ABSTRACTS

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Sub-7 fs radially polarized pulses by post-compression in thin fused silica plates

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Optics Express
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We experimentally demonstrate the post-compression of radially polarized 25 fs pulses at 800 nm central wavelength in a multiple thin plate arrangement for the first time, to the best of our knowledge. Sub-7 fs pulses with 90 μJ energy were obtained after dispersion compensation, corresponding to a compression factor of more than 3.5. Preservation of radial polarization state was confirmed by polarized intensity distribution measurements. Linear projections of the radially polarized pulses were also fully characterized in the temporal domain.

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High temporal contrast ultrashort pulses generated by nonlinear ellipse rotation in multipass cells

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Laser Physics Letters
18 (2021) 6, 065401

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The simultaneous nonlinear spectral broadening and temporal cleaning of ultrashort pulses by the combination of the multipass cell (MPC) technique and nonlinear ellipse rotation are proposed and investigated with numerical simulations. The performance of the gas-filled MPC is studied at 800 and 1030 nm central wavelengths with mJ energy level. The results indicate that at least 103 contrast enhancement is feasible with 50% internal efficiency while the beam quality is preserved during propagation. At the same time, nonlinear spectral broadening allows for a more than five-fold temporal compression. The technique is tested at 20 mJ energy and it is presumably suitable for the generation of high contrast, high energy few-cycle pulses, too.

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High-order phase-dependent asymmetry in the above-threshold ionization plateau

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J. Phys. B
54 (2021) 035005

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Above-threshold ionization spectra from cesium are measured as a function of the carrier-envelope phase (CEP) using laser pulses centered at 3.1 µm wavelength. The directional asymmetry in the energy spectra of backscattered electrons oscillates three times, rather than once, as the CEP is changed from 0 to 2π. Using the improved strong-field approximation, we show that the unusual behavior arises from the interference of few quantum orbits. We discuss the conditions for observing the high-order CEP dependence, and draw an analogy with time-domain holography with electron wave packets.

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Saturating multiple ionization in intense mid-infrared laser fields

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New Journal of Physics
23 (2021) 053026

https://doi.org/10.1088/1367-2630/abf583

The interpretation of experimental data from novel mid-infrared few-cycle laser sources requires an understanding of ionization mechanisms and knowledge about related ion yields. Experimental studies have indicated sequential double ionization as the dominant process above 10^{14} Wcm^{-2}. These results contradict a recent prediction that in this spectral region, non-sequential processes dominate the double ionization of xenon up to intensities of about 10^{15} Wcm^{-2}. In either case, the ratio of doubly to singly charged xenon yield reported in previous studies has been limited to a few percent, indicating a regime well below the onset of saturation of the double ionization process. We present an experimental study of double ionization of xenon and krypton atoms exposed to intense near four-cycle pulses at 3.2 µm. Our experiments rely on the ion microscopy technique, which facilitates the detection of ions originating from a restricted region within the interaction volume, thereby reducing the impact of focal averaging. Our measurements suggest that at intensities of close to 1.2×10^{14} Wcm^{-2}, double ionization of xenon and krypton is already significantly saturated. In particular, we find a doubly to singly charged yield ratio of about 75 percent for xenon and 25 percent for krypton. We compare our results with the predictions of different models accounting for the effects of volume averaging and focal geometry. We find that inthe deeply saturated regime of our experiment, the Perelomov–Popov–Terentyev theory significantly underestimates the observed double ionization yield.

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Single-shot electron imaging of dopant-induced nanoplasmas

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New Journal of Physics
23 (2021) 053011

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We present single-shot electron velocity-map images of nanoplasmas generated from doped helium nanodroplets and neon clusters by intense near-infrared and mid-infrared laser pulses. We report a large variety of signal types, most crucially depending on the cluster size. The common feature is a two-component distribution for each single-cluster event: a bright inner part with nearly circular shape corresponding to electron energies up to a few eV, surrounded by an extended background of more energetic electrons. The total counts and energy of the electrons in the inner part are strongly correlated and follow a simple power-law dependence. Deviations from the circular shape of the inner electrons observed for neon clusters and large helium nanodroplets indicate non-spherical shapes of the neutral clusters. The dependence of the measured electron energies on the extraction voltage of the spectrometer indicates that the evolution of the nanoplasma is significantly affected by the presence of an external electric field. This conjecture is confirmed by molecular dynamics simulations, which reproduce the salient features of the experimental electron spectra.

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Simultaneous spectral phase shift characterization in two frequency bands

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Optics Communications
500 (2021) 127332

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The precise knowledge of spectral phase shift in various optical elements is crucial for applications with ultrashort pulses. Spectrally resolved interferometry is a versatile, commonly used technique to measure material dispersion. However, the bandwidth of the employed light source limits the spectral region where the phase shift can be determined using this method. In this paper, we introduce a modified version of spectrally resolved interferometry, which enables the reconstruction of the spectral phase shift at the fundamental and the second harmonic wavelengths of the illuminating light source from a single interferogram, and hence doubles the evaluation bandwidth originally available. The presented method is experimentally validated by measuring several dielectric and semiconductor material plates.

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Dispersive mirror characterization and application for mid-infrared post-compression

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Journal of Optics
23 (2021) 065501

https://doi.org/10.1088/2040-8986/abf88e

This paper presents a second harmonic assisted spectrally resolved interferometric technique that can overcome the limited spectral resolution of commercially available spectrometers in the mid-infrared. The discussed scheme was validated by measuring the group delay of several well-known and frequently used materials. Our main motivation was to characterize the spectral phase shift of newly designed and manufactured dispersive mirrors to be used for mid-infrared (MIR) post-compression. These mirrors were successfully implemented in the post-compression stage of our MIR laser system, where pulse duration was shortened below two optical cycles and the pulse peak power increased by 30.3% compared to the original output.

eli attosecond

All-optical experimental control of high harmonic photon energy

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We generate high-order harmonics in a gaseous medium with tunable photon energy using time-domain interferometry of double pulses in a noncollinear generation geometry. The method is based on the fact that the generated harmonics inherit certain spectral properties of the driving laser. The two temporally delayed laser pulses, identical in all parameters, are produced by a custom-made split-and-delay unit utilizing wave-front splitting without a significant energy loss. The arrangement is easy to implement in any attosecond pulse generation beamline, and is suitable for the production of an extreme ultraviolet source with simply and quickly variable central photon energy, useful for a broad range of applications.

