Field Emission and Growth Properties of Vertically Aligned Carbon Nanofiber Field Emitter Sources

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Electron beam technology is a strong candidate for patterning the generations of lithographically produced semiconductor devices that apparently are beyond the reach of optical lithography, i.e. with line widths of 70 nm and smaller. However, writing with a single electron beam is slow and therefore expensive. The digital electrostatic e-beam array lithography (DEAL) concept under development at Oak Ridge National Laboratory (ORNL) proposes writing simultaneously with millions of electron beams from a massively parallel and easily programmable field emitter array. For a reliable lithography system a robust field emitter source is needed with low turnon field and reliable steady operating characteristics.

The field emitter sources currently being developed for the DEAL application are vertically aligned carbon nanofibers (VACNFs). The growth of completely deterministic patterned arrays of VACNFs (Fig. 1) with high aspect ratios has been achieved at moderate temperatures (~700°C). A novel PECVD process using a DC acetylene/ammonia plasma is used to grow the VACNFs from electron beam lithographically patterned catalyst dots [1]. Aspects of the growth process will be presented and issues associated with the fabrication/growth of such field emission devices will be discussed.

Field emission measurements reveal that VACNFs are good field emitters with emission threshold fields as low as 12 V/ μm, and that emission appears to be continuous over large areas of relatively sparse VACNF "forests". Such VACNFs have also displayed continuous emission for 140 hours (the longest period tested) of 100 nA operation at 10^{-6} torr vacuum conditions, corresponding to more than one year of operation at a (proposed) 1% duty cycle.

Field emission properties of individual VACNFs have been measured with a scanned probe system capable of positioning a 1 μm diameter probe tip above an individual VACNF. Field emission thresholds of the individual VACNFs are in the range of 15-25 V/μm with variation as much as 50% as shown in Fig. 2. The maximum measured field emission current from an individual VACNF is greater than 5 μA. The field emission I-V characteristics (Fig. 3) from the individual VACNFs display Fowler-Nordheim like behavior. The calculated geometric enhancement factor is slightly larger than that determined by the aspect ratio of the carbon nanofibers. This may be due to enhanced tunneling through adsorbate layers on the emitters and sub-nanometer roughness on the tip of the VACNF.

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[1] Merkulov, V.I., et al., Appl. Phys. Lett. 2000; 76(24): 3555-3557.

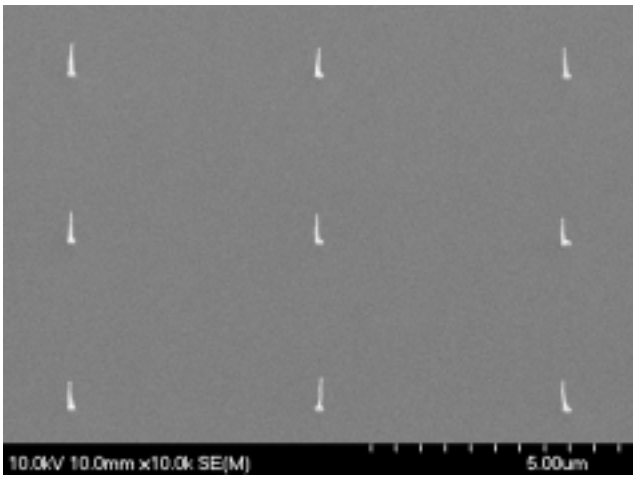

Fig. 1 SEM image of VACNFs grown on a 5 µm pitch with a PECVD process from an EBL patterned catalyst dot array.

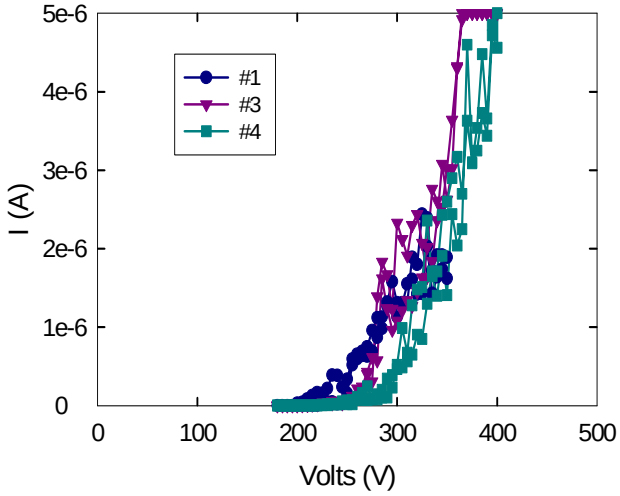

Fig. 3 Scanned-probe I-V measurements of individual VACNFs. Field emission currents > 5 µA are obtained (~ 500 kA/cm^2 for 30-nm tip diameter).

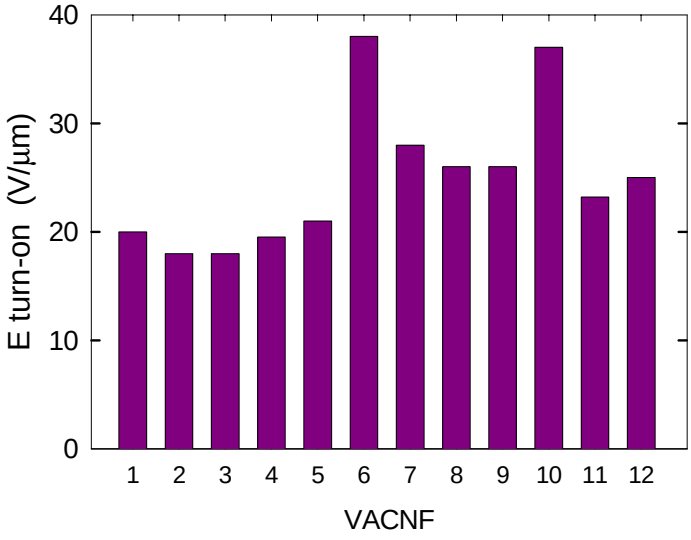

Fig. 2 Turn-on electric field for 1nA field emission current from individual VACNFs.