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Effects of gas composition on the growth of multi-walled carbon nanotube

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Abstract

This paper studies the effects of different gas compositions on the growth of multi-walled carbon nanotube (MWCNT) films by using an electron cyclotron resonance chemical vapor deposition (ECR-CVD) method. The Raman spectrum was employed to explore the composition of the MWCNT films grown under different mixtures of C_3H_8 and H_2. The results showed that the optimum relative intensity ratio of the D band to G band (i.e., I_D/I_G) is 2 for the cases considered in this study. In addition, the morphology and microstructure of the MWCNTs were examined by field emission scanning electron microscopy (FE-SEM) and field emission gun transmission electron microscopy (FEG-TEM). Furthermore, atomic force microscopy (AFM) and scanning thermal microscopy (SThM) were used to study the surface topography and thermal properties of the MWCNTs.

Keywords: Carbon nanotubes; Gas composition; Material properties; ECR-CVD

1. Introduction

Carbon nanotubes (CNTs) have attracted great interest since they were discovered in 1991 [1], due to their exceptional mechanical and electronic properties. Many applications of CNTs have been reported, such as probes in atomic force microscope (AFM) [2,3], electron emitters for field emission display (FED) [4,5], nanofillers for composite materials [6,7], electrodes for fuel cells [8,9], nanoscale electronic devices for micro/nanoelectromechanical systems (N/MEMS) [10]. Recently, multi-walled nanotubes have been found to possess potential for the development of frictionless nanomotors, nanoactuators, nanobearings and nanosprings [11]. Therefore, the extensive research on CNTs may lead to new applications of other nanostructures and nanoengineering [12].

The catalytic chemical vapor deposition (CVD) method is one of the most promising approaches and has been widely used to grow CNTs on the substrate with the assistance of metallic catalysts. The method includes a gas flowing over metallic catalytic particles, such as Fe, Co and Ni, and a gas mixture containing a carbon precursor such as acetylene, carbon monoxide, and methane. With the CVD method, CNTs can be grown at desired locations with a specified direction. In recent years, different catalytic CVD methods for growing CNTs have been developed, such as that of Merkulov et al. [13] and Cojocaru et al. [14] who utilized plasma enhanced chemical vapor deposition (PE-CVD) to grow multi-walled carbon nanotubes (MWCNTs) onto substrates coated with a suitable transition metal catalyst. Chen et al. [15] and Wu et al. [16] utilized the electron cyclotron resonance chemical vapor deposition (ECR-CVD) process to synthesize CNTs at low temperature.

In this paper, the growth process of MWCNTs on a nickel coated silicon substrate, using electron cyclotron resonance chemical vapor deposition with the mixed gases of C_3H_8/H_2, is studied. Electron cyclotron resonance (ECR) ECR ion sources are ideal for ion-assisted deposition due to high ionization efficiency, even at low pressures. In addition, the correlation between the morphology and microstructure of the MWCNTs and the deposition condition are investigated through the use of some advanced instruments.

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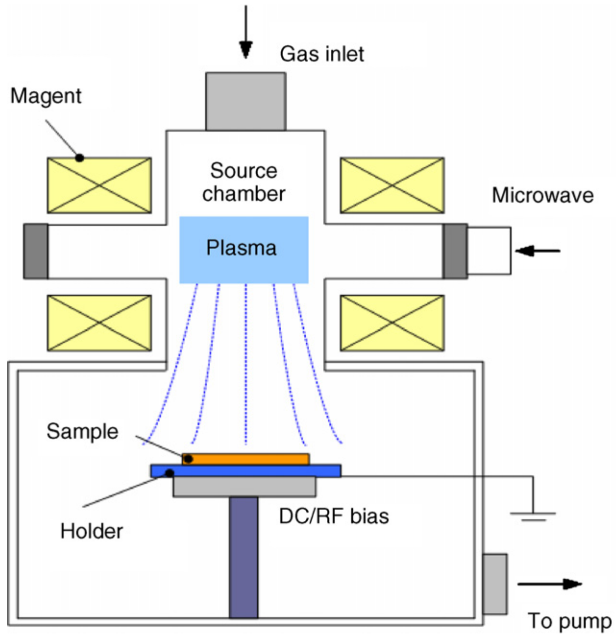

Fig. 1. The schematic diagram of the ECR-CVD system.

2. Experimental details

Nickel catalyst film with a thickness of 5–10 nm was deposited on n-type silicon wafer substrate of 10 mm × 10 mm in size by using ion beam sputtering at room temperature. Then CNT growth was carried out in an electron cyclotron resonance chemical vapor deposition system with a base pressure below 10^{-6} Torr at the ECR power of 400 W and the substrate temperature of 600 °C for 5 min, as shown in Fig. 1 [16]. During the growth process, propane (C_3H_8) was chosen as the reactive gas mixed with hydrogen (H_2), and the different flow rates of C_3H_8:H_2 were set at: 1:1, 1:2, 1:3, 1:4, and 2:3, respectively. Generally, acetylene and propane can be used for dissociation in the gas phase. Propane was used in this study because it provides a lower temperature flame than acetylene and is safer than acetylene.

