalent parallel localized electrochemical deposition under standard plating conditions. Furthermore, these nano-relief structures form a unique interdigitating junction structure between the depositor and the substrate, significantly enhancing the bond strength between the depositor and the substrate. The shear test results indicating the bond strengths can be up to 100 MPa, significantly exceeding that of conventional localized electrochemical deposition techniques. With the incorporation of electrochemical inhibitors, crystalline growth during electrochemical deposition is regulated, realizing efficient and controllable deposition of high-density copper microstructures. The hardness and elastic modulus of the deposited copper were tested to be 0.95 GPa and 67.99 GPa, respectively, approaching those of forged copper. For microstructure arrays on a centimeter scale, the electrodeposition time can be reduced from hundreds of hours to tens of minutes. This method is not only applicable to metallic conductive substrates but can also be extended to localized electrochemical deposition on semiconductor materials, offering promising prospects for the high-efficiency, high-performance, and practical manufacturing of metallic complex structured devices.

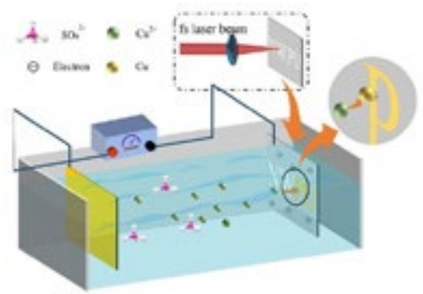

Figure 1 Schematic diagram of localized electrodeposition based on ultrafast laser surface modification[1].

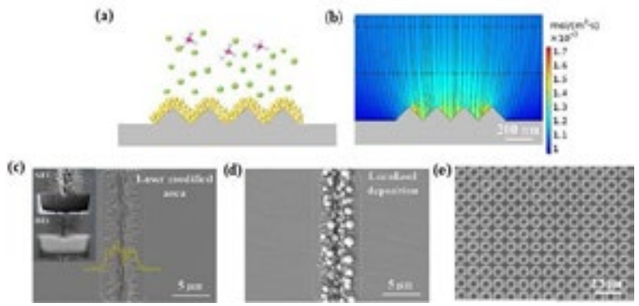

Figure 2(a) Schematic diagram of tip effect. (b)Simulation result of fluid field. (c)Surface after laser modification. (d)Surface after electrodeposition. (e) Circle array of deposited copper.

[1] Jinlong Xu and Guodong Zhang et.al, High-efficiency localized electrochemical deposition based on ultrafast laser surface modification, Surface & Coatings Technology, 471, 129923, (2023).

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Pulse quality refinement enabled by programmable spectral shaping in high-power ultrafast fiber laser

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Abstract: High power ultrafast fiber lasers have been widely used in scientific and industrial applications, such as nonlinear frequency conversion, strong field physics, precision micromachining, and advanced manufacturing [1, 2], owing to its high peak power, short pulse duration, and good beam quality. The average power of ultrafast fiber laser could and has been boosted to 10s of kilowatt (kW) level through coherent beam combination [3], since single fiber emitter power restrained to below 1 kW. Further scaling the average power of single fiber emitter could suffered from severe hazardous nonlinear effects during fiber amplification, including self-phase modulation (SPM), stimulated Raman scattering (SRS), gain narrowing, etc., leading to compressed pulse quality degradation. It is challenging to boost the average power of single fiber amplifier into the kW class while maintaining short pulse duration in good quality. Traditional method to generate high power ultrafast pulse employs Chirped-pulse amplification (CPA) [4], which mitigates these effects by stretching the pulse duration in time domain first, then pulse energy scaling while maintaining relative low peak power in gain fiber, at last a bulk grating pair compressor is utilized to compress the pulse back into short duration with high peak power. However, the grating compressor offers limited capability to compensate residual higher-order dispersion or nonlinear phase besides group delay dispersion (GDD), leading to a nearly picosecond pulse duration with large pedestal, and eventually lower down the peak power of ultrashort pulse. To address this issue, programmable spectral modulation devices have been explored to manipulate the seed spectral phase and amplitude before amplification, enabling the generation of high-fidelity femtosecond pulses with negligible pedestal [5]. Such spectral pre-shaping has become an attractive technique to improve compressed-pulse quality at the kW-level average power.

