Piezoelectric Carbon Nanotube Tape for use in Sensor Technology

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Co-Investigators

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Purpose of Program

- Purpose of research is to develop piezoelectric CNT tape for use as sensing elements in vibration gyroscopes and accelerometers for small satellites
- CNT/P(VDF-TrFE) tape has potential to be robust with high strength and superior thermal properties

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

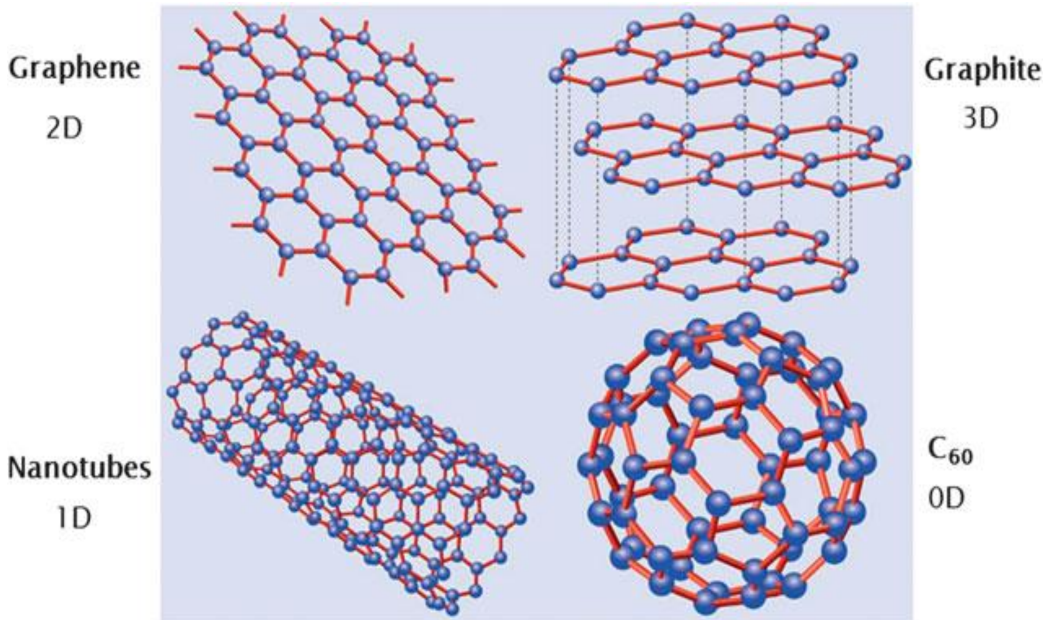
Background

- Synthesis techniques include:

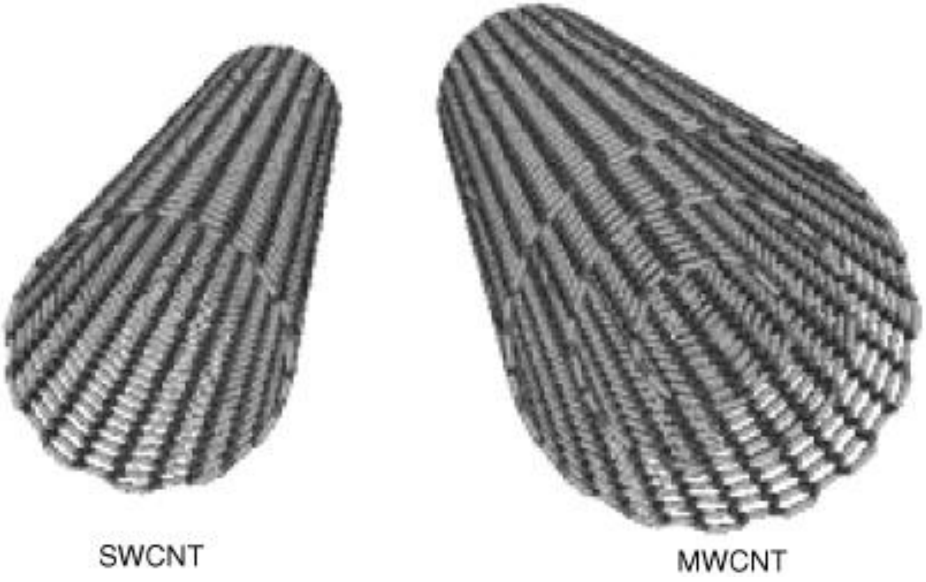
1. Arc Discharge
2. Laser Ablation
3. Plasma Torch
4. Chemical Vapor Deposition (CVD)

