Aligned Carbon Nanotube Tape for Sensor Applications

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Background

- Carbon nanotubes (CNT) have been of intense interest since discovery in 1991
- They exhibit superior mechanical and thermal properties as well as unique electrical properties
- CNTs can be either single-wall or multi-wall

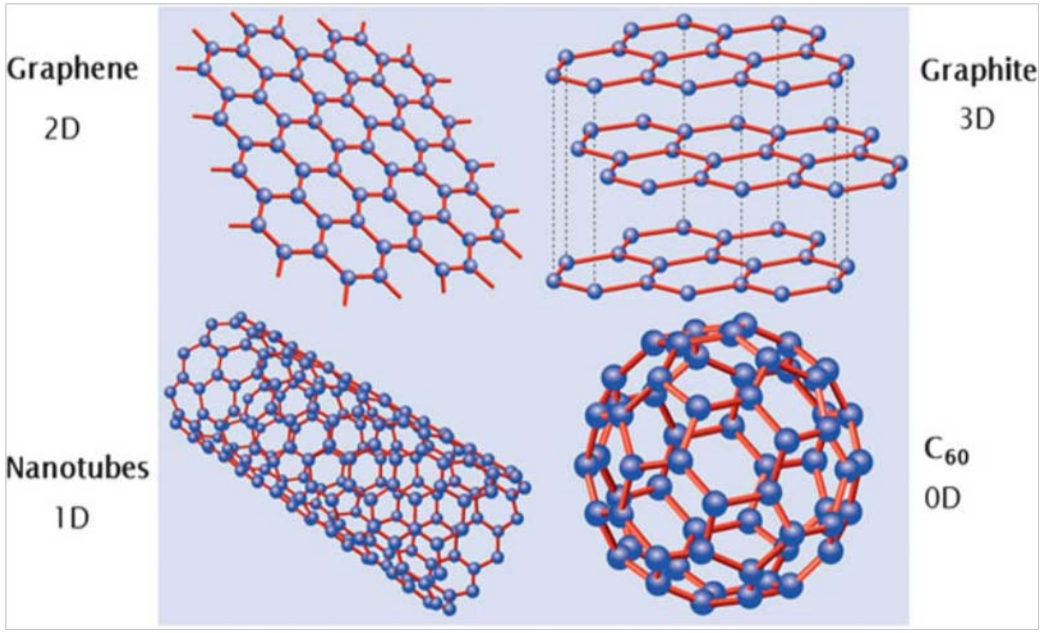
Background

- Synthesis techniques include:

