Atomic Layer Deposition Encapsulation of Carbon Nanotubes with Al_2O_3

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Carbon NanoTubes (CNTs) possess remarkable material and electrical properties, and have many potential applications in the field of nano-electronics [1]. However, it is difficult to integrate CNTs, which are bottom-up fabricated, with top-down fabrication methods, including many wet and plasma etches. The need to protect CNTs for further processing has been reported [2], but a study of the quality of protection has not been undertaken. To that end, we have explored Atomic Layer Deposition (ALD) as a method to encapsulate CNTs in order to protect them from future processing steps.

We encapsulated CNTs in Al_2O_3 by ALD (chosen because Al_2O_3 can be subsequently removed by vapor HF without damaging the CNTs) and tested the effectiveness of the ALD encapsulation from processing steps that would otherwise destroy the CNTs. To determine the effectiveness of the ALD sheath protecting the CNTs, we fabricated CNT-FETs, growing our CNTs on quartz wafers and transferring to a target wafer using the transfer method described in [3].

SEM images of non-sheathed CNTs before and after 20 seconds of O_2 plasma etch at 30W are shown in Figure 1. Figure 2 shows CNTs after ALD coating in 2nm of Al_2O_3 and following the same O_2 plasma etch. All of the non-sheathed CNTs are removed by this etch, while the majority of the ALD sheathed CNTs remain. Since the CNTs were configured as a FET, they could be further characterized electrically. Figure 3 shows the I-V curves for non-sheathed CNT-FETs before and after O_2 plasma treatment. The lack of source-drain current and the lack of CNTs observed in SEM indicate complete etching. ALD sheathed CNT-FETs however showed similar I-V curves both before and after O_2 plasma etch (Figure 4), indicating that the CNTs had remained intact through the etching process. However, after a 5 minute exposure to vapor HF and subsequent O_2 plasma treatment the devices again showed complete CNT removal. The slight degradation in source-drain current observed after O_2 etch of the ALD sheathed CNTs is attributable to not all CNTs being fully sheathed, as etched “missing” CNTs can be observed under SEM as well.

We have shown that ALD coating of CNTs sufficiently protects CNTs from future processing that would otherwise etch or effect them, and can later be removed to re-expose the CNTs. This approach enables CNTs to be integrated with common top-down fabrication techniques. Further applications of this technique, such as using ALD-coated CNTs for nano-lithography or other processes, are currently under investigation.

References:

[1] J. Robertson, G. Zhong, S. Hofmann, B.C. Bayer, C.S. Esconjauregui, H. Telg, C. Thomsen, “Use of Carbon Nanotubes for VLSI interconnects,” *Diamond and Related Materials,* vol. 18, issue 5-8, p.957-962

[2] H. Wei, N. Patil, A. Lin, H.-S.P. Wong, S. Mitra, “Monolithic Three-Dimensional Integrated Circuits using Carbon Nanotube FETs and Interconnects,” IEEE Intl. Electron Devices Meeting, Baltimore, MD, Dec. 2009.

[3]N. Patil, A. Lin, E.R. Myers, R. Koungmin, A. Badmaev, C. Zhou; H.-S.P. Wong, S. Mitra, "Wafer-Scale Growth and Transfer of Aligned Single-Walled Carbon Nanotubes," *IEEE Transactions on Nanotechnology* , vol.8, no.4, pp.498-504 (July 2009)

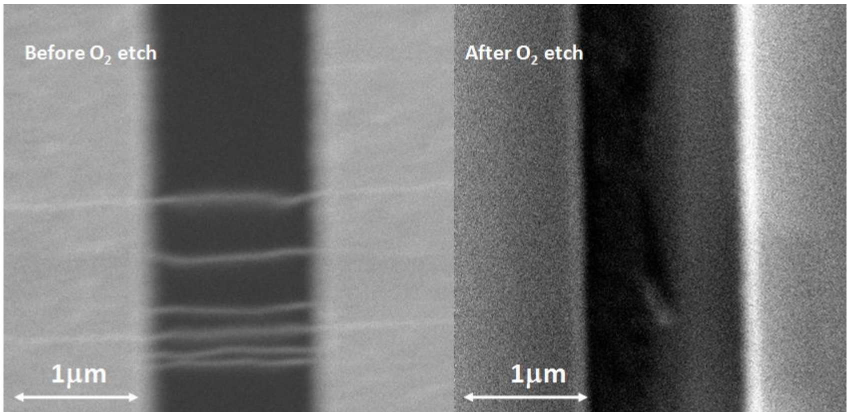

Figure 1: SEMs showing CNT-FETs without an Al_2O_3 sheath before and after O_2 plasma etch. The CNTs are completely removed by the etch.

