# CARBON NANOTUBE REINFORCED POLYMERS FOR RADIATION SHIELDING APPLICATIONS

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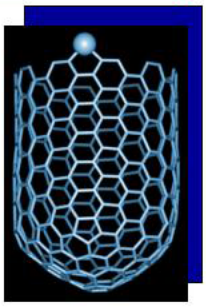
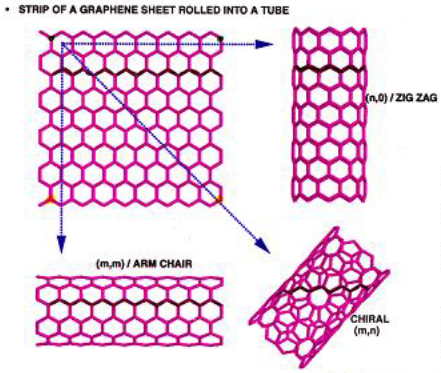
# Carbon Nanotube

CNT is a tubular form of carbon with diameter as small as 1 nm.
Length: few nm to microns.



CNT is configurationally equivalent to a two dimensional graphene sheet rolled into a tube.

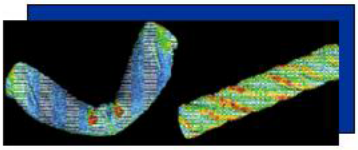


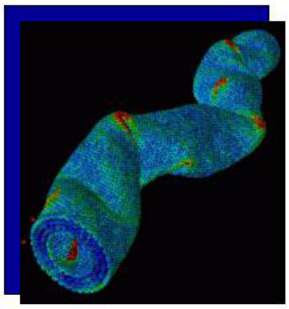

CNT exhibits extraordinary mechanical properties: Young's modulus over 1 Tera Pascal, as stiff as diamond, and tensile strength ~ 200 GPa.

CNT can be metallic or semiconducting, depending on chirality.

# CNT Properties

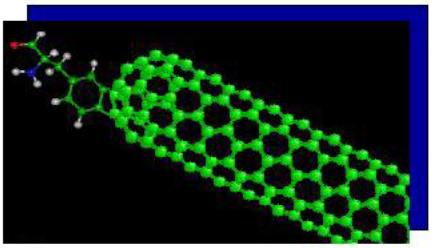
- The strongest and most flexible molecular material because of C-C covalent bonding and seamless hexagonal network architecture
- Young's modulus of over 1 TPa vs 70 GPa for Aluminum, 700 GPA for C-fiber
  - strength to weight ratio 500 time > for Al; similar improvements over steel and titanium; one order of magnitude improvement over graphite/epoxy
- Maximum strain ~10% much higher than any material
- Thermal conductivity ~ 3000 W/mK in the axial direction with small values in the radial direction





# CNT Properties (cont.)

- Electrical conductivity six orders of magnitude higher than copper
- Can be metallic or semiconducting depending on chirality
  - 'tunable' bandgap
  - electronic properties can be tailored through application of external magnetic field, application of mechanical deformation…
- Very high current carrying capacity
- Excellent field emitter; high aspect ratio and small tip radius of curvature are ideal for field emission
- Can be functionalized



# Background

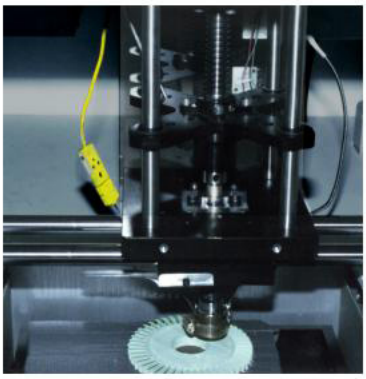
- Extended deep space exploration voyages
  - Human beings and electronics need protection
- Radiation environment
  - Electrons, ions, and secondary neutrons due to particle interactions
- Hydrogen rich materials
  - Better flux shielding characteristics than Al, alloys

## Background (cont'd)

- Addition of carbon to shield materials
  - Improved neutron reflective capabilities
- Hydrocarbon-based polymers
  - Polyethylene (PE) - low neutrons flux transmission
- Extrusion freeform fabrication (EFF)
  - Multiple layers, complex shapes and parts
  - Alignment of fibers - improved properties

# Extrusion Freeform Fabrication (EFF)

The Stratasys 3-D Modeler with retrofitted high-pressure extrusion head



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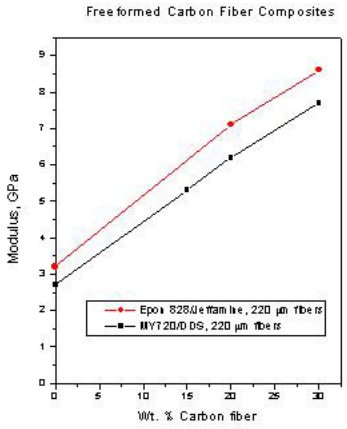


