MEMS Process Compatibility of Multiwall Carbon Nanotubes

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Carbon Nanotubes (CNTs) have recently seen increasing use in Microelectromechanical System (MEMS) devices due to their small size, high strength, and unique electrical and thermal properties. However, while CNTs have been successfully incorporated into devices using some standard MEMS processes, the literature has in general explored only those processes that are directly relevant to the fabrication of a particular device. A comprehensive reference describing the compatibility and behaviour of many different typical MEMS processes, such as those produced by Williams et al. [1-2], does not exist for CNTs. This paper is an attempt to present a consistent and broad assessment of the effect of a suite of 23 common MEMS processes on CNTs based on new experiments and a survey of the existing literature. As Williams' papers are invaluable aids in selecting fabrication processes for a device fabrication plan, it is hoped that this report will aid MEMS fabricators in selecting processes for CNT-based devices, by demonstrating which processes are benign, and which cause substantial damage to CNTs.

Each process was initially screened by collecting SEM images before and after processing. Some processes caused massive bulk etching or structural damage to the CNTs; example processes in this category include the various dry plasma etch processes depicted in figure 1. It is assumed that these processes will not be of interest for use with CNTs, so no further analysis was conducted. However, for processes which did not cause substantial bulk damage detectable by SEM, high-resolution TEM was used to determine the level of damage caused by a given process. Arc-discharge tubes were examined and compared before and after each process, in the same 20- to 30-nm region on the tube whenever possible, to look for changes at the atomic level. Each sample was prepared by suspending the tubes in isopropyl alcohol and mixing ultrasonically for 30 minutes. The solution was then evaporated onto TEM grids, leaving isolated tubes. The entire grids were processed. Examples of before and after TEM images, for amorphous carbon deposition and xenon difluoride etching are shown in figures 2 and 3, respectively.

In general, CVD deposition of material onto the CNTs works well. Amorphous materials were deposited in conformal, uniform coatings, as were polycrystalline materials above a critical thickness. Wet etches and dry chemical etches without ion bombardment or atomic oxygen, which typically exhibit good selectivity compared to plasma etches, also tended to leave the nanotubes mostly undamaged or only slightly damaged. On the other hand, plasma etching processes with direct ion bombardment or atomic oxygen present were shown to cause significant damage to nanotubes at a bulk scale.

References

[1] K. R. Williams and R. S. Muller, J. MEMS, **5**, 4 (1996).
[2] K. R. Williams, K. Gupta, and M. Wasilik, J. MEMS, **12**, 6 (2003).

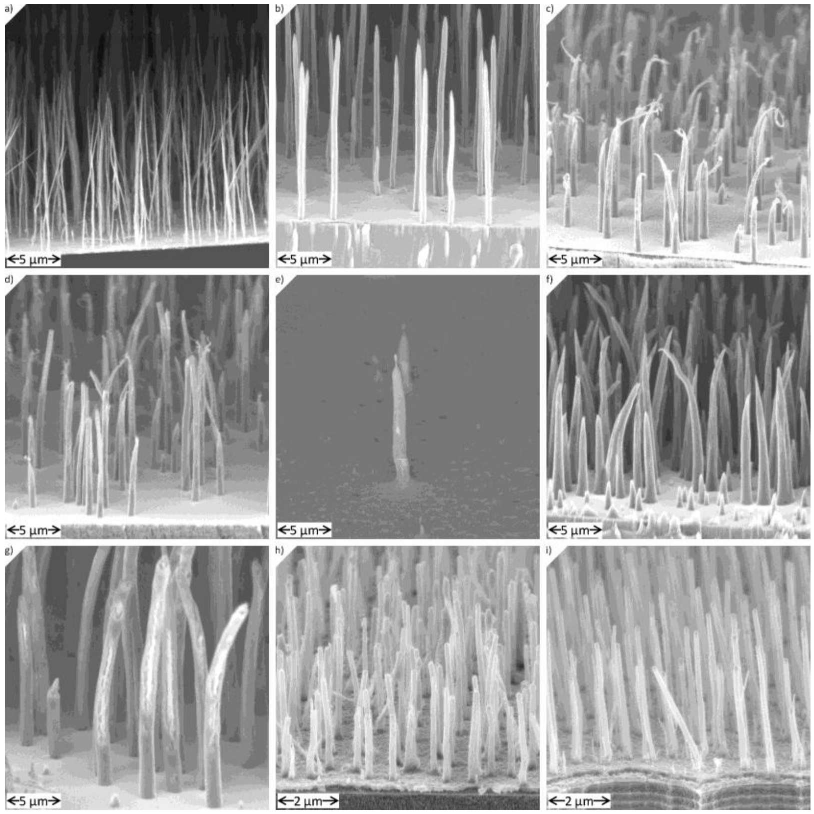

Figure 1. Unprocessed CNTs are shown in (a). Ion etch process inflict substantial damage on the tubes, for the following chemistries: Argon (b), SF_6 (c), SF_6/O_2 (d), CF_4/O_2 (e), CHF_3/CF_4 (f), and CF_4 (g). Little or no damage was observed for SF_6/O_2 cryogenic etching (h), and Bosch Process DRIE (i). These last two results are shown on smaller tubes (similar to those in Fig. 2a) and at a higher magnification. Common damage modes include tip sharpening due to the field concentration in the tip region (b—g), and bending due to tube weakening and defect introduction (c,d,f,g).

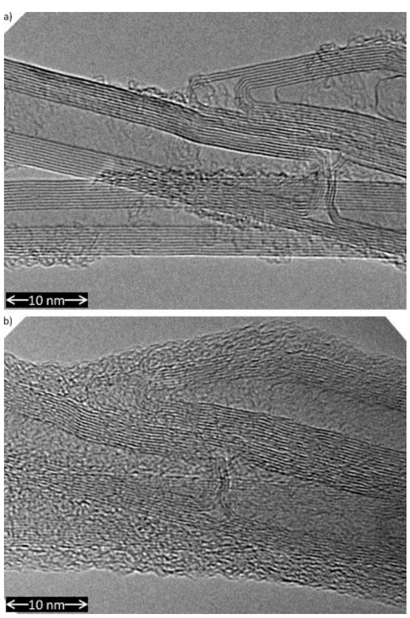

Figure 2. Amorphous silicon deposited on CNTs by PECVD. (a) Unprocessed arc-discharge CNTs showing some defects and amorphous carbon material. (b) The same tubes, with amorphous silicon coating. Only slight defects are introduced to the tube structure.

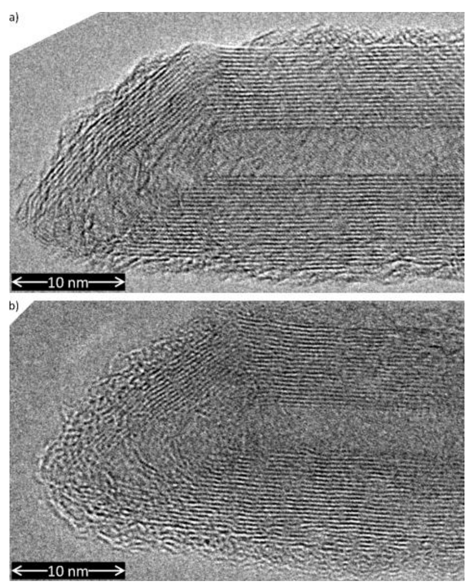

Figure 3. Xenon difluoride did not cause any significant damage to the CNTs. The tube shows good crystallinity after the etch (b) compared with before the etch (a).