Carbon Nanotube Field Emission Electron Gun Microassembly for Maskless Lithography

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Micro-column technology has been well implemented by others for advanced miniature, low-voltage scanning electron microscopy.[1] This system employs a thermal field emitter making further miniaturization difficult. As such it currently cannot be used to realize a densely packed array of micro-columns for parallel beam applications, such as maskless electron beam lithography. The carbon nanotube (CNT) field emitter point source is an attractive alternative for such applications. Despite the desirable qualities of these emitters, others have encountered challenges regarding reliability and integration with micro-column technology. Here we present our mechanically and electrically reliable, silicon based CNT electron gun which possesses a form factor that is compatible with MEMS microassembly techniques. We will describe in detail our progress in improving this electron source technology and its integration into an array, together with system level development of a parallel e-beam lithography system.

Previously we demonstrated a unique microassembly technique for the electron gun. It consists of two individual MEMS components, the gate electrode and the CNT cathode, which fit together for accurate alignment. Originally the silicon cathode contained a monolithic pillar (∅23 μm) with a single nanotube attached at the top.[2] When the pillar type CNT cathode was assembled with the gate structure the turn-on voltage was relatively high at 474 V. Turn-on voltage is conventionally defined as the gate potential needed to extract 1 nA of electron emission current from the cathode. The high turn-on voltage is a direct result of the large surface area of the top of the pillar and the associated field screening. Theoretically, the electric field at the CNT tip can be further enhanced by decreasing the surrounding support structure surface area. Thus we replaced the broad pillar support structure with a pyramid support structure which contains a high aspect ratio, pointed tip. The corresponding experimental structure is shown in Fig. 1. As predicted, after the addition of the MEMS gate assembly the structure yielded a turn-on voltage of 383 V, lower than that of the pillar CNT cathode. The measured field emission current-voltage characteristics along with the corresponding Fowler-Nordheim characteristics are plotted in Fig. 2. The projection of the electron beam emitted through the gate electrode onto a phosphor screen is shown in Fig. 3. Based on simulations of our micro-column, only 100 nA of cathode current is required to achieve the probe current needed to pattern a wafer. Therefore, the electron gun will operate in the 500 V regime, well below the breakdown voltage of the electron gun dielectric.

In order to mitigate the intrinsic yield loss associated with the current MEMS fabrication process, we adopted a modular gun array architecture. Using the array test stand shown in Fig. 4, we will be able to evaluate each gun element in the array and replace it if necessary. Using a custom high-voltage switch and user interface, each electron gun is individually monitored and controlled to provide the desired electron dose to the substrate. A piezoelectric stage will provide the scanning mechanism for pattern generation. We will outline its integration and the associated hardware and software. In summary, we report the progress that has been made in our development of a MEMS based carbon nanotube electron gun array for parallel, maskless lithography.

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[1]Agilent Technologies, 2010, U9320A 8500 Field Emission Scanning Electron Microscope (FE-SEM), http://www.home.agilent.com/agilent/product.jspx?nid=-33760.940647.00&cc=US&lc=eng (January 10, 2011)

[2]Ribaya, B. P., Niemann, D. L., Makarewicz, J. S., Blake, D. F., and Nguyen, C. V., 2010, *Carbon nanotube field emission electron gun array for micro-column scanning electron microscopy and maskless lithography,* EIPBN 2010.