Here we present a high-power Yb-doped fiber CPA system that employs a reflective amplitude-modulation spatial light modulator (SLM) as a spectral shaper ahead of main fiber power amplifier, which could effectively reduce the pedestal of compressed pulse, concentrating more energy in the main pulse, leading to a high-quality sub 400-fs pulse at average power of 522 W. Figure 1 plots the experimental schematic, including a mode-locked oscillator, stretcher & preamplifiers, main power amplifier, and compressor. The spectral modulator and followed power compensation fiber amplifier is depicted in detail. The seed pulse centered at 1050 nm with 258 MHz rep-rate was first stretched to ~2 ns through a chirped fiber Bragg grating (CFBG); with a maximum 1.7-kW pump power launched in the main fiber amplifier, we could generate 1.4-kW signal pulse average power; amplified stretched pulse was de-chirped with a pair of reflection gratings in the end. As shown in Fig. 2(a), autocorrelation (AC) trace exhibits a reduction in the pulse pedestal while employing SLM to modulate the seed spectral shape, leading pulse

energy concentrating in the main pulse increased from 85.5% to 88.3%. We could generate a total 650 W output power under 50% pump power, approximately 522 W signal pulse was obtained after pulse compression. Figure 2(b) plots the dechirped pulse AC trace, the pulse pedestal is reduced and 3% more energy concentrating in the main pulse. Further power scaling is limited by accumulated nonlinear phase, which cannot be effectively suppressed by SLM shaping for now.

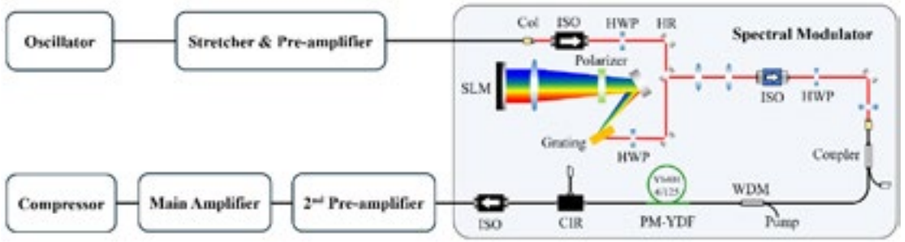

Figure 1. Schematic of the high-repetition-rate, kilowatt-class femtosecond fiber laser system. PM-YDF: polarization-maintaining Yb-doped gain fiber; WDM: wavelength-division multiplexer; Pump: pump; HWP: half-wave plate; ISO: isolator; Col: collimator; Grating: diffraction grating; HR: high-reflector mirror; Coupler: fiber coupler; CIR: optical circulator; Polarizer: polarizer; SLM: spatial light modulator.

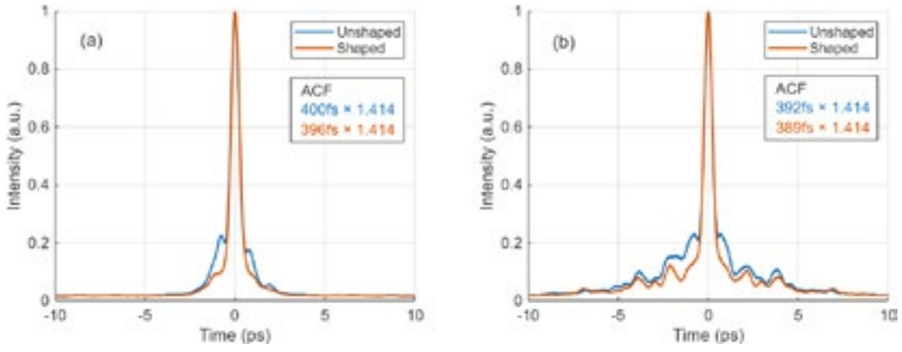

Figure 2. (a) Seed pulse autocorrelation trace before SLM shaping (blue curve) and after shaping (orange curve); (b) Autocorrelation traces at 50% pump power (SLM unshaped: blue curve, SLM shaped: orange curve).

Keywords: High-power, ultrafast fiber laser, amplitude modulation SLM.