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Phys. Rev. Applied
16 (2021) L011001

https://doi.org/10.1103/PhysRevApplied.16.L011001

eli attosecond

LaSo SeSo

Quantum-optical spectrometry in relativistic laser–plasma interactions using the high-harmonic generation process: a proposal

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Photonics
8 (2021) 6, 192

https://doi.org/10.3390/photonics8060192

Quantum-optical spectrometry is a recently developed shot-to-shot photon correlation-based method, namely using a quantum spectrometer (QS), that has been used to reveal the quantum optical nature of intense laser–matter interactions and connect the research domains of quantum optics (QO) and strong laser-field physics (SLFP). The method provides the probability of absorbing photons from a driving laser field towards the generation of a strong laser–field interaction product, such as high-order harmonics. In this case, the harmonic spectrum is reflected in the photon number distribution of the infrared (IR) driving field after its interaction with the high harmonic generation medium. The method was implemented in non-relativistic interactions using high harmonics produced by the interaction of strong laser pulses with atoms and semiconductors. Very recently, it was used for the generation of non-classical light states in intense laser–atom interaction, building the basis for studies of quantum electrodynamics in strong laser-field physics and the development of a new class of non-classical light sources for applications in quantum technology. Here, after a brief introduction of the QS method, we will discuss how the QS can be applied in relativistic laser–plasma interactions and become the driving factor for initiating investigations on relativistic quantum electrodynamics.

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Highly efficient few-cycle laser wakefield electron accelerator

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Plasma Phys. Contr, F. 63 (2021) 065019

https://doi.org/10.1088/1361-6587/abf80d

A significant part of the laser wakefield acceleration (LWFA) research effort focuses on studying high-energy, quasi-monoenergetic electron beams. For other applications, such as the production and application of intense betatron x-ray radiation, Bremsstrahlung γ-rays and positron beams, the beam's spectral quality is secondary to the number of electrons produced. This work discusses 3D particle-in-cell simulations of a highly efficient LWFA acceleration process, generating a broad spectrum of electrons, driven by a 12 TW few-cycle laser on high-density gas targets. In some cases, laser absorption in plasma exceeds 80%, and up to 27% of the driving laser energy is transferred to electrons over 20 MeV leaving the plasma. We also observe a deceleration of the accelerated beam at the plasma downramp and plasma exit, which arises from transitioning from laser-driven to beam-dominated wake, and also from the induced axial electric field. This effect is similar to magnetic vortex acceleration, where the induced axial electric field, instead of accelerating plasma ions, would slow down the opposite-charged electron beam and also a strong return current and backward electron beam.

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Sliding-wave acceleration of ions in high-density gas jet targets

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Phys. Rev. E
103 (2021) 053210

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A hybrid mechanism of ion acceleration is investigated which demonstrates the higher spectral density of protons at high energies. The interaction of few-cycle terrawatt laser pulses with near-critical density gas target is studied with the help of two-dimensional particle-in-cell simulation. The generation of few MeV protons with high spectral concentration near cutoff is attributed to the propagation of solitary waves in the decaying density profile of the gas jet. Plasma dynamics at longer time scale is explained by semianalytical modeling and conditions for solitary wave breaking are presented.

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Absorption of pulsed terahertz and optical radiation in earthworm tissue and its heating effect

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The transmission of THz, near-infrared (1030 nm), and green (515 nm) pulses through *Eisenia andrei* body wall is studied, which consists of epithelial layer and circular and longitudinal muscles. Samples with the full-body cross-section were also investigated. The transmitted power for the green pulses followed the Beer-Lambert law of exponential attenuation for all thicknesses and tissue structures. Different body wall and body center absorption coefficients were found in case of infrared pulses. In the THz range, the body wall absorption coefficient steadily increases from about 80 cm^{-1} at 0.2 THz to about 273 cm^{-1} at 2.5 THz. Numerical estimation indicates that THz pulses of 5-µJ energy and 1-kHz repetition rate (5-mW average power) cause only a small temperature increase of about 0.4 K, suggesting that heating has minor contribution to biological effectiveness.

SeSo

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J. Infrared, Millimeter, and THz Waves (2021)

https://doi.org/10.1007/s10762-021-00827-1

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Terahertz pulses induce segment renewal via cell proliferation and differentiation overriding the endogenous regeneration program of the earthworm Eisenia andrei

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Biomedical Optics Express
12 (2021) 4, 1947-1961

https://doi.org/10.1364/BOE.416158

Terahertz (THz) irradiation of excised Eisenia andrei earthworms is shown to cause overriding of the genetically determined, endogenously mediated segment renewing capacity of the model animal. Single-cycle THz pulses of 5 μJ energy, 0.30 THz mean frequency, 293 kV/cm peak electric field, and 1 kHz repetition rate stimulated the cell proliferation (indicated by the high number of mitotic cells) and both histogenesis and organogenesis, producing a significantly higher number of regenerated segments. The most conspicuous alteration in THz-treated animals was the more intense development of the new central nervous system and blood vessels. These results clearly demonstrate that THz pulses are capable to efficiently trigger biological processes and suggest potential applications in medicine.

eli attosecond

Generation of high-quality GeV-class electron beams utilizing attosecond ionization injection

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Acceleration of electrons in laser-driven plasma wakefields has been extended up to the 10 GeV energy within a distance of 10s of centimeters. However, in applications, requiring small energy spread within the electron bunch, only a small portion of the bunch can be used and often the low-energy electrons represent undesired background in the spectrum. We present a compact and tunable scheme providing clean and mono-energetic electron bunches with less than one percent energy spread and with central energy on the GeV level. It is a two-step process consisting of ionization injection with attosecond pulses and acceleration in a capillary plasma wave-guide. Semi-analytical theory and particle-in-cell simulations are used to accurately model the injection and acceleration steps.

