Carbon Nanotube Field Emission Electron Gun Array for Micro-Column Scanning Electron Microscopy and Maskless Lithography

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Micro-column technology, as conceived by Chang *et al*. at IBM,[1] has been proposed for miniaturization of the scanning electron microscope (SEM) and for multiple electron beam lithography (EBL). The micro-column SEM offers several advantages for research and industry laboratories, such as non-destructive low voltage inspection, as well as for field deployment of SEM technology in NASA spaceflight missions for investigating the origins of our universe. The micro-column array presents the advantage of redundancy for spaceflight missions. For e-beam lithography, the micro-column array would enable major technology advancement since EBL is presently a slow, serial process employed for developing photolithography masks or for direct, maskless patterning.

Our group demonstrated a carbon nanotube (CNT) field emission electron gun technology which overcomes two obstacles that have prevented micro-column technology's use in practical applications: (1) cathode emitter instability related to thermal dissipation and (2) inaccurate alignment of the electron beam with respect to lens elements. The carbon nanotube field emitter, such as the one shown in the inset of Fig. 1a, dissipates 1000 times less power than traditional Schottky emitters, thus relaxing the thermal constraints that are critical to electron gun miniaturization and its integration with a micro-column. Furthermore, as shown in Fig. 1, we demonstrated a microelectromechanical systems (MEMS) based fabrication process for the electron gun which ensures precise alignment of the CNT cathode with the electron extracting anode. The process involves bonding an individual multi-walled CNT to a nickel coated silicon structure to form the cathode (Fig. 1a), milling an aperture through a molybdenum coated silicon nitride/oxide membrane by focused ion beam to form the anode (Fig. 1b), and stacking the cathode and anode together to construct the electron gun (Fig. 1c). By employing silicon components we are able to utilize standard processing techniques to make sure the tip of the CNT emitter is aligned well with the center of the anode aperture. The field emission data presented in Fig. 2 demonstrates the feasibility of this approach. This silicon based electron gun will be integrated with a MEMS based micro-column.

Our MEMS based fabrication approach for the CNT electron gun is highly scalable and makes device fabrication across a wide area possible. We will present a 3×3 array of CNT electron guns, as depicted in Fig. 3. For EBL such an array would greatly increase speed, as a large substrate area can be exposed by nine electron beams performing in parallel instead of just one working serially. Each electron gun is electrically addressable and has a dedicated dose control circuit to maintain constant current and to ensure the desired electron dose is delivered to the e-beam resist uniformly. Data exhibiting each electron gun operating independently and in parallel will be presented. In summary, we demonstrate a MEMS fabrication process which makes manufacturing an array of high brightness CNT electron guns possible.