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Ultrafast Dynamics of Liquid Water Induced by Strong Terahertz Field

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Abstract: Liquid water at room temperature exhibits ultrafast molecular motions and complex dynamic behavior. The hydrogen bonds connecting water molecules have characteristic energies and intrinsic motion frequencies that fall within the terahertz (THz) frequency range. THz radiation is a unique tool for probing and manipulating the ultrafast dynamics of water molecules. We developed an experimental platform based on a strong THz pump broadband THz probe setup, along with a dual-filament-guided continuous liquid film generation system. Using single-shot THz nonlinear spectroscopy, we investigated the ultrafast dynamics of the interaction between intense THz pulses and water. Experimental results reveal distinct relaxation evolution patterns in the THz dielectric properties of water under varying THz pump field strengths, reflecting a synergistic competition between impact ionization caused quasi-free electrons and dynamics of hydrogen-bond networks induced by the strong THz field. Based on the impact ionization theory and the ab initio molecular dynamics (AIMD) simulation, we effectively explain the experimental phenomena. This work demonstrates direct observation of coupled electron-hydrogen bond dynamics in water, providing new experimental pathways for exploring radiation chemistry, ultrafast solvation processes, and non-equilibrium reaction pathways in biomolecular environments.

Keyword: ultra-intense Terahertz, liquid water, impact ionization, hydrogen-bond dynamics

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Generation of deep-sub-cycle optical pulses by the mid-infrared laser

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Abstract: We introduce a novel scheme to generate deep-sub-cycle optical pulses by converting deep-sub-wavelength spatial confinement into deep-sub-cycle temporal confinement via inverse Compton scattering. The method utilizes a relativistic electron bunch interacting with a mid-infrared laser field tightly confined in a slit nanostructure. Simulations of a 2-MeV, 50-as electron bunch with a confined 4.4-μm driving field yield a unipolar, 99-as extreme ultraviolet (EUV) pulse, corresponding to just 0.26 optical cycles at its 2.6 PHz peak frequency. While the pulse's deep-sub-cycle character is widely tunable via the driving field parameters, this uncovers a fundamental trade-off with the scattered photon number; a slight relaxation in confinement can boost the photon number nearly tenfold while the pulse remains deep-sub-cycle. This work establishes a robust and flexible pathway for producing ultrashort deep-sub-cycle pulses, offering novel design methods for next-generation light sources in ultrafast science.

Keywords: Deep-sub-cycle, inverse Compton scattering, relativistic electron bunch, mid-infrared laser

Cross-Timescale Dynamics of Dehalogenation in Photoenzymatic Catalysis: Mechanistic Insights from Nanosecond to Picosecond Electron Transfer

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Abstract: Photoenzymatic catalysis utilizes photoexcited flavin cofactors (FMN/FAD) to drive non-natural radical reactions, offering a sustainable pathway for asymmetric synthesis. Among these transformations, dehalogenation serves as the critical step for acyl radical generation, where its kinetic efficiency directly governs overall catalytic performance. This study investigates dehalogenation mechanisms in flavoenzyme lactate monooxygenase (LMO) and ene-reductase from caulobacter segnis (CsER). Despite both utilize $FMNH^-$ as the cofactor, they exhibit strikingly distinct electron transfer (ET) kinetics.

In LMO-catalyzed dehalogenation, initial ET from photoexcited reduced flavin ($FMNH^{-}$*) to α-, β-, and γ-acyl halides occurs on nanosecond timescales (1.1–6.2 ns), with efficiency governed by substituent position and protein microenvironment. Transient absorption (TA) spectroscopy reveals that all three substrate classes undergo ET within nanoseconds yet follow strikingly divergent pathways: α/β-halogenated substrates (e.g., bromoacetate, ethyl 3-bromopropionate) exhibit ultrafast C-X (halogen) bond cleavage generating acyl radicals that combine with the flavin semiquinone (FMNH•) to form covalent N5-flavin adducts. The γ-halogenated esters (e.g., methyl 4-chlorobutyrate) undergo exclusively unproductive back electron transfer (bET, τ = 8.2 ns) without dehalogenation. Molecular docking and Marcus theory analysis demonstrate cooperative control of ET kinetics by Halogen-flavin distance (3.3–5.1 Å), thermodynamic driving force (ΔG^0 = –0.26 to –0.01 eV) and reorganization energy (λ = 0.88–1.35 eV). Radical combination kinetics (1–11 ns) further depend on substrate conformational flexibility and hydrogen-bonding networks with residues (Tyr44/Tyr152/His290). These results establish positional substitution effects as the decisive factor in catalytic efficiency.