1. Arc Discharge
2. Laser Ablation
3. Plasma Torch
4. Chemical Vapor Deposition (CVD)

Background

CNT is one allotrope of carbon



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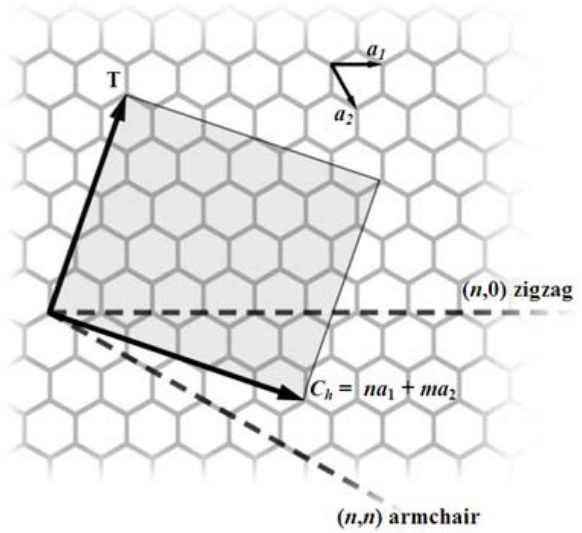
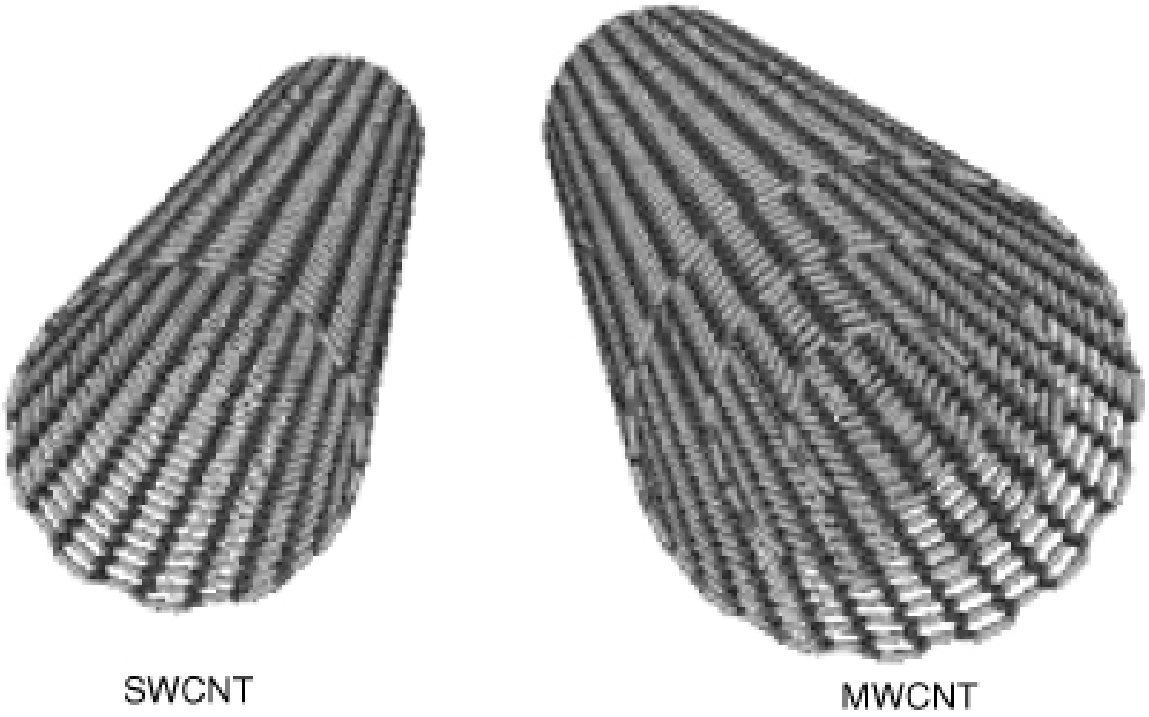


The (*n*,*m*) nanotube naming scheme can be thought of as a vector ($\mathbf{C}_h$) in an infinite graphene sheet that describes how to "roll up" the graphene sheet to make the nanotube. **T** denotes the tube axis, and $\mathbf{a}_1$ and $\mathbf{a}_2$ are the unit vectors of graphene in real space.

Background



SWCNT

MWCNT

Background

CNTs Being Investigated for Various Sensors Including:

