Field Emission Properties of Boron Nitride Nanotubes

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Abstract. We have measured electrical transport properties of boron nitride nanotubes using an in-situ manipulation stage inside a transmission electron microscope. Stable currents were measured in a field emission geometry, but in contact the nanotubes are insulating at low bias. At high bias, the nanotubes show stable, reversible breakdown current.

INTRODUCTION AND EXPERIMENT

We have performed field emission and contact current-voltage measurements on individual boron nitride (BN) nanotubes. Figure 1 shows the setup for the measurements. The nanotubes were manipulated with a piezo-driven manipulation stage inside a transmission electron microscope (TEM). The BN nanotubes are double-wall nanotubes synthesized by arc discharge[1], and purified by ultrasonic assisted filtration[2]. The as-purified BN nanotube samples are electrically insulating in bulk, but for the TEM in-situ measurements, the nanotubes were mixed with a conductive epoxy (Epo-Tek H20E) in a volume ratio of approximately 1:1. The resulting composite was then cleaved before loading into the TEM, and TEM imaging verified that clean nanotubes were protruding from the surface of the composite. The second electrode for the electrical measurements was a 50 micron gold wire. For field emission experiments, the tips of the protruding nanotubes were positioned 6 micron from the surface of the wire, and for contact I/V measurements, the tips of individual nanotubes were gently brought into contact with the gold wire by the piezo manipulator. Control experiments were also performed to verify that the conductive epoxy itself does not field emit at the voltages applied in these experiments. The current was monitored in all cases with a high gain preamplifier (DL Instruments 1211).

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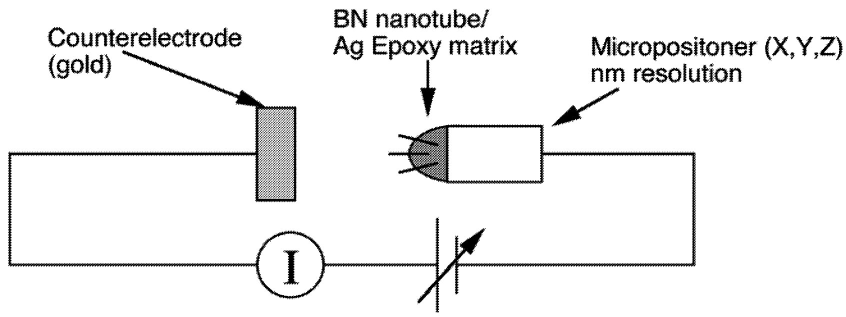

FIGURE 1. The experimental setup for electrical measurements inside the TEM.

RESULTS AND DISCUSSION

Figure 2 shows the results of field emission experiments. The turn-on voltages are approximately 150 volts. This is twice the turn-on voltage measured in control experiments we performed using carbon nanotube samples in similar geometries. The current densities, however, are similar in both cases. One notable difference between

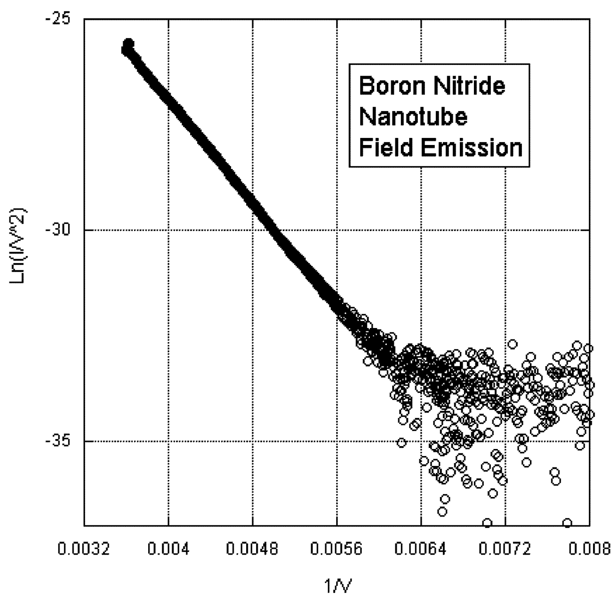

FIGURE 2. Fowler-Nordheim plot of the current-voltage characteristic of field emitting BN nanotubes.

the field-emission behavior of BN and carbon nanotubes is the current-voltage characteristic. Generally, field emission is characterized using the theory of Fowler and Nordheim[3], which predicts a linear relationship between $\ln(I/V^2)$ and V^{-1}. For carbon nanotubes, however, the theory often breaks down, frequently with the current showing saturation at high fields, or two distinct Fowler-Nordheim slopes[4]. For the field emission for BN nanotubes we observed a single slope in the Fowler-Nordheim plot. Additionally, carbon nanotubes usually have a noisy, switching behavior associated with gas molecules adsorbed to the tips of the nanotubes[5]. We observe no such behavior, and the BN nanotubes actually show stable field emission with less noise than for typical carbon nanotube samples. This may have implications for the use of BN nanotubes as stable field emission sources for lighting and flat panel displays.

The field emission properties of BN nanotubes are surprising given that they are predicted to be wide bandgap semiconductors[6, 7], and therefore electrically insulating. To test whether or not individual nanotubes are in fact insulating, the nanotube tips were brought into contact with the gold counter-electrode. For all BN nanotubes observed, there was no conduction at low bias. It is known that often carbon nanotubes can have high contact resistance, but we can rule out contact resistance for the case of BN nanotubes, because we can increase the bias through 10 volts with no conductance or damage to the tube. When this is done with carbon nanotubes, the nanotubes will mechanically fail or burn-out between 2 and 4 volts, even in cases when there is no conductance at low bias. BN nanotubes, therefore,

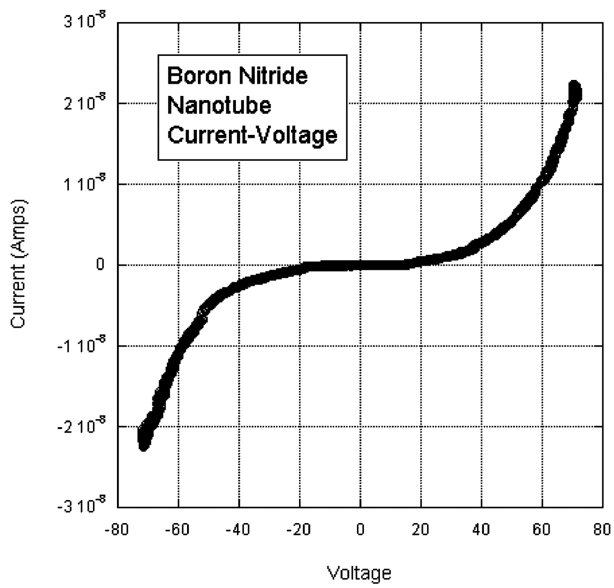

FIGURE 3. The current-voltage characteristic of a typical BN nanotube under contact conditions.

are a good dielectric material up to approximately 10 volts. At higher bias voltages, however, all of the BN nanotubes observed pass current, but do so in a reversible, nondestructive manner. Figure 3 shows a typical current-voltage relation for individual BN nanotubes. The breakdown generally occurs between 12 and 25 volts, and has a characteristic reminiscent of gas-discharge tubes.

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