Carbon Nanotube Field Emitters for Micro-Column Scanning Electron Microscopy and Nanolithography

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Micro-column technologies for the miniaturization of SEM and multiple electron-beam lithography have been in development since Chang *et al.* at IBM[1,2] first proposed the micro-column concept in 1989. An example is the ETEC[3] development of micro-columns for electron-beam lithography application. Presently micro-column technologies have limited practical applications due to two major challenges: 1) emitter stability coupled with thermal dissipation; and 2) fabrication challenge in aligning an electron-beam with micrometer accuracy with respect to micro-column lens elements.

Carbon nanotubes (CNTs) have been recognized as ideal cold field emitters due to their highly stable graphitic structure. CNTs have a low sputter coefficient and experience minimal electromigration, resulting in a small degree of tip structure modification during field emission. The low 1-2 V/μm extraction field required for CNT emitters also dissipates about 1000 times less power as compared to traditional Schottky emitters, thus relaxing the thermal constraints that are a critical factor in the miniaturization of an electron gun and its integration with a micro-column. Additionally, an individual CNT has shown to have low energy spreads, about 0.2 eV, and high reduced brightness values of $(1.3\pm0.5)\times10^9$ to $(3\pm1)\times10^9$ A sr^{-1} m^{-2} V^{-1}.[4-6] These beam characteristics promise to give low chromatic aberration and simpler electron optics for micro-column fabrication.

These aforementioned characteristics point to the numerous advantages for utilizing a CNT emitter as the micro-column electron source. In this presentation, we report our on-going development of a micro-column SEM as a potential spaceflight instrument for planetary exploration that utilizes CNT emitter and MEMS technology. We fabricated a CNT cathode by attaching a single multi-walled CNT to a Si micro-fabricated structure.[7] We achieved highly controlled alignment of the CNT emitter with respect to the Si microstructure with this fabrication scheme, as seen in Fig. 1a. Sufficient and stable current upwards of a few hundred nanoamperes for SEM and lithography applications is demonstrated by the field emission I-V characteristics in Fig. 1b.

Utilizing MEMS technology we also demonstrated the fabrication of a CNT emitter gun by a novel templating technique, as schematically presented in Fig. 2. By an interlocking mechanism the cathode structure can be templated with the SiO_2/Si_3N_4 membrane extractor electrode. We demonstrated alignment of the

CNT emitter with respect to the extractor electrode with micrometer precision. Field emission data from this electron gun will be reported. In summary, we demonstrated a CNT emitter cathode and electron gun MEMS fabrication process that achieves precise alignment of the CNT emitter structure. Our novel approach to fabrication of the CNT-based electron gun overcomes the long-standing problems of both emitter stability coupled with thermal dissipation and structural alignment for micro-column electron beam development.

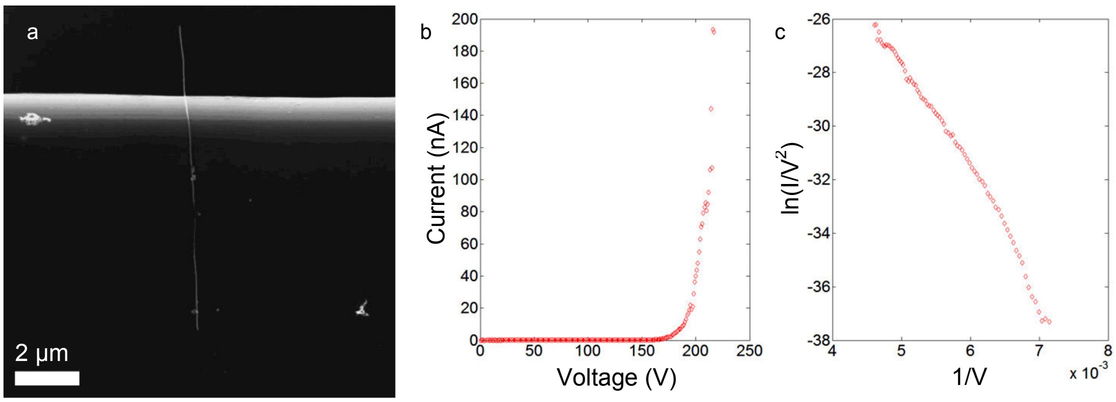

Figure 1. *(a) SEM micrograph of a mechanically and electrically stable, MEMS based nanotube cathode. (b) Field emission current-voltage data and (c) corresponding Fowler-Nordheim plot of the cathode.*

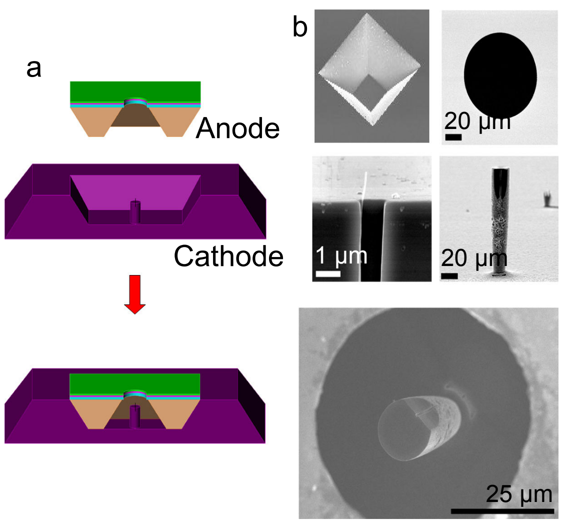

Figure 2. *(a) Schematic representation of the MEMS-based templating technique for the fabrication of a CNT electron gun. (b) SEM images of various MEMS components for the CNT gun structure: Top – Membrane for the extracting anode and the focused ion beam milled aperture; Middle – CNT attached to the MEMS cathode structure; Bottom – top-down view of the gun with CNT cathode through the FIB milled aperture.*

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