1. Pressure Sensors
2. Flow Sensors
3. Acoustic Sensors
4. Chemical Sensors
5. Temperature Sensors

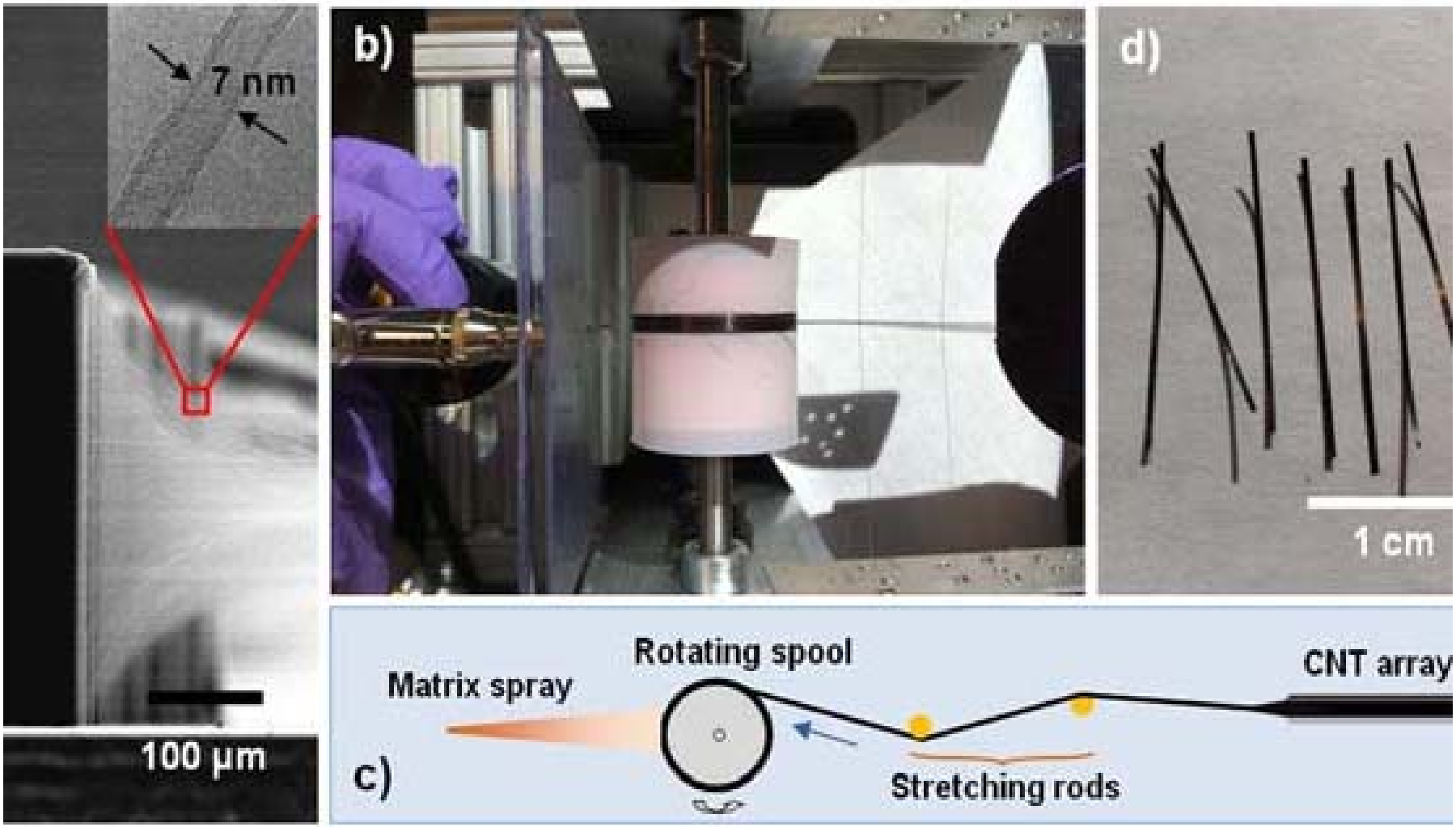
Background

- We are interested in sensor applications for spacecraft including:
- Gyroscopes
- Accelerometers
- Structural Health Monitoring

