Fabrication of Low-Density Vertically Aligned CNT Forests

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Abstract:

Carbon nanotubes (CNT) are a tubular nano-material made of carbon atoms and utilized by some applications due to its remarkable characteristics. The effect of growth conditions on the morphology of the CNT has been investigated for the correlation of morphology and characteristics. In the present work, the effect of growth parameters—including catalyst element, plasma properties, and the thickness of catalyst layer—on the morphology of CNT was studied to fabricate low-density CNT forests. As a result, we successfully demonstrated the fabrication of low-density CNT forests by optimizing growth parameters. The low-density CNT forests were fabricated by using 5-nm-thick nickel catalyst via low pressure chemical vapor deposition (LPCVD).

Introduction:

Carbon nanotube (CNT) is composed of one or several graphene sheets rolled into a tube and has nanoscale diameter [1]. Several noticeable characteristics of CNT, e.g. high thermal and electrical conductivity, attract increasing attention and are applied to generate the devices with outstanding performance. One of the applications of CNT is the diode array [2], which was developed by the NanoEngineered System and Transport (NEST) laboratory at the Georgia Institute of Technology. A diode array that consists of a metal-oxide-metal structure based on CNTs is capable of rectification at ultrahigh-frequencies. Conversely, this device requires low-density CNT forests for fabricating the robust device with curable resin and improving performance.

Generally, CNTs are fabricated using catalyst via chemical vapor deposition (CVD), and the morphology of CNT depends on growth conditions of CVD and surface conditions [3]. Growth conditions are plasma properties, the gases used for carbon source and facilitating CNT growth, catalyst elements, particle sizes of catalyst, structures under catalyst, etc. In this work, we focused on three parameters—catalyst element, existence of plasma, and catalyst size—for fabricating low-density CNT forests, because the listed parameters are assumed dominant to morphology of CNT and are easy to control.

The primary objective of this study was the investigation of the effect of the above parameters on the morphology of the CNT growth and fabrication of low-density CNT forests. Nickel (Ni) and iron (Fe) were used as different types of catalyst elements. LPCVD and plasma-enhanced CVD (PECVD) were used as different plasma properties. Additionally, 3, 5 and 7-nm-thick catalysts were used as different particle size of catalyst because the catalyst particle size is involved in catalyst layer thickness.

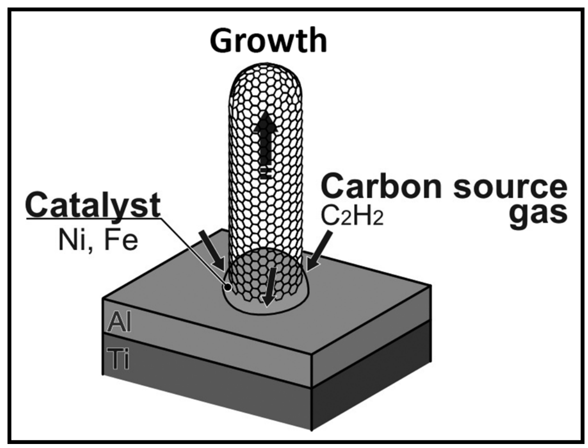

Figure 1: Schematic of CNT base-growth by CVD.

Experimental Procedure:

The fabrication process of the sample for CNT growth is given herein. Using electron-beam evaporator, 30-nm-thick Ti, 10-nm-thick Al were serially deposited as under layers onto a Si wafer. The catalyst layer, which had corresponding thickness and was composed of Ni or Fe, was formed for shaping different sizes of the catalyst particles. The CNTs were grown by using different growth conditions through CVD techniques as base-growth model, as shown in Figure 1.

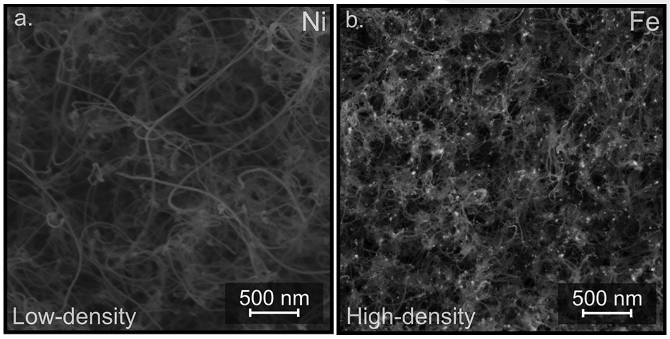

Figure 2: FE-SEM images of CNT morphology using different catalyst element; (a) Ni and (b) Fe.