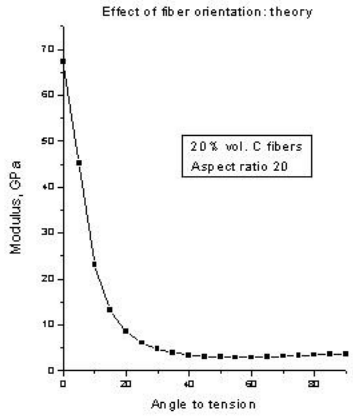

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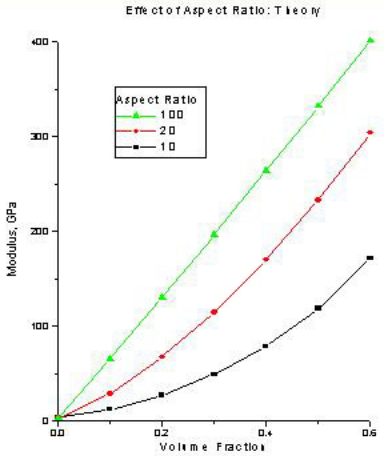

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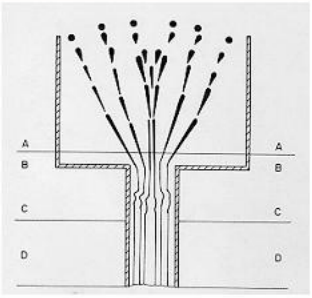
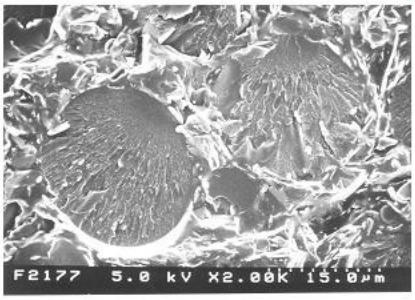
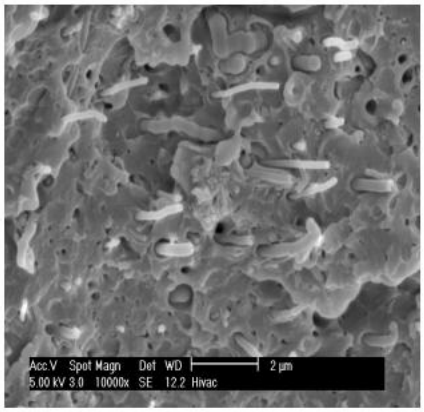



Schematic of fibrillation through an orifice




SEM of PEOx/polystyrene copolymer after EFF/Heat treatment

# Extrusion Freeform Fabrication (EFF)




- Extrusion effect
  - Fracture surface
  - Vapor-grown carbon fiber reinforced composite
  - Shows alignment of the fibers

# Scope of Research

- Addition of carbon nanotubes to PE
  - Functionalization (SWNTs, f-SWNTs)
  - Dispersion and alignment in the polymer
    - methodology and optimization
  - Innovative EFF concept
  - As reinforcing agents
    - improved strength
    - enhanced reflective capability to certain wavelengths of neutron radiation
    - Multifunctionality

# Materials and Experiments

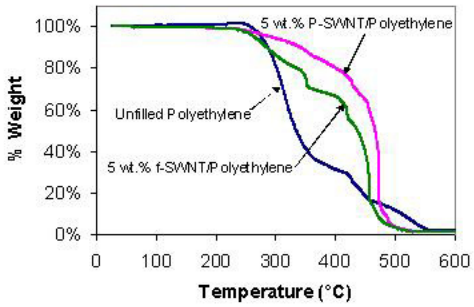
- Single wall nanotubes (SWNTs) from CNI
  - Purified (p-SWNTs)
  - Functionalized via fluorination (f-SWNTs)
- PE (medium $M_w$)
- Dispersion of SWNTs
  - Incipient wetting
  - High shear mixing
- Composite processing
  - EFF, multiple extrusion for alignment improvement

# PE/SWNT Nanocomposites

- Fabricated 2-in diameter samples for radiation testing
- Fabricated 1-in diameter for the MISSE experiment

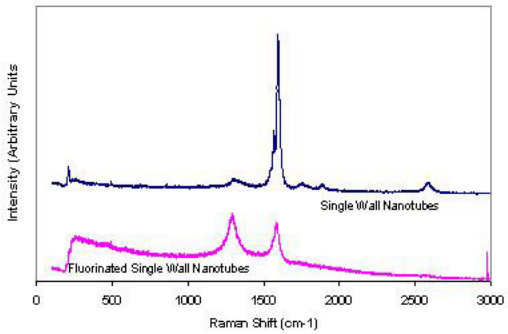
# TGA Analysis

- TGA
  - Comparison between filled and unfilled PE
  - Thermal stability increases with addition of SWNTs (reduced weight loss)
  - Increased oxidation resistance



# Raman Spectroscopy

- Defines alignment of SWNTs in EFF processed nanocomposites
  - Parallel and perpendicular to the extrusion direction
  - Typical Raman spectra (figure)

