FIELD EMISSION FROM A SINGLE CARBON NANOCOIL

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Carbon nanocoils (CNCs) have remarkable properties of electron field emission due to their unique physical and chemical structures. L. Pan, *et. al.* have measured the emission properties from a patterned large area with many coils [1]. In this paper, we have investigated the field emission from an individual carbon nanocoil, which was grown by catalytic chemical vapor deposition (CCVD), mounted on a sharpened tungsten needle.

Carbon nanocoils were synthesized on a Fe/ITO/porous silicon substrate by CCVD. First the porous silicon film was formed on the silicon substrate by electrochemical anodization in hydrofluoric acid with ethanol. Then indium-tin-oxide (ITO) of 100 nm in thickness and iron (Fe) of 15 nm were sputtered on the substrate. We used a flow reactor at atmospheric pressure to synthesize CNCs by catalytic decomposition of acetylene in a mixture gases of argon and hydrogen at 730 °C for 30 min. We have characterized the morphology of the grown CNCs using a scanning electron microscope (SEM) and a transmission electron microscope (TEM). Figure 1 shows the SEM micrograph of CNCs synthesized near the edge of the substrate. Many CNCs with filament-like shapes were grown on the substrate. Previous research by L. Pan, *et. al.* indicated that Fe and ITO act as catalysts for growing CNCs [2] and our experiments shows that the size of CNCs was reduced by using a porous silicon substrate.

We have investigated the field emission characteristics from a individual carbon nanocoil mounted on a sharpened tungsten needle. First, the tungsten needle was etched in KOH electrochemically to obtain the sharpened tip, of which the radius was less than 100 nm, as shown in Fig. 2. Next the sharpened needle installed on a XYZ manipulator was approached to the CNCs on the edge of the substrate and a DC voltage was applied between the coil and the needle. The generation of arc discharge could bond the individual coil to the end of the needle. Figure 3 shows the SEM micrograph of the fabricated sample for the emission experiments. The length of the coil was about 25 μm. Figure 4 shows the TEM micrograph of the coil, which consists of two coiled fibers.

The field emission from the individual carbon nanocoil was measured in 1.5×10^{-6} Pa vacuum chamber. The emitted electrons from the coil were confirmed by the observation of the emitted light from a phosphor (ZnO, Zn) anode screen placed above the coil tip. Figure 5 shows the emission current from the individual coil as a function of the applied voltage between the coil and the screen at the coil-screen gap of 200 μm. It showed that the threshold voltage, at which the current exceeds 1 nA, was 1.2 V/μm. The maximum emission current from the individual coil was about 29 μA at 1100V applied voltage between the coil and the screen. Figure 6 shows a representative emission pattern from the coil, which looks like a double ring. A proper explanation of the pattern shape is under investigation.

In summary, we have synthesized carbon nanocoils by catalytic chemical vapor deposition and investigated the field emission from an individual carbon nanocoil. The observed emission characteristics of the individual carbon nanocoil promise practical applications especially on multi-electron beam nanolithography.

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III. Results and Discussion

For the armchair (5,5) and zigzag (10,0) with one thousand atoms, we have calculated the LDOS and DOS with and without the applied field respectively. We have found that there are only two kinds of LDOS at different sites in each ring of CNT due to the symmetry of CNT. These two kinds of LDOS of armchair (5,5) and zigzag (10,0) in the end of tube are shown in Fig 1a and 2a, where the red one and the blue one represent two adjacent sites. A sharp peak appears at the Fermi surface of (10,0) nanotubes, while it is not apparent in (5,5) armchair nanotubes. It means that the (10,0) zigzag nanotube has strongly localized states at the Fermi surface. When the electric field (F=2.5 MV/m) turns on, the particle-hole symmetry of LDOS is broken and shifts to the lower energy shown in Fig 1b and 2b. The local DOS at a site in the middle of a CNT is similar to the total DOS, which is corresponding to the results given by R. Saito[4]. The DOS for armchair (5,5) and zigzag (10,0) SWNTs with and without applied field are shown in Fig 3, where the red one and the blue one represent F=0 and F=2.5MV/m, respectively. It can be seen that two sharp peaks of DOS for zigzag (10,0) appear at about $\pm 3eV$, and there is a gap at the Fermi surface. It is similar to the LDOS that the particle-hole symmetry is broken by the applied electronic field for both armchair and zigzag carbon nanotubes. It is interesting to notice that the gap of DOS for zigzag disappear when the electronic field turns on. These results can provide useful information for the field emission experiments.

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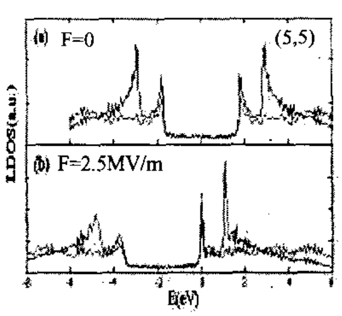

Fig.1 The two different kinds of LDOS at a particular site in the end of (5,5) armchair nanotubes. (a) F=0, (b) F=2.5 MV/m. (The red one and the blue one represent two adjacent sites.)

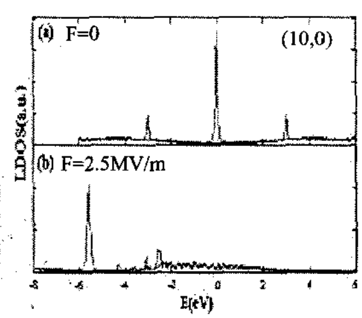

Fig.2 The two different kinds of LDOS at a particular site in the end of (10,0) zigzag nanotubes. (a) F=0, (b) F=2.5 MV/m. (The red one and the blue one represent two adjacent sites.)

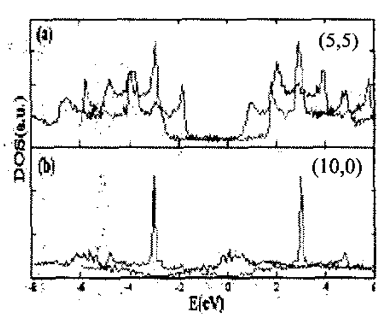

Fig.3 the effect of applied field F=2.5 MV/m on the DOS. (a) (5,5) armchair nanotubes, (b) (10,0) zigzag nanotubes. (The red one and the blue one represent F=0 and F=2.5MV/m.)