Patterned Growth of Carbon Nanotubes

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We demonstrate a simple and effective method for growing large-scale, high-density, and well-patterned carbon nanotubes (CNTs). CNTs were patterned on a quartz (SiO_2) substrate by using a copper TEM grid as a mask. The CNTs were grown by annealing of the milled iron phthalocyanine (FePc) at 800 °C in a flow of Ar-5% H_2 gas. The produced CNTs exhibit uniform morphology and the frame of TEM grid on the substrate defines the position of CNT deposition.

1. Introduction

It is a very important approach to grow large scale CNTs on designed patterns and at desired locations for integrating CNTs into nanoscale devices. Aligned CNTs on quartz substrate (SiO_2) have been synthesized using various chemical vapor deposition (CVD) methods [1-4]. Three-dimensional architectures of organized CNTs have been created on SiO_2 substrates using a CVD process with the precursor of a mixture of ferrocene and xylene [5-9]. Here, we report a simple and effective method for growing large-scale, high-density, and well-patterned carbon nanotubes using iron phthalocyanine as a precursor. CNTs were patterned on a SiO_2 substrate by using a copper TEM grid as a mask. The frame of TEM grid on the substrate defines the position of CNT deposition and the CNTs were grown by annealing of the iron phthalocyanine (FePc) at 800 °C in a flow of Ar-5% H_2 gas. The produced CNTs exhibit uniform morphology structures.

2. Experiments

Iron phthalocyanin (FePc) was used as the precursor material because it contains both the carbon source and the metal catalyst required for carbon nanotube growth. To enhance the nanotube growth process, a high energy ball milling treatment was used before the annealing process. FePc was milled in argon gas for 100 hrs with a steel rolling mill and a 300 Kpa pressure was set up prior milling. Ball milling of FePc at room temperature has been found to be able to increase significantly nanotube formation yield. In addition, high-energy mechanical grinding reduces the vaporization temperature from 400 to 200 ºC by creating an activated structure in FePc. [10] After ball milling, around 0.3 grams of FePc were heated under an Ar-5% H_2 gas flow (50 ml/min) at 800 ºC. When the temperature of the furnace reaches to 800 ºC, the combustion boat loaded with milled powder was pushed into the hot zone 5 cm away from substrate and held for 15 minutes. A small SiO_2 circle was used as the substrate and regular patterns were created by placing a TEM grid on the circle. The TEM grid was lifted off after annealing. The morphology of as-grown CNTs on the surface of the patterned SiO_2 substrate was examined using field-emission scanning electron microscopy (SEM) (Hitachi S4500 instrument). Nanotubular structures were investigated using transmission electron microscopy (TEM) (300 keV Philips CM300 instrument).

3. Results and discussion

SEM image in Fig. 1(a) shows the TEM grid before it was removed from the quartz substrate. Fig. 1(b) shows squares covered by a large of CNTs.

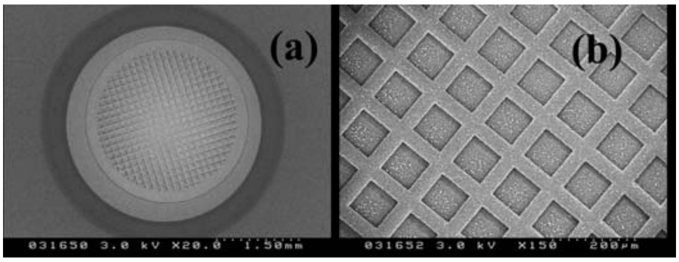

Fig. 1: TEM grid with CNT coating. The TEM grid defined the deposition of CNTs, which are only formed at each square area. (b) high-magnification image of the grid (a).

3.1 Morphology of carbon nanotubes

The typical morphology of the as-grown CNT deposit is shown in the SEM image of Fig. 2(a-b). After annealing the TEM grid was removed from substrate and the pattern was showed in fig. 2(a). Large quantities of CNTs grew on the 100 µm blocks corresponding to the squares of the copper grid, the pattern being produced uniformly in a microscopic scale of 3 mm. It is expected that patterns with different configurations and larger areas can be achieved by using this simple method. Fig. 2(c) indicates the well-defined boundaries of the deposits. Fig. 2(d) reveals the morphologies of individual CNTs. The length of the nanotubes can be up to ~15µm, and their diameters are around 80 nm on average.

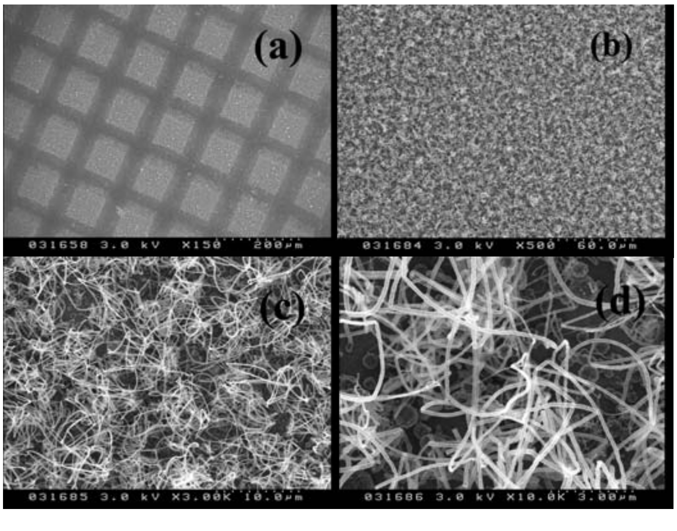

Fig. 2 The morphology of the as-grown CNT deposit. (a): CNT pattern after TEM grid was lifted off. (b-d): larger magnification of as-grown CNTs.

3.2 Structures of carbon nanotubes

Some CNT samples were removed from the substrate and deposited directly on a TEM copper grid for TEM analysis. TEM images showed in Fig. 3(a) reveal the tubular structure of CNTs. A high magnification image of a single carbon nanotube in Fig. 3(b) indicates multi-wall structure. The formation mechanisms of the carbon nanotubes during pyrolysis have been investigated by several groups. Iron plays important catalyst role because one end of nanotubes is connected to iron particles from TEM observation.

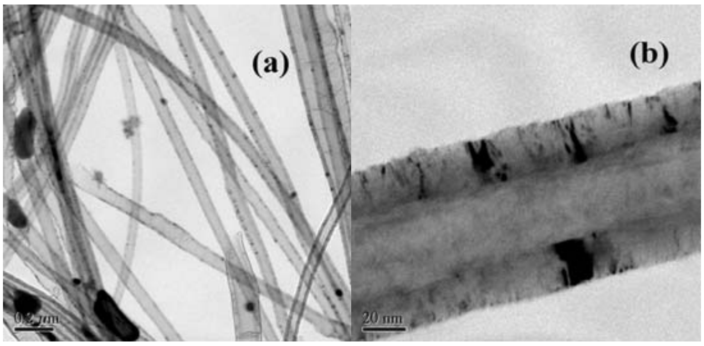

Fig. 3: TEM images showing multi-walled cylindrical structures of CNTs.

4. Conclusions

A simple and effective approach for growing large-scale, high density and well-patterned CNTs has been realized. In this method, the TEM grid was employed as a mask to define the locations of CNTs. The produced CNTs exhibit uniform morphology and multi-walled tubular structure.

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