Microsc. Microanal. 8 (Suppl. 2), 2002
DOI 10.1017.S1431927602103783
1142CD

Focused Ion Beam Assisted Nanofabrication – Patterned Growth of Carbon Nanotubes

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A focused ion beam (FIB) system effectively combines a scanning ion microscope and a precision machining tool. FIB systems use a variety of heavy metal ions, which are focused into diameters smaller than 0.1 μm with current densities of several A/cm^2. The two most important features of the FIB are the capability to remove material by sputtering (micromachining) and to add material by ion-induced chemistry, which permits localized deposition of materials with submicron dimensions. The spatial resolution of an FIB microscope approaches to a few nanometers, and there are contrast mechanisms available other than those of electron microscopy. Coupled with secondary ion mass spectroscopy (SIMS), which gives chemical maps of very good lateral and vertical spatial resolution in addition to spectra, an FIB system provides attractive capabilities for research into nanotube device fabrication.

In an effort to synthesize carbon nanotubes with controlled positions, we used an FEI 611 FIB system equipped with several gas-injection nozzles for the deposition of pre-designed substrate patterns. Carbon nanotubes were then synthesized on the top of these patterns. The ion beam-induced chemical deposition for the fabrication of submicron patterns was accomplished by directing a gaseous compound via the capillary needle-sized nozzle of the gas-injector in a FIB system so that various patterns of platinum could be deposited. These submicron patterns could be made of different materials depending on the gas compounds used. The shape of the patterns could also be controlled by carefully moving the needle nozzles. Fig. 1 shows an array of platinum pillars deposited in our FIB system using a gas precursor containing a metal compound ($C_9H_{16}Pt$). In order to synthesize carbon nanotubes on the top of these deposited patterns, various transition-metal catalysts such as Fe, Co, or Ni had to be sputter-coated on the surface of the patterns. The focused ion beam was used to sputter off the catalyst coated in areas other than the deposited patterns. This process effectively localizes the catalyst within the patterned areas.

The second method we used to prepare carbon nanotube substrates involved coating a piece of silicon with a liquid catalyst. The preparation of the liquid catalyst is similar to that reported by Cassell, et al. [1]. However, we have developed different treatment conditions for the liquid catalyst that are suitable for the growth of carbon nanotubes on the patterns created by the FIB system. The major components of the liquid catalyst-precursor materials consist of inorganic chloride precursors ($AlCl_3 \cdot 6H_2O$, $SiCl_4$, $FeCl_3 \cdot 6H_2O$, and MoO_2Cl_2), a removable triblock copolymer (P-103) serving as the structure-directing agent for the chlorides, and the alcohol mix (EtOH/MeOH) for dissolution of the inorganic and polymer compounds. The liquid precursor was spin-coated on the surface of the silicon substrate with patterns generated by the FIB. The focused ion beam was then used to sputter the substrate surface to create a pattern in which some areas contain catalyst coatings and some areas do not. Fig. 2 shows the image of a catalytic pattern generated by the FIB. Note that the small dots are the areas containing catalyst precursor materials.

To grow carbon nanotubes, these prepared substrates were placed into a chemical vapor deposition reactor. A hydrocarbon gas of acetylene was used. The reactor was kept at a pressure of 76 torr and the growth temperature was about 700 C. Fig. 3 shows the nanotubes formed on the tops of FIB-deposited Pt pillars. Fig. 4 demonstrates the formation of the nanotubes on one of the catalyst dots as those shown in Fig. 2. These images indicate that all the nanotubes formed within the catalyst-covered areas outlined by the FIB. Note that the densities of the tubes and their alignment are quite different between these two types of samples. For the substrate coated with liquid catalyst, the nanotubes are aligned perpendicular to the substrate surface (Fig. 4). For the platinum pillars coated with cobalt metal catalysts, the nanotubes are less dense and grow horizontally connecting one pillar with another. A systematic study is in progress toward the further development of this nanofabrication technique.

References

[1] A.M. Cassell, N.R. Franklin, T.W. Tombler, E.M. Chan, J. Han, and H.J. Dai, *J. Am. Chem. Soc.*, Vol. 121 (34), 7975 (1999).

