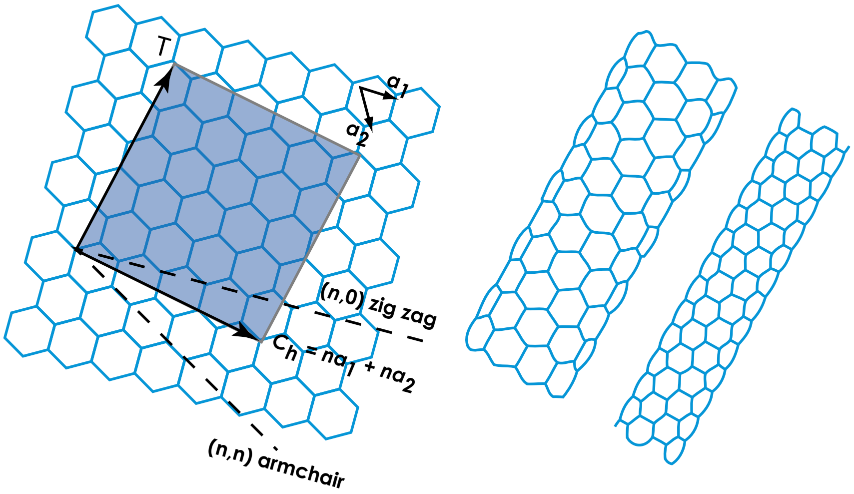
Nanotailor, Inc.

Single-Walled Carbon Nanotube Technology

What are Single Walled Carbon Nanotubes (SWNTs)?



Carbon nanotubes (CNTs) are an allotrope (form) of carbon with a cylindrical form The various types of CNTs include Single Walled Carbon Nanotubes (SWNT), Double Walled Carbon Nanotubes (DWNT) and Multi-Walled carbon Nanotubes (MWNT). Nanotubes possess extremely valuable properties that make them useful in a wide variety of applications including, nanotechnology, electronics, optics and material science. Properties of interest are their high thermal and electrical conductivity, tremendously high mechanical strength, high chemical resistance, diminutive size, low density and optical activity. No other material has such a high number of these properties existing at one time, especially at the magnitudes that CNT provides. These are among the may reasons CNT's are valuable specialty materials.

The most interesting CNT are SWNTs. SWNTs are a single cylinder construct. Its electrical, mechanical and thermal properties are superior to the other CNTs. These tubes have a diameter between 0.7 and 7.0 nanometers (nm) whereas the length of a nanotubes can easily reach lengths of 15,000 nm. Although DWNTs and MWNTs are nanoscopic in diameter, their aspect ratio (diameter to length ratio) does not yield the same surface area or the interaction that is possible due to the large surface area SWNTs provide.

DWNT and MWNT have attractive properties for a wide variety of applications due to the low cost. For example, when the highest electrical conductivity is not required, these can be substituted for SWNTs at a lower cost. However, when ultimate properties are required, there are no substitutions for the Single Walled Carbon Nanotube.

Benefits

Why are SWNTs interesting?
Carbon nanotubes are being used in a wide variety of applications. These include applications such as medical, microelectronics, microanalysis, material science and chemical containment.

Applications

Medical

SWNTs offer the opportunity for improved medical treatments. Some examples include ultrasmall, implantable defibrillators (pacemakers); smaller, more portable field equipment; improvements on implantable biosensors; smaller and improved hearing aids; better access to electrochemical analysis of biological materials; and use as a delivery agent of medicines and other treatments at the cellular level.

Developing a low cost useful material fabricated entirely of SWNTs is still years if not decades away. Buckypaper is a material fabricated entirely of SWNTs. However, it doesn't have high cohesion strength, and as a result it easily tears. Therefore, SWNTs have to be incorporated into other materials to realize their potential. As such much investigation in SWNT incorporation into other materials has been performed. SWNTs are up to 250 times stronger than steel and around 10 times lighter. There are various military examples which can utilize these features such as armored technology including bullet proof vests, tank bodies and warrior helmets; as well as structural appliances such as aircraft wings, helicopter blades and ballistics. Other applications include futuristic cabling for a space elevator which allows materials and equipment to be launched from the earth into geosynchronous orbit, as well as high performance athletic equipment (bikes, golf clubs and baseball bats, for example).

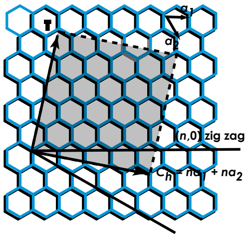
SWNTs thermal properties are on the order of diamonds which is an order of magnitude higher than aluminum, silver, gold and copper. Thus, SWNTs can allow materials near very hot sources such as engines, flames and other heat sources to efficiently offload thermal input. SWNTs thermal properties are augmented by its mechanical properties for high stress, high heat applications such as space craft re-entry, pistons in engines, etc. As a result, these combined abilities provide for improvements which may lead to new optimization for many heat sources, heat exchangers, engines and associated technologies.

Another extremely beneficial property is its electrical conductivity (on the order of that of Copper). Given, its thermal, strength and dimensional properties, SWNTs offer many opportunities of exploitable applications. A small survey of these applications includes ultra small and efficient utility lines for electrical and telephone service, electro-magnetic interference shielding for various applications including aircraft, lightning strike surfaces for applications such as buildings and air crafts, and organic electronics and devices such as photovoltaics, capacitors, circuits and device connectors.

