Nano-Optics in the Strong-Field Regime

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An exciting non-perturbative regime of light-matter interactions is reached when the amplitude of the external electromagnetic fields that are driving a material approach or exceed the field strengths that bind the electrons inside the medium. In this strong-field regime, light-matter interactions depend on the amplitude and phase of the field, rather than its intensity, as in more conventional perturbative nonlinear optics. Traditionally, such strong-field interactions have intensely been investigated in atomic and molecular systems and this resulted in the generation of high harmonic radiation and laid the foundations for contemporary attosecond science. During the last decade, however, a new field of research has emerged, the study of strong-field interactions in solid-state nanostructures [1]. By using nanostructures, specifically those made out of metals, external electromagnetic fields can be localized on length scales of just a few nanometers, resulting in greatly enhanced field amplitudes that can exceed those of the external field by orders of magnitude in the vicinity of the nanostructures. This not only leads to dramatic enhancements of perturbative nonlinear optical effects but also significantly increases photoelectron yields.

In particular, I will review our recent results on ultrafast strong-field photoemission from nanoplasmonic structures including the non-adiabatic tunneling of photoelectrons [2] and photoelectron rescattering in the multi-photon-induced photoemission regime [3].

The carrier-envelope phase (CEP) is a powerful knob to steer interactions of laser light with matter in the strong-field regime, as evidenced by numerous studies of ultrafast electron dynamics in atomic, molecular and solid-state media. Precise characterization of CEP or CEP changes in time or space is a key ingredient in applying electric-field sensitive techniques to study and control ultrafast electron processes in matter. Thus, characterizing and controlling CEP in space can support strong-field nanooptics experiments [1] or PHz optoelectronics.

I will also present a novel, on-chip scanning CEP probe that is capable of measuring 3D CEP maps in the vicinity of a few-cycle laser beam focus for laser pulses having only ∼pJ-nJ pulse energy without having to use vacuum equipment for this purpose [4]. The measurement principle and some results are described in detail in [5].

I will also feature recent results on how to use dielectric-metal heterostructures to enhance CEP dependent signal levels significantly. In addition, experiments on revealing the mechanisms of the ultrafast current generation process will also be presented. We also demonstrate a method to sculpt the CEP of few-cycle pulses in the vicinity of the focal volume.

In addition, I will also review our recent experimental results on our novel free space pump/plasmon probe experiments with which (in addition to the investigation of hot electron dynamics), we could also realize an ultrafast nano-optical signal switching scheme [6].

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