In contrast, CsER-catalyzed dehalogenation exhibits ultrafast ET characteristics (τ = 7 ps). While subsequent kinetic steps converge on nanosecond timescales across both enzymatic systems, CsER uniquely employs hydrogen atom transfer (HAT) for substrate hydrofunctionalization. Notably, when CsER catalyzes intermolecular reactions, a bicooperative substrate effect accelerates ET between $FMNH^{-}$* and halogenated substrates to 4 ps, enhancing radical initiation efficiency by 43% confered to single-substrate system. The radical addition step proceeds in 80 ps. Terminal HAT requires ~5 ns for completion. Crucially, competitive pathways emerge. Back electron transfer (BET, τ = 51 ps) from the second substrate to FMNH• kinetically competes with radical addition (80 ps). The branching ratio dictates quantum yield, highlighting the critical need to suppress parasitic BET.

This study elucidates that the disparity in ET rates primarily stems from the synergistic interplay between substrate binding conformations and the electrostatic environment of the protein cavity, establishing fundamental kinetic principles for the rational design of high-efficiency photoenzymatic catalysts and expansion of substrate scope.

Methods

Protein samples preparation, transient absorption spectroscopic experimental, time-correlated single photon counting (TCSPC) experimental, molecular dynamics (MD) simulation, Cyclic voltammetry experiments, Gibbs free energy and reorganization energy calculation, molecular docking calculation.

Keywords: Ultrafast Dynamics; Flavoenzyme; Photodehalogenation; Transient Absorption; Electron Transfer;

Pre-chirp and gain jointly managed nonlinear amplification

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Abstract: Nonlinear fiber amplification based on gain management enables the generation of femtosecond laser pulses with durations below 50 fs using a simple and stable system. To achieve amplified pulses with higher energy, narrower pulse widths, and better compressed pulse quality, it is essential to better balance dispersion, dynamic gain, and nonlinear effects during the amplification process. The seed pulse energy influences both gain extraction and nonlinear effects during amplification.

Following the seed source, a pre-amplification stage and an acousto-optic modulator (AOM) were incorporated to adjust the repetition rate to 11.53 MHz . Then the seed was directed into a pre-chirp module for pre-chirp management. The pre-chirped seed pulse subsequently entered a 5-meter single-mode polarization-maintaining ytterbium-doped fiber (PM-YDF) to achieve gain and pre-chirp jointly managed fiber amplification.

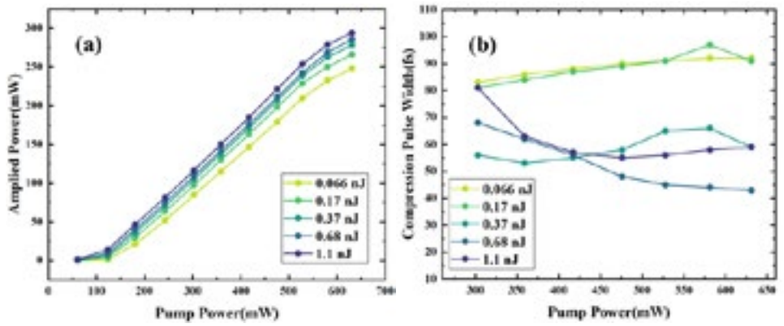

Fig.1. (a) Gain management amplification efficiency and (b)amplification pulse width after compression with different seed pulse energy.

With a pre-chirp set at +29723 fs², we measured the efficiency of the gain-managed amplification and the variation in compressed pulse width at seed energy of 0.066 nJ, 0.17 nJ, 0.37 nJ, 0.68 nJ, and 1.1 nJ. As the seed energy increased, the amplification efficiency improved from 40% to 48%. However, at seed energy of 0.066 nJ and 0.17 nJ, the compressed pulse width after amplification was 92 fs. When the seed energy was increased to 0.37 nJ, the compressed pulse width decreased to 59 fs. Further increasing the seed energy to 0.68 nJ reduced the compressed pulse width to 43 fs. At last, increasing the seed energy to 1.1 nJ resulted in the compressed pulse width rising to 67 fs.

To further investigate the influence of the pre-chirp on gain-managed amplification, the pre-chirp was adjusted

based on compression results. At a seed energy of 0.17 nJ, the narrowest pulse width was 63 fs when the pre-chirp was +16290 fs². With the seed energy of 0.37 nJ, the narrowest compressed pulse width was 49 fs when the pre-chirp was increased to +35555 fs².

