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Fabrication and Test of Single Nanotube Emitter as Point Electron Source

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Carbon nanotubes (CNTs) exhibit excellent characteristics in field-induced electron emission with high brightness, stable emission current, long lifetime and narrow energy distribution [1-3] and these excellent properties make CNTs a promising candidate to outperform the tungsten cold field-emission point electron source. Though much effort has been devoted to make large-area carbon nanotube-based cathode, it is still a formidable task to attach one single CNT to a metal probe tip to obtain a point electron emitter and it usually involves a sophisticated nanomanipulator [4]. Here we describe a simple, successful, and efficient method to fabricate single nanotube electron emitters with good controllability. The fabrication is a two step process involving (a) producing micron-sized carbon fibers which contain single nanotubes at their cores [5] and (b) exposing the nanotubes and attaching the fiber-base to a metal probe tip. At the cross section of a fractured carbon fiber, a nanotube, usually multiwalled, sticks out due to its different fracture toughness from the carbon fiber that is made mostly of amorphous carbon. The protruded MWNTs are usually 7 ~ 30 nm in diameter and 100 nm to several microns in length.

A typical morphology of the produced structure is shown in FIG. 1, where the MWNT is indicated by the arrows, and the length of this single MWNT is estimated to be 2 μm. The MWNT grown in this way is very well crystallized as shown in the micrograph and the inset at high resolution. With fewer structural defects in the nanotube, the Joule heating of the filament in operation will be reduced and therefore improving the emission life time. The field emission characteristics of these nanotubes have also been measured. The data show that this kind of structure results in a larger field enhancement factor, γ, defined as $\gamma = E_{loc}/E_{app,}$ where E_{loc} is the local and E_{app} the applied (or macroscopic) electric field, respectively. The large enhancement factor is mainly due to its large length (> 1 μm) and small diameter (< 10 nm). The turn-on field for 1 nA emission current is usually about 1 V/μm. This turn-on field is smaller than most single CNT emitters that have been reported. In the low current range (below 20 nA), the F-N (Fowler-Nordheim) plot fits well with the F-N equation, but in the high current range (larger than 20 nA), the I-V curve shows saturation at 1 μA. The maximum current we obtained from a single MWNT is around 10 μA. From FIG. 3 and the Fowler-Nordheim equation, it is calculated that the field enhancement factor is about 3000. When a 40 nm long and 7 nm wide CNT was run at 390 nA (in a 10^{-8} Torr vacuum) emission for more than 200 hours, no apparent degradation of the nanotube was observed.