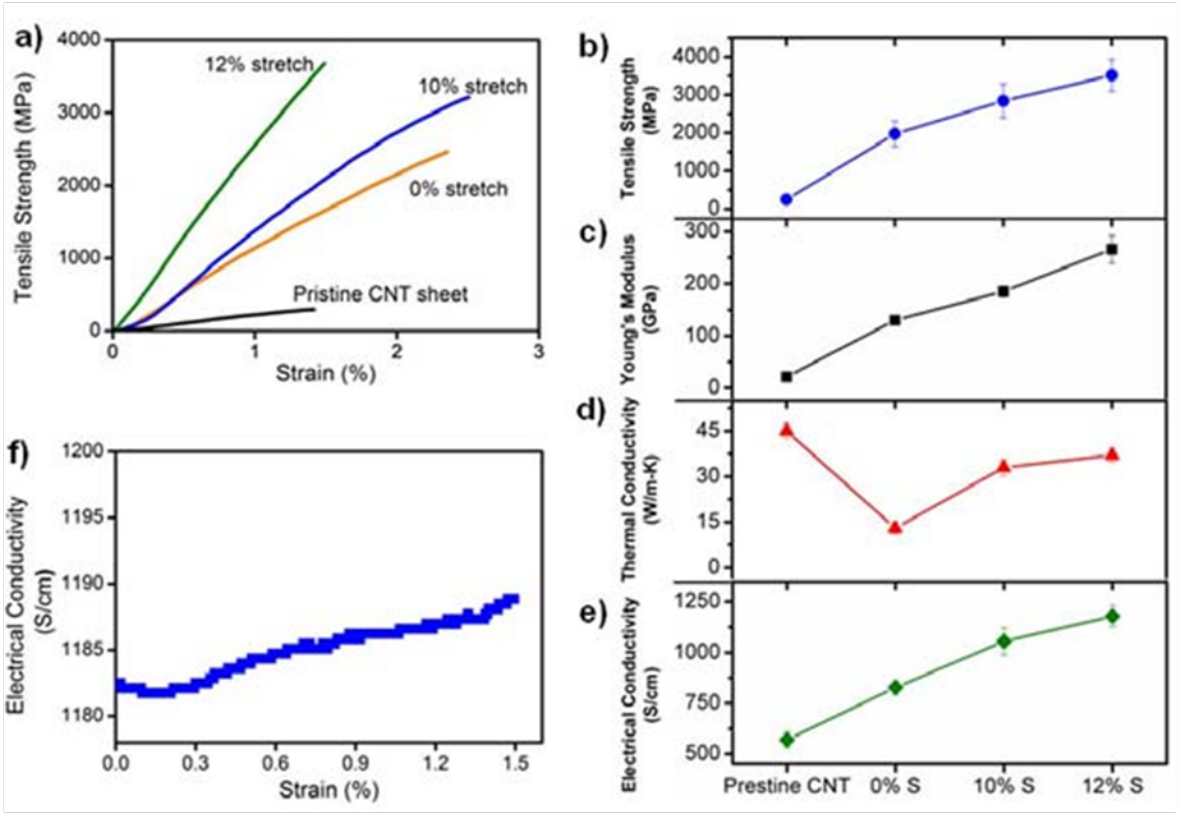
Background

- Professor Yuntian Zhu and his group at NCSU have developed a unique processing method for CNTS
- Vertical arrays of MWCNTs are grown on a silicon substrate via thermal CVD
- Arrays are then drawn into CNT yarn and onto a take-up reel
- During winding, a polymer solution is sprayed onto the CNT yarn => CNT Tape
- Stretching before winding yields a highly aligned CNT Tape

Background


7 nm
100 µm
b)
d)
1 cm
Rotating spool
Matrix spray
CNT array
c)
Stretching rods

Background

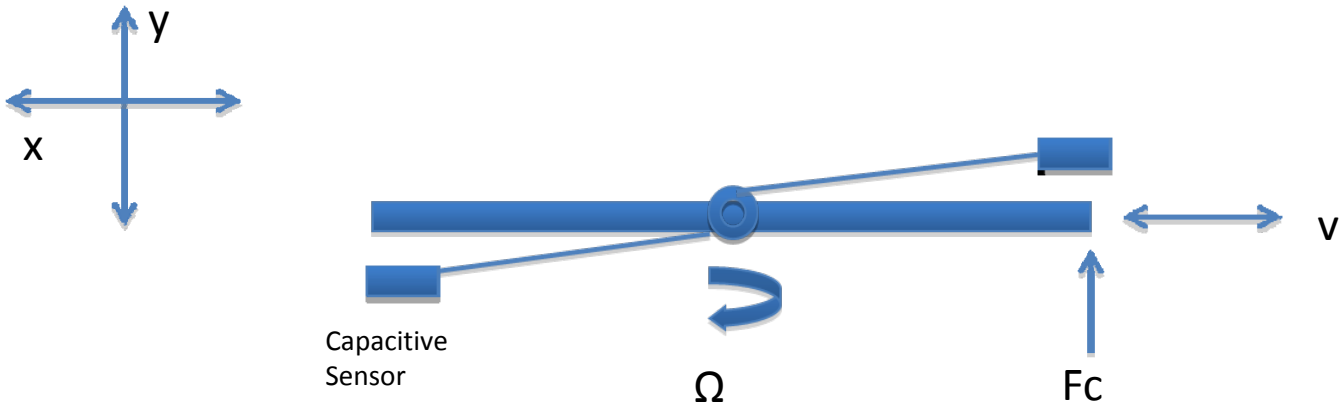

a)
Tensile Strength (MPa)
Strain (%)
12% stretch
10% stretch
0% stretch
Pristine CNT sheet
b)
Tensile Strength (MPa)
c)
Young's Modulus (GPa)
d)
Thermal Conductivity (W/m-K)
e)
Electrical Conductivity (S/cm)
Prestine CNT
0% S
10% S
12% S
f)
Electrical Conductivity (S/cm)
Strain (%)

