NanoMi: a modular platform for terahertz-integrated UTEM

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Establishing terahertz coupled ultrafast techniques on NanoMi: A modular electron microscopy platform

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Abstract— **Ultrafast electron microscopy techniques allow for the dynamic structure of materials to be studied. Currently these methods are achieved by modifying a commercial electron microscope to grant optical access to both the cathode and sample regions. The temporal resolution is limited by the duration of the electron bunch probe, which can be compressed via interaction with a single cycle terahertz pulse inside a waveguide. The necessary modifications for optical access and waveguide integration may not be viable on all commercial systems, with the potential to compromise the column. NanoMi is an open-source, modular electron microscopy platform that is highly amenable to customization, making it ideal for establishing ultrafast functionality in addition to exploring terahertz-electron interactions.**

I. INTRODUCTION

Pump probe techniques with ultrafast electron pulses and laser-pulse-excited samples, namely ultrafast transmission electron microscopy (UTEM) and ultrafast electron diffraction (UED), have been established over the past two decades [1], [2]. For UED a single electron probe is sufficient, while UTEM requires a probe consisting of many electrons. Even for sub femtocoulomb bunches, space charge effects become appreciable, inducing an energy chirp that increases the temporal width of the electron bunch [3]. Recent works have demonstrated the ability to compensate for this effect by recompressing the electron bunch through interaction with a single cycle terahertz (THz) pulse inside a waveguide structure. Deflection, acceleration, and lensing of the electron bunch is also possible by varying the polarization and arrival time of the THz pulse [4]-[6]. For a tapered parallel plate waveguide (TPPWG) there is the added benefit of field enhancement from spatially confining the radiation, increasing the effects of the THz-electron interaction. At present, UTEM and UED capabilities have been attained by modifying commercial electron microscope columns to facilitate coupling ultrafast laser pulses to both the cathode for photoemission of electron bunches, and sample for photoexcitation. These modifications are specific to each microscope and risk compromising the column, while integration of a TPPWG structure for THz manipulation of the electron bunches adds further complexity to accessing ultrafast electron microscopy techniques.

NanoMi is an open-source electron microscopy (EM) platform with the capacity to be tailored to various use cases [7]. All components can be manufactured for a relatively low cost, are modular, and ultra-high vacuum (UHV) compatible. Conflat™ hardware is used to house the system, allowing the column to be combined with existing UHV systems, or designed to provide ample optical access to the cathode and sample. The electron-optics are independent of the column so components can be positioned by the user and custom devices can be incorporated. A central mounting system that mimics a traditional laser-optics bench is used, and aligns components to the electron-optic axis. Electrostatic einzel lenses are utilized, owing to their ease of manufacturing and to avoid the need for water cooling equipment that is necessary when operating high current electromagnetic lenses. Electrostatic deflectors and stigmators are implemented for beam steering and astigmatism correction. Figure 1a shows an einzel lens assembly. In Figure 1b a lens, deflector, and stigmator positioned in the central mounting system are depicted. The operating software is written using Python, and is available on GitHub [8], making further development accessible to the end user. A digital camera is focused on the scintillator screen at the end of the column to capture images, which can be viewed and processed in real time using Panta-Rhei Image Viewer by CEOS GmbH.

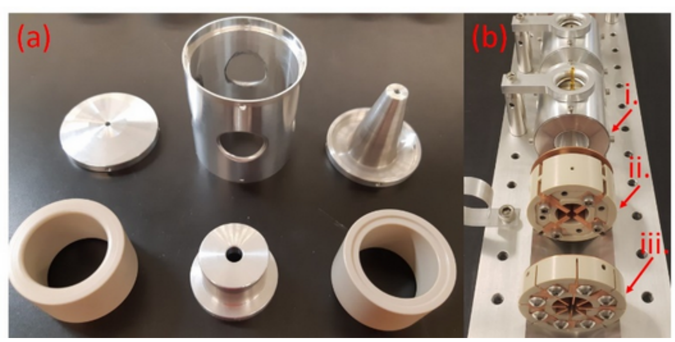

Fig. 1. (a) Electrostatic einzel lens assembly, the beige components are a machinable insulator to isolate the internals from the housing. (b) Electrostatic einzel lens (i), deflector (ii), and stigmators (iii).

II. RESULTS

There are currently two iterations of the NanoMi column under development. The first iteration (v1, Figure 2a) was designed to achieve transmission electron microscopy (TEM), scanning electron microscopy (SEM), scanning tunneling electron microscopy (STEM), and electron diffraction (ED). At the time of writing, we have achieved TEM and SEM with image resolutions of approximately 500 nm at accelerating voltages of 30 kV.

The second iteration (v2, Figure 2b) NanoMi column is under construction and was explicitly designed to be mounted on top of a laser-optics table so that an ultrafast laser and THz source may be coupled into the column for exploring UTEM, UEM, and THz-electron interactions. Our THz source makes use of a titled pulse front scheme to achieve phase matched optical rectification of 800 nm, 100 fs pulses in $LiNbO_3$ [9], [10]. This generates 2 ps single cycle THz pulses with energies of 2.2 μJ, and peak field strengths of up to 100 kV/cm as measured by electrooptic sampling in ZnTe. Using these field parameters, preliminary simulations yield deflections of up to 10 cm at the scintillator or energy increases of up to 30 keV depending on THz polarization and waveguide orientation.

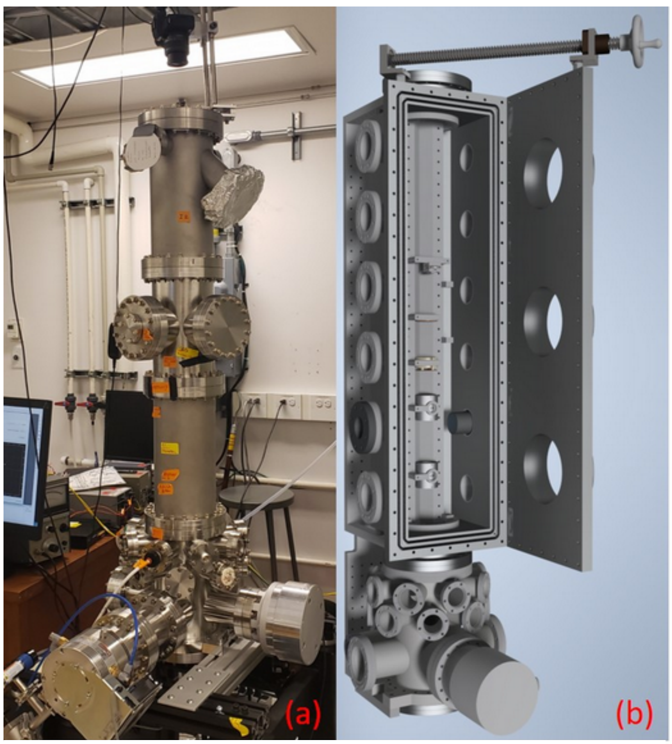

Fig. 2. (a) v1 of the NanoMi column, the scintillator screen and electron source are located at the top and bottom of the column respectively. (b) v2 of the NanoMi column that is currently under constructed and is designed to mounted on top of a laser-optics table.

III. Summary

NanoMi is an open-source, modular electron microscopy column that is amenable to user customization. A laser source for UTEM and UED applications can be incorporated into the system without any modifications to the column. Furthermore, NanoMi serves a platform for electron beam based experimentation, as the modularity allows for new components to be seamlessly integrated into the system. As such, a THz waveguide can be positioned along the electron-optic axis to provide bunch compression along with additional lensing, deflection, and acceleration capabilities.

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