SWNTs are especially attractive for incorporation into matrices (the material in which SWNTs are incorporated). SWNTs can enhance a wide variety of organic and metallic matrix properties by incorporating less than 5% SWNT by weight into the matrix. These enhancements are made even more attractive as the density of SWNTs are very low, and can improve matrix properties without altering weight negatively.

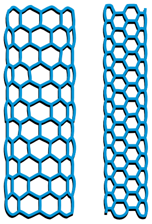
Depending on its chirality or specific molecular configuration as is shown in Figures 1 and 2, SWNTs are further differentiated. That is, armchair SWNTs can behave like metals. Other chiral forms are semiconducting/semi-metallic. As a result, the electrical and optical properties of SWNTs can provide very specific device performance.

Figure 1:



Definition of chirality

Figure 2:



Examples of a 10,0 armchair (right) and a 5,5 zig-zag (left) nanotubes

There are several other technologies and applications for which SWNTs have shown promise, making them the world's most promising material technology.

Applications

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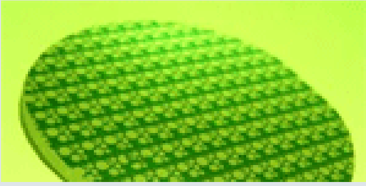
Microelectronics



SWNTs offer low resistivity, low mass density, and high chemical and thermal stability for improved device performance. These properties give promise to areas such as microcircuits, nanowires, and transistors for miniature electronics.

Consumer Products

SWNT properties will lead to improvements in consumer products such as pagers, cell phones, laptop and handheld computers, as well as, toys, power tools, and automotive components.

Scanning Force

Because of the size, mechanical and electrical properties of SWNTs, they make excellent probing tips for specialized microscopy.

What are their limitations?

Although the promise of these materials is tremendous, it has been found that integration of SWNTs into materials is very difficult. Firstly, SWNTs are made of SP2 hybridized carbon atoms. This means that carbon which naturally desires to be connected with four other species will only be connected to three other Carbons. This architecture gives SWNTs their unique properties and chemically results in many difficulties when integrating them into other materials. Secondly, the aspect ratio of SWNTs is on the average many thousands (or more) to one which results in a very large surface area. Given its strong preference for itself and its large surface area, SWNT molecules more readily bind to themselves forming SWNT bundles rather than mixing uniformly with the desired matrix molecules.

Mechanical separation through sonication and/or high shearing can temporarily separate the molecules. Other technologies have been researched including surfactants, in-situ polymerization and mechanical mixing. These technologies have partially worked but do not totally overcome SWNTs strong affinity to themselves. Therefore, bundling will occur over time, resulting in sub-optimal dispersion. Overcoming this limitation is paramount to realizing the true strength of SWNTs as a composite filler.

The most recent technology to combat these SWNT limitations for nanotubes is functionalization. In this technology, small molecules are inserted on the SWNT's backbone post-production as shown in Figure 3. The technology degrades the backbone of the nanotube via the use of harsh acids and then the backbone is regenerated through functionalization. However, holes in the backbone are invariably left which are labeled defects. The resulting functionalized SWNT is more easily incorporated into a wide variety of materials; however the SWNT properties are degraded due to the high number of defects.

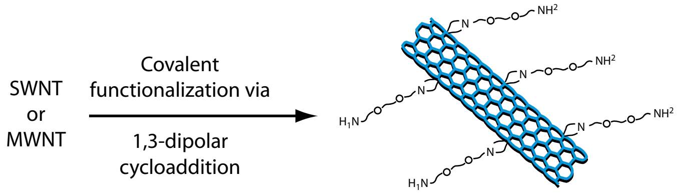


Figure 3: Functionalization of a SWNT molecule using a small chain di-amine.

Lastly, nanotubes are conventionally manufactured via a metallic catalyst. OSHA and EPA have found that these metal catalysts are harmful , . And so, improved technology is required to either remove these catalyst or to form nanotubes without the use of metals in the first place.

Why is Nanotailor the answer?

Our Tubes Are Better For Two Significant Reasons

Nanotailor's SWNTs are produced without a metal catalyst and they are functionalized during production, not after as in other processes. This means that chemical treatment is not required to remove metal impurities and that acids are not required to functionalize our SWNTs. Therefore our SWNTs have no defects or structural limitations, as they are not exposed to harsh acids. Moreover, they are safer and healthier due to the lack of metal impurities. Thus, these materials can be easily incorporated into other materials without the limitations provided by similar products in the marketplace.

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[1] es.epa.gov/ncer/publications/nano/pdf/lamNT-Tox-EPA-NSF-Talk-Breviated.pdf
[2] www.osha.gov/dts/chemicalsampling/data/CH_244000.html

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SWNTs last longer and perform better than conventional silicon as tips in materials science research and development, production quality control of semiconductor materials, data storage media, and evaluation of biological samples.

Materials

SWNTs do not negatively affect a polymer's mechanical properties. Instead, SWNTs reinforce the composite allowing for higher amounts of stress, transition, and thermal strain to be observed. Examples include long-lasting bone and joint implants, or as dopants to create electrically conductive polymers, or as a monitor of composites in critical applications (e.g., aircraft).

Molecular Containment

SWNTs can also be used to contain various elements such as Hydrogen for fuel cells and Lithium boron hydrate for radiation shielding.