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New Journal of Physics
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SeSo

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Two-color laser-plasma electron and positron acceleration

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11778 (2021) 117780I

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Recently, there have been some theoretical studies on the use of two-color intense laser pulses for the laser wakefield acceleration (LWFA) research. Here, we experimentally demonstrate a laser-plasma accelerator driven by relativistic copropagating two-color laser pulses (CTLP) in pure helium and in helium-nitrogen mixed gas targets where we observed significant enhancements in the energy spectra of the electron beams (Sci. Adv. 5. eaav7940, 2019). Such enhancement has been further confirmed in a real-application, where electrons from the CTLP-driven LWFA scheme are used in a bremsstrahlung-based positron beam generation configuration, which led to a significant boost in the positron beam energy as well. Numerical simulations suggested that the trailing second-harmonic relativistic laser pulse can sustain the acceleration structure (i.e., the plasma wave) for much longer distances after the preceding fundamental laser pulse is depleted in the plasma medium. Therefore, our experimental work confirms the advantage and robustness of the CTLP-driven LWFA scheme over the standard LWFA driven by a single-pulse of equivalent power. This paves the way towards a significant down-sizing of laser-plasma electron accelerators making their use in scientific and technological applications extremely attractive and affordable.

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Ultrashort, MeV-scale laser-plasma positron source for positron annihilation lifetime spectroscopy

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Phys. Rev. Accel. Beams
24 (2021) 073402

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Submicron defects represent a well-known fundamental problem in manufacturing since they can significantly affect performance and lifetime of virtually any high-value component. Positron annihilation lifetime spectroscopy is arguably the only established method capable of detecting defects down to the subnanometer scale but, to date, it only works for surface studies, and with limited resolution. Here, we experimentally and numerically show that laser-driven systems can overcome these well-known limitations, by generating ultrashort positron beams with a kinetic energy tuneable from 500 keV up to 2 MeV and a number of positrons per shot in a 50 keV energy slice of the order of 103. Numerical simulations of the expected performance of a typical mJ-scale kHz laser demonstrate the possibility of generating MeV-scale narrow-band and ultrashort positron beams with a flux exceeding 105 positrons/s, of interest for fast volumetric scanning of materials at high resolution.

SeSo

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Generation and collective interaction of giant magnetic dipoles in laser cluster plasma

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Scientific Reports
11 (2021) 15971

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Interaction of circularly polarized laser pulses with spherical nano-droplets generates nanometer-size magnets with lifetime on the order of hundreds of femtoseconds. Such magnetic dipoles are close enough in a cluster target and magnetic interaction takes place. We investigate such system of several magnetic dipoles and describe their rotation in the framework of Lagrangian formalism. The semi-analytical results are compared to particle-in-cell simulations, which confirm the theoretically obtained terrahertz frequency of the dipole oscillation.

SeSo

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Pair production seeded by electrons in noble gases as a method for laser intensity diagnostics

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Phys. Rev. A
104 (2021) 052801

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In this paper we explore the possibility of using the process of electron-positron pair creation in strong laser fields as a tool for measuring the intensity of the corresponding laser radiation. In the initial state we consider either a free electron gas or a gas of neutral xenon, the electrons of which get ionized. Once these seed electrons gain sufficient energy in the external laser field, they can emit high-energy photons which subsequently decay producing electron-positron pairs via the Breit-Wheeler mechanism. By detecting the resulting positrons, one can recover the value of the laser intensity by means of the one-to-one correspondences deduced in this paper. We analyze two different configurations of the external field: the setup involving an individual focused laser pulse and the combination of two counterpropagating laser pulses. Performing numerical calculations and analyzing their accuracy, we demonstrate that based on our estimates, the laser intensity can be determined within the range 10^{23}–10^{26} W/cm^2 with a relative uncertainty of 10–50%.

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Compact intense extreme-ultraviolet source

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Optica
8 (2021) 7 960-965

https://doi.org/10.1364/OPTICA.421564

High-intensity laser pulses covering the ultraviolet to terahertz spectral regions are nowadays routinely generated in a large number of laboratories. In contrast, intense extreme-ultraviolet (XUV) pulses have only been demonstrated using a small number of sources including free-electron laser facilities and long high-harmonic generation (HHG) beamlines. Here, we demonstrate a concept for a compact intense XUV source based on HHG that is focused to an intensity of 2×10^{14} W/cm^2, with a potential increase up to 10^{17} W/cm^2 in the future. Our approach uses tight focusing of the near-infrared (NIR) driving laser and minimizes the XUV virtual source size by generating harmonics several Rayleigh lengths away from the NIR focus. Accordingly, the XUV pulses can be refocused to a small beam waist radius of 600 nm, enabling the absorption of up to four XUV photons by a single Ar atom in a setup that fits on a modest (2 m) laser table. Our concept represents a straightforward approach for the generation of intense XUV pulses in many laboratories, providing exciting opportunities for XUV strong-field and nonlinear optics experiments, for XUV-pump XUV-probe spectroscopy and for the coherent diffractive imaging of nanoscale structures.

