Microgated In-Situ Grown Carbon Nanotube Field Emitter Arrays

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In the pursuit of a robust field emitter array (FEA), we find carbon nanotubes (cNT) as attractive candidates on account of their chemical, structural, and electronic properties. They possess extremely high current-carrying capacity and mechanical strength. Their natural small diameters and high aspect ratios produce high geometric field enhancement (hence low operating voltages). We attribute the observed high stability and absence of arcing to the lack of a solid surface dielectric, precluding charge trapping and facilitating emission (1).

Numerous works have been published on cNT emitters in a diode configuration. Although the macroscopic threshold fields are low, micro-gating is required for low voltage and high transconductance. To date, the two general approaches to gating are based on 1) application of cNT grown ex-situ (e.g. using paste or electrophoresis) and 2) in-situ growth of cNT using CVD. We have used the second approach.

We have fabricated two different configurations of integrally gated cNT FEAs, one with cNTs grown on the tips of gated silicon posts and the other with cNTs grown inside open gated apertures. We used sputter-deposition of Fe or Ni catalysts, their selective removal from insulator components, and cNT growth in a hot-filament assisted cold-wall CVD reactor using ethylene and ammonia gases at substrate temperatures of 650-700C. The resulting cNTs have diameters of 20-30 nm, which we believe to be multi-walled.

Figure 1 shows a schematic and a SEM image of a single cell of the cNT-on-silicon post emitter. We obtained a maximum anode current of 1.1 mA at 41 V gate bias (Fig.2) from the 33,000-cell array (~1mm^2 area), even though cNTs grew on only 5-10% of the posts. DC emission tests over many hours under both UHV and under 10^{-5} torr Xe ambient showed stable operation without degradation. Significant emission enhancements were observed when operating at high temperatures (700C) and with H_2O vapor and H_2 exposure. Electron energy distributions measured as a function of gate voltage (Fig.3) reveal a current saturation phenomenon at energies just below the Fermi level, suggesting a limit in electron transport at the emission sites.

Figure 4 shows the anode and gate currents obtained from a 40-cell array of a gated cNT FEA having the second configuration (open cells). All cells contained cNTs. Of particular interest is the very low gate current which is important for devices requiring high emission currents.

We have observed a general lack of arcing damage in these emitters, which we attribute to the low operating voltages and the lack of a surface oxide.

In conclusion, we have demonstrated the fabrication of two different configurations of in-situ grown microgated cNT FEAs. The emission results bode well for a robust FEA.

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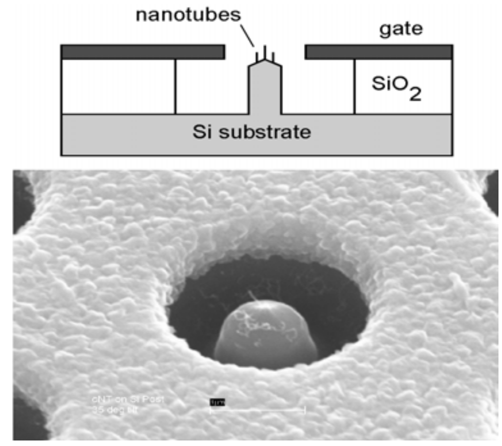

Fig. 1. Gated cNT-on-silicon post FEA cell. MWNTs were grown on Si post centered in a 2.5 micron chrome gate.

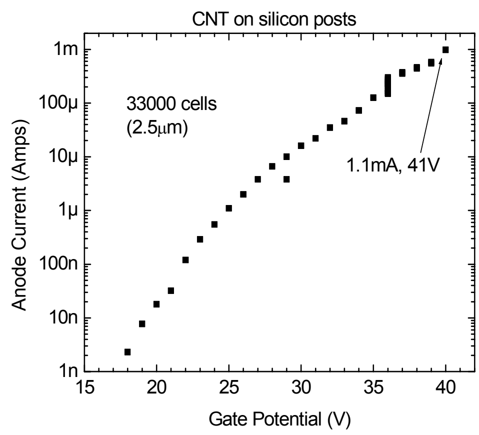

Fig.2. I.-V plot of emission anode current from an array of gated cNT-on-Si post FEA.

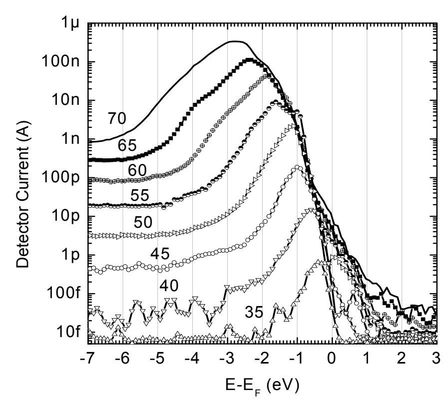

Fig. 3. Emission energy spectra of cNTs grown on gated Si posts. Gated voltages are marked.

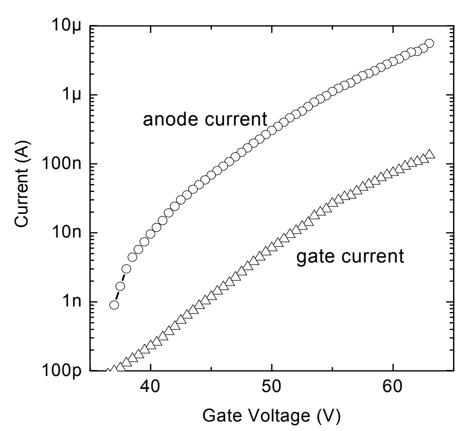

Fig. 4. I-V plots of anode and gate currents from a 40-cell array of gated cNT emitters grown inside open apertures