Shaping free electron wavepackets with structured light

<u>Sven Ebel</u>[1,*] and Nahid Talebi[2,3,⊥]
[1]POLIMA—Center for Polariton-driven Light-Matter Interactions, University of Southern Denmark, 5230 Odense, Denmark
[2]Institute of Experimental and Applied Physics, Kiel University, 24098 Kiel, Germany
[3]Kiel Nano, Surface and Interface Science KiNSIS, Kiel University, 24118 Kiel, Germany

[*] sleb@mci.sdu.dk
⊥ talebi@physik.uni-kiel.de

Abstract

Controlling free-electron momentum states is of high interest in electron microscopy to achieve momentum and energy resolved probing and manipulation of physical systems. Free-electron and light interactions have emerged as a powerful technique to accomplish this. Here, we demonstrate both longitudinal and transverse phase control of a slow electron wavepacket by extending the Kapitza-Dirac effect to spatially-structured pulsed laser beams. This extension enables both inelastic and elastic stimulated Compton scattering. The interaction reveals the formation of distinct electron transverse momentum orders, each demonstrating a comb-like electron energy spectrum. By exerting complete control over light parameters, including wavelength, field intensity, pulse duration, and spatial mode order, as well as their combinations, it is possible to coherently control the population of these electron energy-momentum states that are separated by a few meV energy and multiple photon momentum orders. This free-space electron-light interaction phenomenon possesses the capability to coherently control the energy and momentum of electron beams in electron microscopes. Moreover, it has the potential to facilitate the selective probing of various material excitations, including plasmons, excitons, and phonons, and performing matter-wave interferometry with transversely shaped electron beams.