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Detailed study of quantum path interferences in high harmonic generation driven by chirped laser pulses

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New Journal of Physics
23 (2021) 123012

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We investigate the electron quantum path interference effects during high harmonic generation in atomic gas medium driven by ultrashort chirped laser pulses. To achieve that, we identify and vary the different experimentally relevant control parameters of such a driving laser pulse influencing the high harmonic spectra. Specifically, the impact of the pulse duration (from the few-cycle to the multi-cycle domain), peak intensity and instantaneous frequency is studied in a self-consistent manner. Simulations involving macroscopic propagation effects are also considered. The study aims to reveal the microscopic background behind a variety of interference patterns capturing important information both about the fundamental laser field and the generation process itself. The results provide guidance towards experiments with chirp control as a tool to unravel, explain and utilize the rich and complex interplay between quantum path interferences including the tuning of the periodicity of the intensity dependent oscillation of the harmonic signal, and the curvature of spectrally resolved Maker fringes.

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Time-resolved photoelectron imaging of complex resonances in molecular nitrogen

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J. Chem. Phys.
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We demonstrate how strong-field multiphoton transitions between dynamically shifted atomic levels can be traced in the energy spectra of emitted photoelectrons. Applying an ultrafast and intense laser pulse, two-photon Rabi oscillations are induced between two bound states of an atom. A third photon from the same pulse directly ionizes the atom, thus the emitted photoelectrons coherently probe the underlying dynamics. As the instantaneous energy of photoelectrons follows the pulse intensity envelope, modulated by the ac Stark shifts, electrons emitted with the same energy but at different times—at the rising and falling edge of the pulse—will interfere leading to pronounced dynamic interference pattern in the spectra. We investigate this phenomenon both numerically and analytically by developing a minimal three-state model that incorporates two-photon coupling and dynamically shifted atomic levels. On the example of atomic lithium (2s → → 4s → continuum) we show how the individual ac Stark shifts and the two-photon Rabi frequency are reflected through the asymmetry, shifting and splitting of the interference structure of the computed photopeaks.

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Analysis of two-color photoelectron spectroscopy for attosecond metrology at seeded free-electron lasers

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New Journal of Physics
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The generation of attosecond pulse trains at free-electron lasers opens new opportunities in ultrafast science, as it gives access, for the first time, to reproducible, programmable, extreme ultraviolet (XUV) waveforms with high intensity. In this work, we present a detailed analysis of the theoretical model underlying the temporal characterization of the attosecond pulse trains recently generated at the free-electron laser FERMI. In particular, the validity of the approximations used for the correlated analysis of the photoelectron spectra generated in the two-color photoionization experiments are thoroughly discussed. The ranges of validity of the assumptions, in connection with the main experimental parameters, are derived.

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Complex attosecond waveform synthesis at FEL FERMI

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New Journal of Physics
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Free-electron lasers (FELs) can produce radiation in the short wavelength range extending from the extreme ultraviolet (XUV) to the X-rays with a few to a few tens of femtoseconds pulse duration. These facilities have enabled significant breakthroughs in the field of atomic, molecular, and optical physics, implementing different schemes based on two-color photoionization mechanisms. In this article, we present the generation of attosecond pulse trains (APTs) at the seeded FEL FERMI using the beating of multiple phase-locked harmonics. We demonstrate the complex attosecond waveform shaping of the generated APTs, exploiting the ability to manipulate independently the amplitudes and the phases of the harmonics. The described generalized attosecond waveform synthesis technique with an arbitrary number of phase-locked harmonics will allow the generation of sub-100 as pulses with programmable electric fields.

eli attosecond

SeSo

Paraskevas TZALLAS

Generation of optical Schrödinger cat states in intense laser–matter interactions

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Nature Physics
17 (2021) 1104–1108

https://doi.org/10.1038/s41567-021-01317-w

The physics of intense laser–matter interactions is described by treating the light pulses classically, anticipating no need to access optical measurements beyond the classical limit. However, the quantum nature of the electromagnetic fields is always present. Here we demonstrate that intense laser–atom interactions may lead to the generation of highly non-classical light states. This was achieved by using the process of high-harmonic generation in atoms, in which the photons of a driving laser pulse of infrared frequency are upconverted into photons of higher frequencies in the extreme ultraviolet spectral range. The quantum state of the fundamental mode after the interaction, when conditioned on the high-harmonic generation, is a so-called Schrödinger cat state, which corresponds to a superposition of two distinct coherent states: the initial state of the laser and the coherent state reduced in amplitude that results from the interaction with atoms. The results open the path for investigations towards the control of the non-classical states, exploiting conditioning approaches on physical processes relevant to high-harmonic generation.

attosecond

Paraskevas TZALLAS
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Ponderomotive shifts induced by intense laser-driven coherent extreme ultraviolet radiation

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J. Phys. B
54 (2021) 084002

https://doi.org/10.1088/1361-6455/abf9f1

Signatures of strong-field effects induced by an intense attosecond pulse train, synthesized by the superposition of a Ti:sapphire laser high-order harmonics are observed in atomic two-photon ionization. Ponderomotive shifts in the photoelectrons' kinetic energies have been measured in the non-resonant two-photon ionization of Helium atoms induced by the interaction with extreme ultraviolet radiation at intensities on the order of 10^{15} Wcm^{-2}. These results inaugurate the topic of strong-field phenomena in experimental laser based attosecond science. .