Background

CNT is one allotrope of carbon



Background



Background

CNTs Being Investigated for Various Sensors Including:

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

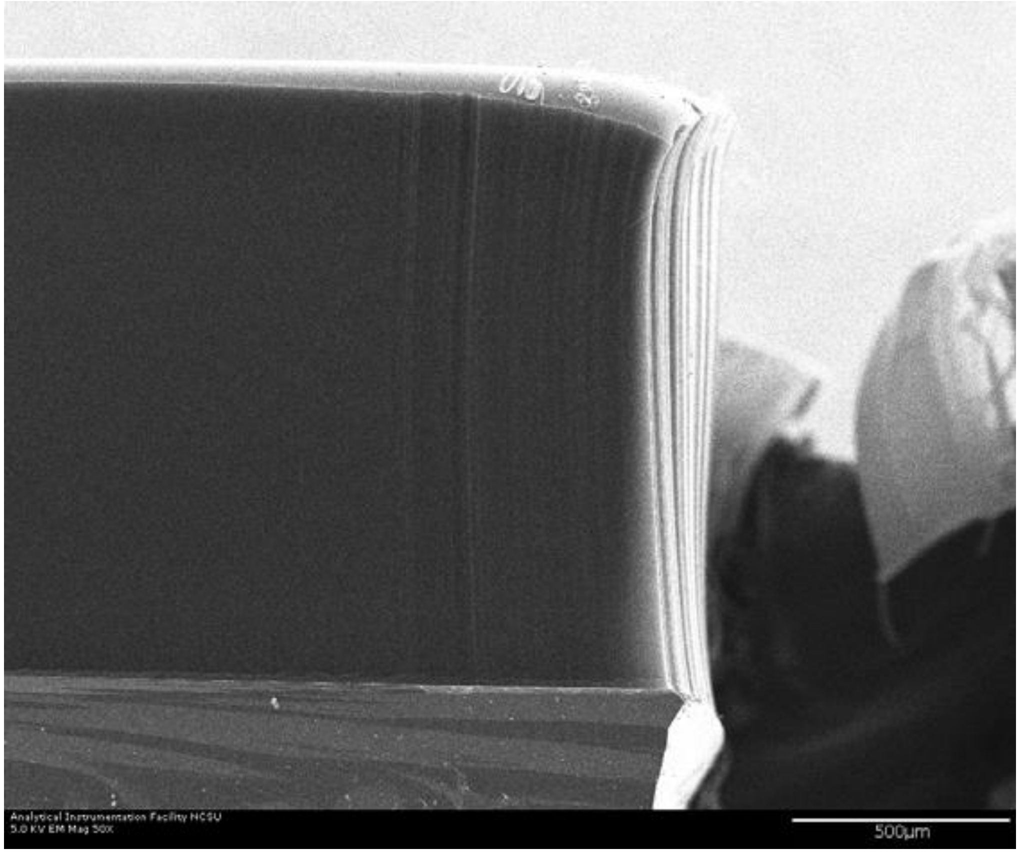
Background

- We are interested in sensor applications for spacecraft including:
- Gyroscopes
- Accelerometers
- Structural Health Monitoring
- These will use CNT Tape as Active Elements

