Lecture 5. Applications of Single-Walled Carbon Nanotubes

The purpose of the lecture: to provide information on the applications of single-walled carbon nanotubes.

Expected results: to master the applications of single-walled carbon nanotubes.

Microelectronics

Single-walled carbon nanotubes are a model 1D electronic system. The electronic properties of SWCNTs are closely linked to their structure, which is defined by the chiral indices (n, m). Whereas the relationship between n and m defines whether they are metallic and semiconducting, the absolute value of (n, m) defines the magnitude of the band gap in semiconducting SWCNTs. Based on their electronic band-gap (Eg), SWCNTs can be broadly classified into metallic (Eg = 0), quasi-metallic (Eg ≈ kT), and semiconducting (Eg >> kT). It is easy to see that semiconducting SWCNTs could find application as field-effect transistors (FETs) and metallic SWCNTs could be used as interconnects in nanoelectronic circuits, but not vice versa. Indeed, any and all components in nanoelectronics could be constructed out of specific types of SWCNTs, allowing for an all-CNT electronic world, making SWCNTs one of the most versatile electronic materials.

The performance of SWCNTs in electronic devices ensures extremely high carrier mobility and ballistic transport, ambipolar carrier transport, ultrafast switching, zero hysteresis, and extremely high current-carrying capacity. Lately these have all been demonstrated on individual SWCNT devices.

First SWCNT-Based Computer

Miniaturization of electronic apparatus/devices/components has been the major motivation behind the semiconductor industry, and the main improvements in computational power and energy efficiency have been seen in the last two decades. Although advancement in this technology will be continued, there is also a requirement to explore alternative technologies. Digital circuits of transistors based on CNTs have the potential to surpass silicon-based technology by improving the energy efficiency (more than an order of magnitude).

Therefore, CNTs are an exciting accompaniment to existing semiconductor technologies. Researchers at Stanford University announced the world’s first CNT-based computer with a one-bit 178-transistor proof-of-concept processor in September 2013. This CNT computer runs an operating system with multitasking capability. It is a substantial advancement in this field because CNTs are prominent among a variety of emerging technologies that are being considered for next-generation highly energy-efficient electronic devices.

Smaller, faster, and cheaper electronic devices bring with them the problem of heat dissipation due to large circuitry in small volume, which might effect the efficiency of the device. Due to the very high electrical and thermal conductivities of CNTs, they are extremely efficient for conducting and controlling electricity and heat. They are so small that it takes very small energy to switch them off. The combination of efficient conductivity and low energy to switch off make CNTs excellent candidates to serve as smart electronic transistors. Energy dissipation in silicon-based systems has been a major concern and is a major benchmark in pushing CNTs toward practical use.

Solar Cells

One of the promising applications of SWCNTs is their use in solar panels, due to their strong characteristic of UV/Vis/NIR absorption. Research has shown that they can provide a sizable increase in efficiency. Solar cells developed at the New Jersey Institute of Technology use a CNT complex, formed by a mixture of CNTs and fullerenes to form snake-like structures. Fullerenes trap electrons, but they cannot make electrons flow.

Sunlight excites the polymers, and the buckyballs will grab the electrons. CNTs, behaving like copper wires, will then be able to make the electrons or current flow.

Additional research has been conducted on creating SWCNT hybrid solar panels to increase the efficiency further. These hybrids are created by combining SWCNTs with photoexcitable electron donors to increase the number of electrons generated. It has been observed that the interaction between the photoexcited porphyrin and SWCNT generates electron–hole pairs at the SWCNT surfaces. This phenomenon has been observed experimentally and contributes practically to an increase in efficiency.

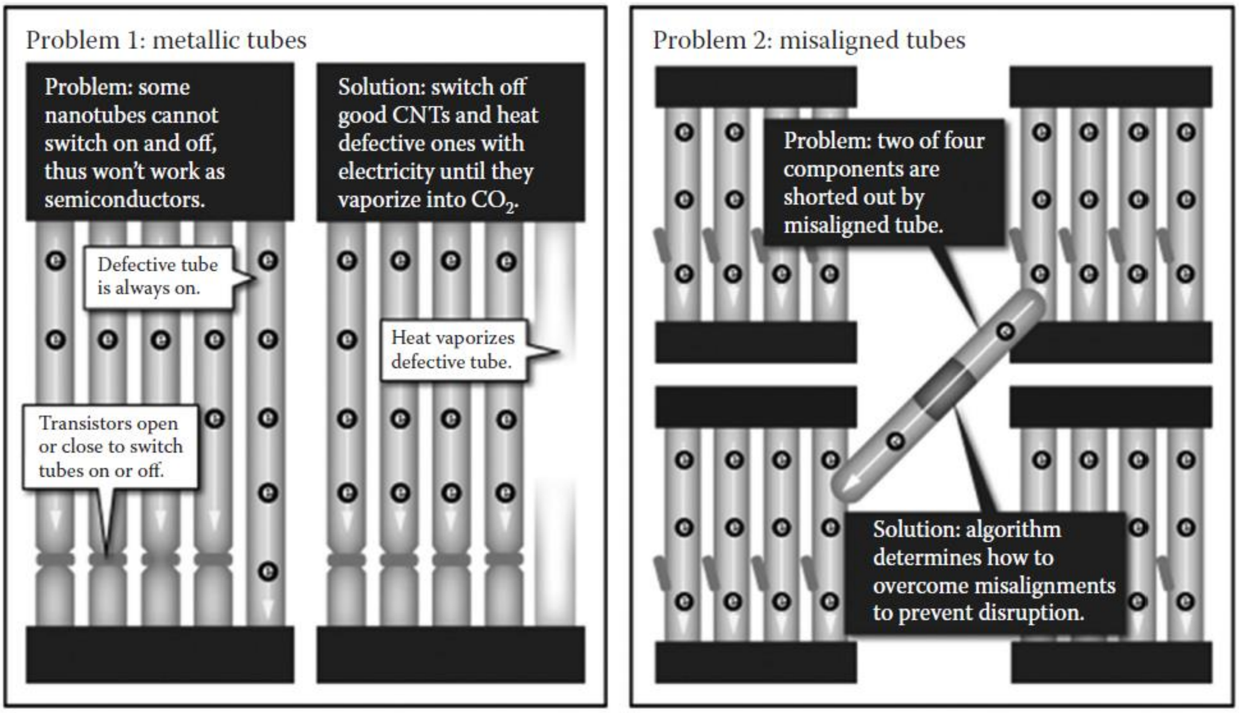

FIGURE. A scheme for the problems and their solution in designing a CNT-based computer.