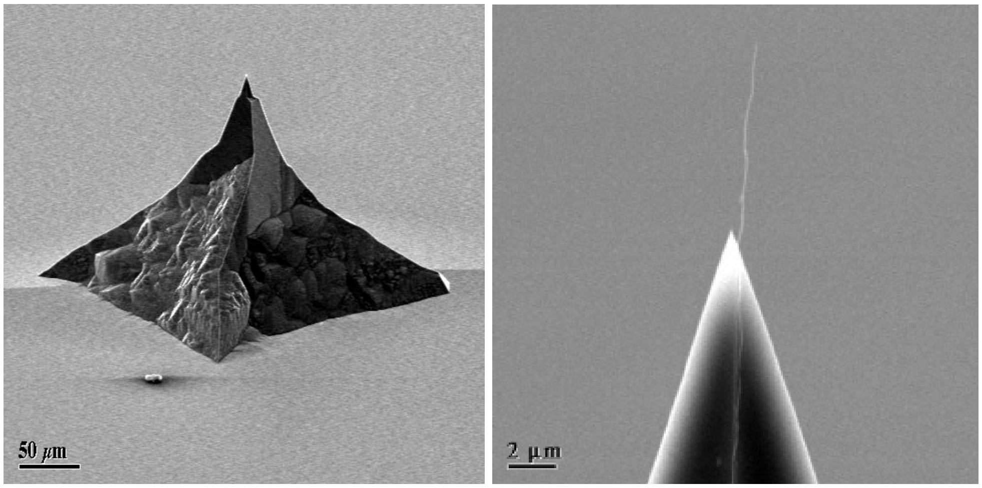

Figure 1. SEM images of the experimental field emission cathode showing the pyramidal geometry of the silicon support structure and the single carbon nanotube attached at the pyramid tip.

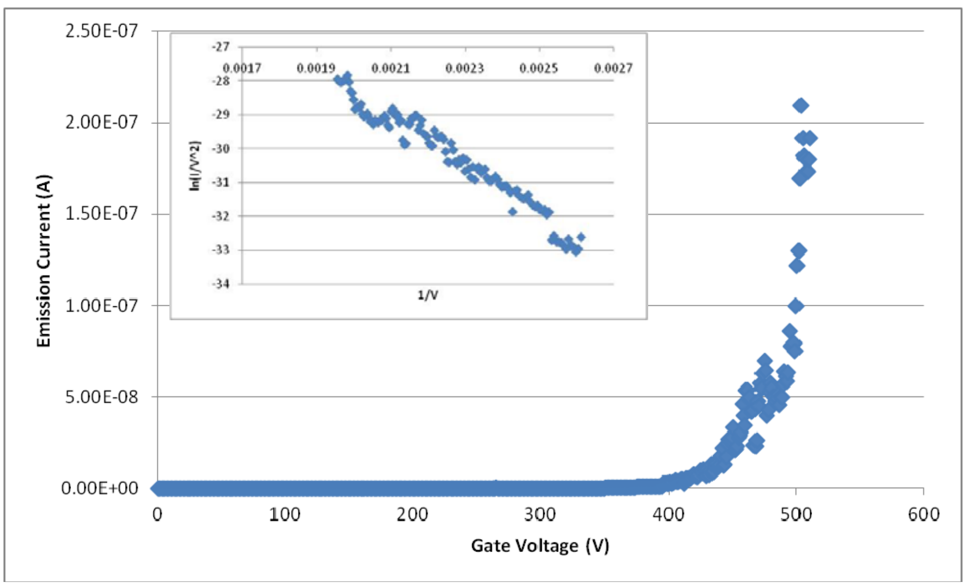

Figure 2. Experimental electron beam current emitted from the carbon nanotube electron gun. Inset: Corresponding Fowler-Nordheim plot.

Figure 3. Field electron microscope image of the e-beam emitted from the CNT electron gun.

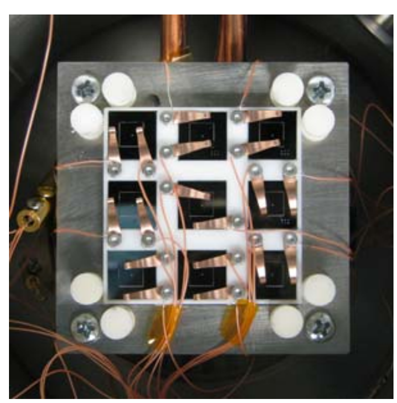

Figure 4. Experimental vacuum test stand to evaluate the CNT electron gun array.