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EDITORIAL

Ultrafast phenomena on the nanoscale

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"Ultrafast phenomena on the nanoscale" merge two large and highly successful fields of modern research: ultrafast science and nanoscale physics. Ultrafast science, which produces and analyzes events as short as attoseconds, is often explored through studies of atoms and molecules, while nanoscale research focuses on condensed matter. Joining these two fields is only natural because their intrinsic time and length scales match almost perfectly. In fact, all important electronic processes in solids take place on attosecond to femtosecond time scales as determined by the spectral bandwidths and electron interaction (collision) times. In space, important phenomena in condensed matter such as plasmonic energy localization, electron scattering, the skin effect as well as the steering of electronic matter waves, etc. take place over distances of around 10 nm. Ultrafast phenomena on the nanoscale are currently becoming an active field of research and it is exciting to see researchers from diverse backgrounds moving it forward.

This fertile encounter can be explored in various ways. For example, ultrafast laser pulses can be utilized to probe electronic behavior in solids, and, vice versa, the electronic response of the optically driven electronic system might lead to new ultrafast and highly-nonlinear effects. The large, and still rapidly growing, field of ultrafast plasmonics is the currently most visible representative of this direction.

The collection of contributions in this special issue reflects the various directions from which the cross section of "ultrafast and nanometer-small" science can be tackled. F. Faisal, one of the fathers of multiphoton processes in strong laser fields, (at the time, exclusively an atomic physics phenomenon), discusses related effects in the hottest nano-material currently explored: graphene (p. 171). M. F. Ciappina et al. (p. 97) and B. Fetić et al. (p. 107) investigate how inhomogeneous electric near-field distributions near nanoscale structures are influencing high harmonic generation processes. Here, the decay length of the near field is so small that the trajectories of the electrons involved in the high-harmonic generation process are modified. Experimental work in this direction, exploiting the enhanced near-field, is reported by I.-Y. Park et al. (p. 87), whose article will certainly help to clarify the discussion on their highly visible and much-debated work published a few years ago. Similarly, however focusing on electrons, P. D. Keathley et al. (p. 144) investigate strong-field phenomena in electron emission from a tip array. H. Yanagisawa (p. 126) shows a study on electron emission mechanisms of ultrashort-pulse-driven tips, and S. V. Yalunin et al. (p. L12) apply theoretical models to explain previously measured data in greater clarity. S.M. Forman et al. (p. L19) take another step forward and translate the ultrashort pulse duration via laser-driven electron emission into the X-ray domain with bremsstrahlung generation.

Several papers turn the perspective around to study ultrafast responses in near-field, plasmonic, and surface effects. M. Becker et al. (p. L6) measure the temporal response of plasmonic antennae, Mårsell et al. (p. 162) image photoelectrons exited by EUV photons from nanomaterials, D. J. Park et al. (p. 135) infer the near-field in front of a tip with the help of electron spectra, and J. S. Prell et al. (p. 151) simulate streaking spectra to learn about the plasmonic response of nanoparticles. Vella et al. (p. L1) probe the ultrafast thermal response of a silicon tip by atom probe tomography. Leipold et al. (p. 199) discuss ultrafast dynamics of localized light modes.

Also, a collection of articles is devoted to the ultrafast response of artificial atoms, mostly quantum dot structures. B. P. Fingerhut et al. (p. 31) present simulations on 2D spectroscopy on self-assembled quantum dots to reveal exitonic and biexitonic couplings. C.-H. Chuang et al. (p. 43) perform femtosecond transient absorption spectroscopy on cadmium selenide quantum dots and investigate different relaxation processes. K. Müller et al. (p. 49) employ pump-probe spectroscopy to monitor tunneling of electrons and holes in single and coupled quantum dots.

Other nanomaterials are discussed as well. N. Erhard et al. (p. 180) perform pump-probe spectroscopy to distinguish different types of photocurrent generation mechanisms in nanowire-based electric circuits. J. Z. Kamiński et al. (p. 118) predict a resonant tunneling current through a semiconductor heterostructure in the presence of both light and DC fields. G. Kyas et al. (p. 189) study theoretically how energy is transferred from a photo-exited supramolecular complex to a nearby metal nanoparticle. Furthermore, M. Huang et al. (p. 74) show that in laser material processing plasmonic effects help grating fabrication on the nanoscale.

Novel techniques are the focus of two articles. M. Gabrysch et al. (p. 59) discuss imprinting XUV phase grating on wide-band semiconductors to probe free carrier dynamics with the help of a time-delayed infrared pulse. R. Frank (p. 66) shows how highly-nonlinear effects in a photonic structure can be used to switch light with light.

This special issue starts with a review by J.-Y. Bigot and M. Vomir (p. 2) on ultrafast magnetization dynamics in nanostructures showing various time and length scales involved and how they are linked to the underlying spin dynamics. It goes on to carry a broad range of research. It is heartening to see the often interdisciplinary nature of the approaches employed and various types of articles. The abundance of simulations and novel techniques indicate that this field is developing and growing, and the many original contributions indicate the fast pace of the progress. We expect a bright future for our research, because though this joint research has shrunk to the nano-scale, our opportunities keep expanding.

Peter Hommelhoff is Professor of physics at University of Erlangen and head of a Max Planck Research group at MPQ in Garching. From 2003 – 2007 he did a postdoctoral stint at Stanford University with Mark Kasevich. Prior to that he was a PhD student in T. W. Hänsch's group at University of Munich, working on Bose-Einstein condensation on a chip. In 1999, he obtained a diploma in physics from Swiss Federal Institute of Technology (ETH) Zürich. His current research interests span from attosecond physics at nanotips via acceleration of electrons with laser light at photonic structures to novel quantum optics experiments with free electrons.

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