SeSo US

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1 kHz laser accelerated electron beam feasible for radiotherapy uses: A PIC-Monte Carlo based study

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**Nucl. Instr. and Meth. in Phys. Res. A
987 (2021) 164841**

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Laser wakefield acceleration (LWFA) offers a promising compact solution for the production of high and very high energy electron (VHEE) beams, which have an ultrashort pulse duration with a high instantaneous dose rate and small source size. These unique properties are of radiobiological as well as clinical interest. In this paper we focus on the potential application of high repetition rate LWFA electron beams for radiobiology and radiotherapy. On the basis of particle-in-cell (PIC) and Monte Carlo simulations we propose that, using a commercially available 1 kHz laser system one can generate electron beams with 35.7 MeV mean energy and 3 pC electron bunch charge at 1 kHz repetition rate to deliver a dose rate of 18 Gy/min, which could be extremely useful for real radiotherapy applications. Thanks to the high repetition rate, dose delivery can be performed with high precision making this system a potential alternative to conventional clinical electron accelerators.

eli attosecond

US

Comparison of shear wave elastography and dynamometer test in muscle tissue characterization for potential medical and sport application

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Pathol. Oncol. Res. 27 (2021) 1609798

https://doi.org/10.3389/pore.2021.1609798

Skeletal muscle status and its dynamic follow up are of particular importance in the management of several diseases where weight and muscle mass loss and, consequently, immobilization occurs, as in cancer and its treatment, as well as in neurodegenerative disorders. But immobilization is not the direct result of body and muscle mass loss, but rather the loss of the maximal tension capabilities of the skeletal muscle. Therefore, the development of a non-invasive and real-time method which can measure muscle tension capabilities in immobile patients is highly anticipated. Our aim was to introduce and evaluate a special ultrasound measurement technique to estimate a maximal muscle tension characteristic which can be used in medicine and also in sports diagnostics. Therefore, we determined the relationship between the results of shear wave elastography measurements and the dynamometric data of ndividuals. The measurements were concluded on the m. vastus lateralis. Twelve healthy elite athletes took part in our preliminary proof of principle study—five endurance (S) and seven strength (F) athletes howing unambiguously different muscle composition features, nine healthy subjects (H) without prior sports background, and four cancer patients in treatment for a stage 3 brain tumor (T). Results showed a high correlation between the maximal dynamometric isometric torque (Mmax) and mean elasticity value (E) for the non-athletes [(H + T), (r = 0.795)] and for the athletes [(S + F), (r = 0.79)]. For the athletes (S + F), the rate of tension development at contraction (RTDk) and E correlation was also determined ($r = 0.84$, $p < 0.05$). Our measurements showed significantly greater E values for the strength athletes with fast muscle fiber dominance than endurance athletes with slow muscle fiber dominance ($p < 0.05$). Our findings suggest that shear wave ultrasound elastography is a promising method for estimating maximal muscle tension and, also, the human skeletal muscle fiber ratio. These results warrant further investigations with a larger number of individuals, both in medicine and in sports science.

eli attosecond

US

Analysis of ionizing radiation induced DNA damage by superresolution dSTORM microscopy

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Pathol. Oncol. Res.
27 (2021) 1609971

https://doi.org/10.3389/pore.2021.1609971

The quantitative detection of radiation caused DNA double-strand breaks (DSB) by immunostained γ-H2AX foci using direct stochastic optical reconstruction microscopy (dSTORM) provides a deeper insight into the DNA repair process at nanoscale in a time-dependent manner. Glioblastoma (U251) cells were irradiated with 250 keV X-ray at 0, 2, 5, 8 Gy dose levels. Cell cycle phase distribution and apoptosis of U251 cells upon irradiation was assayed by flow cytometry. We studied the density, topology and volume of the γ-H2AX foci with 3D confocal microscopy and the dSTORM superresolution method. A pronounced increase in γ-H2AX foci and cluster density was detected by 3D confocal microscopy after 2 Gy, at 30 min postirradiation, but both returned to the control level at 24 h. Meanwhile, at 24 h a considerable amount of residual foci could be measured from 5 Gy, which returned to the normal level 48 h later. The dSTORM based γ-H2AX analysis revealed that the micron-sized γ-H2AX foci are composed of distinct smaller units with a few tens of nanometers. The density of these clusters, the epitope number and the dynamics of γ-H2AX foci loss could be analyzed. Our findings suggest a discrete level of repair enzyme capacity and the restart of the repair process for the residual DSBs, even beyond 24 h. The dSTORM superresolution technique provides a higher precision over 3D confocal microscopy to study radiation induced γ-H2AX foci and molecular rearrangements during the repair process, opening a novel perspective for radiation research.

eli attosecond

US

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Electron dose rate and oxygen depletion protect zebrafish embryos from radiation damage

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Radioth. and Oncology
158 (2021) 7-12

https://doi.org/10.1016/j.radonc.2021.02.003

Background and purpose: In consequence of a previous study, where no protecting proton Flash effect was found for zebrafish embryos, potential reasons and requirements for inducing a Flash effect should be investigated with higher pulse dose rate and partial oxygen pressure (pO_2) as relevant parameters.

Materials and methods: The experiments were performed at the research electron accelerator ELBE, whose variable pulse structure enables dose delivery as electron Flash and quasi-continuously (reference irradiation). Zebrafish embryos were irradiated with ~26 Gy either continuously at a dose rate of ~6.7 Gy/min (reference) or by 1441 electron pulses within 111 µs at a pulse dose rate of 109 Gy/s and a mean dose rate of 105 Gy/s, respectively. Using the OxyLite system to measure the pO_2 a low- ($pO_2 \leq 5$ mmHg) and a high-pO_2 group were defined on basis of the oxygen depletion kinetics in sealed embryo samples.

Results: A protective Flash effect was seen for most endpoints ranging from 4 % less reduction in embryo length to about 20–25% less embryos with spinal curvature and pericardial edema, relative to reference irradiation. The reduction of pO_2 below atmospheric levels (148 mmHg) resulted in higher protection, which was however more pronounced in the low-pO_2 group.

