Light-induced ultrafast photoemission and conductance phenomena in nanoscale systems

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Nanoparticles as targets of short (femto- or attosecond) light pulses [1] mean a unique combination, where the resolution neither in space nor in time could have been achieved a few decades ago. This experimentally accessible spatio-temporal domain can be related to novel quantum mechanical phenomena and raises new questions.

Short, intense bursts of electromagnetic radiation impinging on metallic surfaces induce a photoemission process which is far beyond the traditional picture: both multiphoton and tunneling processes can have important role. Additionally, when resonance conditions are satisfied, plasmonic field enhancement appears, allowing for genuine high field effects to be detected.

We analyze the possibility of light-field control of electrons in the vicinity of plasmonic nanoparticles excited by short laser pulses. The time dependence of the laser field (red oscillating curve in Fig. 1) is assumed to be given by

$$\mathbf{E}_L(t) = \hat{\mathbf{x}}\mathcal{E}_0 \cos(\omega_0 t + \varphi_{\text{CEP}}) \exp\left(-\frac{t^2}{2\tau^2}\right), \qquad (1)$$

where ω_0 is the carrier frequency, and φ_{CEP} denotes the carrier-envelope phase (CEP) of the laser pulse. Typical, state of the art femtosecond ($\tau \approx 2-3$ fs) laser pulses are in the near or mid infrared range, thus their duration is equivalent to only a few optical cycles. This means that not only the temporal envelope of the electric field, but also the true time evolution of the field strength ("waveform") has important role. We focus on the interaction of matter and CEP stabilized laser pulses (with pulse by pulse reproducible waveforms).

Having calculated the net electric field of the incident laser pulse and localized plasmons, we observe subwavelength electric field localization with few-cycle oscillations under slightly off-resonant conditions. Additionally, the electric field can "steer" the photoemitted electrons, i.e., the value of φ_{CEP} determines the final direction these electrons tend to leave the interaction region [2].

When the interaction of the laser pulse and a nanoscale object is weaker, the external electric field – instead of initiating photoemission – can induce or modulate electric currents, and this effect may be used e.g., for ultrafast electronics applications or for the determination of the CEP of the pulse [3].

As an example, we consider ring-like structures with a short laser pulse being focused at the center. The most suitable theoretical model for this phenomenon is based on nonequilibrium Green's functions (NEGF) [4, 5]. We introduce a model, where the combination of the Dyson and Keldysh equations leads to a time evolution that can be calculated efficiently, and have a clear physical interpretation as well. Using this approach, we observe that the current flowing through a nanoscale semiconductor ring depends on the CEP of the exciting laser pulse. Additional, spin-dependent applications will also be discussed.

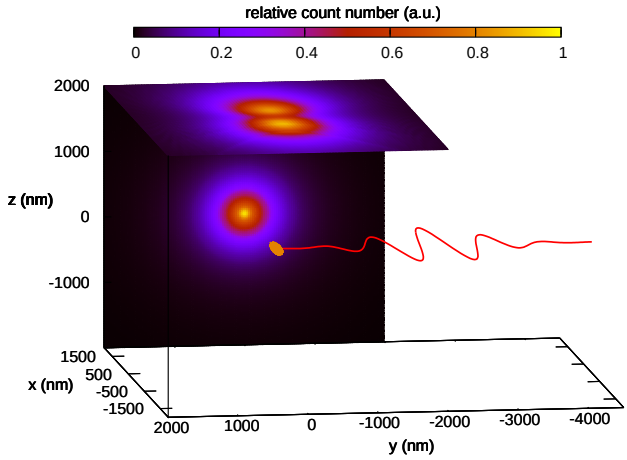

FIG. 1. A laser pulse (represented by the red wave) impinging on a nanoellipsoid (plotted by orange). The photoemitted electrons can be detected e.g., at the planes where characteristic electron count distributions are shown.

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