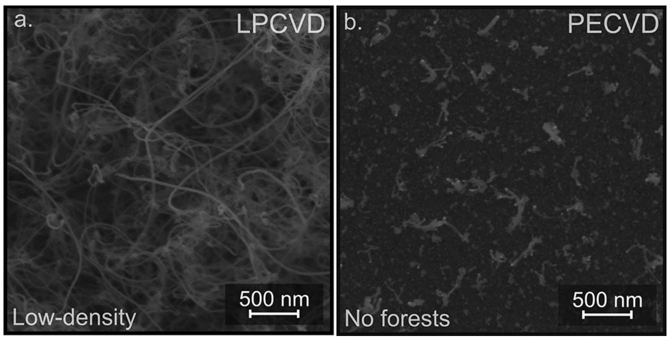

Figure 3: FE-SEM images of CNT morphology using different plasma properties; (a) LPCVD and (b) PECVD.

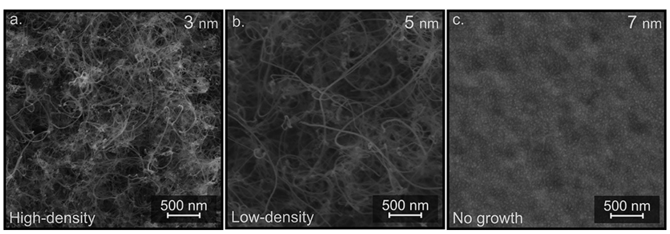

Figure 4: FE-SEM images of CNT morphology using different thickness; (a) 3 nm, (b) 5 nm and (c) 7 nm.

Results and Conclusions:

Effect of Catalyst Element. Figure 2 shows field emission scanning electron microscope (FE-SEM) images of CNT forests formed by using different catalyst elements. Other parameters of CNT growth are as follows: 10 min of growth time, LPCVD as growth technique, and 5-nm-thick of catalyst. As a result, the use of Ni catalyst contributed to fabricate low-density CNT forests. On the other hand, when Fe was utilized as a catalyst, the density of CNT forests was higher than the one using Ni catalyst.

Effect of Plasma Properties. Figure 3 shows FE-SEM images of CNT forests fabricated by using different plasma properties. Other parameters of CNT growth are as follows: 10 min of growth time, Ni as catalyst element, and 5-nm-thick of catalyst. LPCVD is suitable for growing low-density CNT forests. No CNT forests were grown using plasma, PECVD, as shown in Figure 3 (b). Normally, the plasma facilitates the CNT growth and enables CNT growth at low temperatures, but the use of plasma did not contribute to expedited CNT growth, in the case of this study. The cause of non-formation of CNT forests by using plasma is assumed that the plasma etched the catalyst particle and deposited carbon before it became a vertically aligned CNT.

Effect of Catalyst Layer Thickness. Figure 4 shows FE-SEM images of CNT forests grown by using different catalyst thicknesses. Other parameters of CNT growth are as follows: 10 min of growth time, Ni as catalyst element, and LPCVD as growth technique. The thickness of catalyst involves the particle size of catalyst as described above, and the correlation between particle size and the density of CNT is expected to be inverse proportion. In fact, the dependence between thickness involved in particle size and the density of CNT is indicated as shown in Figure 4. Nevertheless, 7-nm-thick Ni is unsuitable to fabricate low-density CNT because the film was formed with increasing thickness and particle size.

The growth and morphology of CNT were varied by different growth parameters. Consequently, the formation of low-density CNT forests can be demonstrated by using 5-nm-thick Ni catalyst via LPCVD.

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Future Work:

In the future, we plan infiltrated low-density CNT forests with curable resin for the design and fabrication of CNT-based robust electronic devices.

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