DIAMOND NANOWIRES

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Introduction

Nanometer scale one-dimensional materials, such as nanotubes and nanowires, have attracted extensive interest in recent years because of their unique quantum properties and potential applications as nanoconnectors and nanoscale devices[1-4]. Since the discovery of carbon nanotubes in 1991, various one-dimensional materials have been fabricated. However, until now there has been no report on the synthesis of diamond nanotubes or nanowires. Here we report the preparation of single-crystal diamond nanowires produced by hydrogen plasma treatment of carbon nanotubes.

Experiment

The purified multiwalled CNTs were dispersed onto silicon substrates, and then were placed into the radio-frequency plasma-enhanced chemical vapor deposition (PECVD) reaction chamber. After the samples were heated to a temperature of about 1000 K, hydrogen was fed into the chamber at a gas flow rate of 50 sccm to maintain the reactant pressure at 150 Pa and plasma with a power density of 0.5 W/cm^2 was initiated simultaneously. After reaction for several hours, the specimens were cooled down in vacuum. Scanning electron microscope (SEM) and transmission electron microscope (TEM) was used to characterize the morphologies and microstructure of the products. Raman spectra and X-ray Diffraction (XRD) confirmed the diamond structure of the nanowires.

Results and Discussion

From the experiments we know that the CNTs transfer firstly to diamond nanoparticles(DNPs), then DNPs transfer to DNWs. Fig.1a shows the TEM image of a CNTs specimen after treatment in hydrogen plasma at temperature of 1000 K for 10 hours. Instead of ordred concentric graphite sheets of multiwalled CNTs, many nanoparticles were formed on the original CNTs walls after hydrogen plasma treatment. The inset of Fig.1a shows the electron diffraction pattern that corresponds to the diamond spacings. High-resolution TEM, Raman spectra and XRD also confirmed the diamond structure of the particles. (not shown).