Experimental

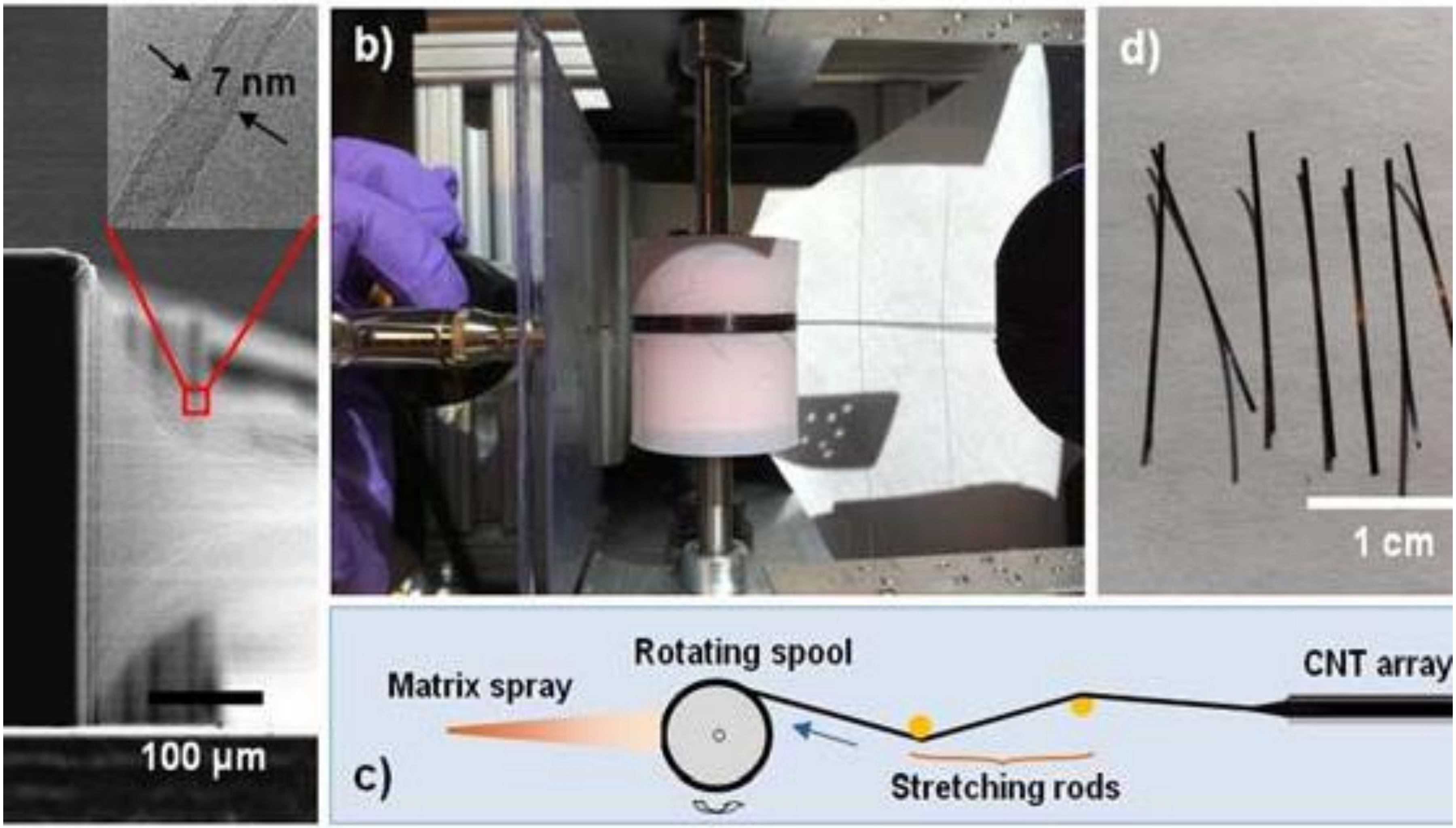
- P(VDF-TrFE) (70/30) Copolymer dissolved in DMSO, 0.2 w/o, 5 w/o and 10 w/o
- Solution sprayed onto CNT tape as it is wound onto take-up reel; 100 micrometers thick
- Tape removed from reel and dried in vacuum oven at 100C for 24 hours
- Tape removed and pressed using glass weight above Curie Temperature to induce beta phase growth; 90 micrometers thick
- Beta phase is most polarizable of all the phases
- 10 w/o $BaTiO_3$ added to solution to increase piezoelectric response
- Piezoelectric Effect measured using Radiant Technologies Tester

Experimental



1.5 millimeter tall vertically aligned carbon nanotube array grown on a silicon substrate.

