Electrostatically focussed integrated field emission electron sources with single vertically aligned carbon nanofiber cathodes

M. A. Guillorn,[a] A. V. Melechko,[b] D.K. Hensley, V. I. Merkulov, L. R. Baylor, J. H. Whealton, D. H. Lowndes, and M. L. Simpson

Oak Ridge National Laboratory, Oak Ridge, TN 37831

[a] Also with Department of Materials Science and Engineering, Univ. of Tennessee, Knoxville, TN 37996
[b] Also with Center of Environmental Biotechnology, Univ. of Tennessee, Knoxville, TN 37996

Recently, the integration of nanostructured graphitic carbon based materials into microfabricated FE device structures has received a great deal of attention in the literature. In particular, microscale electron guns using carbon nanotubes (CNT) and carbon nanofibers (CNF) as FE cathodes have been investigated by a number of groups and shown to possess operating characteristics highly desirable of any FE electron source. These properties include low threshold field for the initiation of electron emission, the ability to operate for extended periods of time in moderate vacuum and high emission current density. However, of this class of materials only the vertically aligned CNF (VACNF) may find application in electron sources where the formation of a highly focused beam is required. This arises from the fact that single VACNF emitters can be synthesized completely deterministically (1-3). While CNT-based devices have been demonstrated that operate at lower voltages and higher currents than similar VACNF-based structures (4,5), precise control over the location or density of the emission sites within the electron gun structure has yet to be demonstrated.

In our previous work, we have shown that it is possible to realize microfabricated FE device structures with single VACNF cathodes (4,5). These devices can be fabricated using wafer scale techniques compatible with large-scale manufacturing. In this work we present results on microfabricated VACNF FE sources with integrated focusing electrodes (Fig. 1). These devices were operated at pressures of 10^{-6} Torr for extended periods of time without experiencing a degradation of performance. A typical FE current-voltage (*I-V*) curve is shown in Fig. 2. Although the operating voltage may appear somewhat high for these devices when compared to similar CNT-based devices, it is in reasonable agreement with the values expected from the VACNF aspect ratio and the geometry of the gun structure. The focusing effect of these devices was investigated using a phosphor screen. By changing the voltage on the focus electrode while keeping constant voltages on the cathode and gate it was possible to change the diameter of the emitted beam (Fig. 3). These results fit well to simulations of the device performance and demonstrate that VACNF-based FE devices are quite promising for applications that require well-focused microscale electron sources.

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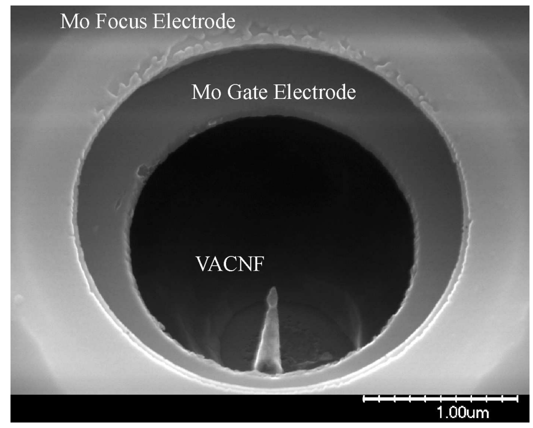

Figure 1. Scanning electron micrograph of a completed triode electron gun with a single VACNF cathode taken at 30° from normal incidence.

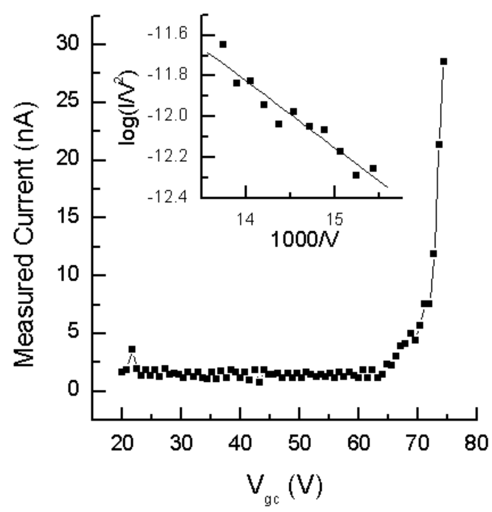

Figure 2. FE I-V curve of a single VACNF triode source obtained with the cathode at 0V, the gate and focus swept together positively and a Cu anode placed 2 mm away from the device at 1kV. INSET: Fowler-Nordheim plot of the I-V data showing a reasonable linear fit. The current collected at the gate and focus electrode were less than 1 % of the total emitted current measured at the cathode. The anode collects ~99% of this current demonstrating the efficiency of these devices.

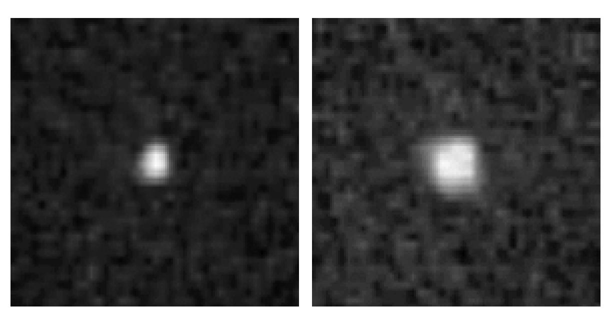

Figure 3. Images obtained during device testing from a phosphor coated conductive glass anode. Both images were obtained at the same magnification with –90 V applied to the cathode, 0 V applied to the gate and 1kV applied to the phosphor. The image on the left was obtained with –30 V on the focus electrode while 0 V was applied to this node during acquisition of the image on the right.