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The electrical and structural properties of carbon nanotubes grown by microwave plasma-enhanced chemical vapor deposition method for organic thin film transistor

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ABSTRACT

Carbon nanotubes (CNTs) were grown on Ni/TiN/Si and Ni/TiN/glass substrates by microwave plasma enhanced chemical vapor deposition using methane and hydrogen gases. Firstly, TiN buffer (200 nm) and Ni catalyst (60 nm) layers were deposited on the glass and Si wafers by radio frequency magnetron sputtering method. The substrate DC bias voltage as the main process parameter was changed from 0 to −250 V in −50 V intervals and the synthesis temperature was maintained at the condition of 600 °C. The effects of DC bias voltage on structural and electrical properties of the synthesized CNTs were investigated. The length of CNTs is changed by supplying substrate DC bias voltage. It is observed that negative bias is more Profitable for obtaining the vertically aligned CNTs than that without bias. As the multi-walled CNTs, the increase of DC bias voltage decreases the I_D/I_G ratio and the disorder of CNTs, and also it is attributed to the improvement of the crystal quality of CNTs and the reduction of conductivity of CNTs.

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1. Introduction

Carbon nanotubes (CNTs) have recently been considered as a promising candidate material for application as field emitter, nano-electronic devices [1–3], owing to their unique physical and chemical properties (ultrahigh mechanical strength, aspect ratio, tunable electrical and thermal conductivities) [4–6]. For industrial applications, such as flat panel displays or field emitters, it is desirable to produce vertically aligned CNTs with uniform properties. Recently, it has been proposed that aligned CNTs can also be achieved by the application of electric bias to the substrate during growth, Y. Avigal et al. [7] reported the bias effect such that the CNT alignment occurred only when a positive bias was applied to the substrate where as no aligned growth occurred under a negative bias and no tube growth was observed without bias. On the country, several researchers reported some different observations that aligned nanotubes could also be grown under negative substrate biases [8–10]. This discrepancy may indicate that the bias effect is not fully understood yet.

In this study, we synthesized CNTs on the glass and Si substrate by microwave plasma enhanced chemical vapor deposition (MPECVD). In addition, the effects of bias voltage on the grown behavior, structural, and electrical properties of CNTs were investigated.

2. Experimental

To grow CNTs, the TiN buffer layer and Ni catalyst layer were deposited on the glass and Si wafers by radio frequency (RF) magnetron sputtering method. The thicknesses of TiN and Ni layers were 200 nm and 60 nm, respectively. In this work, a 200 nm TiN layer was used as buffer layer, which prevented an interaction between substrate and Ni layer. The Ni deposited glass and Si substrates were put on a graphite substrate stage in the plasma chamber. The plasma chamber was pumped down to a base pressure of 0.17 Pa by a rotary pump. Then, the working pressure was fixed to 2.13 kPa by the inserted hydrogen gas, and the substrate was heated by a graphite coil. The pretreatment of the substrates for CNT synthesis was carried out as the follows: A microwave, having a frequency of 2.45 GHz and a maximum power 1.5 kW, was switched on to initiate the test substrate temperature with microwave power of 800 W. By this process, the Ni film was pretreated by the plasma bombardment for 30 s. After that the methane (10 sccm) and hydrogen (80 sccm) gases were introduced into a chamber while the chamber pressure was held upon 2.13 kPa. The process of CNT synthesis was continued for 5 min with 800 W microwave power and various DC bias voltages from 0 to −250 V.

The growth properties of CNTs was evaluated using field emission scanning electron microscopy (FE-SEM, Jeol JSM-6700F, 5.0 kV). The structural properties of CNTs were investigated by Raman spectrometer (Jasco MRS-3000) which used a 532.01 nm single wavelength and a 3.5 mW laser power. Also, the electrical properties of CNTs grown by MPECVD method were studied by a four point probe measurement.

3. Results and discussion

Fig. 1 shows the cross-sectional FESEM images of CNTs synthesized on a glass substrate with various DC bias voltages at the growth temperature of 600 °C for 5 min. This figure exhibits the influence of

