doi:10.1017/S143192761100345X
Microsc. Microanal. 17 (Suppl 2), 2011

Vapor Phase Editing of Carbon Nanotube Based Nanodevices: Use of the NanoBot® Nanomanipulator with Gas Delivery

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A vapor phase editing process is described for (1) precise nanometer-scale linear etching (i.e., cutting) operations, including nanotube cutting, shortening, cleaning, and other individual carbon nanotube (CNT) operations, and (2) precise micron-scale area etching operations, including cleaning entire areas of unwanted nanotube growth. Applications that motivated the work include fabrication and repair of carbon nanotube based scanning probe microscope tips and carbon nanotube based electron emitters. It has been shown that operating gas delivery nozzles carried by the NanoBot® nanomanipulator can result in optimized localized precursor pressure and flux at reduced chamber pressures. Because it is impossible to directly measure the localized precursor pressure at the sample the local pressure has been computed by knowing the chamber pressure and the gas nozzle geometry using a program that initially developed by Kohlmann et al. [1]. Support by the National Science Foundation is acknowledged [2].

Figure 1 shows the use of a box scan to successfully cut a CNT laying on a surface. The CNT etching was performed using full screen TV scan at 500 kx magnification. In this example the CNT was cut in 11 seconds. Figures 2a (before) and 2b (after) show the use of a line scan to cut a set of suspended CNTs with a great precision and Figures 2c (before) and 2d (after) show the use of a box scan to successfully cut a pair of free standing CNTs that may be connected in a loop at the free end.

Figure 3 shows the visualization of the water vapor flow from the nozzle as the nozzle-sample gap was reduced. The flow lines are explained as a result of electron beam induced ionization of the water molecules. The results of the tests show that with this SEM CNTs could not be imaged at beam energies of more than 20 keV but CNT imaging was fine for lower beam energies. The larger beam energies also introduced sample charging and drift. Effective CNT etching required stable imaging for several minutes at high magnification.

An important conclusion is that the CNT etching time and rate improved for a smaller gap between the sample and the nozzle, as shown in Figure 4 (left). A trend was also observed in which the probe current decreased for a smaller gap, as shown in Figure 4 (right). The change in the probe current as a function of distance is interpreted as ionization and competitive positive current flow which increases with decreased spacing because of the enhanced local pressure. Because the smaller nozzle distance shows faster etching rates and lower sample currents, the results from Figure 4 lead to a conclusion that increased local pressure is responsible for the increased etching rate.

References

[1] K. Kohlmann, M. Thiemann, and W.E. Bringer, *Microelectronic Engineering* 13 (1991), 279.
[2] This research was supported by the National Science Foundation under Award No. IIP-0712036, STTR Phase I: Selective Carbon Nanotube Etching.

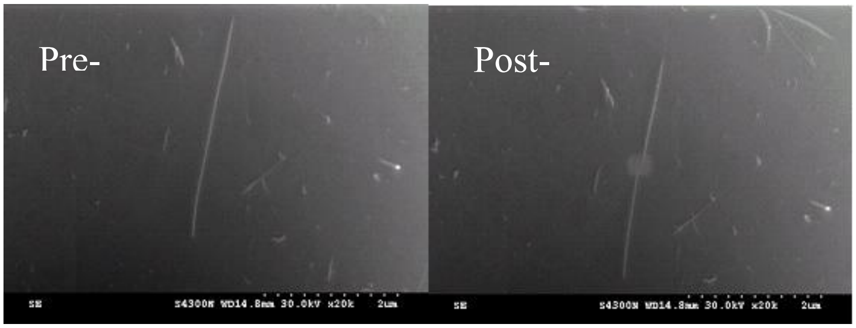

FIG. 1. Example of carbon nanotube cutting using a box scan.

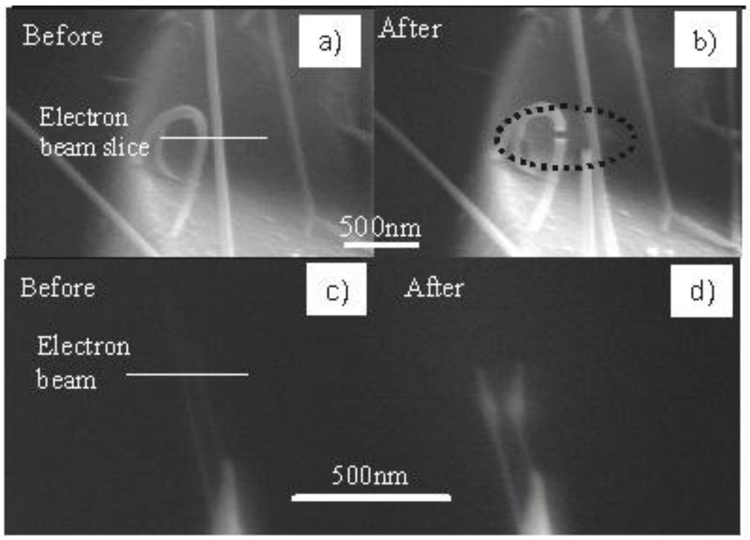

FIG. 2. CNTs etched using a line scan (a), and cut in a box scan (b).

FIG. 3. Visualization of the water vapor flow from the nozzle as the nozzle-sample gap was reduced, from left to right image.

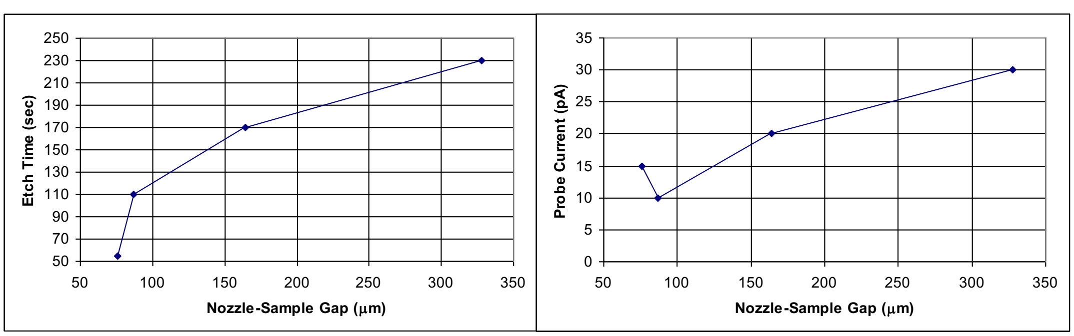

FIG. 4. Demonstration of improved CNT etching time vs. nozzle-sample distance (left). Probe current vs. nozzle-sample distance is also shown (right).

https://doi.org/10.1017/S143192761100345X Published online by Cambridge University Press