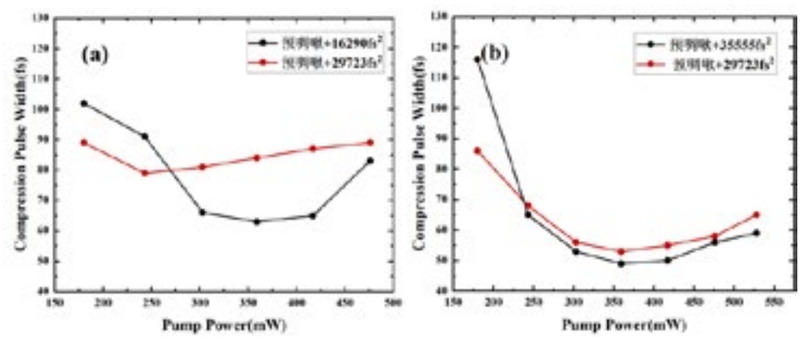

Fig.2. (a) Compressed pulse width corresponding to different pre-chirp amounts with the seed energy of 0.17 nJ.

(b) Compressed pulse width corresponding to different pre-chirp amounts with the seed energy of 0.37 nJ.

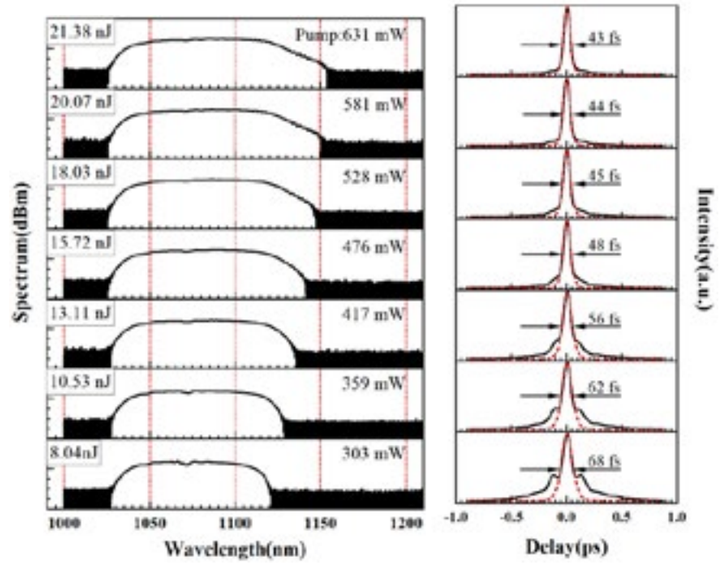

Fig.3. Gain-managed amplification spectrum and compressed pulses with the seed energy of 0.68 nJ and the pre-chirp of +29723 fs².

According to experimental results, ultrashort pulses with a central wavelength of 1083 nm, pulse energy of 21.38 nJ, pulse width of 43 fs, and peak power of 437 kW were obtained with the seed pulse energy of 0.68 nJ and the pre-chirp of +29723 fs². Furthermore, the pre-chirp significantly impacts nonlinear effects during amplification. Our experimental findings indicate that, while keeping the seed pulse energy constant, adjusting the pre-chirp can

effectively improve the compression quality of the amplified pulse. This work provides insights for further optimization of gain-managed amplification.

Keywords: Fiber amplification , Nonlinear amplification , Gain managed amplification , Ultrafast pulse amplification .

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The Development of Spatial Resolution in Single-Shot Ultrafast Active Compressed Imaging

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Abstract: Since the advent of ultrafast imaging technology, there has been progressively clearer understanding of transient changes in the microscopic world. The well-known phenomena such as transfer of photosynthetic energy, nuclear fusion and protein structure formation occur at extremely fast time scales (fs-ns), where ultrafast imaging plays an important role. For instance, visualizing the dynamic process of protein folding not only enhances our comprehension of protein function but also offers insights into disease mechanisms and facilitates drug development. Traditional pump-probe technology captures a time slice information per measurement, reconstructing an ultrafast film of transient phenomena through repetitive experiments. Unfortunately, this approach fails to preserve the authenticity of observation for transient phenomena such as optical rogue waves and inertial confinement fusion, which exhibit stochastic behavior or difficult to reproduce.

