Fabrication of Carbon Nanotube Field Emission Guns for Potential Maskless Lithography

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The carbon nanotube (CNT) cold field emitter has tremendous potential for advanced imaging and lithography applications because of its stable chemical structure, low turn-on field, and high current density.[1] Most importantly, individual CNTs exhibit low energy spreads and high brightness values compared to state-of-the-art emitters. Herein, we present field emission data for CNT cathodes and a MEMS fabrication method for CNT electron guns.

We have developed a fabrication technique for stable CNT cathodes,[2] consisting of an individual nanotube attached to a silicon structure, as seen by the SEM images in Fig 1(a). The field emission data in Figs. 1(b) and 1(c) demonstrate the low turn-on voltages for CNT cathodes and high field enhancement factors β. Previously, we demonstrated that the field emission properties of CNT electron sources are highly dependent on the nanotube structure itself as well as the cathode support structure.[3] As shown in Fig. 1, our precise fabrication method affords cathode support structures of varying geometry, thus enabling modulation of field emission characteristics such as turn-on fields. The utilization of the MEMS fabrication technique also enables us to fabricate CNT electron guns. Figure 2 shows accurate alignment of a single CNT cathode structure with an extracting anode aperture, achieving microscale precision by a simple templating method. An array of electron guns for high-throughput maskless lithography may be fabricated using this novel technique. Presently, general control of the CNT tip structures at nanoscale is not possible and therefore the field emission characteristics will vary from one emitter to another, as seen in the I-V field emission characteristics in Fig. 1. This requires that each gun in the array be individually electrically addressable in order to precisely control electron dose for lithography. For this purpose, we introduce a circuit model based on Fowler-Nordheim theory, representing each gun in the array as a voltage-controlled variable resistor, as shown in Fig. 3. This simple circuit model and our novel MEMS fabrication method have the potential for developing high-throughput maskless nanolithography with precise dose control.

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[1] Meyyapan M. *Carbon Nanotubes: Science and Applications,* 1st ed. Boca Raton: CRC, 2004.
[2] Ribaya BP, Leung J, Brown P, Rahman M, Nguyen CV. A study on the mechanical and electrical reliability of individual carbon nanotube field emission cathodes. *Nano Lett*, submitted.
[3] Niemann DL, Ribaya BP, Gunther N, Rahman M, Leung J, Nguyen CV. Effects of cathode structure on the field emission properties of individual multi-walled carbon nanotube emitters. *Nanotech* 18 : 485702, 2007.

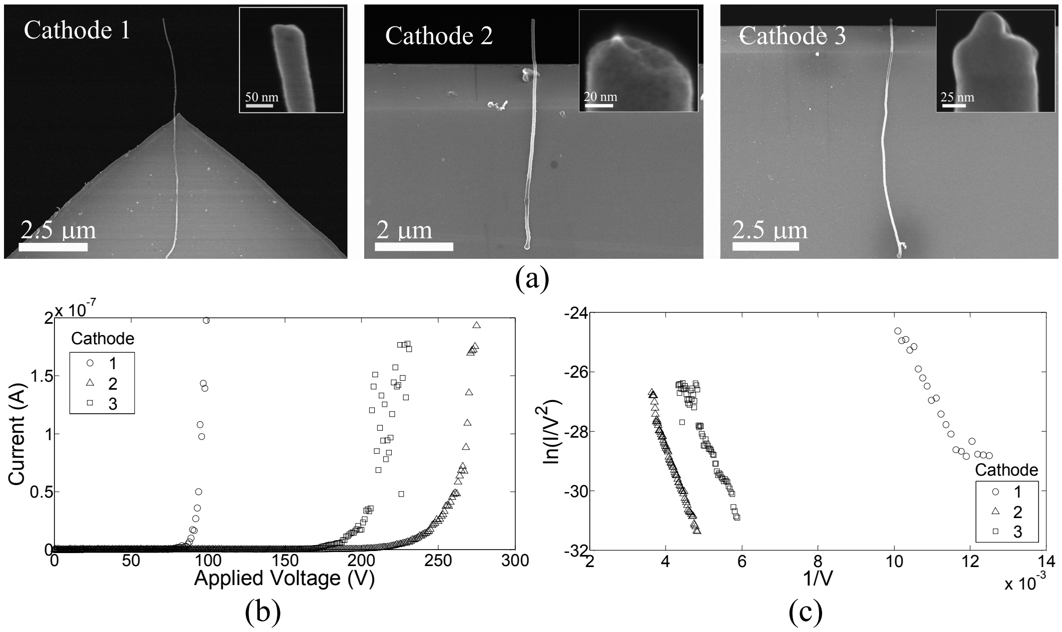

Figure 1. (a) SEM micrographs of three cathode structures each comprised of an individual CNT attached to nickel-coated silicon microstructure. (b) Field emission I-V data and (c) F-N plots for 10-µm cathode to anode separation. β for Cathodes 1, 2, and 3 are 3.7×10^{7} m^{-1}, 1.99×10^{7} m^{-1} and 2.49×10^{7} m^{-1}, respectively.

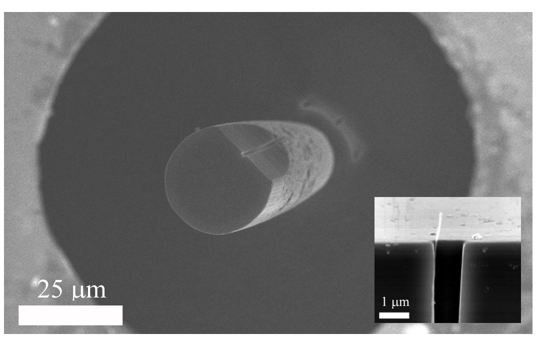

Figure 2. SEM image of a CNT electron gun fabricated by the MEMS templating method. SEM image of cathode tip shown in the inset.

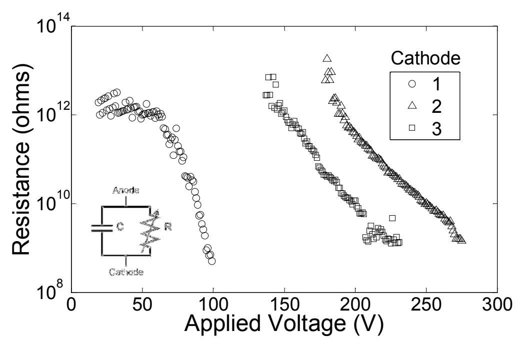

Figure 3. Resistance vs. applied voltage characteristics for the cathodes in Fig. 1(a). The circuit model for a CNT emitter shown in the inset.