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Effects of Electron-Gun and Laser Parameters on Collection Efficiency and Packet Duration in Ultrafast Electron Microscopy

Erik Kieft,[1] Karl B. Schliep,[2] Pranav K. Suri,[2] and David J. Flannigan[2]

[1]FEI Achtseweg Noord 5, 5651 GG Eindhoven, The Netherlands.

[2]Department of Chemical Engineering and Materials Science, University of Minnesota, 421 Washington Avenue SE, Minneapolis, Minnesota 55455, USA.

Real-space imaging of full-morphological, angstrom-scale structural dynamics occurring on the femtosecond (fs) timescale is possible with ultrafast electron microscopy (UEM) via the stroboscopic pump-probe methodology enabled by interfacing an otherwise standard TEM with a short-pulsed laser system [1-3]. The technology has matured to the point that commercial systems, such as the FEI Tecnai Femto, are now available [4]. The base platform for the Tecnai Femto is FEI's Tecnai G2 20 200 kV instrument with a thermionic electron gun. In UEM mode, the LaB_6 is operated cold such that electron emission occurs only during photo-illumination. Despite this, nanosecond single-shot imaging and diffraction – wherein $>10^7$ electrons per packet reach the specimen – are possible with a Tecnai-based UEM equipped with a conventional thermionic electron gun [5,6]. While this illustrates that sufficient photoelectrons for such experiments are generated in an otherwise unmodified Tecnai TEM, the parameter space for application-specific optimal electron-gun and photoelectron-generating laser properties remains ill-defined. Quantitatively and systematically mapping such parameter space is challenging due to the large number of variables affecting photoelectron packet properties [7-9].

Here, we describe the effects of thermionic gun configuration (e.g., Wehnelt aperture diameter and relative position of the LaB_6 emission source) and photoelectron-generating laser-pulse duration on electron collection efficiency (CE) and temporal duration (Δt_{50}), respectively. Specifically, we use General Particle Tracer (GPT) code [10] to simulate the evolution of fs photoelectron packets generated from a cold LaB_6 source in an otherwise standard Wehnelt assembly, as is the case for UEM mode in the Tecnai Femto instrument. Considered in the simulations were the effects of electron path lengths, energy spread, and Coulombic interactions, and we tracked the temporal and energy spreads, brightness, and CE as a function of various parameters. Properties of the photoelectron-generating laser pulse (e.g., spot size on the LaB_6, duration, and energy) and geometry of the gun (e.g., relative axial LaB_6 position and Wehnelt aperture diameter) were systematically varied in order to investigate the resulting electron packet properties. Three discrete UEM modes were considered: single electron (1 electron/packet), burst (10^3 electrons/packet), and single shot (10^7 electrons/packet).

Results of the simulations suggest that there exists an optimal LaB_6 position relative to the Wehnelt aperture wherein a CE of 100% can be achieved for the single-electron mode and, additionally, that CE increases approximately linearly up to and beyond 90% for both burst and single-shot modes with increasing Wehnelt aperture diameter. Moreover, we found that only marginal increases in the overall temporal resolution can be achieved by decreasing the photoelectron-generating laser-pulse duration from 280 to 10 fs owing to evolution of the packet properties in the gun region and the acceleration tube. The goal of these simulations is to provide a starting point for experimentally mapping parameter space accessible with UEM instruments based on otherwise standard self-biasing thermionic electron guns while also providing insight into challenges associated with achieving high temporal and spatial resolutions [11].

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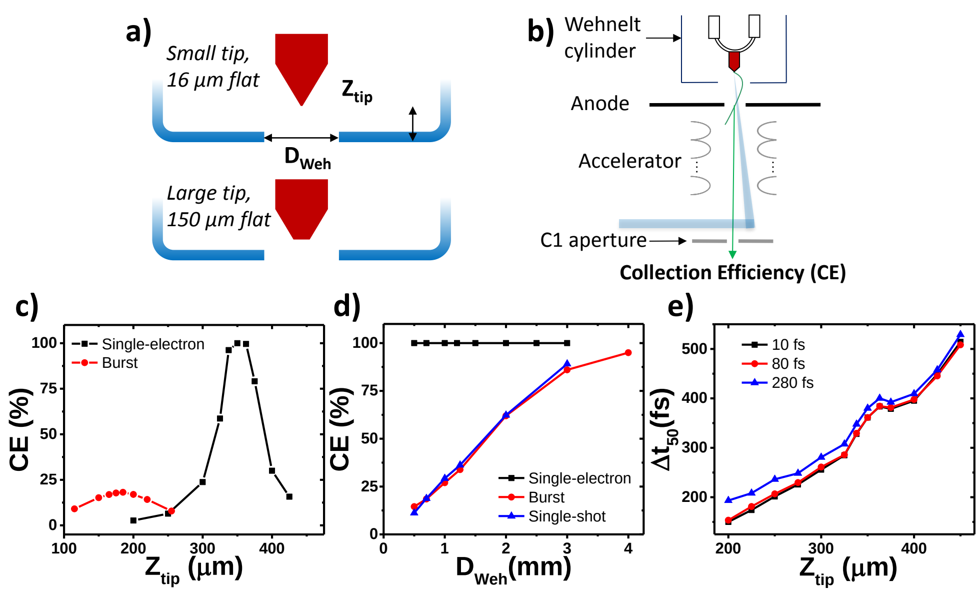

Figure 1. **(a)** Schematic of the thermionic gun showing the Wehnelt cylinder and LaB_6 with aperture diameter (D_{Weh}) and gun-tip height (Z_{tip}) defined. **(b)** Schematic of the thermionic gun geometry in the Tecnai Femto with pertinent components labeled and collection efficiency (CE) illustrated. **(c)** Effect of Z_{tip} position on CE for the single-electron and burst modes for D_{Weh} = 0.7 mm. **(d)** Effect of D_{Weh} at optimal Z_{tip} position on CE for each mode studied. **(e)** Effect of photoelectron-generating laser-pulse duration (10, 80, and 280 fs) on temporal resolution (Δt_{50}) as a function of Z_{tip} position.