To overcome this limitation, single-shot ultrafast imaging technology provides an irreplaceable advantage for studying non-repetitive phenomena by completely capturing the spatiotemporal evolution of transient processes in one measurement. However, current single-shot ultrafast imaging techniques—whether direct imaging or computational imaging—face the key challenge of the trade-off between the number of captured frames and spatial resolution. The root of this problem lies in the inherent limitations of these two imaging methods. Direct imaging requires the spatiotemporal information of transient phenomena to be directly acquired on the detector, which leads to the need for strict division of the imaging area of the detector to prevent the overlap of images between frames. For this reason, while this method ensures relatively high spatial resolution, the number of frames is severely limited. On the other hand, computational imaging combined with compressed sensing allows spatiotemporal mixing of signals, enabling the capture of dozens to hundreds of frames. However, the extremely high compression ratio leads to significant loss of detail in the reconstructed images. Therefore, to avoid losing key spatiotemporal information of transient phenomenon within the study's time window, it is necessary to develop novel single-shot ultrafast imaging technologies that balance both the number of frames and spatial resolution.

Here, our research group innovatively developed a series of methods to improve the spatial resolution of ultrafast compressed imaging based on compressed ultrafast spectral-temporal imaging technology. It includes High-channel Spectral-temporal Active Recording (H-STAR), High-frequency Enhanced Compressed Active Photography (H-CAP), Round-View Projection Ultrafast Compressed Imaging (RVP) and Multi-dimensional Spatial-temporal Projection Ultrafast Compressed Imaging (MSP). These technologies iteratively optimize each other and continue to make breakthroughs in key indicators such as spatial resolution and frame count. At present, our imaging system has shown outstanding performance in capturing ultrafast phenomena such as femtosecond laser self-fo-

cusing, air plasma evolution and femtosecond laser-material interaction. It achieves a high frame number of 200 frames and an ultra-high spatial resolution of 690 nm, providing a more powerful tool for studying non-repeatable ultrafast phenomena. In the future, with the coordinated development of optical design, computational algorithms and detector technology, single-shot ultrafast compressed imaging is expected to further break through the existing performance limits and promote the progress of scientific research and industrial applications.

Keywords: ultrafast compressed imaging, high spatial resolution, high frame number, transient processes

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Femtosecond Laser Micropatterning of Ga-Based Liquid Metal for Multifunctional Soft Tactile Electronic Skins

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Abstract: Soft tactile electronic skins, which can emulate human tactile perception, require electrode materials that exhibit high conductivity, stretchability, and adaptable microstructures to enable multifunctional sensing. Gallium-based liquid metals (LMs), such as eutectic gallium-indium (EGaIn), are promising candidates due to their inherent conductivity, fluidity, and biocompatibility. However, precisely micropatterning these LMs into functional configurations remains a significant challenge, hindering their integration into advanced soft electronic systems. Conventional microfabrication techniques, such as photolithography and inkjet printing, encounter limitations in terms of resolution, scalability, and compatibility with liquid-phase materials. To overcome these limitations, we propose a novel femtosecond laser micropatterning approach that enables high-resolution and customizable structuring of LMs for the development of multifunctional soft tactile electronic skins.

This study utilized the characteristics of the ultrashort pulse duration and high peak intensity of femtosecond lasers to achieve high-precision microfabrication on soft polymer substrates. Meanwhile, with the assistance of hydrogel-assisted technology, the microstructure regulation and patterning of LMs thin films were successfully achieved. By optimizing key laser parameters—including fluence, scan speed and scan spacing—we demonstrate the direct fabrication of programmable microstructures, such as flexible circuit, pressure sensors, and tactile arrays, on flexible elastomeric substrates. A key innovation lies in exploiting the unique wettability properties of LMs. By precisely depositing LM onto the complex micro- and nanostructures fabricated by femtosecond lasers, three-dimensional microstructuring of LMs was achieved, thereby overcoming the limitations inherent to traditional two-dimensional patterning and enabling the development of flexible electronic components with superior electrical performance.