Technical Approach

For this effort, will concentrate on three applications:

- **Vibration Gyroscope** – utilizes piezoelectric properties of the tape and Coriolis effect
- **Accelerometer** – utilizes the piezoresistive property
- **Strain Gauge** – utilizes piezoresistive property
- Accelerometer and Strain Gauge can also utilize piezoelectric effect

Technical Approach



$$Fc = -2m\Omega \times v$$

Vibration Gyroscope Concept

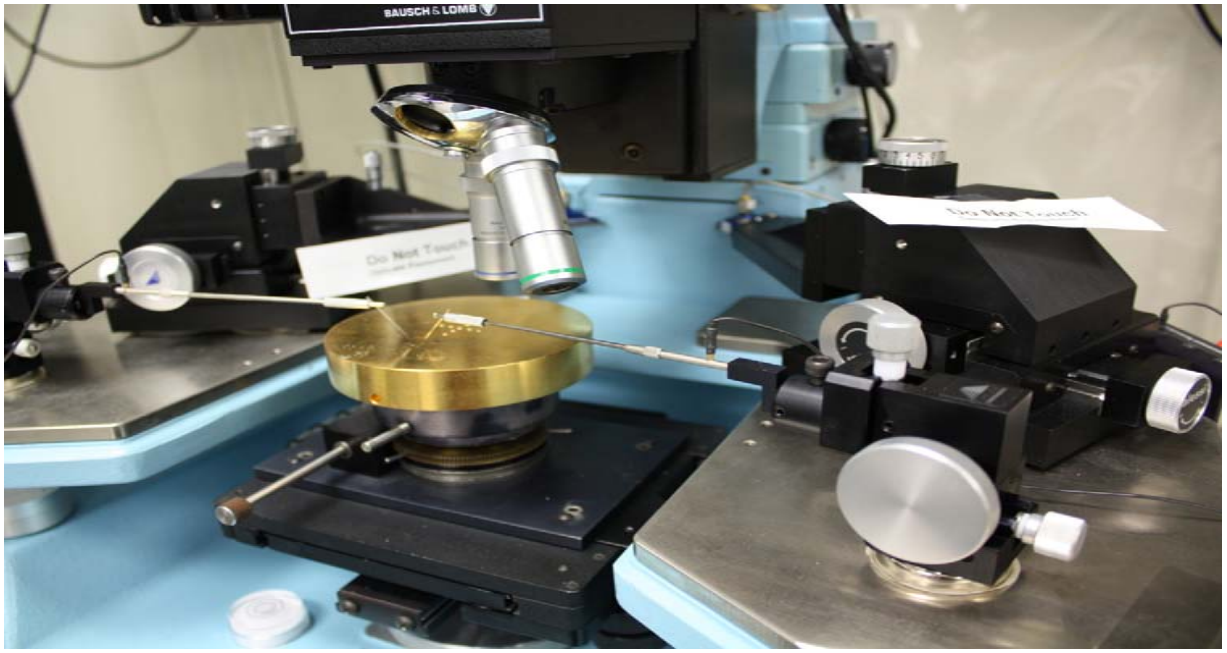
Technical Approach

- Test piezoelectric properties using facilities at the Microfabrication Laboratory (AMRDEC)
- Enhance piezoelectric effect using polyvinylidine fluoride and P(VDF-TrFE) which is readily polarizable – Spray matrix solution while winding fiber; Sandwich of CNT tape and PVDF film (DOE – Two Level)
- Construct and test prototype vibration gyroscope
- Construct and test prototype accelerometer using cantilever design
- Test strain sensitivity of CNT tape against industrial strain gauge
- Embed CNT tape in composite samples as well as on surface and test to failure (4-point bend)

