Photon-Induced Time Resolved Electron Spectroscopy and Holography with Slow Electrons

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Photon-induced near-field electron microscopy [1] involving electrons at relativistic energies has been demonstrated as a versatile tool for coherent controlling the phase of the electron wavepackets [2], as well as resolving dynamics of collective excitations such as plasmons [3]. It is generally assumed that the near-field mediated interactions between electrons and light can be taken place only for high-energy electrons. This is due to the fact that the momentum transfer between light and matter waves is easily manifested when fast electrons are involved.

Here, we investigate the interaction of slow and fast electrons with free-space electromagnetic waves [4], as well as near-field light [5, 6]. In particular we investigate the possibility of freely propagating Gaussian light waves for initiating quantum coherent dynamics in the phase of the electron wavepackets. Additionally, we will show that shaped light might be utilized to develop a generalized Kapitza-Dirac effect, and by virtue of this generalization, a novel boson-sampling principle involving fermionic matter waves is proposed.

We will further show that in contrast to the generally adopted picture, it is the scalar potential and not the vector potential which significantly mediates the electron-light interaction at the near-field zone of nanoparticles, when the Coulomb gauge is applied. Moreover, the intensity of the coupling strength is inversely proportional to the electron velocity. In other words, there are two competing factors governing the electron-light interactions: interaction time and momentum-matching principle. Whereas slow electrons are more sensitive to the electromagnetic interactions, fast electrons are more delocalized probes of photonic density of states; namely, less bound photonic states are required to mediate the energy transfer between faster electrons and light, compared to the slow electrons. Nevertheless, simulations stemming from first principles demonstrate the suitability of slow-electron point-projection setups for both time-resolved spectroscopy as well as holography (Fig. 1).

References:

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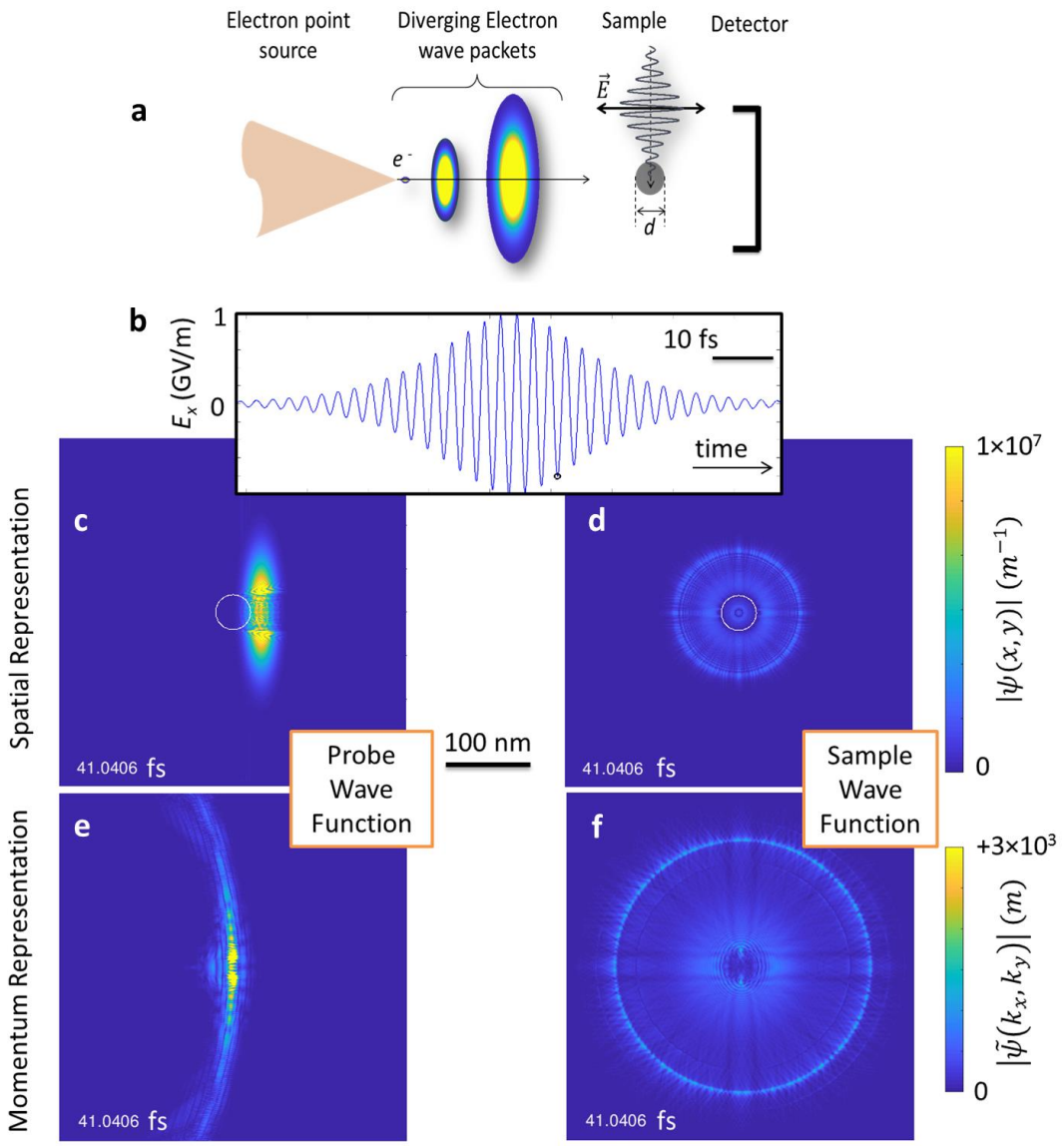

Figure 1. Time-dependent Hartree-Fock simulations for the interaction of a propagating electron wave-packet (Probe) with the localized electron wavepacket inside the carbon nanorod (Sample). The carbon nanorod is modelled by a cylindrically symmetric step potential at the height of the carbon work function. (a) Schematics of a point-projection electron microscope for time-resolved spectroscopy and holography. The system includes a point-projection electron source with divergent electron beams. For simulations the sample (a carbon nanorod) is positioned at the distance of 2 μm from the source. The initial conditions for the electron wavepacket are the kinetic energy of 60 eV, transverse and longitudinal broadenings of 0.5 nm and 2 nm, and for the laser is the maximum field amplitude of $E_0 = 1 \times 10^{10}$ Vm^{-1}, carrier wavelength of $\lambda_0 = 800$ nm, and temporal broadening of $W_s = 10$ fs. (b) temporal representation of the *x*-component of laser pulse, and snapshots of the electron wave function in the real (c and d) and the momentum (d and e) spaces, for the probe (c and e) and the sample (d and e) wave functions.