Fabrication and characterization of field emission devices based on single vertically aligned carbon nanofibers

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Field emission (FE) of electrons from nanostructured graphitic carbon-based materials including single and multiwalled carbon nanotubes (CNT) and carbon nanofibers (CNF) has been an area of intense investigation in recent years. Research performed by numerous groups indicates that these materials possess several advantageous characteristics for FE applications, namely very low threshold voltages, V_{th} , for the initiation of electron emission and extraordinary environmental stability. Most of the work in this field has focused on measurements of the FE properties of mats of randomly oriented CNTs and CNFs that were deposited or grown onto a variety of flat substrates and also within integrated gated cathode structures that use these materials as FE elements. The aforementioned gated cathode structures possess operating characteristics desirable in any FE device ~i.e., low V_{th} and high FE currents. However, the CNT/CNF material in these devices is likely to contain numerous, randomly distributed FE sites (electron sources), which is an obstacle for generating a well-focused electron beam as required in applications such as electron microscopy or electron-beam lithography.

In the present work, we demonstrate fabrication and FE tests of diode- and triode-type well structures that utilize a *single* vertically aligned carbon nanofiber (VACNF) as a FE cold cathode (1, 2) and therefore allow for a well-focused electron beam. VACNFs were deterministically synthesized using large-scale, and therefore commercially viable, fabrication processes: lithography and plasma-enhanced chemical vapor deposition (PECVD) (3, 4). Deterministic VACNF growth implies the ability to control the location, length, diameter, and to some extent the shape and orientation of VACNFs and is an important, and in many cases necessary, component of device fabrication. The PECVD growth of VACNFs utilized dc glow discharge with a mixture of acetylene and ammonia as the gas source. The electrostatic gating structure was fabricated using a combination of traditional micro- and nanofabrication techniques, including electron-beam and photolithography, PECVD oxide deposition, and chemical-mechanical polishing. Examples of the resultant diode and triode –type well structures are shown in Fig. 1 and 2.

The obtained devices display operating characteristics inherent to other nanostructured graphitic carbon-based FE devices: they can operate in a moderate vacuum for extended periods of time without experiencing a degradation of performance and large FE currents can be obtained. A typical current-voltage curve is shown in Fig. 3. Although V_{th} 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 well structure. By decreasing the diameter of the gate aperture and increasing the aspect ratio of the VACNF, it should be possible to lower the operating voltage of these devices into a regime comparable to the CNT-based devices that have been reported previously. The percentage of the emitted current measured at the gate electrode is quite low (~1%), which indicates that the emitted electron beam is highly collimated. These results show that VACNF-based FE devices are quite promising for applications that require well-focused electron emission from a microscale structure.

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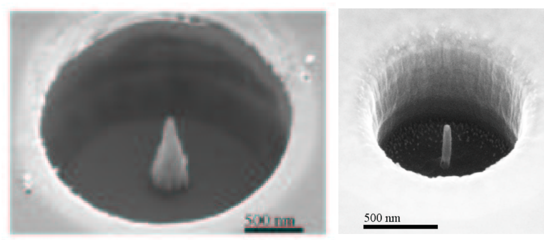

Figure1. Scanning electron micrograph of a completed diode-type gated cathode structure with conically (left) and cylindrically (right) shaped vertically aligned carbon nanofiber as cold cathode.

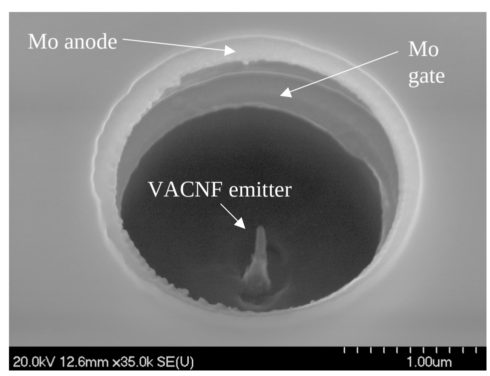

Figure 2. Scanning electron micrograph of a completed triode-type gated cathode structure

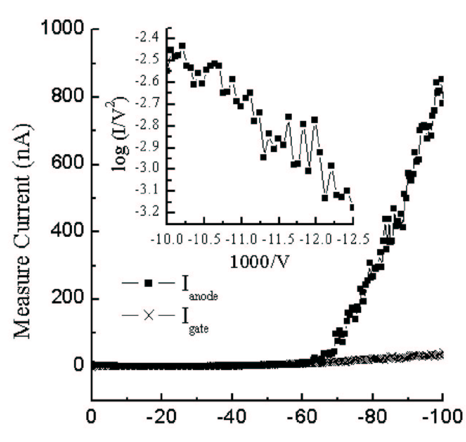

Figure 3. Field emission *I* –*V* curve for a VACNF-based FE gated cathode structure operating in a triode mode. Inset: Fowler–Nordheim plot of the FE *I* –*V* data.