Technical Approach

Radiant Tester Precision Premier II

Technical Approach

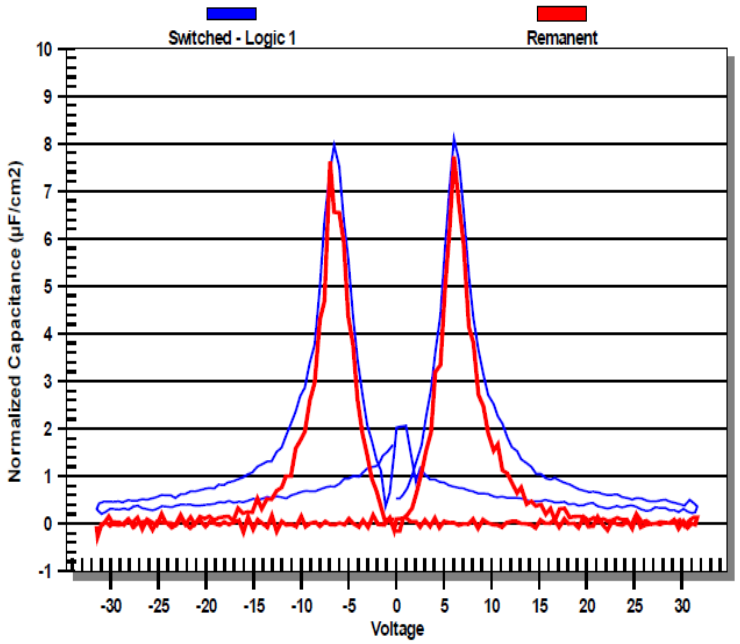


Devices under test (DUT) are set under the probes for the drive signal connection and the return connection.

Technical Approach

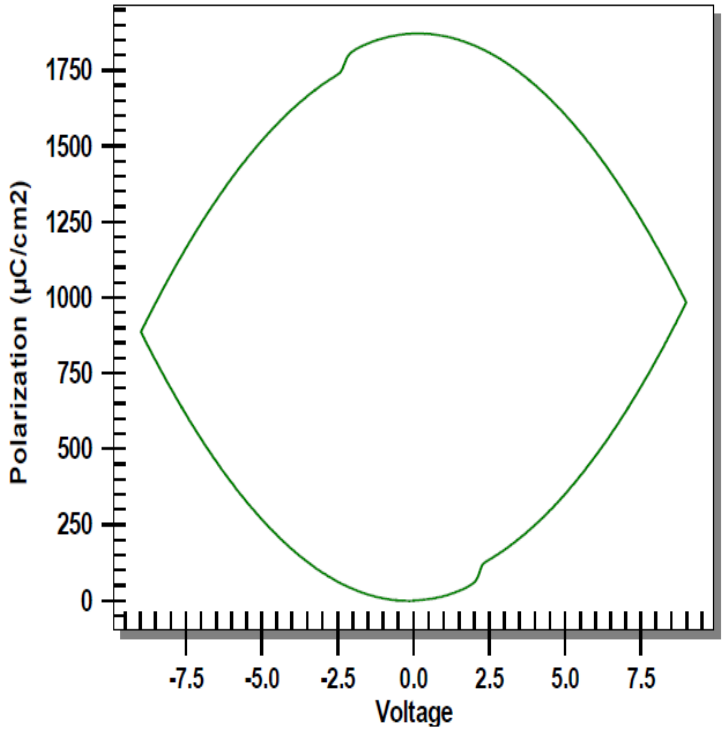
- A piezoelectric device exhibits an electrical response from a mechanical applied stress.
- A piezoelectric device has both capacitance and resistance properties in which by applying an electric field from a waveform will exert a mechanical stress that can be monitored for a response.
- The typical waveform applied is a sinusoidal waveform of a defined voltage for a defined period. The defined voltage is driven from 0 volts to the positive defined volts then back to 0 and driven to negative defined volts then back to 0.
  - Example. Vmax set to 10V and period set to 10 ms.
  - Voltage will start at zero, go to 10 volts, return to zero, go to -10 volts and return to zero during 10 ms.
- Applying this electrical field to a DUT, the capacitance response and resistance response can be observed.

Technical Approach



Using the advance capacitance function allows for the DUT to be stressed with an applied signal to monitor the capacitance response from the applied stress.

Technical Approach



- Using the hysteresis function allows for the DUT to be stressed to monitor the polarization response from the applied electrical field.
- This a typical resistance response.

