FEM Study on Carbon Nanotube Electron Emitters and In-situ TEM Study on Electrical Transport of a Cu/Carbon Nanotube Composite

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Our recent studies on field emission microscopy (FEM) of adsorbates on carbon nanotube (CNT) field emitters and on in-situ transmission microscopy (TEM) of electrical transport and mass flow of a suspended carbon nanotube encapsulating cupper (Cu) nano-rod are reported.

1. FEM study on molecules and metal clusters adsorbed on multi-walled CNT emitters

Field emission (FE) of electrons from a multi-wall CNT (MWCNT) with a closed cap occurs preferentially from carbon-pentagons at the cap, and field emission microscope (FEM) images consisting of bright pentagonal rings are observed. Adsorption of a gas molecule onto a clean pentagon brings about a change in the FEM images from the pentagonal ring to a bright spot with a sudden increase in emission current. It has been revealed that the adsorption and desorption of gas molecules are one of the origin of current fluctuation in FE.

Recently, molecular images and dynamics of adsorbates on MWCNT emitters have been reported; for N_2 and CO_2 molecules, dumbbell-shaped images, reflecting their molecular shapes, and for methane adsorption, a cross-like pattern, corresponding to the symmetry of the molecules viewed along the two-fold symmetry axis, were observed. In the case of aluminum (Al) clusters that was deposited on the MWCNT tips, FEM images revealing atomic detail of the cubo-octahedron structure, which is characteristic morphology of Al fine particles, were observed. Discussion on the spatial resolution in FEM for MWNTs suggests the probable observation of atomic structures with a resolution of the order of 0.3 nm.

2. In-situ TEM study on electrical transport and structure change of a Cu nano-rod encapsulated in a thin-walled CNT

The diameter and the length of the Cu filled CNT employed for in-situ TEM study were 18 nm and 256 nm, respectively. The thickness of the CNT wall was about 1 nm, consisting of several layers of graphite. Some spherical Cu particles adhered to the CNT. The electric voltage was applied between the two ends of the CNT inside the TEM. At 1.4 V, the current increased to 10 μA, corresponding to a current density of 4.0×10^6 A/cm^2, and at the same time the Cu nano-rod started to move to an end of CNT where the debris Cu particles adhered, leaving the CNT sheath. After the shrinkage of the Cu nano-rod, an empty CNT was left. From the variation in the total resistances measured for the different lengths of the Cu nano-rod, electric resistivities of the CNT and the Cu nano-rod were measured to be 3.0×10^{-5} Ωm and 1.2×10^{-4} Ωm, respectively. The resistivity of the CNT is comparable to that of graphite, whereas the resistivity of the Cu nano-rod is much higher than that of bulk Cu. A probable cause of the high resistivity of the Cu nano-rod is scattering of carriers by its surface.