Experimental results demonstrate that devices based on LMs fabricated by femtosecond laser exhibit excellent performance, including: (1) Stretchable flexible circuits that are strain-insensitive and capable of maintaining a stable electrical response (with resistance variation of less than 3%) even under strains exceeding 50%; (2) Embedded low-crosstalk tactile sensor array composed of a 10×10 pixels, capable of achieving pressure mapping on curved surfaces; (3) Highly sensitive and high-speed soft capacitive pressure sensor based on interlocked microstructures, exhibiting a sensitivity of 45.33 kPa^{-1}, microsecond-level response time, and the ability to detect minute pressures as low as 0.14 Pa. This sensor enables multi-functional detection of pressure, vibration, and texture, with performance surpassing that of traditional flexible sensors; (4) Flexible pressure sensor based on stepped microstructures of LMs, which achieves a highly linear response and can be used for non-destructive, real-time, and convenient

identification of skin scar dimensions. By integrating these sensing capabilities with machine learning algorithms, the system achieves real-time recognition of complex patterns and textures, demonstrating its broad application potential in the fields of human-machine interfaces and soft robotics.

This three-dimensional patterning ability of LM is of great significance in the fabrication of high-performance micro- and nanoelectronic devices. Its scalability and good compatibility with various substrates offer broad prospects for the development of next-generation wearable electronic devices and bio-integrated systems. Future research directions will focus on the complex interactions between lasers and materials to expand sensing capabilities and enhance environmental adaptability. This innovation not only expands the boundaries of soft electronics but also makes it possible to manufacture biomedical devices and intelligent prosthetics with excellent adaptability.

Keywords: Femtosecond laser; Liquid metal; Soft electronics; Tactile sensing; Micropatterning.

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Development of high-repetition rate OH planar laser induced fluorescence using Ti: sapphire laser

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Abstract: This presentation focuses on the application of Ti:sapphire-based planar laser-induced fluorescence (PLIF) of OH molecules for flame morphology in combustion diagnostics. Flame morphology measurement plays a vital role in understanding combustion processes and validating numerical models, and the OH-PLIF technique has been widely used due to its non-intrusive nature and real-time capability.

In traditional OH-PLIF thermometry, the dye laser and optical parametric oscillator (OPO) are the primary sources used to tune the excitation wavelength to match OH electronic transitions. However, both approaches have inherent limitations. The dye laser system is constrained by the dye solution circulation rate, which restricts pulse energy and repetition rate. Although OPOs offer higher repetition rates and better beam quality, their cascade nonlinear conversion leads to lower energy efficiency and broader linewidths, often ranging from several to tens of nanometers. This is incompatible with the narrow-linewidth requirement of resonance excitation. Although seeding an OPO with a narrow-linewidth laser can suppress the output linewidth, this increases system complexity and sensitivity to misalignment and environmental fluctuations.

In contrast, the Ti:sapphire laser provides a promising alternative due to its wide tunable range (650–1100 nm), high output stability, and excellent beam quality. It combines the advantages of solid-state lasers with sufficient spectral resolution for resonance excitation, making it well-suited for tracking flame morphology and temperature measurement.

In this work, we demonstrate a Ti:sapphire-based OH-PLIF system capable of performing spatially resolved two-dimensional flame morphology imaging. The linewidth of the oscillator was stabilized using three equilateral prisms made of SF10 glass. The optimal output coupler transmissivity was determined to be 25%, with a pumping configuration of 527 nm, 1 kHz, and 15 mJ. The maximum power was 3.22 W at 850 nm and the linewidth was suppressed to approximately to 0.5nm. Second-harmonic generation (SHG) was achieved using a type-I phase matched LBO crystal, yielding a maximum output power of 1.6W with an optical-to-optical conversion efficiency of 50%. Subsequently, the fundamental 850nm laser and its second harmonic at 425nm were mixed to produce a 283nm ultraviolet radiation for exciting OH radicals, achieving a maximum output power of 0.5 W. The 283 nm laser beam was reshaped into a light sheet with dimensions of 0.5 mm × 100 mm using a pair of cylindrical lenses. The Dragon 200 Bunsen burner was employed as the flame source in this experimental setup, utilizing n-butane as the fuel to generate a stable premixed flame with a maximum adiabatic temperature of approximately 1300 °C. The high-speed camera with image intensifier was used to capture the fluorescence image with 1280*800 resolution.

Representative results will be shown for Bunsen flame, demonstrating the ability to quantify combustion structure. The study successfully demonstrates the potential of Ti:sapphire lasers in combustion diagnostics, providing a highly efficient and stable approach for exciting OH fluorescence. With its compact and integrated system design,

this method not only simplifies the instrumentation and enhances operational convenience but also holds promise for real-time, high precision combustion diagnostics capable of meeting the demands of complex practical environments.