Technical Approach

Advantages of using CNT Tape

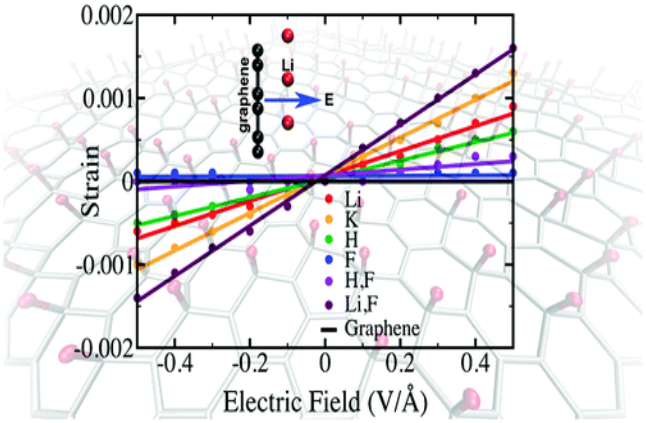
- CNT tape is easier to manufacture and cheaper than micromachining silicon or other ceramic piezoelectric used in gyroscopes and accelerometers
- CNT tape properties can be modified during manufacture for specific application
- CNT tape has enhanced mechanical and thermal properties in addition to unique electrical properties
- CNT tape as a strain gauge in Structural Health Monitoring will provide an excellent material to embed within composite structures

Possible Future Work

- Graphene and CNTs show superior mechanical, thermal and electrical properties
- However, due to crystallographic symmetry considerations, neither of these materials are piezoelectric
- Graphene, a 2-D material shows mirror symmetry
- CNTs can be achiral and chiral
- Achiral nanotubes such as zigzag and armchair show mirror symmetry
- Chiral nanotubes show inversion symmetries

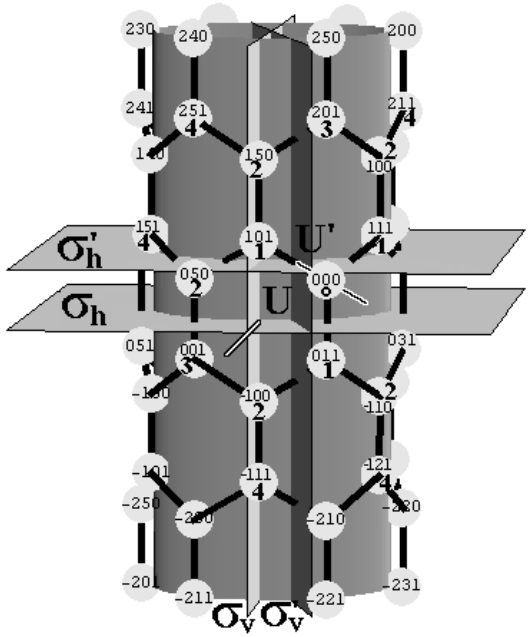
Possible Future Work

- One method to break crystallographic symmetry is through ion adsorption
- In graphene, Ong and Reed used DFT to show that adsorption of Li on one side of graphene or adsorption of Li on one side and fluorine on the other broke symmetry and induced piezoelectric effect



Possible Future Work

- Achiral SWCNTs show mirror symmetries



Possible Future Work

- The mirror symmetry of the achiral nanotube in the previous slide can be broken via ion implantation
- First, vertical arrays of CVD grown CNTS can be ion implanted across one end of the tubes breaking the horizontal mirror symmetry
- Another option is to produce CNT tape and ion implant on one side thus breaking vertical mirror symmetry
- MWCNT's consist of a number of walls/tube of varying types of achiral and chiral tubes
- Assumed the achiral symmetries will be broken yielding the piezoelectric effect

Possible Future Work

- Graphene films will be grown on Cu foils via thermal CVD and removed by dissolving Cu foil with ferric chloride; graphene films will then be placed on suitable substrate
- Sputtering will be used to adsorb ions on one side of the film which will be inverted such that the graphene film does not directly face the target – Reduce knock-on effects
- Ion implantation of vertical arrays and CNT tape will be performed
- Piezoelectric properties will be measured
- Since using Li ions, capacitance will also be measured
- STM will be used to I.D. electron DOS and band structure
- Prototypes for accelerometers, gyroscope and ultracapacitors will be designed and tested

Conclusions

- CNTs have been shown to have superior mechanical, thermal and electrical properties
- Highly aligned CNT tape is superior in all of these areas
- Using PVDF and P(VDF-TrFE) as matrix material will induce piezoelectric effect in the tape
- This piezoelectric tape can then be utilized in vibration gyroscopes, accelerometers and structural health monitoring