Enhanced Electron Modulation in Photon Induced Near-Field Electron Microscopy (PINEM) with Shaped Light Fields

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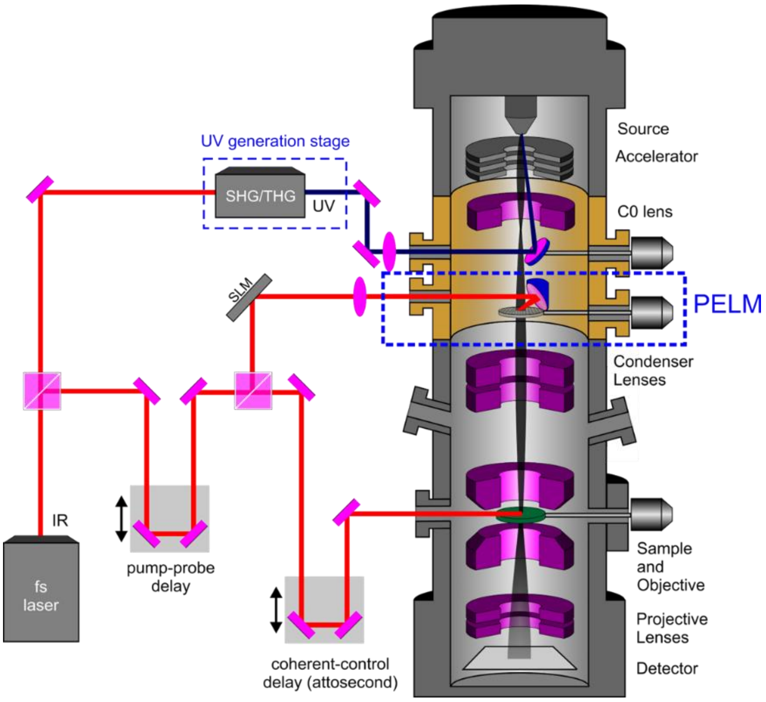
Photon Induced Near-Field Electron Microscopy (PINEM) is an advanced imaging technique based on the inelastic coupling between electrons and photons in presence of a surface or a nanostructure. This technique is employed to study the transient behavior of near-fields created by photons proximal to nanostructure and has been mainly used as an innovative imaging method for nanoscale materials science and biological systems. Recently, we instead exploited the quantized nature of electron-light interactions that is intrinsic to PINEM to have a versatile and dynamic control of the electron wavefunction. Indeed, it is already possible to arbitrarily control light fields through spatial light modulators (SLMs) and our goal is to exploit PINEM to transfer this tunability to electron beams, thereby broadening the capabilities of ultrafast TEMs (UTEMs).

Our experiments are conducted on an UTEM, specifically a JEOL 2100 TEM modified as shown in the figure. In this setup, a 200 keV electron beam interacts with a femtosecond IR laser beam within a Photonic-based ELectron Modulator (PELM), an additional module of our TEM with an extra sample holder. The laser profile is shaped using a HOLOEYE Phase-Only SLM. We probe the electron-light interaction either by energy filtering imaging with a Gatan GIF QuantumSE or by imaging the momentum plane of the electron beam with a DECTRIS QUADRO.

We used the SLM to impart an Hermite-Gaussian shape to the laser profile and, through energy filtering, we imaged at different defocuses only the electrons that interacted with light. By comparing the obtained data with simulations, we determined the coherence length of the electron to be $\delta = 50$ nm. This crucial parameter sets an upper limit to the laser pattern size at the interaction plane such that it can be completely transferred to the electron beam. Additionally, we reconstructed the laser beam profile at the interaction plane by acquiring momentum images with a micrometric aperture at the image plane in different positions. Following this, we began to explore different SLM patterns, verifying their expected outcomes using the aperture method. This exploration revealed a high degree of consistency between our expectations and the observed results, confirming the effectiveness of our method.

In conclusion, our findings demonstrate the potential of using shaped light fields in PINEM for enhanced tunability of electron modulation. The ability to control the electron wavefunction with such precision opens up new possibilities for the study of electron-light interactions. This could have far-reaching implications for various scientific domains, including life sciences, materials science, and nanotechnology. Our method represents a significant advancement in the field of electron microscopy and sets the stage for future research in this dynamic field.



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