Structural and Electrical Aspects of Close-Packed and Well-Aligned Carbon Nanotube Films on Silicon Carbide (0001)

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A carbon nanotube (CNT) has attracted attentions of many researchers since its discovery because of interesting properties originated from low dimensionality. The CNT is closed at its edge with a hemispherical fullerene what we call a “cap”. In the previous CNT research, anomalous electronic states nearby the cap were reported in the theoretical and the experimental scanning tunneling microscopy and spectroscopy (STM-STS) studies\textsuperscript{[1, 2]}. For actual applications, that the controlled aligning of CNTs is significantly important. It is well known that a close-packed and well-aligned CNTs film is directly formed on the SiC substrate with SiC surface decomposition\textsuperscript{[3]}. The properties of the CNT film is expected to reflect the peculiar features which are derived from CNT’s nature and its alignment. This method is a unique technique to form aligned CNT film directly on the wide-bandgap SiC substrate, which would be suitable for the power-device applications. In this study, we investigated the structures of the CNT films together with the in-plane electrical properties and the transport mechanism with various CNT lengths.

Growth of the close-packed and well-aligned CNT film was carried out in an electric furnace at elevated temperatures. The 4H-SiC (0001) substrates were heated in a vacuum of about $1 \times 10^{-2}$ Pa. The CNT length (film thickness) was precisely controlled by annealing temperatures and holding times. We prepared the CNT films with a thickness of $5 \sim 200$ nm. The length, structure and the presence of caps were directly observed with a transmission electron microscope (TEM). We measured the resistivity, carrier density and mobility of the film with electrodes in a van der Pauw geometry at every 10 K between 300 K and 20 K.

Figure 1 shows the TEM images of the CNT films. In all films, the close-packed CNTs with caps were observed on SiC. Figure 2 shows the temperature dependence of the resistivity of the CNT films. In the CNT films thicker than 210 nm, the resistivity decreased with decreasing temperature, while in the thinner films, the resistivity increased with decreasing temperature. These behaviors indicate the different electric conduction mechanisms with respect to the length of the CNTs, which would derive from the structural difference. The cross-section of the CNTs is shown in Fig. 2(b). The electric conduction is originated from the electron transport in mazy graphene walls existing between the CNTs and the variable range hopping between the CNTs.

References
FIG. 1. TEM images of the CNT films with a length of (a) 14 nm, (b) 20 nm and (c) 65 nm formed on SiC substrate directly. These images show that the CNT films are well-aligned, highly dense and maintain direct bonds with the SiC surface atoms.

FIG. 2. (a): Resistivity-temperature dependence of four CNT films with a length of 6.5, 30, 90 and 160 nm. Inset show resistivity-temperature dependence normalized by the value at 300K. It is clear that the CNT film with a length of 90 nm has a crossover temperature. (b) Schematic image of electrical measurement in van der Pauw geometry. Yellow arrows in Top-view and Side-view images show a direction of current.