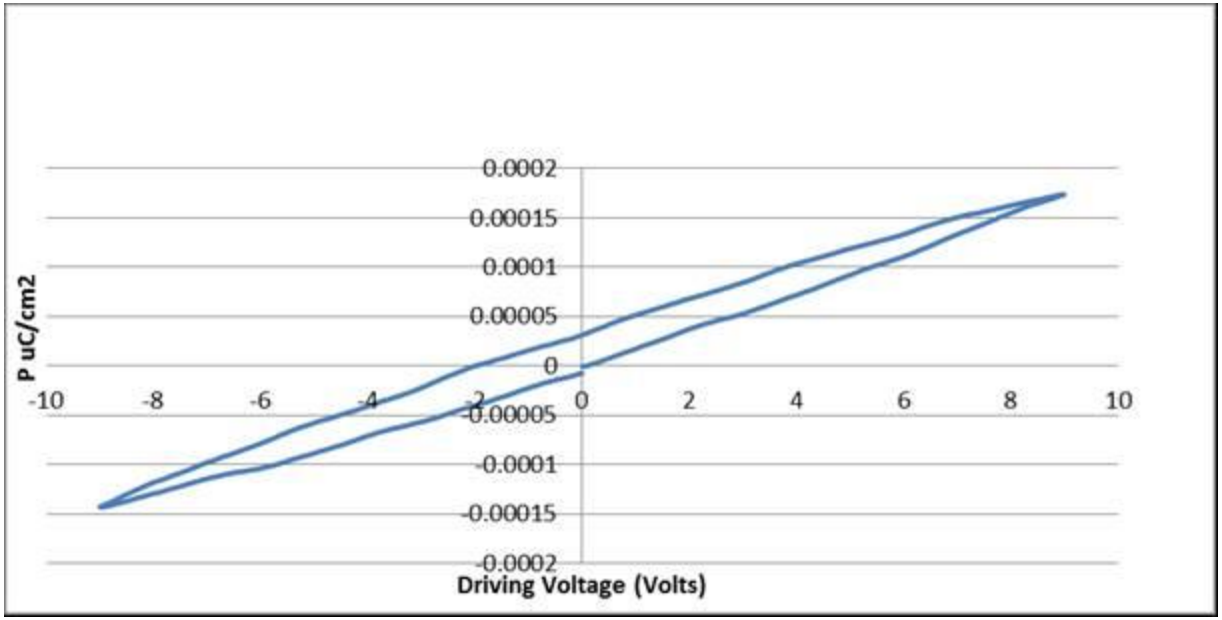
Production of CNT Tape



Results

Initial Hysteresis Curve for CNT/P(VDF-TrFE) 0.2 w/o

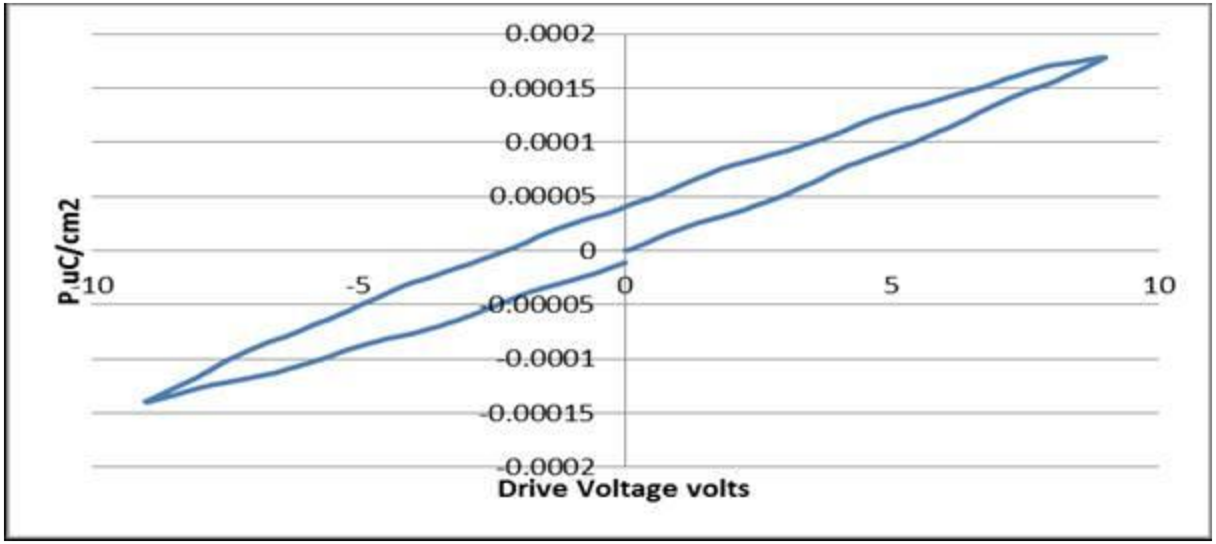
Pr = 16 uC/cm2 – Measured with Radiant Tester



