Ponderomotive femtosecond laser manipulation of the free electron wavefunction

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Through the ponderomotive potential a light field acts like a refractive index medium for free electron matter waves, basically inverting the usual roles of light and matter in optics. This subtle quantum mechanical effect is however very weak and extremely high laser intensities are required to realize measurable effects, precluding practical applications until quite recently. In 2001 Freimund et al. [1] showed in a ground-breaking experiment how an electron beam can be diffracted by a standing wave of light, thus realizing a light-based phase grating for electron matter waves, enabling electron interferometry. Only last year Schwartz et al. [2] succesfully demonstrated phase contract imaging with electrons by using a CW laser beam stored in a high-finesse optical cavity as a Zernike phase plate for electrons, which is of great importance to the life sciences. Implementation of Spatial Light Modulators (SLMs) to structure the light field interacting with the electron beam would allow even more intricate phase manipulation of the electron waves, thus enabling, for example, new methods for aberration correction. It is however not directly obvious how to accomplish this with CW laser beams inside a high-finesse optical cavity.

Interestingly, mode-locked femtosecond laser oscillators readily provide the required peak power, without the need for optical cavities. Moreover, we have recently developed microwave-based Ultrafast Electron Microscopy [3,4], providing synchronized pulsed electron beams with the same time structure – femtosecond pulse durations and 75 MHz to 3 GHz repetition rates – as femtosecond laser oscillators. We will present results of detailed numerical simulations demonstrating the feasibility of a femtosecond-laser based Zernike phase plate for electrons, and of a femtosecond-laser based coherent electron beam splitter. The simulations illustrate the complex and subtle phenomena involved in the scattering of electron wave packets by pulses of light. The prospects of employing an SLM for advanced manipulation of the electron phase will be addressed and experimental progress will be reported.

References:

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