Conclusion: The Flash experiment at ELBE showed that the zebrafish embryo model is appropriate for studying the radiobiological response of high dose rate irradiation. The applied high pulse dose rate was confirmed as important beam parameter as well as the pivotal role of pO_2 during irradiation.

eli attosecond

US

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Topological aspects of cavity-induced degeneracies in polyatomic molecules

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Int. J. Quantum Chem. (2021) e26750

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Conical intersections are degeneracies between multidimensional potential energy surfaces of molecular systems. It is well known that, besides these phenomena significantly modify the spectroscopic and dynamical properties of molecules, their presence in a molecular system has noticeable topological implications, as well. Such a consequence is the appearance of the topological or geometric phase. Conical intersections not only occur in nature but they can also be created by light. This can either be classical laser light or quantum light in an optical cavity. As a showcase example, by placing the formaldehyde (H_2CO) molecule into a cavity, the topological properties (e.g., geometric or Berry phase) of the emerging light-induced conical intersection have been investigated for different cavity parameters and geometrical arrangements.

US

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Born–Oppenheimer approximation in optical cavities: from success to breakdown

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Chem. Science
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The coupling of a molecule and a cavity induces nonadiabaticity in the molecule which makes the description of its dynamics complicated. For polyatomic molecules, reduced-dimensional models and the use of the Born–Oppenheimer approximation (BOA) may remedy the situation. It is demonstrated that contrary to expectation, BOA may even fail in a one-dimensional model and is generally expected to fail in two- or more-dimensional models due to the appearance of conical intersections induced by the cavity.

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Nonadiabatic phenomena in molecular vibrational polaritons

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J. Chem. Phys.
154 (2021) 064305

https://doi.org/10.1063/5.0033338

Nonadiabatic phenomena are investigated in the rovibrational motion of molecules confined in an infrared cavity. Conical intersections (CIs) between vibrational polaritons, similar to CIs between electronic polaritonic surfaces, are found. The spectral, topological, and dynamic properties of the vibrational polaritons show clear fingerprints of nonadiabatic couplings between molecular vibration, rotation, and the cavity photonic mode. Furthermore, it is found that for the investigated system, composed of two rovibrating HCl molecules and the cavity mode, breaking the molecular permutational symmetry, by changing ^{35}Cl to ^{37}Cl in one of the HCl molecules, the polaritonic surfaces, nonadiabatic couplings, and related spectral, topological, and dynamic properties can deviate substantially. This implies that the natural occurrence of different molecular isotopologues needs to be considered when modeling realistic polaritonic systems.

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Signatures of light-induced nonadiabaticity in the field-dressed vibronic spectrum of formaldehyde

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J. Chem. Phys.
154 (2021) 124308

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Nonadiabatic coupling is absent between the electronic ground *X* and first excited (singlet) *A* states of formaldehyde. As laser fields can induce conical intersections between these two electronic states, formaldehyde is particularly suitable for investigating light-induced nonadiabaticity in a polyatomic molecule. The present work reports on the spectrum induced by light—the so-called field-dressed spectrum—probed by a weak laser pulse. A full-dimensional ab initio approach in the framework of Floquet-state representation is applied. The low-energy spectrum, which without the dressing field would correspond to an infrared vibrational spectrum in the *X*-state, and the high-energy spectrum, which without the dressing field would correspond to the $X \rightarrow A$ spectrum, are computed and analyzed. The spectra are shown to be highly sensitive to the frequency of the dressing light allowing one to isolate different nonadiabatic phenomena.

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Attila TÓTH

Probing strong-field two-photon transitions through dynamic interference

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J. Phys. B: At. Mol. Opt. Phys. 54 (2021) 035005

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We demonstrate how strong-field multiphoton transitions between dynamically shifted atomic levels can be traced in the energy spectra of emitted photoelectrons. Applying an ultrafast and intense laser pulse, two-photon Rabi oscillations are induced between two bound states of an atom. A third photon from the same pulse directly ionizes the atom, thus the emitted photoelectrons coherently probe the underlying dynamics. As the instantaneous energy of photoelectrons follows the pulse intensity envelope, modulated by the ac Stark shifts, electrons emitted with the same energy but at different times—at the rising and falling edge of the pulse—will interfere leading to pronounced dynamic interference pattern in the spectra. We investigate this phenomenon both numerically and analytically by developing a minimal three-state model that incorporates two-photon coupling and dynamically shifted atomic levels. On the example of atomic lithium (2s → → 4s → continuum) we show how the individual ac Stark shifts and the two-photon Rabi frequency are reflected through the asymmetry, shifting and splitting of the interference structure of the computed photopeaks.

eli attosecond

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Strong-field control by reverse engineering

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Phys. Rev. A 104, 063102

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Based on the idea of reverse engineering, we design an optimal laser pulse to control strong-field multiphoton atomic transitions. Starting from the time-dependent Schrödinger equation of the full system, we adiabatically eliminate the nonessential states and apply the rotating-wave approximation to arrive at an effective two-state representation that involves dynamic Stark shifts and multiphoton coupling. Solving this equation inversely for the field, we obtain an analytical laser pulse shape that is expected to induce the full system's evolution according to user-defined quantum pathways. In our procedure, the amplitude and phase of the laser pulse are engineered such that the dynamically shifted electronic states are resonantly coupled during the action of the pulse at each moment of time. As a result, the driven system evolves from an arbitrary initial population distribution to any desired final quantum state superposition at a predefined rate. The proposed scheme is demonstrated using the example of the 3s→4s two-photon transition of atomic sodium. By solving the time-dependent Schrödinger equation of the single-active electron with two different methods, either propagating time-dependent coefficients of many field-free states or directly propagating the three-dimensional electronic wave packet on a grid, we demonstrate the robustness as well as the limitations of the presented reverse engineering scheme.

eli attosecond

US

Alexander I. KULEFF

All-XUV pump-probe transient absorption spectroscopy of the structural molecular dynamics of di-iodomethane

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Phys. Rev. X
11 (2021) 031001

https://doi.org/10.1103/PhysRevX.11.031001

In this work, we use an extreme-ultraviolet (XUV) free-electron laser (FEL) to resonantly excite the I: $4d_{5/2}$–σ* transition of a gas-phase di-iodomethane (CH_2I_2) target. This site-specific excitation generates a 4d core hole located at an iodine site, which leaves the molecule in a well-defined excited state. We subsequently measure the time-dependent absorption change of the molecule with the FEL probe spectrum centered on the same I: 4d resonance. Using ab initio calculations of absorption spectra of a transient isomerization pathway observed in earlier studies, our time-resolved measurements allow us to assign the timescales of the previously reported direct and indirect dissociation pathways. The presented method is thus sensitive to excited-state molecular geometries in a time-resolved manner, following a core-resonant site-specific trigger.

