High-conductivity boron-doped carbon nanotubes

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A new and simple method of growing multiwalled nanotubes significantly enhances their conductivity.

Carbon nanotubes (CNTs) are one-dimensional materials consisting of rolled-up graphite sheets. These structures are promising as nanowires in integrated circuits, as tips for scanning-probe microscopy, in conducting films, and as electron emitters.

For these applications, however, the nanotubes must have high electrical conductivity. Current methods produce a mixture of tubes that have either metallic or semiconducting properties, depending on the direction (called chirality) along which graphite sheets are rolled up. We have developed a method of doping CNTs to enhance their conductivity, independent of their chirality.

The conductivity of other carbon materials is strongly affected by doping. Doping with alkali metals enhances the conductivity of graphite and fullerenes, resulting in superconductivity. Diamond has been found to become superconductor after it undergoes a metal-insulator transition by boron doping, even though undoped diamond is an insulator. The CNT crystal structure is intermediate between that of two-dimensional graphite and three-dimensional diamond. Considering these properties, we speculated that introduced elemental boron in CNTs would enhance their conductivity.

The boron-doped multi-walled carbon nanotubes (MWNTs), shown in Figure 1 were grown using chemical vapor deposition (CVD). In this process, carbon gas is flowed in an electric furnace onto a substrate whose surface is pre-coated with catalyst. This process can produce MWNTs with any diameter and at any position simply by selecting the size and the position of the catalyst. We developed a novel CVD process that uses a methanol solution of boric acid as a source material, which is vaporized to provide boron to the carbon gas.

To measure the conductivity of the boron-doped MWNTs, we fabricated groups of four nanosized electrodes on individual CNTs using electron beam lithography, as shown in Figure 1.

2. Measurements of individual nanotubes using the four-point method are necessary to evaluate the electric conductivity accurately.

The temperature dependence of the conductivity for various tubes is shown in Figure 3. The conductivity of boron-doped MWNTs is one or two orders of magnitude higher than that of a commercially available MWNTs at room temperature. Furthermore, although the conductivity of the commercially available nanotubes decreases with decreasing temperature, the boron-doped MWNTs maintain high conductivities of $10^{2}-10^{3} \Omega^{-1}\text{cm}^{-1}$ even at the very low temperature of 0.6K.

High-conductivity CNTs are promising materials for a wide variety of applications. Our boron-doping method produces

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Figure 2. Scanning-electron micrograph image of an individual MWNT with four nanosized electrodes fabricated using electron-beam lithography.

Figure 3. Boron-doped MWNTs show higher conductivity than a commercially available MWNTs, even at very low temperatures.

large amounts of highly conductive MWNTs at low cost. In the future, we will investigate whether further increasing the concentration of boron creates superconductivity in CNTs.

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References