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Attosecond view of the photoelectric effect and optical-field-induced current in dielectrics

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Fundamental electronic processes in condensed matter like electron transport on atomic length scales, the plasmonic response in metals or the dielectric response in insulators occur on attosecond time scales. In the first part of my talk, I discuss how a streak camera operating at optical frequencies provides a time-resolved view of the photoelectric effect [1]. Photoelectrons emitted from metal surfaces by an attosecond extreme ultraviolet laser pulse are time-stamped by a few-cycle visible/near-infrared laser pulse. This technique allows for measuring the relative emission time of valence and core electrons with a precision of tens of attoseconds, thereby addressing the intrinsic dynamics of the photoemission. I present recent studies of a free-electron metal [2] as well as of oxygen-covered tungsten single crystals. The origin of the observed attosecond delays in the emission of photoelectrons from different initial states is discussed. In the second part of the talk, I report on electric current in dielectrics induced and controlled by ultrashort optical fields [3]. For very short periods of time, electric fields exceeding 10 V/nm, i.e. fields significantly beyond the threshold for dc dielectric breakdown, can be applied to insulators. In this regime, insulators exhibit a highly nonlinear dielectric response, resulting in an increase in conductivity by many orders of magnitude. Applying 1.5-cycle laser pulses to unbiased metal-dielectric-metal nanogaps, we demonstrate the generation of directly measurable photocurrents whose magnitude and directionality can be controlled with the carrier-envelope phase of the laser pulse, i.e. by the shape of the laser electric field. Such currents can be switched on and off on sub-femtosecond timescales as evidenced by employing two cross-polarized and time-delayed pulses. The ultrafast field-controlled current generation in a dielectric nanostructure may represent a first step towards the realization of optical-field-controlled electronics.

References:

[1] A.L. Cavalieri et al., Nature 449, 1029 (2007).
[2] S. Neppl et al., Phys. Rev. Lett. 109, 087401 (2012).
[3] A. Schiffrin et al., Nature (2013), doi:10.1038/nature11567.