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Péter FÖLDI
Sándor VARRÓ

Describing high-order harmonic generation using quantum optical models

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Photonics
8 (2021) 7, 263

https://doi.org/10.3390/photonics8070263

Optical generation of high-order harmonics is a prototypical example of nonlinear light–matter interactions in the high-field regime. Quantum optical effects have recently been demonstrated to have a significant influence on this phenomenon. These findings underline the importance of understanding the dynamics of the quantized electromagnetic field during high-order harmonic generation. In the following, we discuss the challenges that are related to the theoretical description of this process and summarize the results that were obtained using the high-field, multimode generalization of well-known quantum optical models that are based on the concept of the two-level atom.

Sándor VARRÓ

Quantum optical aspects of high-harmonic generation

S. VARRÓ

Photonics
8 (2021) 7, 269

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The interaction of electrons with strong laser fields is usually treated with semiclassical theory, where the laser is represented by an external field. There are analytic solutions for the free electron wave functions, which incorporate the interaction with the laser field exactly, but the joint effect of the atomic binding potential presents an obstacle for the analysis. Moreover, the radiation is a dynamical system, the number of photons changes during the interactions. Thus, it is legitimate to ask how can one treat the high order processes nonperturbatively, in such a way that the electron-atom interaction and the quantized nature of radiation be simultaneously taken into account? An analytic method is proposed to answer this question in the framework of nonrelativistic quantum electrodynamics. As an application, a quantum optical generalization of the strong-field Kramers-Heisenberg formula is derived for describing high-harmonic generation. Our formalism is suitable to analyse, among various quantal effects, the possible role of arbitrary photon statistics of the incoming field.

The present paper is dedicated to the memory of Prof. Dr. Fritz Ehlotzky, who had significantly contributed to the theory of strong-field phenomena over many decades .

Quantum interference in strong-field ionization by a linearly polarized laser pulse and its relevance to tunnel exit time and momentum

SZ. HACK, SZ. MAJOROSI, M. G. BENEDICT, S. VARRÓ, and A. CZIRJÁK

Szabolcs HACK
Sándor VARRÓ
Attila CZIRJÁK

Phys. Rev. A
104 (2021) L031102

https://doi.org/10.1103/PhysRevA.104.L031102

We investigate the liberation of an atomic electron by a linearly polarized single-cycle near-infrared laser pulse having a peak intensity that ensures tunneling. Based on phase space analysis and energy distribution in the instantaneous potential, we reveal the importance of quantum interference between tunneling and over-the-barrier pathways of escape. Tunneling is blurred both in space and time, and the contribution of tunneling at the mean energy is almost negligible. We suggest and justify improved initial conditions for a classical particle approximation of strong-field ionization, based on the quantum momentum function, and we show how to reconstruct them from the detected momentum of an escaped electron.

US

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Quantum-optical description of photon statistics and cross correlations in high-order harmonic generation

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Phys. Rev. A
104 (2021) 033703

https://doi.org/10.1103/PhysRevA.104.033703

We present a study of photon statistics associated with high-order harmonic generation (HHG) involving one-mode and intermodal correlations of the high harmonic photons. The aim of the paper is to give insight into the nonclassical properties of high-order harmonic modes. To this end, we use a simplified model describing an elementary quantum emitter: the model of a two-level atom. While the material system is extremely simplified in this description, the conclusions and the methods may be generalized for more complex cases. Our primary interest is an effective model of HHG in which the exciting pulse is classical and the harmonics are quantized, although we touch upon the more generalized, fully quantized model as well. Evolution of the Mandel parameter, photon antibunching, squeezing, and cross correlations are calculated. Results imply that with respect to a single quantized emitter, nonclassicality of the harmonics is present: sub-Poissonian photon statistic and squeezing can characterize certain optical modes, while strong anticorrelation can also be present.

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Péter FÖLDI

Analytic expression for the charge carried by a locally excited Bloch state

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Phys. Rev. B
103 (2021) 245204

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We consider the time evolution of Bloch electrons after a local excitation, like an interaction with a focused laser pulse that irradiates only a part of the sample. The disturbance caused by the excitation propagates along the sample towards detectors. We focus on the measurable time integral of the usually rapidly oscillating current. In the long time limit this integral is the total charge that is displaced by the excitation. We develop an analytic way for calculating this charge. The results are verified using an analytic example with quadratic dispersion in one dimension. Additionally, numerical calculations are also performed in order to visualize the relevant physical processes in a wide band gap material that is excited by a laser pulse.

eli attosecond

US

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Iodide expulsion at photoirradiated mixed halide perovskite interface

P. S. MATHEW, G. F. SAMU, CS. JANÁKY, and P. V. KAMAT

ECS Meeting Abstracts
MA2021-01 686

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Visible light irradiation of a mixed halide perovskite (with bromide and iodide in the X-site) in contact with a solvent like dichloromethane (DCM) leads to selective expulsion of iodide from the film. This causes a concurrent blue-shift in band edge. We find that addition of Cs to A-site reduces the mobility of iodide ions under photoirradiation. In the absence of a solvent, these mixed halide perovskites undergo phase segregation, the rate of which decreases with the addition of Cs. Interestingly, the iodide expulsion rate in DCM is strongly dependent on the rate of photoinduced segregation. At Cs atomic concentrations greater than 50%, the films become stable as the iodide expulsion is largely suppressed. The role of the A-site cation in dictating the mobility of halide ions will be discussed in the talk.

