



Carbon Nano-
tubes: Present
and Future
Commercial
Applications

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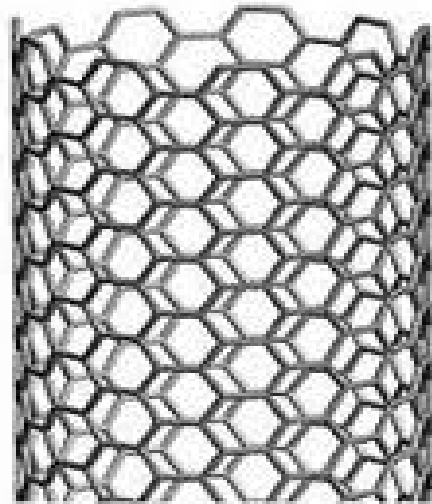
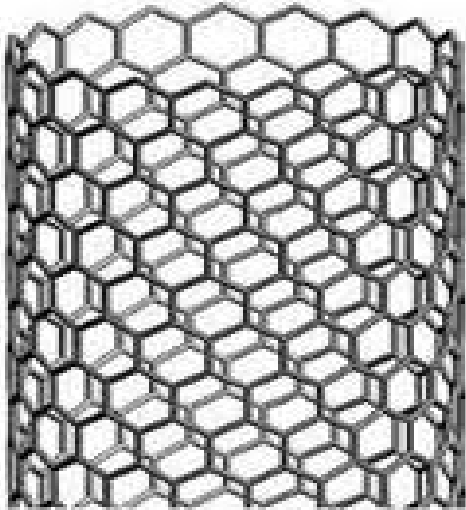
Outline

- ***CNT Types, Properties***
- ***CNT Synthesis and Processing***
- ***CNT Applications***

- I. Fabrication*
- II. Coating and Films*
- III. Microelectronics*
- IV. Energy Storage*
- V. Environment*
- VI. Biotechnology*

What is CNT:-

Carbon nanotubes (CNTs) are seamless cylinders of one or more layers of graphene.

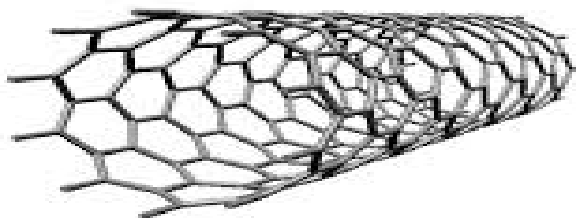


CNT TYPES:-

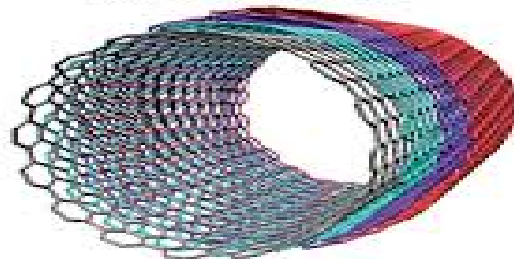
Two types of CNT

1. *SWNT(Single wall Nano tubes)*
2. *MWNT(Multi wall Nano tubes)*

Single-walled CNT



Multi-walled CNT



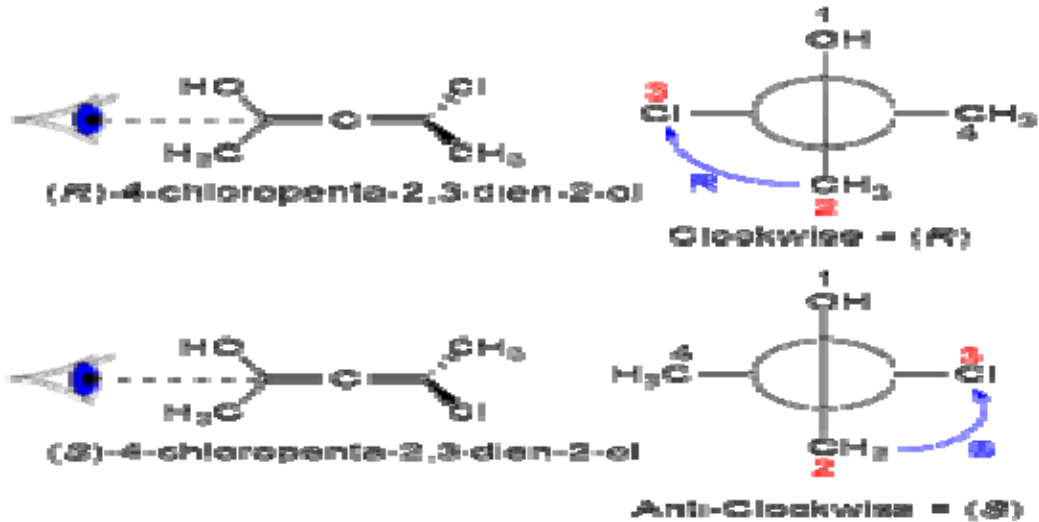
Comparison

SWNT	T
<ul style="list-style-type: none">• <i>Open ended Structure.</i>	<ul style="list-style-type: none">• <i>Closed ended Structure.</i>