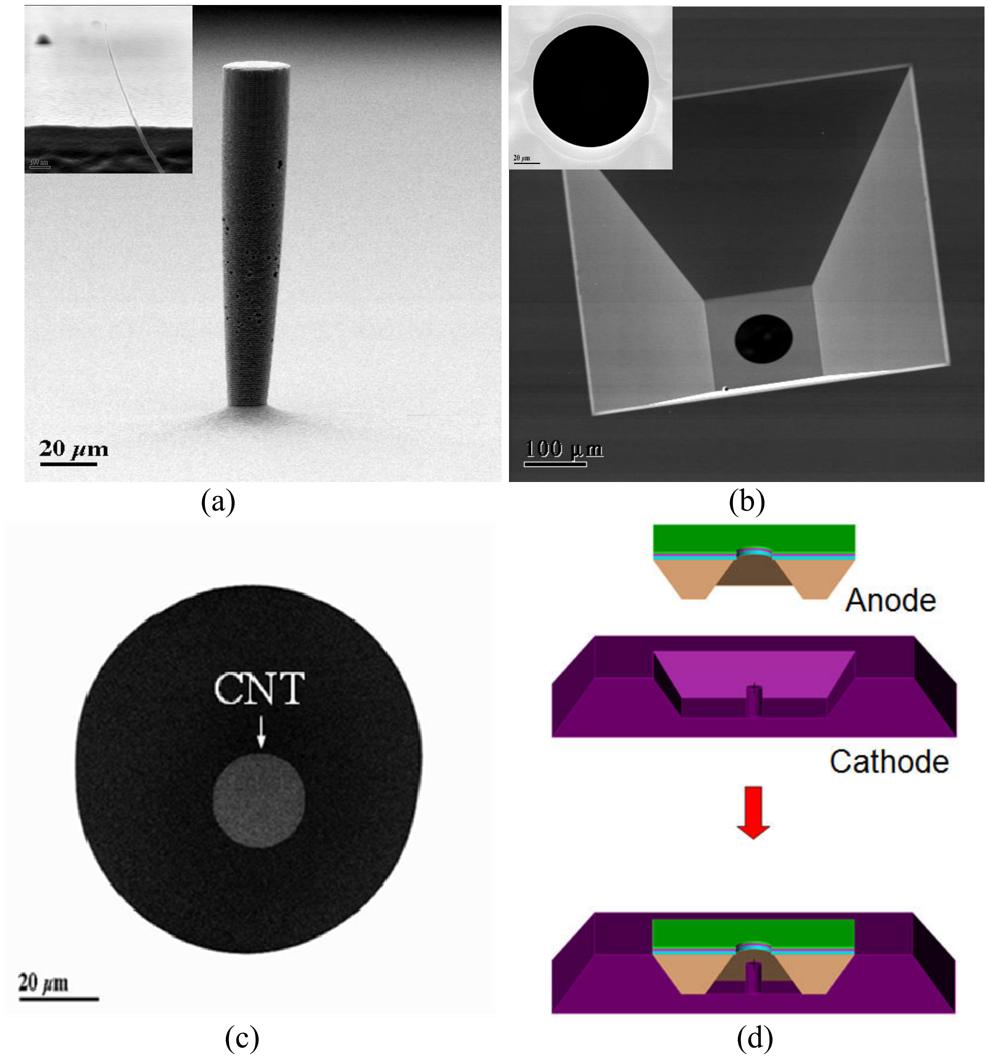

Figure 1. (a) Cathode: Single multi-walled carbon nanotube attached to the edge of a nickel-coated silicon pillar. (b) Anode: Silicon nitride / silicon dioxide / molybdenum membrane window with a 100 µm aperture milled by focused ion beam. (c) Electron gun: Assembled by stacking the cathode and anode. (d) The electron gun assembly process.

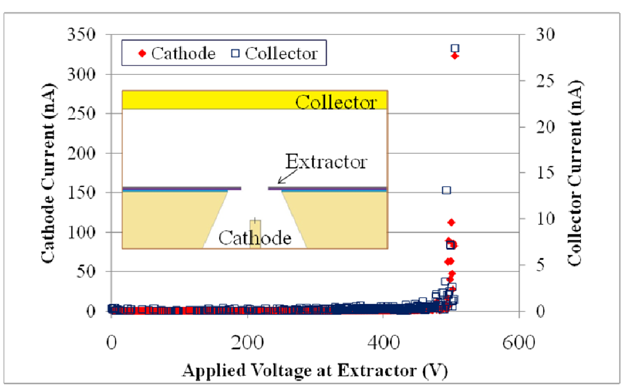

Figure 2. Field emission current versus voltage data for the electron gun shown in Fig. 1c.

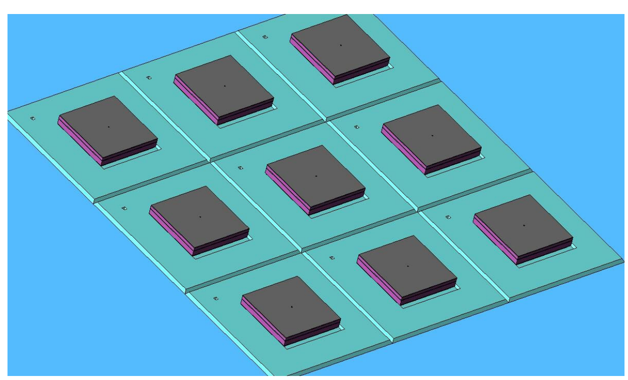

Figure 3. Isometric view of the 3×3 array of carbon nanotube electron sources.

[1] T.H.P. Chang, D.P. Kern, and M.A. McCord, J. Vac. Sci. Technol. B 6 (1989) 1885.