Chapter 13
CNT Applications in Electrical Conductors, “Quantum Nanowires,” and Potential Superconductors

Contents

13.1 Overview

Due to their electronic properties, as extensively discussed in a chapter in Part I of this book, CNTs have been considered for applications as *electrical conductors* (to replace metals), *quantum nanowires* or *quantum wires* (ideal one-dimensional conductors), potential *superconductors*, and other similar, conductivity-based applications.

13.2 Simple Electrical Conductors

Many laboratory-level or very small-scale studies have been carried out demonstrating the very high current-carrying capacity of CNTs [391–393]. CNTs doped with iodine or iodine monochloride have been shown to have specific conductivity exceeding that of common current carrier metals such as Cu and Al [391, 392]. And Cu–CNT composites have been shown to have among the highest observed specific conductivity of any electrical conductors [393].

Despite all the above-cited, very promising studies, however, to date there are no CNT-based electrical wires or other conductors in the commercial market or even under development. The reasons for this are the same as the reasons for the lack of success in a host of other potential applications for CNTs, as described elsewhere in this book: the inability to fabricate practical materials that are at least somewhat commercially competitive.

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13.3 "Quantum Nanowires"

Individual SWCNTs (but not MWCNTs or bundles or groups of SWCNTs) have the potential to behave like "quantum nanowires" or "quantum wires" (ideal, one-dimensional conductors) because theoretical studies have shown that their molecular wave functions may extend over an entire nanotube due to their structural symmetry [11, 394–399].

Electrical transport measurements on individual SWCNTs have appeared to confirm this, with electrical conduction appearing to occur through well-separated, discrete electronic states that are quantum mechanically coherent over distances up to 140 nm [11]. Furthermore, studies carried out in a magnetic field indicate shifting of these electronic states due to the Zeeman effect [11]. Figure 13.1 shows an AFM image of one such SWCNT with observed "quantum nanowire" properties.

Current densities of up to 10^{10} A/cm^2 have been claimed for CNT nanowires, and the performance of CNT wires of about 9 nm diameter and about 3 μm length have been claimed to be equivalent to Au nanowires of the same dimensions [11, 25, 399, 400].

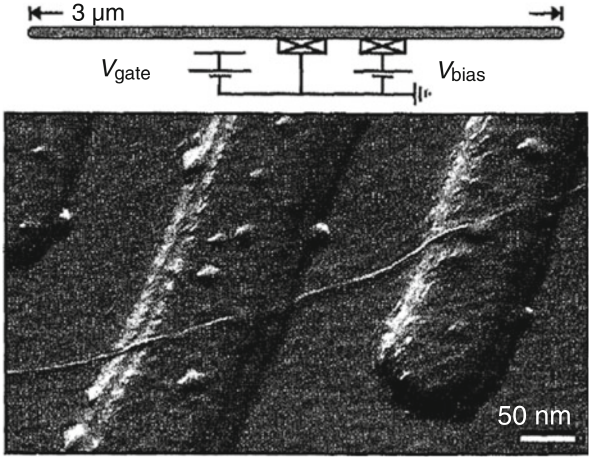

Fig. 13.1 AFM image of a SWCNT with observed "quantum nanowire" properties. The wire sits atop a Si/SiO2 substrate having two 15 nm thick Pt electrodes (seen in the image). The SWCNT shown is of ca. 1 nm diameter and ca. 3 μm long, with ca. 140 nm between the two Pt electrode contacts shown. The third Pt electrode at upper left in the photo is used to apply the gate voltage, as shown in the schematic (After Ref. [11] reproduced with permission)

13.4 Superconductivity

There have been just a few reports of superconductivity in SWCNT-based materials at low temperature, many of which were subsequently not reproducible. Among the most prominent and reproducible studies has been the early study of Tang et al. [401], where SWCNTs with very small diameter were embedded in a zeolite matrix. Among these, those with an approximately 4 Å diameter were found to display superconducting behavior at temperatures below 20 K (with a superconducting transition typically observed at 15 K), as seen via an anisotropic Meissner effect, accompanied by a superconducting gap and fluctuating supercurrent. The authors also showed that their experimental observations agreed with statistical mechanics calculations based on the Ginzburg–Landau free-energy function.

13.5 Problems and Exercises

1. What is, approximately, the highest current-carrying capacity recorded for CNT-based conductors? How does it compare to that of the best among other materials? What are the determinative factors for such high capacities in CNT-based materials? What are the factors preventing the practical implementation of CNT-based conductors, including nm-dimension materials, as of this writing (2016)? As of your reading today?
2. What is a “quantum wire” and how does it defer from a regular conductive wire? In your estimation, what are the factors preventing practical realization and commercial implementation of CNT-based “quantum wires”?
3. What would be the purported advantage of a CNT-based superconductor as compared to more established superconductors, including the higher-temperature “1–2–3” superconductors based on rare-earth materials discovered with much fanfare some decades ago?