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GROWTH, CHARACTERIZATION, AND POTENTIAL APPLICATIONS OF PERIODIC CARBON NANOTUBE ARRAYS

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ABSTRACT

Periodically aligned carbon nanotube (CNT) arrays have been grown on Ni dots made by nanosphere lithography. Optical characterization reveals strong interaction between the nanotubes surface and incident light. Periodic CNT arrays interact strongly with light because their feature size is on the order of a light wave. It is believed that resonant structures such as these will be of interest in many applications where there is a desire to have efficient interaction between a material system and visible to near infrared electromagnetic radiation.

1. INTRODUCTION

Large arrays of aligned CNTs were first made on substrates in 1998 using plasma enhanced chemical vapor deposition (PECVD)[1,2] where the diameter and length of each carbon nanotube was controlled. Spacing and location of the nanotubes was accomplished using electron beam (e-beam) lithography to create a pattern of nickel dots, which serve as a catalyst for nanotubes growth [3,4]. In this paper, we report an alternative technique to deposit periodic Ni dots and subsequently the growth of periodic carbon nanotubes arrays.

2. EXPRIMENTAL

The nickel (Ni) patterns were deposited on and n- and p-type (100) silicon substrates using thermal evaporation. A 150 Å Ni layer was used. The patterned substrate was loaded into a PE-HF-CVD system. Nanotube growth was accomplished by plasma-enhanced chemical vapor deposition. Acetylene and ammonia gases provide the carbon source and catalytic effect, respectively. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were used to characterize the arrays.

3. RESULTS

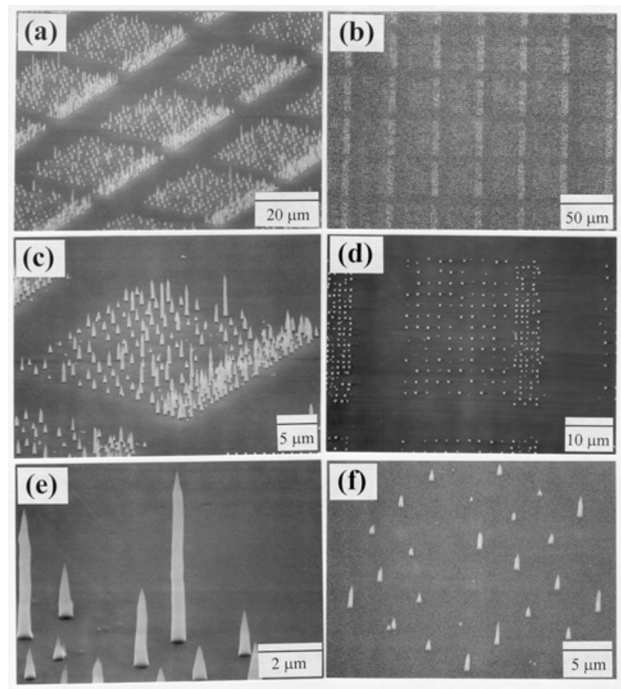

Fig. 1. A series of SEM micrographs from different viewing angles showing growth of carbon nanotube obelisks on an array of submicron nickel dots. (a) An inclined view of a repeated array pattern. (b) A top (normal) view of a repeated array pattern. (c) An inclined view of one array pattern. (d) A top (normal) view of one array pattern. The initial Ni dots (and subsequently the grown carbon structures) are spaced either 2 μm apart (left) or 1 μm apart (right). (e) A magnified view along the edge of one pattern. A sharp, tapered tip is evident. (f) An inclined view of carbon obelisks grown on nickel dots separated by 5 μm.

Fig. 1 shows a series of SEM micrographs of single multiwall carbon nanotubes that were grown on an array of ~100 nm nickel dots. Figures 1a, 1c, 1e, and 1f were taken at an inclined angle, and Figures 1b and 1d are top views taken normal to the substrate. Figures 1a and 1b demonstrate selective growth of the carbon structures on multiple repeated array patterns. Figures 1c and 1d were taken at a higher magnification and show the repeated array pattern where the nanotubes are spaced either 2 μm (left) or 1 μm apart (right). Fig. 2 shows both the SEM and TEM images of one of the arrays with better height control and a single tube.