Reference

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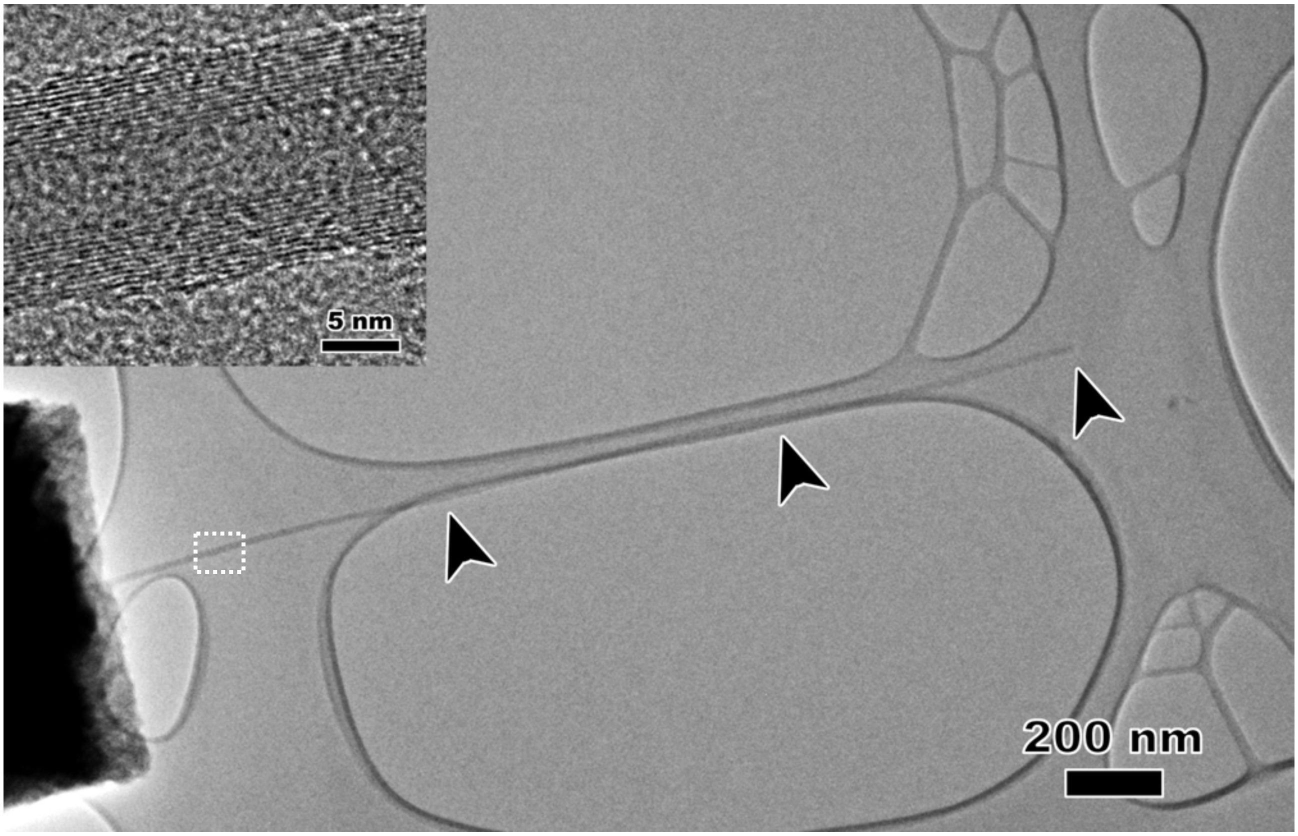

FIG. 1 Single nanotube on micron-sized fiber fractured by sonication. The nanotube is multiwalled with 12 walls, 11.5 nm diameter and 2 μm length. The inserted image is a high resolution image of the MWNT at the rectangle area.

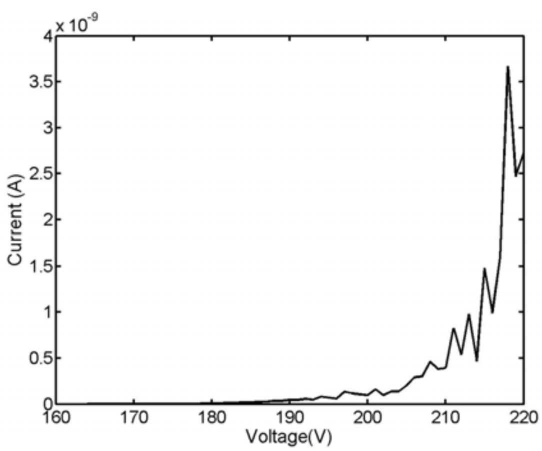

FIG. 2 Total emission current of single nanotube emitter as a function of the applied voltage. Turn-on field is about 1 V/ μm.

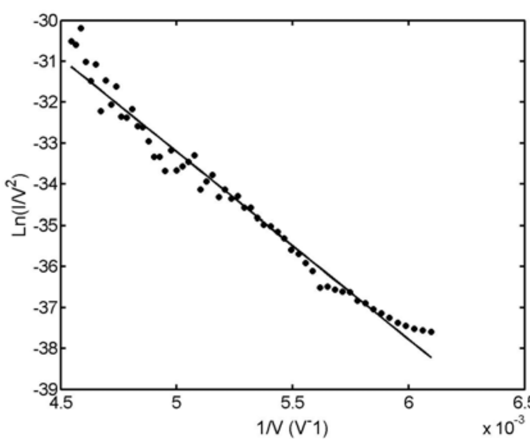

FIG. 3 Fowler-Nordheim plot of single nanotube emitter with field enhancement factor $\gamma \approx 3000$.