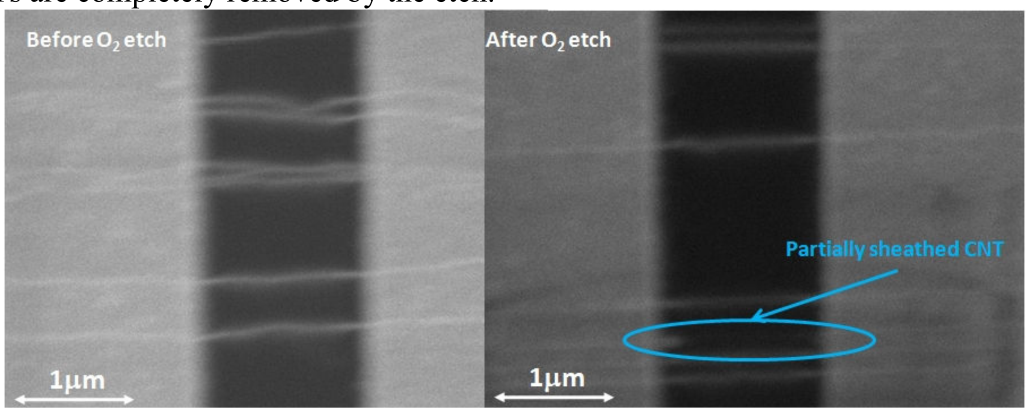

Figure 2: SEMs showing CNT-FETs with an Al_2O_3 sheath before and after O_2 plasma etch. Note that a few of the CNTs are removed, most likely due to non-complete coverage of the CNT. This is correlated in the I-V change shown after O_2 plasma etch in Figure 4.

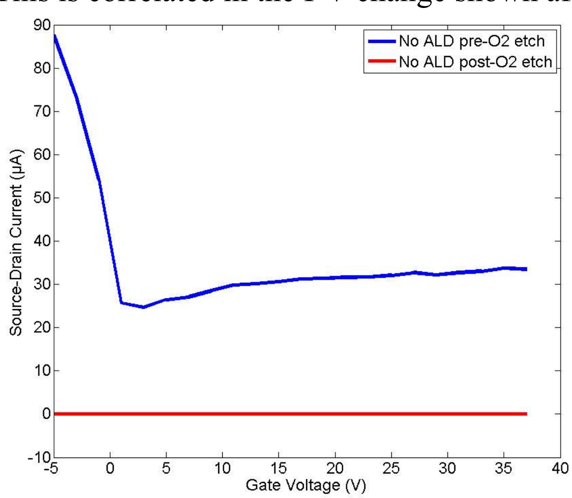

Figure 3: I-V curves for CNT-FETs without Al_2O_3 ALD sheaths. The O_2 plasma etch removes the CNTs completely.

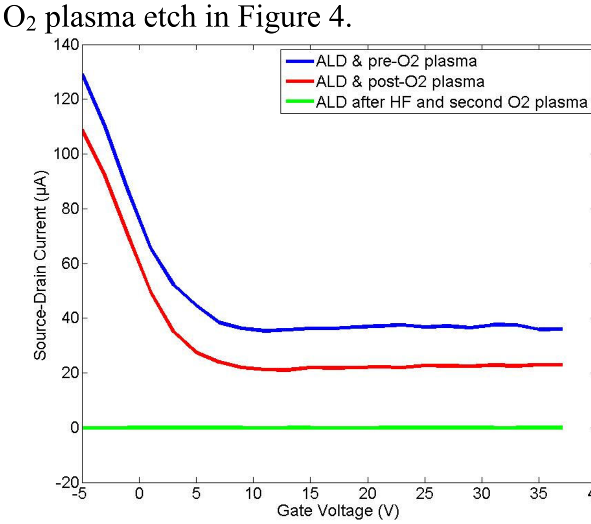

Figure 4: I-V curves for CNT-FETs with Al_2O_3 ALD sheaths. The O_2 plasma etch makes little effect on the electrical performance, but an O_2 plasma after removal of the ALD sheath by vapor HF removes the CNTs completely.