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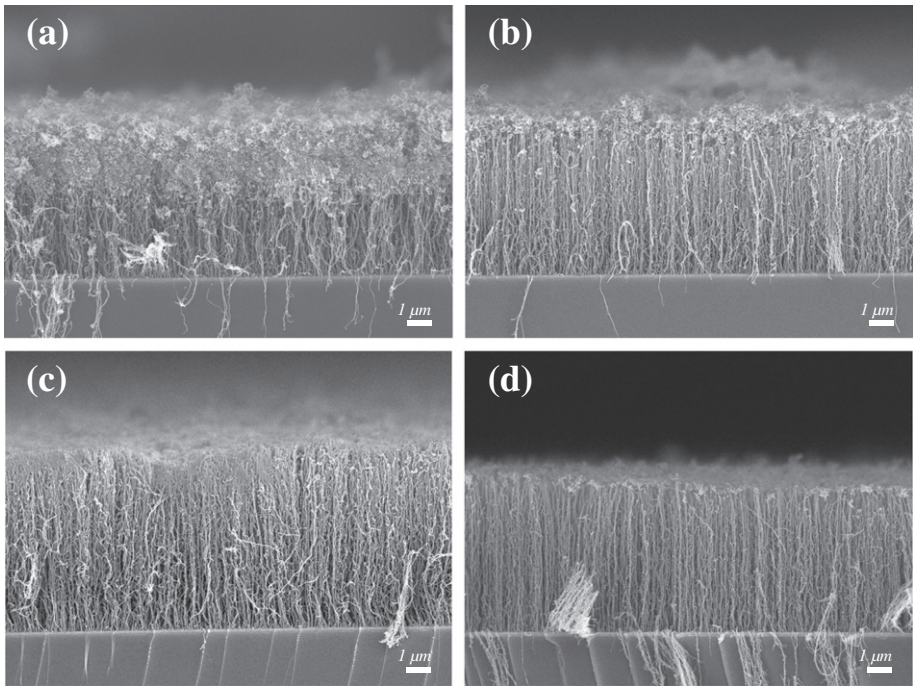

Fig. 1. Cross-sectional FESEM images of CNTs grown on glass substrate at 600 °C with various DC bias voltages: (a) 0 V; (b) −50 V; (c) −150 V; and (d) −250 V.

different DC bias voltages on CNT growth. In case of 0 V, we could see the layer of amorphous carbon and carbonaceous particles over the aligned CNT layer. However, for higher DC bias voltage, the layer of amorphous carbon and the carbonaceous particles is reduced and the CNTs length is increased. And also, we can find that a degree of alignment of synthesized CNTs improved with increasing DC bias voltage.

Fig. 2 shows the cross-sectional FESEM micrographs of CNTs synthesized with various DC bias voltages on Si substrate at 600 °C for 5 min. It was similar with the case of the glass substrate. The length of CNTs increases with increasing DC bias voltage, as seen in Fig. 2.

Fig. 3 shows the variation of the length of CNTs on glass and Si substrates as a function of DC bias voltage conditions under 600 °C substrate temperature. The CNTs' length grown on the glass substrate is longer than that of CNTs grown on the Si substrate. The growth length of CNTs on the glass substrate was saturated about 11.7 μm over the DC bias voltage of −150 V and decreased from DC bias of −200 V. However, the growth length of CNTs on the Si substrate was increased from 3.7 μm to 8.5 μm with increasing DC bias voltage.

Raman spectra have been measured to investigate the crystal quality and structure of CNTs. Fig. 4(a) shows Raman spectra of CNTs grown

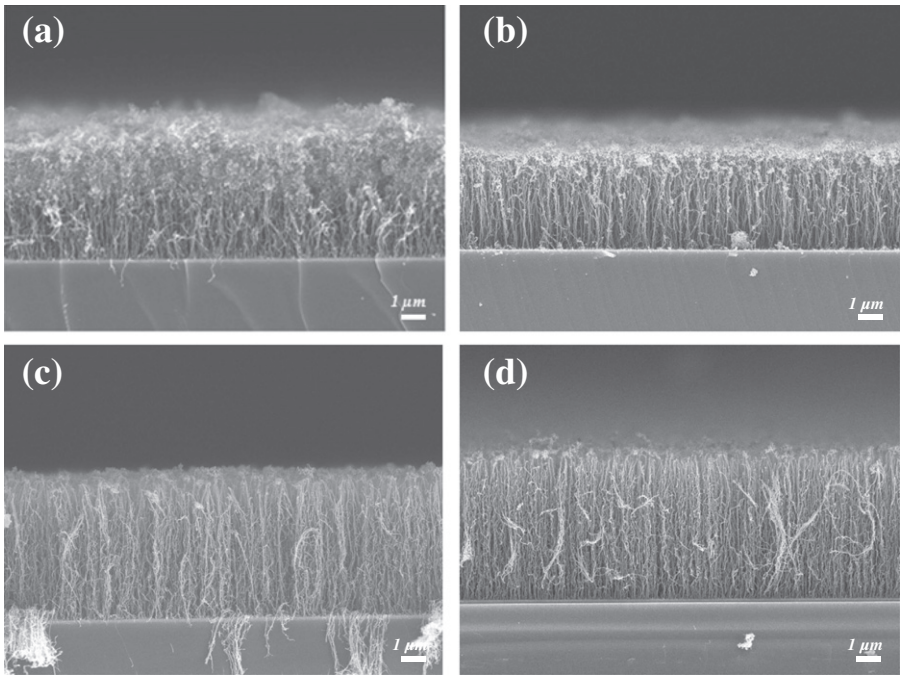

Fig. 2. Cross-sectional FESEM images of CNTs grown on Si substrate at 600 °C with various DC bias voltages: (a) 0 V; (b) −50 V; (c) −150 V; and (d) −250 V.

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