[2] Financial support for this research was provided in part by a start-up fund from Portland State University, and by research fund from the National Science Foundation under award No. DMR-0097575.

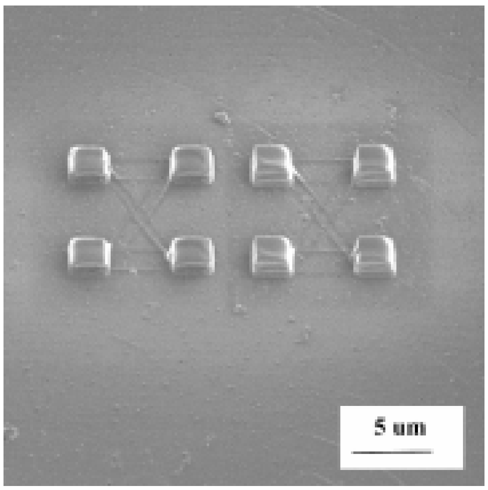
Fig. 1


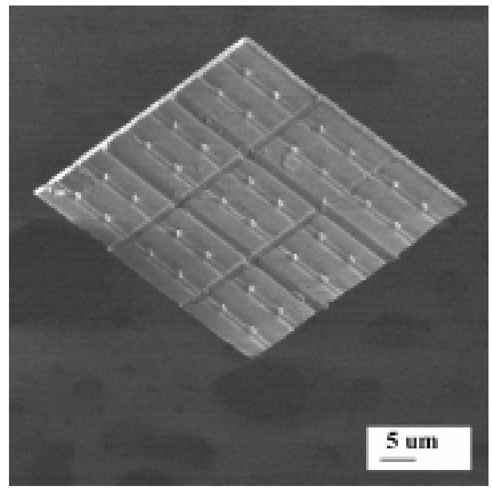
Fig. 2


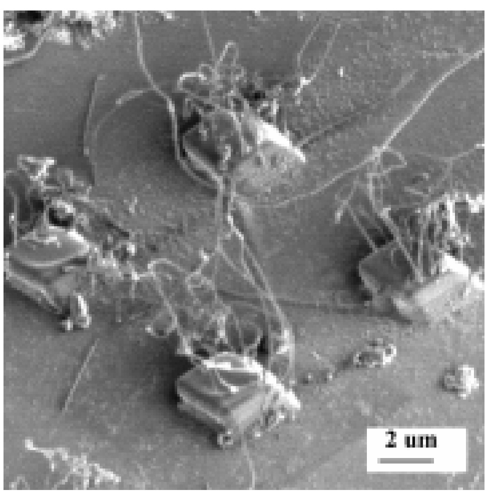
Fig.3


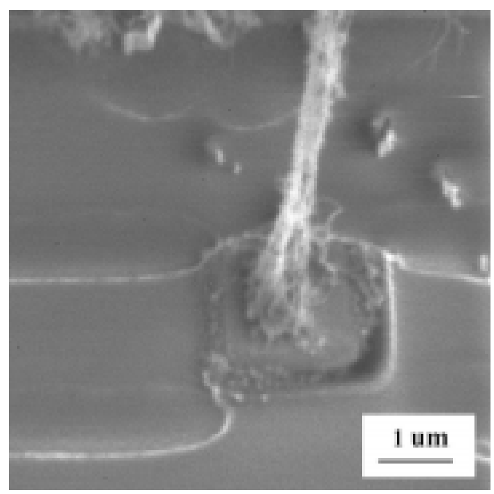
Fig. 4


Fig. 1: A group of Pt pillars deposited by a focused ion beam-induced chemical deposition.

Fig. 2: An array of catalytic dots generated using a using a focused ion beam to sputter off the catalyst coating in areas other than the designed patterns. Note that the small dots are the areas containing catalyst precursor materials.

Fig. 3: Nanotubes of high density formed vertically on the top of one of the catalyst dots as shown in Fig. 2.

Fig. 4: Nanotubes of low density were synthesized using a metal cobalt catalyst, which was suputter-coated on the FIB-generated patterns.