Field Emission Microscopy of Al-Deposited Carbon Nanotubes: Emission Stability Improvement and Atomically-Resolved Image of an Al Cluster

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Field emission (FE) of electrons from a multiwall carbon nanotube (MWNT) with a closed cap provides field emission microscope (FEM) images showing of bright pentagonal rings when the surface of a MWNT cap is clean. 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. In this work, aluminum (Al) was deposited on MWNT field emitters and its effects on FE properties were studied by FEM. A considerable improvement of emission stability was obtained by Al-deposition, and an atomically-resolved image of an Al cluster with face-centered structure was observed by FEM.

A bundle of MWNTs produced by arc discharge was glued on the top of a loop of tungsten (W) wire, and the emitter assembly was installed in an ultra-high vacuum chamber (base pressure, 7×10^{-8} Pa) for FEM experiment [1]. FE measurement of MWNTs before Al deposition was first carried out, and then Al was deposited onto apex regions of MWNTs in the FEM chamber without exposing to air. The amount of Al deposited was in a range from ~1 nm to 11 nm in terms of mean film thickness.

Figure 1 (a) shows *I* - *V* curves of a MWNT emitter prior to Al deposition, and Fig. 1 (b) is the first *I* - *V* curves just after Al deposition. Figure 1 (c) is the second *I* - *V* measurement after the Al deposition, showing that the fluctuation of emission is remarkably reduced. After the first *I* - *V* measurement both the flickering of bright spots in the FEM and the current fluctuation decreased considerably, though the current fluctuation just after the Al deposition was higher than that of the pristine MWNTs without Al deposition. The stabilization of emission current observed after the Al deposition is probably due to the reduction of adsorbed gas molecules migrating on an emitter surface, which owes to the gettering action of Al deposited on MWNTs, i.e., trapping of migrating molecules by Al.

During the study on the effect of Al deposition by FEM, intriguing FEM images suggestive of an Al cluster with atomic resolution were observed. Figure 2 shows FEM images of an MWNT emitter before and after Al deposition. Before the Al deposition, “pentagon” patterns characteristic of clean caps of MWNTs (two MWNTs are visible in this image) are observed (Fig. 2 (a)). By the deposition of Al, as shown in Fig. 2 (b), a spotty pattern with a high symmetry (4-fold symmetry in this case) appeared. The contrast of the spotty pattern is reminiscent of the structure of an atom cluster with a shape of cubo-octahedron, which is a crystal form characteristic of face-centered cubic metals [2]. A model of the structure consisting of 38 Al atoms is illustrated in Fig. 3. The four-fold symmetry of the Al image suggests that the Al cluster is oriented with its [100] direction normal to the nanotube surface. Four bright spots observed in the central part of the Al image correspond to four corners of the top (100) surface. Four dark regions surrounding the central (100) face correspond to (111) faces, which are outlined by bright edges and corners. Since the electric field concentrates at locally protruding atoms which are located at the edges and the corners, tunneling probability of electrons at these atoms is significantly high.

The distance between neighboring atoms along the edge of the (100) surface is 0.286 nm when the lattice constant of the cluster is the same as that of bulk Al. Using the size of the carbon pentagon (ca. 0.25 nm in diameter) as a measure of magnification of these FEM image under an assumption that the pentagon image originates from five carbon atoms, the distance between the bright spots at the corners of the (100) face is estimated to be approximately 0.30 nm, being in good agreement with the nearest neighbor distance on the Al (100) surface.

According to the spatial resolution of FEM discussed by Rose [3], parameters of a tip radius of a MWNT emitter and a tip voltage suggest a resolution of the order of 0.3 nm, indicating that some of atomic detail is observable in the present experimental condition.

References

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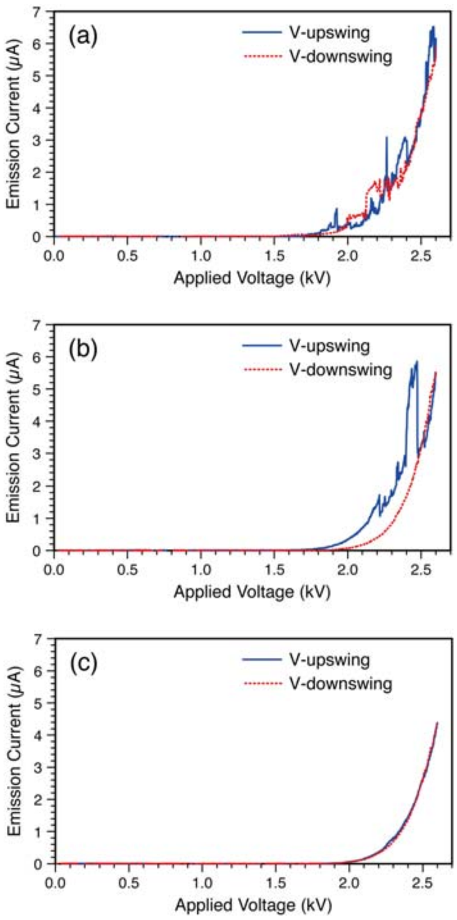

Fig. 1: *I-V* curves. (a) Prior to Al deposition, (b) the first run after Al deposition and (b) the second run after Al deposition.

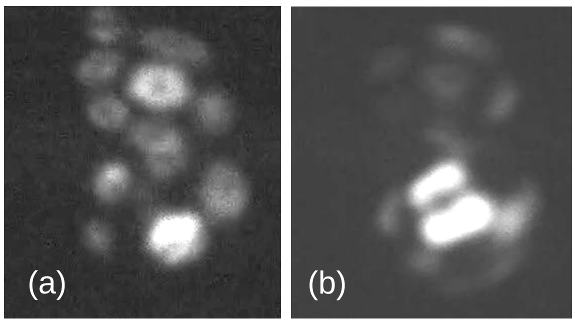

Fig. 2: FEM images of (a) clean MWNT caps and (b) an Al cluster.

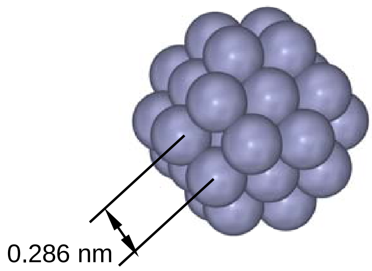

Fig. 3: Cubo-octahedron of an Al_{38} cluster.