The morphology and microstructure of the CNTs were examined by field emission scanning electron microscopy (FE-SEM, Hitachi S4200) and field emission gun transmission electron microscopy (FEG-TEM, Philips Tecnai G2 F20). In addition, atomic force microscopy (AFM, Veeco/TM CP-RII SPM), and scanning thermal microscopy (SThM, Topo Metrix) were used to study the surface topography and thermal properties. The nanomechanical characteristics of CNTs were also investigated using a nanoindentation system. A nanoindenter (Triboscope, Hysitron) was used to compress the nanotubes and generate force–displacement curves. The electrical resistance of the samples was measured by the probe station method.

3. Results and discussions

Fig. 2 shows an SEM image of the Ni catalyst for growing the CNTs after ion beam sputtering deposition. The Ni catalyst was aggregated after the film growth, due to the surface tension

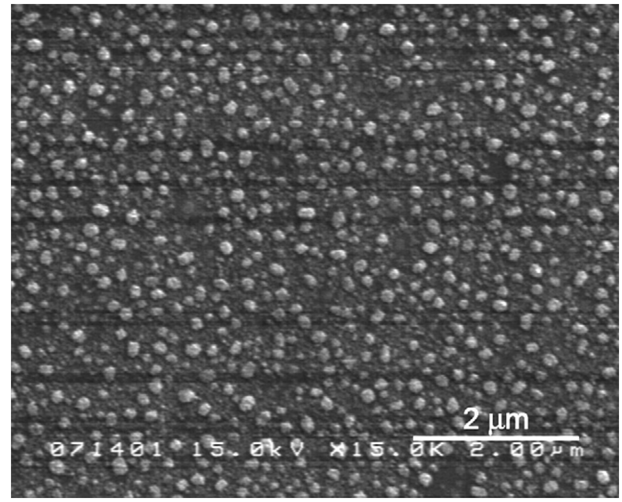

Fig. 2. An SEM image of the Ni catalyst.

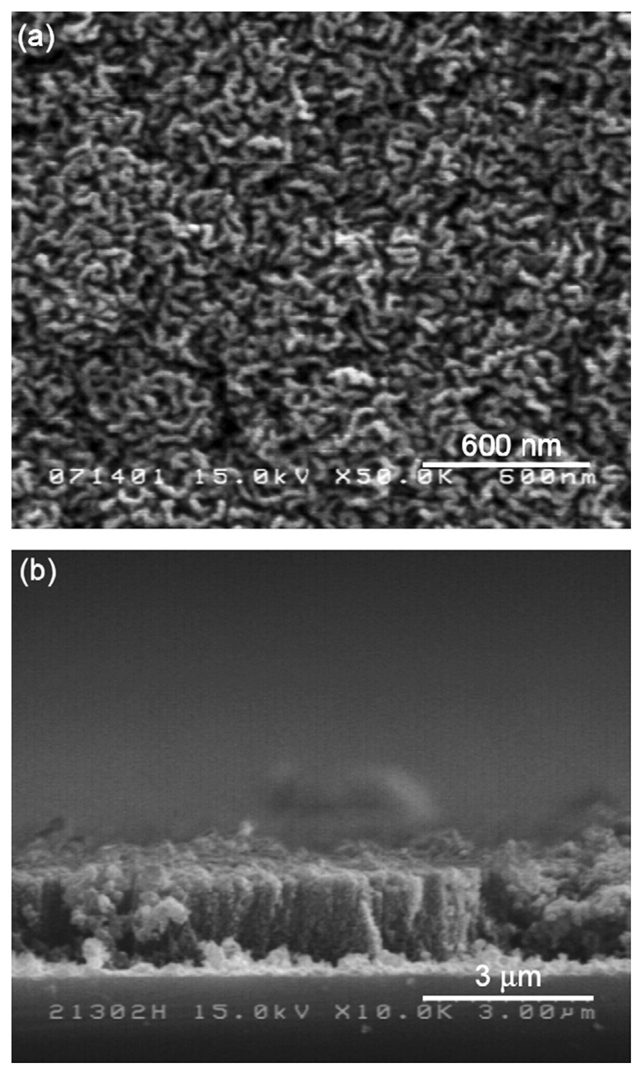

Fig. 3. (a) Top view and (b) cross-section view SEM images of MWCNTs deposited on a Ni catalyst film with C_3H_8:H_2 = 2:3 gas mixture at the ECR power of 400 W for 5 min.