<ul style="list-style-type: none"> • 0.8 to 2 nm Diameter. 	<ul style="list-style-type: none"> • 5 to 20 nm Diameter.
<ul style="list-style-type: none"> • May be Metallic or semi-conductor. 	<ul style="list-style-type: none"> • Only conductive.
<ul style="list-style-type: none"> • Thermal conductivity of $3500 \text{ W m}^{-1} \text{ K}^{-1}$ at room temperature, based on the wall area. 	<ul style="list-style-type: none"> • Carry currents of up to 10^9 A cm^{-2}.

CHIRALITY

Individual CNT walls can be metallic or semiconducting depending on the orientation of the graphene lattice with respect to the tube axis, which is called the chirality.



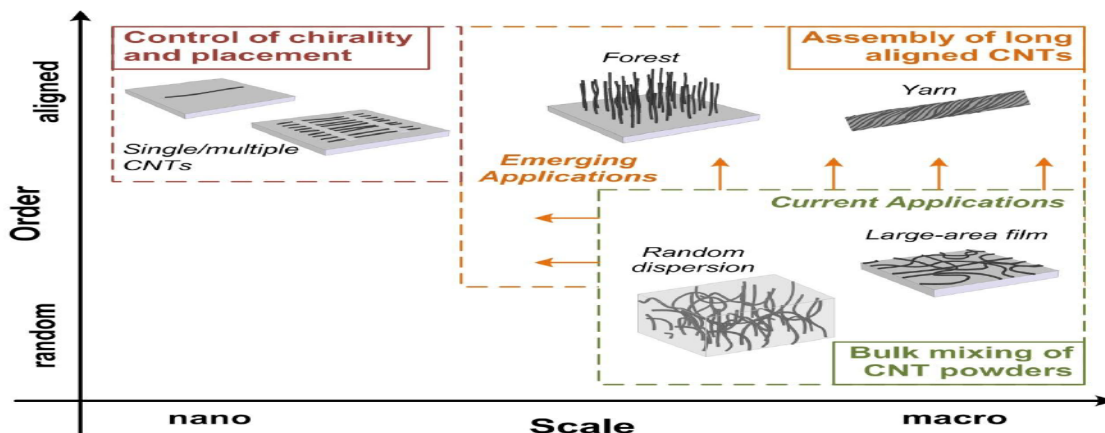
Organizes and Un-Organized CNT:-

Organized CNT :-

They are self aligned either in vertical or horizontal direction.

Un-Organized CNT:-

They are randomly orientated.



Synthesis and Processing of CNT:-

- **Synthesis of MWNT:-**

Using CVD(Chemical vapor deposition) with the fluidized bed reactors that enable uniform gas diffusion and heat transfer to metal catalyst nanoparticles.

- **Benefits of CVD Method:-**

Use of low cost feed stocks, yield increases, and reduction of energy consumption and waste production have substantially decreased MWNT prices.

- **Draw-backs of CVD Method:-**

CVD methods yield contaminants that can influence CNT properties and often require costly thermal annealing and/or chemical treatment for their removal. These steps can introduce defects in CNT sidewalls and shorten CNT length.

Stable CNT Suspension Synthesis

Stable CNT suspensions requires chemical modification of the CNT surface or addition of surfactants. Washing or thermal treatment is typically needed to remove surfactants after deposition of the solution, such as by spin-coating or printing.

Synthesis of long, aligned CNTs

These methods include self-aligned growth of horizontal and vertical CNTs on substrates coated with catalyst particles and production of CNT sheets and yarns directly from floating-catalyst CVD systems.