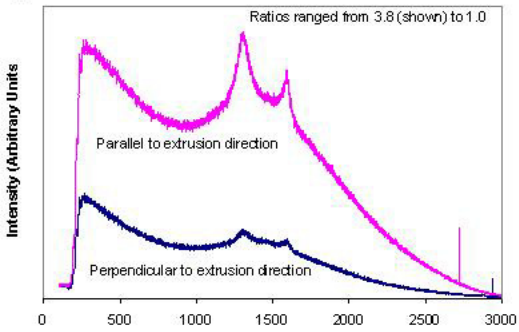


# Raman Spectroscopy (cont'd)

- Improvement in alignment for the f-SWNTs/PE compared to p-SWNTs/PE nanocomposites
  - Possibly due to better dispersion

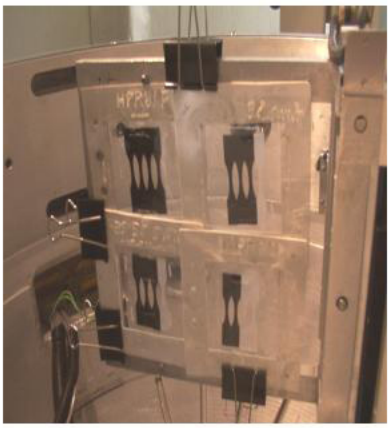
| Composite Blend | Ratio |
|---|---|
| 1.5 wt% f-SWNT/PE | 3.8 |
| 1.5 wt% P-SWNT/PE | 1.29 |
| 5 wt% P-SWNT/PE | 1.35 |

Raman intensity ratios for SWNT/PE composite blends



# Radiation Exposure

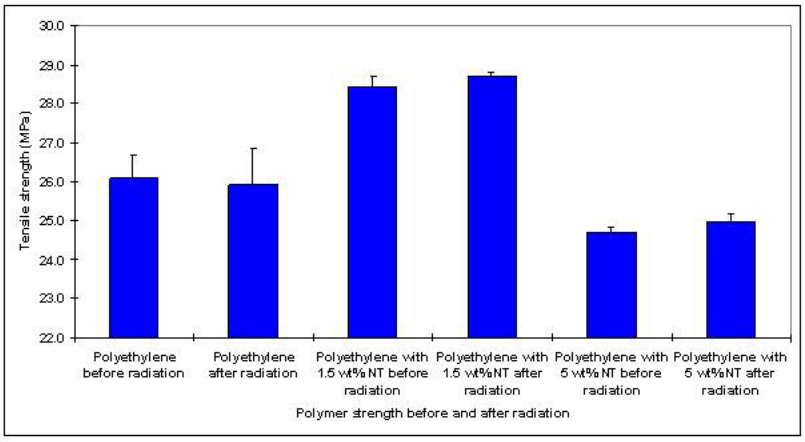
- Radiation testing
  - Texas A&M University Cyclotron Institute
  - Irradiated at 40 MeV,
    - Total fluence of $3x10^{10}$ protons/$cm^2$
    - Flux of $1.5x10^7$ protons/$cm^2$/sec
  - Sample sets in the beamline end station prior to irradiation



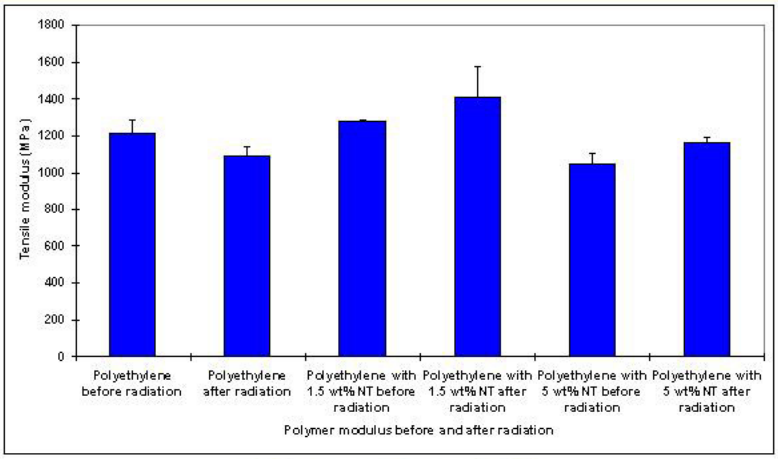
# Mechanical Properties

- Mechanical Testing
  - Tensile tests ASTM D638
  - Non-irradiated and post-irradiated control samples
  - 1.5 wt% for f-SWNTs/PE nanocomposites
  - 5 wt% only for p-SWNTs/PE nanocomposites
  - Fluorination
    - Improved dispersion, improved alignment - improved mechanical properties

# Mechanical Properties



# Mechanical Properties (cont'd)






# Summary

- SWNT addition
  - Improved thermal stability and atomic oxygen resistance for PE
- Preliminary results
  - Alignment of nanotubes improved due to EFF
  - Require improved alignment for better mechanical properties
- Fluorination
  - Improved dispersion, improved alignment - improved mechanical properties

# Summary & Future Work

- Radiation exposure
  - Did not affect mechanical properties of the PE/SWNTs nanocomposites
- Future work focus:
  - Improve the mechanical testing parameters for statistical studies of the properties
  - Comparative study of the properties of PE filled with f-SWNTs and p-SWNTs using the same concentrations

# Acknowledgments

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