AweSEM: Removing Barriers to Innovation with a Tabletop, Low-Cost SEM

C. Kuzyk[1,2], E. Blankenburg[3], G. Robinson-Leith[1,2], H. Li[3], M. Chang[1,2], M. Cen[3], B. Ye[4], G. Hu[3], K. Jessen[1], A. Nojeh[1,2], R. F. Pease[3]

[1] Quantum Matter Institute, [2] Electrical and Computer Engineering Department, University of British Columbia, Vancouver BC,
[3] Electrical Engineering Department, Stanford University, Stanford, CA,
[4] Palo Alto High School, Palo Alto CA, ctkuzyk@ece.ubc.ca

As part of the 'Frugal Science' strategy,[1] we have previously described[2,3] how it should be possible to realize a scanning electron microscope (SEM) that could eventually be manufactured at a price two orders of magnitude less than a conventional SEM. There were several challenges. Most importantly, we are removing the need for a high-vacuum pumping system, as the electron beam is generated, accelerated and focused in a permanently sealed-off tube (i.e. a simple CRT) and the electrons brought out through a small 20 µm wide, 20 nm thick nitride window to a focus outside the tube. As in any atmospheric SEM (e.g. the Hitachi 'Aerosurf'), there is a trade-off between resolution and working distance (WD) between the window and the sample. To maintain 50 nm resolution at 1 mm WD, we estimate the sample should be in an ambient pressure no more than 10 Torr. Such a pressure can be achieved with a $50, single-stage rotary pump. In our experiments so far (Figs. 1 and 2) the sample (a periodic mesh) is at atmospheric pressure. Since the window size is much smaller than the desired maximum field size of about 1 mm, we have designed and built a mechanical x-y stage based on the image stabilizer from a camera lens, driven by a compact microprocessor and displayed on a laptop. A key subsystem is the electron gun which is based on the "Heat Trap" carbon nanotube (CNT) forest thermionic electron emitter[4] (which we have previously demonstrated can survive in a sealed-off vacuum for years), and features a green laser beam focused to a diameter of about 10 µm, with a future goal of 1 µm. Our required emission current density is about 1 A/cm^2, or about 5 µA total current. This is presently supplied by a 12 V powered unit, stepped up to -30 kV (UltraVolt 30-40A). In recent experiments we have demonstrated a system (fig. 1) featuring a sealable tube, and a laser stimulated CNT forest gun generating a 30 kV electron beam that is focused with a permanent-magnet lens outside the tube to form a scanning image using the mechanically scanned x-y stage (Figs. 1 and 2).

With a smaller emission area, only 10 nA total current is required, and for this we are developing a 40 kV battery made up of a printed array of 1 mm^2 cells. We are currently working on an electron detector, as well as improving the resolution by optimizing the lens set-up.

---

[1] Stanford, "Frugal science: Manu Prakash," Stanford 125, 28-Aug-2018. [Online]. Available: https://125.stanford.edu/frugal-science/. [Accessed: 08-Feb-2019]..
[2] C. Kuzyk, C. Aiello, F. Pease, M. Chang, K. Jessen, and A. Nojeh, "Opto-Thermionic Cathodes for SEM," in The 62nd International Conference on Electron, Ion, and Photon Beam Technology & Nanofabrication.
[3] R. F. Pease, M. S. Bull, L. A. Kroo, and M. Prakash, "A Simple and Inexpensive Permanent Magnet Electron Lens," in The 61st International Conference on Electron, Ion, and Photon Beam Technology & Nanofabrication.
[4] Yaghoobi, P., Moghaddam, M. and Nojeh, A. (2011). "Heat trap": Light-induced localized heating and thermionic electron emission from carbon nanotube arrays. *Solid State Communications*, 151(17), pp.1105-1108.

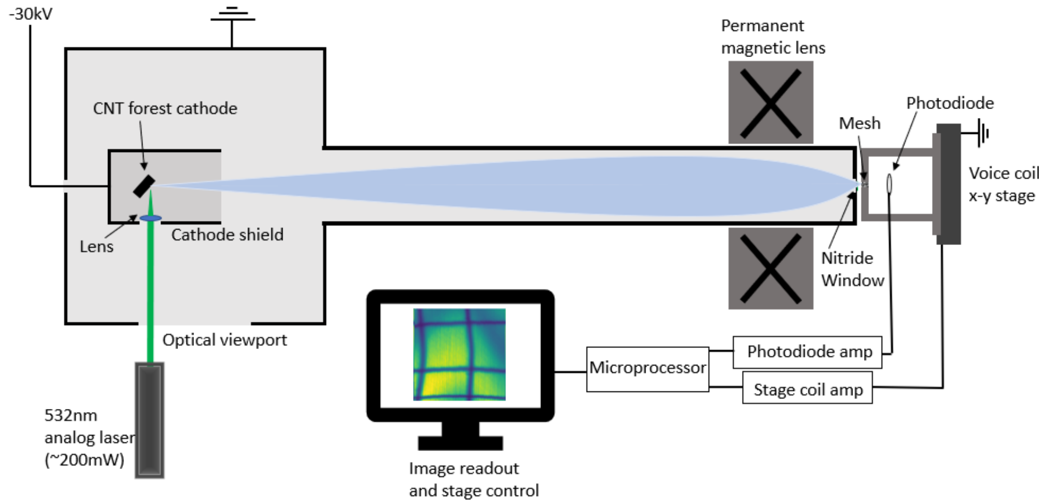

Fig. 1. Schematic of the entire sealed-off system, including laser stimulated CNT forest cathode, permanent magnetic lens, and mechanically scanned stage. The electron beam path length is 12” for reference.

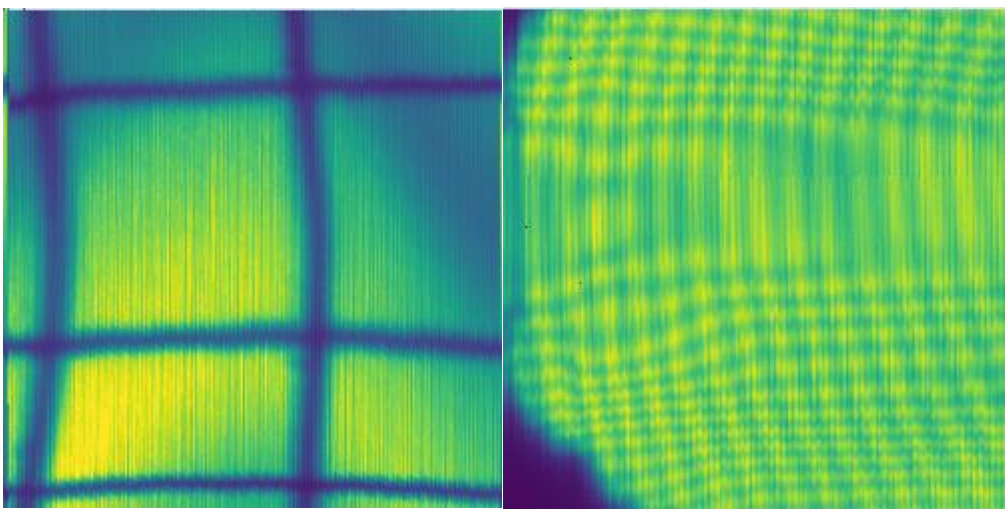

Fig. 2. Images of a metal mesh placed in atmosphere about 100 µm away from the nitride window*: (Left)* pitch 250 µm *(Right)* pitch 42 µm