CNT Plastics

- *MWNTs were first used as electrically conductive fillers in plastics.*
- *Disordered MWNT-polymer composites reach conductivities as high as $10,000 \text{ S m}^{-1}$ at 10 wt % loading.*
- Applications :-
 - I. *Electromagnetic interference (EMI).*
 - II. *Shielding packages and wafer carriers for the microelectronics industry.*
 - III. *Fuel lines and filters that dissipate electrostatic charge.*

Composite Materials:-

For load-bearing applications, CNT powders mixed with polymers or precursor resins can increase stiffness, strength, and toughness. Adding ~1 wt % MWNT to epoxy resin enhances stiffness and fracture toughness by 6 and 23%, respectively, without compromising other mechanical properties.

Composite Materials Applications:-

- *Tennis racquets, baseball bats, and bicycle frames.*
- *To enhance fiber composites(examples include strong, lightweight wind turbine blades and hulls for maritime security boats that are made by using carbon fiber composite with CNT-enhanced resin).*
- *Fabrication of 1-mm diameter carbon fibers with over 35%increase in strength (4.5 GPa) and stiffness (463 GPa) compared with control samples without CNTs.*

“Fuzzy Fibers”

Created by growing aligned CNTs forests onto glass, SiC, alumina, and carbon fibers.

- *Applications:-*

- I. Lightning strike protection.*
- II. Structural health monitoring for aircraft.*

Formation of Superconducting Wires

Coating forest-drawn CNT sheets with functional powder before inserting twist has provided weavable, braidable, and sewable yarns containing up to 95 wt % powder, which have been demonstrated as superconducting wires, battery and fuel cell electrodes, and self-cleaning textiles.

Addition of CNT in Metals

Addition of small amounts of CNTs to metals has provided increased tensile strength and modulus that may find applications in aerospace and automotive structures. Commercial Al-MWNT composites have strengths comparable to stainless steel (0.7 to 1 GPa) at one-third the density (2.6 g cm⁻³).

Transparent Conducting Films

- *CNT based transparent conducting films used as an alternative to indium tin oxide (ITO) transparent conducting films.*

Comparison

<i>CNT</i>	<i>ITO</i>
<i>Low Cost</i>	<i>High Cost</i>
<i>Flexible Displays</i>	<i>Brittle Displays</i>
<i>Can be deposited from solution</i>	<i>Can not deposited from solution</i>

Other use of CNT

- *Use of CNT in Energy Storage*
- *Use of CNT in Biotechnology*
- *Use of CNT in Microelectronics*
- *Use of CNT Coatings*

Producers of CNT powders and dispersions

Company	Country	URL
Arkema	France/USA	http://www.arkema-inc.com/ http://www.graphistrength.com
Bayer MaterialScience AG	Germany	www.bayer.com http://www.baytubes.com/
BlueNano	USA	www.bluenanoinc.com
Catalytic Materials	USA	http://www.catalyticmaterials.com
Chengdu Organic Chemical Co. Ltd.	China	www.timesnano.com
Cnano	China/USA	http://www.cnanotechnology.com
Eden Energy	Australia/India	http://www.edenenergy.com.au/
Eikos	USA	www.eikos.com
Hanwha Nanotech Corporation	South Korea	www.hanwhananotech.com
Hodogaya	Japan	http://www.hodogaya.co.jp
Hyperion Catalysis	USA	www.hyperioncatalysis.com
Hythane Co	USA	http://hythane.net/
Idaho Space Materials	USA	www.idahospace.com
KleanCarbon	Canada	http://www.kleancarbon.com/
Meijo-nano carbon	Japan	www.meijo-nano.com
Mitsubishi Rayon Co.	Japan	http://www.mrc.co.jp
Mitsui	Japan	www.mitsui.com
Nanocyl S.A.	Belgium	www.nanocyl.com
Nanointegris	USA	www.nanointegris.com
Nanolab	USA	http://www.nano-lab.com/
Nanothinx	Greece	http://www.nanothinx.com
Nano-C	USA	http://www.nano-c.com
Raymor Industries Inc.	Canada	www.raymor.com
Rosseter Holdings Ltd.	Cyprus/USA	www.e-nanoscience.com
Shenzhen Nanotech Port Co. Ltd.	China	www.nanotubes.com.cn
Showa Denko K.K	Japan	www.sdk.co.jp
SouthWest NanoTechnologies Inc.	USA	www.swentnano.com
Sun Nanotech Co. Ltd.	China	www.sunnano.com
Thomas Swan & Co. Ltd.	England	www.thomas-swan.co.uk
Toray	Japan	www.toray.com
Ube Industries	Japan	www.ube-ind.co.jp
Unidym Inc.	USA	www.unidym.com
Zyvex	USA	www.zyvex.com