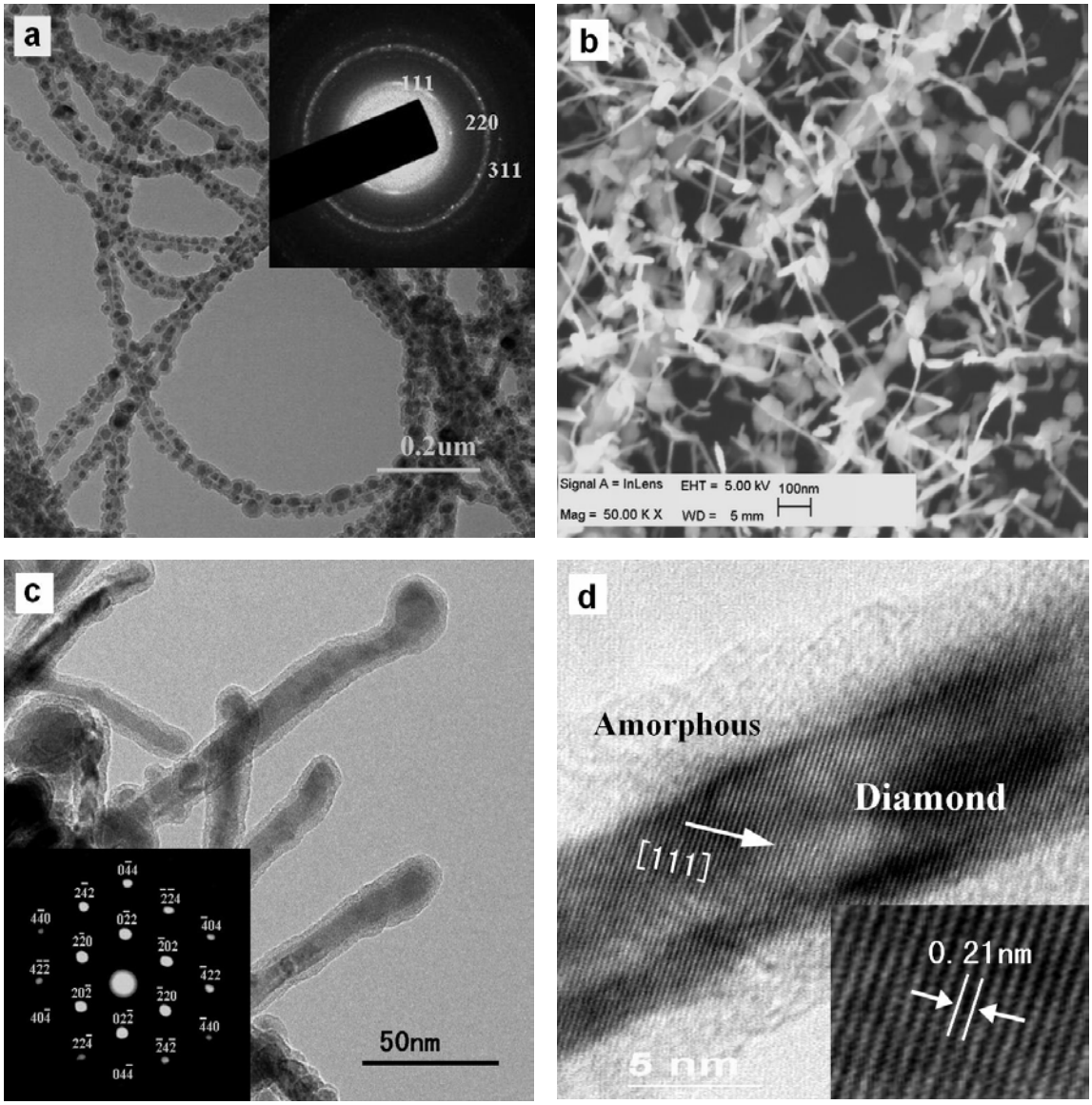

Figure 1 a, TEM image of hydrogen plasma treated MWCNTs (at temperature of 1000 K for 10 hours) shows the diamond crystallites embedded in amorphous carbon clusters and partial reservation of CNT hollow structure. b, SEM image of the nanowires after treatment of MWCNTs in hydrogen plasm at temperature of 1000 K for 20 hours. c, TEM image of the nanowires same to b. The inset shows the selected area electron diffraction pattern of a diamond nanowire from [111] zone axis. d, High-resolution TEM image of a diamond nanowire shows the diamond (111) lattice planes with a d-spacing of 0.21 nm. The inset in is the simulated image of the nanocrystals after image filter processing by Fourier transform.

Fig.1b shows the SEM image of the DNWs from the CNTs specimen after treatment in hydrogen plasma at temperature of 1000 K for 20 hours. Numerous wirelike structures with a uniform diameter attached the side of the treated CNTs can be observed in the image. The diameters of nanowires are in the range of 10-15nm, and their length are up to 200 nanometers. We considered that these nanowires

should be possible to grow from the DNPs formed ahead. The high-resolution TEM (Fig.1c and d) of nanowires confirmed the single crystalline feature of nanowires. Fig.1c (the inset) shows the selected area electron diffraction pattern of a nanowire that corresponds to the [111] zone axis of the diamond structure. Fig.1d gives a lattice image of a nanowire, in which the spacing between the parallel fringes of the crystalline core was measured to be about 0.21nm, which is equal to the spacing of {111} planes of crystalline diamond. In addition, the great contrast difference between the center and the edge of the nanowires in both images indicates that the nanowires indeed have a two-layer structure (similar to Si nanowires[5,6]). The crystalline core is wrapped in an amorphous outer layer with an atomically sharp interface(Fig.1d). The thickness of the crystalline diamond core is in the range of 4-6 nm. Because of its small dimension, unique shape, and high surface-to-volume ratio, DNWs are expected to exhibit unusual quantum confinement effects as well as potentially useful electrical, optical, mechanical, and chemical properties.

This approach to the DNWs synthesis may be apply to other fullerenes or even graphite that can be transformed to DNWs by adjusting the reaction temperature and plasma intensity or, more effectively, using high-energetic hydrogen ion beam. Also, it should be possible to make other nanowires in this way.

Conclusions

Single crystalline diamond nanowires with diameters of 4~6 nm and with lengths up to 200 nm have been successfully synthesized by hydrogen plasma post-treatment of mutiwalled carbon nanotubes. The diamond nanowires were identified to have a core-sheath structure with inner core being diamond crystal and outer shell being amorphous carbon. A growth mechanism similar to the oxide-assisted growth mechanism of Si nanowires was proposed. We believe that the approach outlined here is a step toward the production of diamond nanowires over large areas, and that diamond nanowires will offer more opportunities for both fundamental research and technological applications.

References

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