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NanoMi: An Open Source (Scanning) Transmission Electron Microscope.

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We are developing a modular (scanning) transmission electron microscope (S)TEM, referred to as NanoMi, which is released under an open source license [1] by the National Research Council, Canada; see [2] for updates.

The electron microscope (EM) is a critical enabling tool in the physical, materials and biological sciences but its impact could be increased by the availability of an easy-to-build, customizable instrument capable of modest resolution and suitable for electron beam lithography, specialized experiments and for training personnel. An instrument that can be built for ~50 k$ and ~1 year of student time would fulfill these requirements in many laboratories around the world. Here we describe an initial design of such an instrument.

NanoMi consists of an electrostatic Einzel lens (EL) [3] column suspended in a vacuum chamber (Fig. 1), based on widely available ConFlat™ (CF) vacuum hardware (HW) and off-the-shelf high-voltage power supplies. The use of standard CF HW decreases the cost and enables ultra high vacuum (UHV) operation for surface-science experiments. The separation of the electron optics from the vacuum envelope, together with column modular design, allows NanoMi to be used to study EM principles and as a test bench for electro-optical elements, including electron sources, spectrometers, aberration correctors, ultrafast pump-and-probe experiments etc. The electrostatic column can be adapted for use with ion beams.

The probe-forming section of the column can be used independently as an UHV-compatible SEM or an electron-beam lithography tool. Although it may limit imaging performance, the use of EL (Fig 2) simplifies manufacturing and eliminates the need for water cooling, NanoMi is currently equipped with a JEOL-1400 gun with W-hairpin or LaB_6 filament and the probe-forming system contains three condenser lenses, allowing ~1300x demagnification of the electron source. The imaging system is designed with five lenses in addition to an objective, resulting in over 50,000x maximum screen magnification, Fig 3. The modular design allows any lens to be replaced by a permanent magnet lens, to improve the spatial resolution.

NanoMi target specifications are: STEM and SEM probe size ~10 nm, TEM image resolution ~5 nm and diffraction with 10 – 100 cm camera length at 50 kV incident electron energy. The use of a low acceleration voltage limits the thickness of samples that can be examined in (S)TEM mode but can be advantageous for study of radiation-sensitive materials. In TEM mode, we utilize a Sony α6000 camera with a fixed 50mm lens imaging a scintillator screen, Fig 4. NanoMi is controlled from a single computer that provides DAC control. An in-house piezo mechanism is used for sample stage and aperture movement, allowing sub-nm lateral positioning of 3mm diameter discs for the apertures and sample. The column has a port for an ion pump, although a single turbomolecular pump (TMP) is sufficient for W-hairpin or LaB_6 operation and provides ~$5x10^{-8}$ torr vacuum at the sample plane [4].

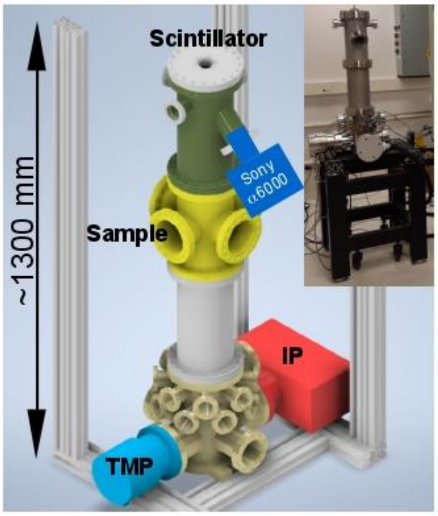

Fig 1. NanoMi column is based on 8" CF hardware. The electron source is placed near a turbopump (TMP) and electrical feedthroughs. A 6-way CF cross houses the sample transfer. Detectors are located at the top of the column. An ion pump can be installed when field emission gun is utilized. Inset: photo of the instrument.

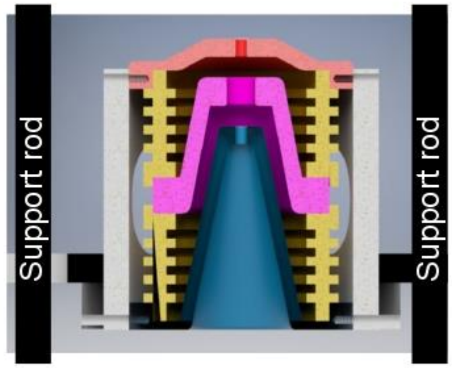

Fig 2. NanoMi Einzel lens. Biased electrode (pink) is placed between two grounded electrodes (blue and red) separated by an insulator (yellow). The entire assembly is placed inside a stainless steel puck with mounts (gray). The column can be composed either of identical lens or various optical elements mounted on support rods (black). The stainless steel puck is about 50 mm tall and about 50 mm diameter.

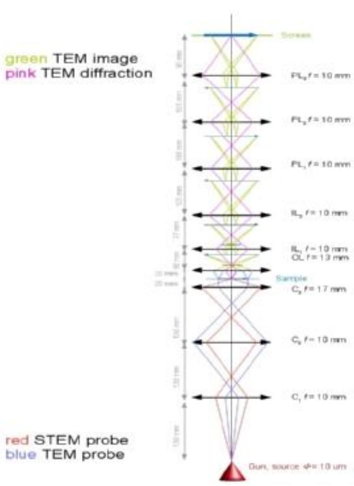

Fig 3. Approximate layout of NanoMi optics. It consists of three probe-forming lens, objective, two intermediate lens and two or three projector lens.

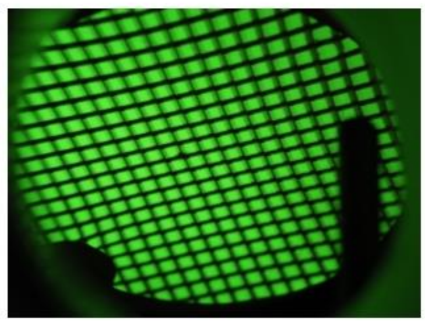

Fig 4. The first image obtained in NanoMi. A 200 mesh Cu grid placed between an electron source and a single Einzel lens was magnified about 100x suggesting focal length ~10 mm at incident energy ~ 15kV.

Figure 1. NanoMi

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