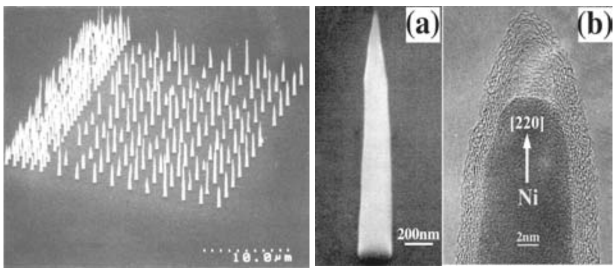

Fig. 2. SEM & TEM images of CNT arrays

Nanosphere lithography was developed as an alternative technique to e-beam lithography because it is more easily commercialized. Fig. 3 shows the SEM images of the Ni dots made by nanolithography. Fig. 4 shows the nanotubes made from the dots. Nanosphere lithography, an alternative, inexpensive and scalable technique has been developed to grow large arrays of CNTs with controlled diameter, length, location, and spacing [5]. These have been optically characterized at various wavelengths in polarization-dependent, reflectance and diffraction studies.

Optical characterization was performed using a fiber-optic spectrometer and pulsed and continuous laser light at various wavelengths. The diffracted beam intensity was quantified for three wavelengths in the visible spectrum. Results for both s and p incident polarization show maximum light intensity when the incident and diffracted beam are at the same angle of incidence. Similar studies were conducted with the zero-order, specular component at the same wavelengths. P-polarized light is seen to conform to Brewster's law, while both s and p components show a general trend of

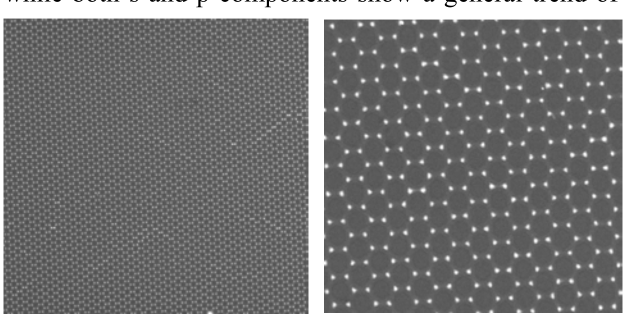

Fig. 3. SEM images of Ni dots made by nanolithography in low (left) and medium (right) magnifications.

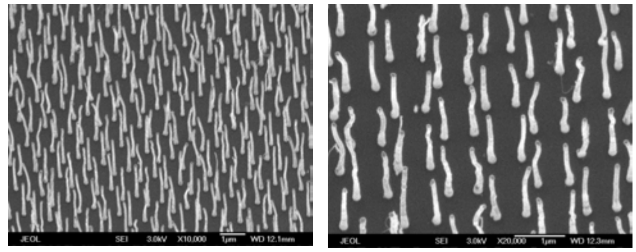

Fig. 4. SEM images of low (left) and medium (right) magnifications of carbon nanotube arrays.

increased scattering with increasing angle of incidence from the nanotubes-array surface. At near-grazing incidence, sharp peaks begin to appear. The peaks change with the orientation of the periodic array and are related to the nanotube spacing.

The results of this study are applicable to the use of CNTs as antennas. Baseline optical measurements indicate that the periodic arrays exhibit properties of optical filtering; band-gap effects similar to those of photonic crystals; polarization effects; and antireflection and demultiplexing capabilities. With further processing many other possibilities can be considered including the realization of passive/active optical devices and energy conversion.

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CONCLUSIONS

An economic technique to make large area periodic arrays of carbon nanotubes was developed. These arrays show very interesting optical properties.