Opto-Thermionic Cathodes for SEM

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As described at EIPBN2017, we are engineering a compact SEM housed in a permanently sealed vacuum tube with a cost less than 1/100th of an average tabletop SEM. Such an instrument requires a cathode that can supply 10 nA with a 1 µm emission area. These specifications are crucial for an economical design as only one lens would be needed to focus the beam to a 50nm spot, and it minimizes the power requirements so that battery power is practical. Additionally, the emission stability must be within 3% over 5 minutes, with a lifetime of at least 1000 hours. The two candidate cathode materials are carbon nanotube (CNT) forests, and LaB_6.

In prior work, Yaghoobi *et al.* reported that a CNT forest wall illuminated with a focused laser beam emitted a surprisingly high electron current, 100 nA from a 4 mW laser beam.[1] This was speculated to be due to the anisotropic structure of the CNT forests, where a focused low power laser beam incident on the forest wall induces localized heating sufficient for thermionic emission. The localized heating also eliminates the challenge of thermal management in the cathode. Models suggest that the radial distribution of emission can be tighter than that of the incident light. To demonstrate the emission spot size experimentally, a parallel plate set-up was built, with the respective plates being a CNT forest cathode and phosphor screen (fig. 1). A laser beam with an estimated spot size of 75 µm was incident on the cathode, and the collecting voltage and distance between the plates were varied. From the resulting phosphor images (fig. 1) we were able to extract two unknowns from the data: an initial maximum electron energy of 1.2 eV and emission spot size of 320 µm (fig. 2). This goes against the initial prediction of a tighter emission spot than that of the incident light but is likely a result of uncertainties in the measurement of the beam distribution on the phosphor screen. Tests to better measure this distribution are underway.

Another method being explored to confine the area of electron emission from the CNT forest is by growing 1 µm diameter CNT forest pillars to limit the potential emission area. Lifetime and emission stability are still inadequate but may well be improved by pre-heating to remove contaminants such as oxygen and water.

Preliminary experiments with laser-irradiated bulk LaB_6 have yielded thermionic electron emission currents more than 1 µA yet requires laser powers exceeding 300 mW. Thin films or micro-pillars of LaB_6 should have improved opto-thermionic efficiency and electron beam properties.

A more practical gun is realized if the electrons are emitted from the opposite side of an irradiated thin structure, and experiments using this configuration are also underway.

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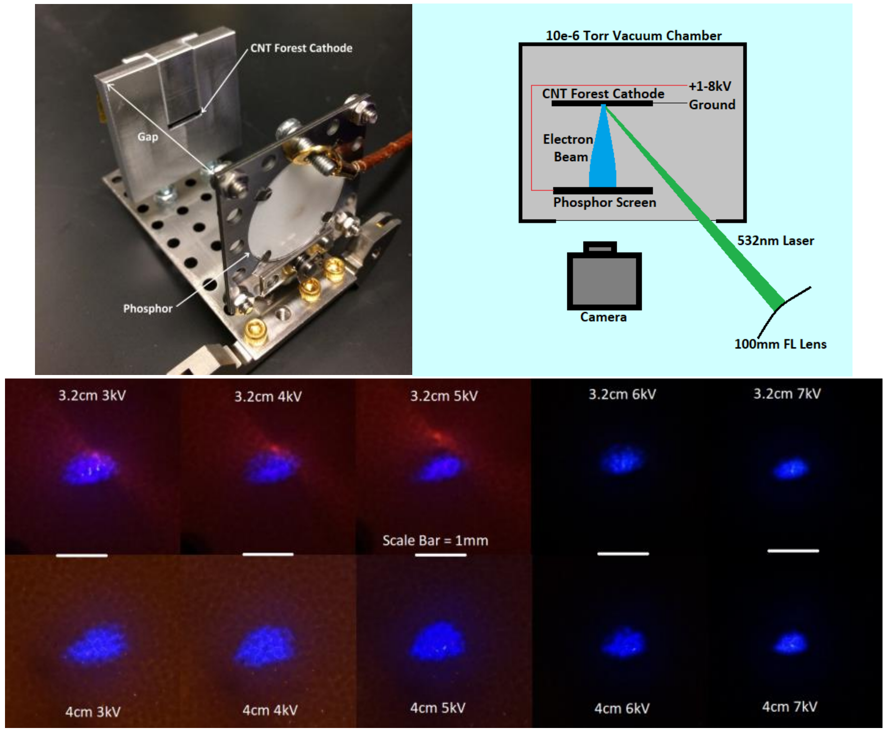
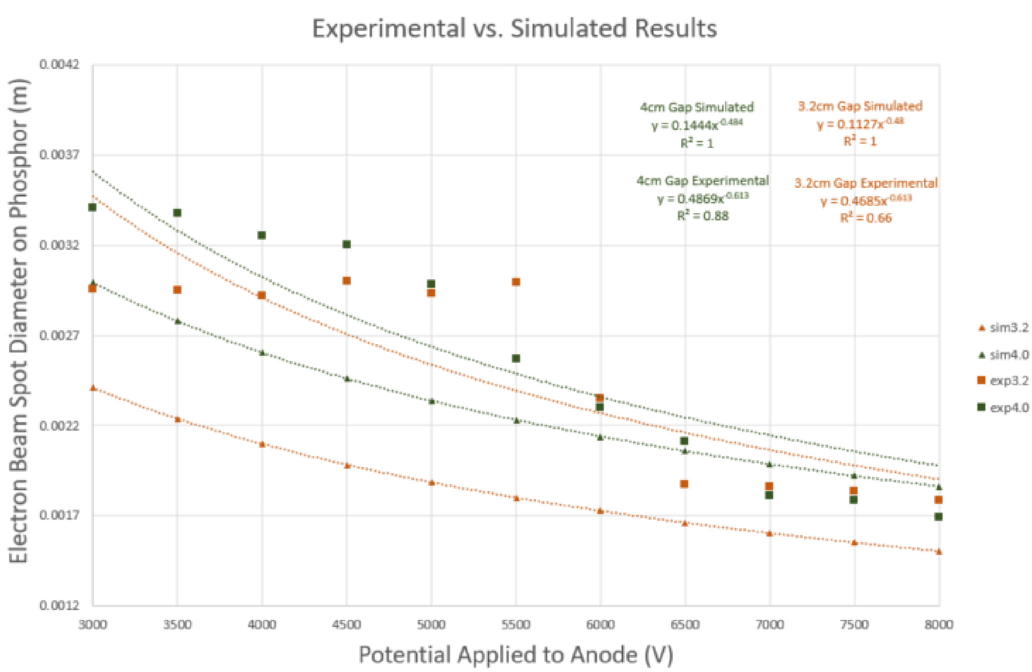
[1] Yaghoobi, P., Moghaddam, M. and Nojeh, A. (2011). "Heat trap": Light-induced localized heating and thermionic electron emission from carbon nanotube arrays. *Solid State Communications*, 151(17), pp.1105-1108.

Figure 1



Top left: Experimental set-up outside of vacuum chamber. *Top Right:* Experimental Schematic. *Bottom:* Image of electron beam on phosphor screen taken at differing CNT forest cathode / anode distances and anode voltages.

Figure 2



Experimental vs. simulated results at differing anode / CNT forest cathode distances and anode voltages