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Radially grown carbon nanomaterials on hollow glass microspheres and their application in composite foams with excellent electromagnetic interference shielding

Mousumi
UPADHYAY KAHALY

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Polymer Composites

https://doi.org/10.1002/pc.26093

In the current study, we investigated the effect of processing temperature in chemical vapor deposition (CVD) on the formation of carbon nanomaterials over the hollow glass microsphere. The surface morphology and structural information of the carbon nanomaterials (CNM)-coated hollow glass microsphere (HGM) were analyzed through scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Then, the 5-CH [CNF-coated HGM (Synthesizing temperature in CVD being 500 °C)], 6-CH [MWCNT-coated HGM (Synthesizing temperature in CVD being 600 °C)], and 7-CH [MWCNT-coated HGM (Synthesizing temperature in CVD being 700 °C)] were individually used as fillers in the epoxy composite foam. Thorough characterization of mechanical and thermo-mechanical behavior suggests that compression stress, compression modulus, and storage modulus of 6-CH-based composite foam are higher than the 5-CH- and 7-CH-based composite foam with the contribution of 10%, 15%, and 20%, respectively. The electromagnetic interference (EMI) shielding effectiveness over the frequency of 8–12 GHz increased from 15 dB for without HGM to 21 dB, 25 dB, and 23 dB for 5-CH, 6-CH-, and 7-CH-based composite foam, respectively. It is also noticed that, 6-CH-based composite foams presented the highest EMI-SE compared to 5-CH- and 7-CH-based composite foams. Enhanced mechanical, thermo-mechanical, and shielding properties of 6-CH-based composite foams are due to improved morphology and quality of CNT grown at 600°C.

US

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Light-field-driven current control in solids with pJ-level laser pulses at 80 MHz repetition rate

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Optica
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Future PHz electronic devices may be able to perform operations on few-femtosecond time-scales. Such devices are based on the ability to control currents induced by intense few-cycle laser pulses. Investigations of this control scheme have been based on complex, amplified laser systems, typically delivering mJ or sub-mJ-level laser pulses, limiting the achievable clock rate to the kHz regime. Here, we demonstrate transient metallization and lightwave-driven current control with 300-pJ laser pulses at 80 MHz repetition rate in dielectric media (HfO_2 and fused silica), and the widebandgap semiconductor GaN. We determine the field strength dependence of optically induced currents in these media. Supported by a theoretical model, we show scaling behaviors that will be instrumental in the construction of PHz electronic devices.

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Complexity of a Co_3O_4 system under ambient-pressure CO_2 methanation: influence of bulk and surface properties on the catalytic performance

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J. Phys. Chem. C
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Although using supported noble-metal catalysts for CO2 hydrogenation is an effective solution due to their excellent catalytic properties, metal oxide supports themselves can exhibit good activity being more economically feasible. This work focuses on investigating the complexity of the Co_3O_4 system during the CO_2 methanation reaction, which is usually accompanied by the formation of unstable dispersions of cobalt oxide and metallic Co. Herein, we have tested different types of Co_3O_4: synthetically prepared mesoporous m-Co_3O_4 (BET surface area, 95 m^2/g) and commercial c-Co_3O_4 (BET surface area, 15 m^2/g; purchased from Merck) in the CO_2 methanation reaction under different reduction temperatures (273–673 K). The reduction temperature was adjusted to 573 K for both the catalysts to reach the optimal Co/cobalt oxide ratio and consequently the best catalytic performance. m-Co_3O_4 is more active (CO_2 conversion 95%) and stable at higher temperatures compared to c-Co_3O_4 (CO_2 conversion 63%) due to its morphology-induced ~66 times higher surface basicity. DRIFTS results showed differences in the detected surface species: formate was observed on m-Co_3O_4 and was proven to contribute to the total methane formation. It was revealed that in CO_2 methanation reaction, both bulk and surface properties such as morphology, cobalt oxidation states, acid–base properties, and presence of defect sites directly affect the catalytic performance and reaction mechanism. Furthermore, 1% 5 nm Pt nanoparticles were loaded onto the Co_3O_4s to check the competitiveness of the catalysts. This study evidences on a cheap noble-metal-free catalyst for CO_2 methanation consisting of m-Co_3O_4 with competitive activity and ~100% CH_4 selectivity.

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Hot branching dynamics in a light-harvesting iron carbene complex revealed by ultrafast X-ray emission spectroscopy

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Iron N-heterocyclic carbene (NHC) complexes have received a great deal of attention recently because of their growing potential as light sensitizers or photocatalysts. We present a sub-ps X-ray spectroscopy study of an Fe^{II}NHC complex that identifies and quantifies the states involved in the deactivation cascade after light absorption. Excited molecules relax back to the ground state along two pathways: After population of a hot ^{3}MLCT state, from the initially excited ^{1}MLCT state, 30 % of the molecules undergo ultrafast (150 fs) relaxation to the ^{3}MC state, in competition with vibrational relaxation and cooling to the relaxed ^{3}MLCT state. The relaxed ^{3}MLCT state then decays much more slowly (7.6 ps) to the ^{3}MC state. The ^{3}MC state is rapidly (2.2 ps) deactivated to the ground state. The ^{5}MC state is not involved in the deactivation pathway. The ultrafast partial deactivation of the ^{3}MLCT state constitutes a loss channel from the point of view of photochemical efficiency and highlights the necessity to screen transition-metal complexes for similar ultrafast decays to optimize photochemical performance.

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