Results

Sample in Previous Slide Direct Poled at 10 Volts for 10 Minutes

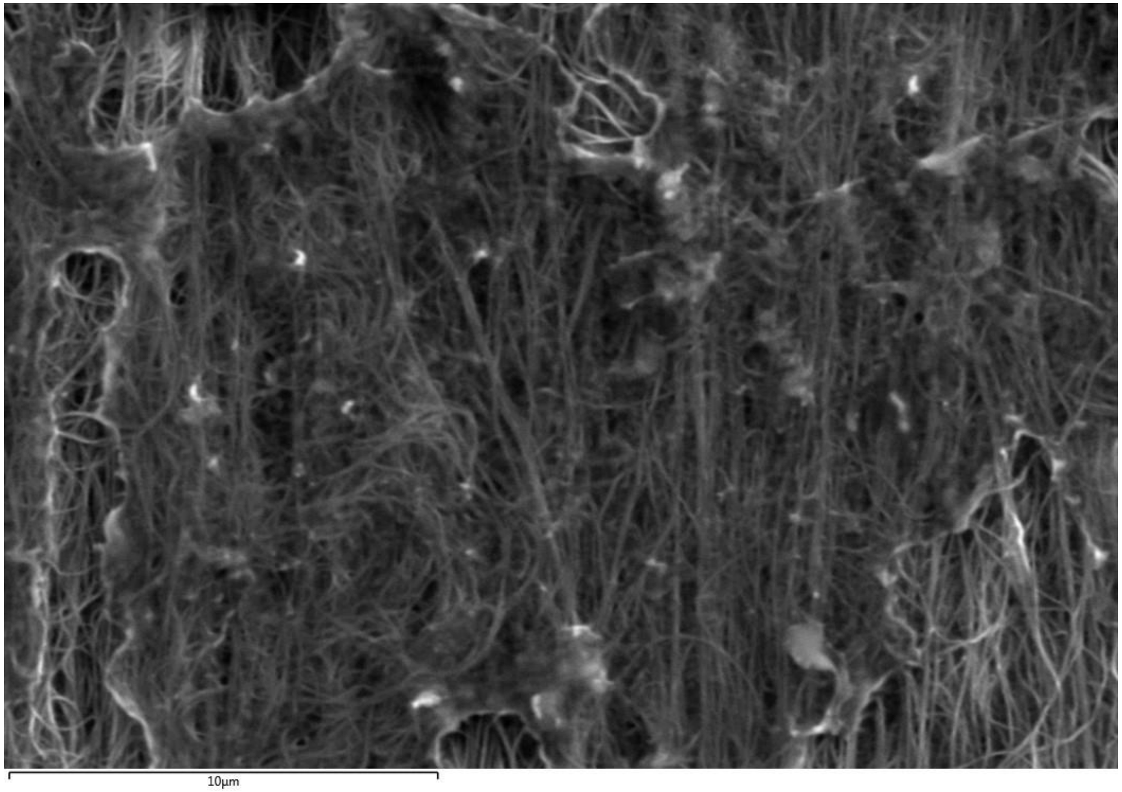
Pr = 22 uC/cm2



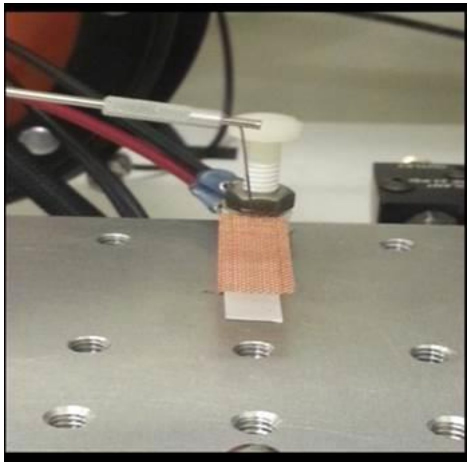
Results

SEM of 0.2w/o P(VDF-TrFE) CNT Tape

500X – SEM Image

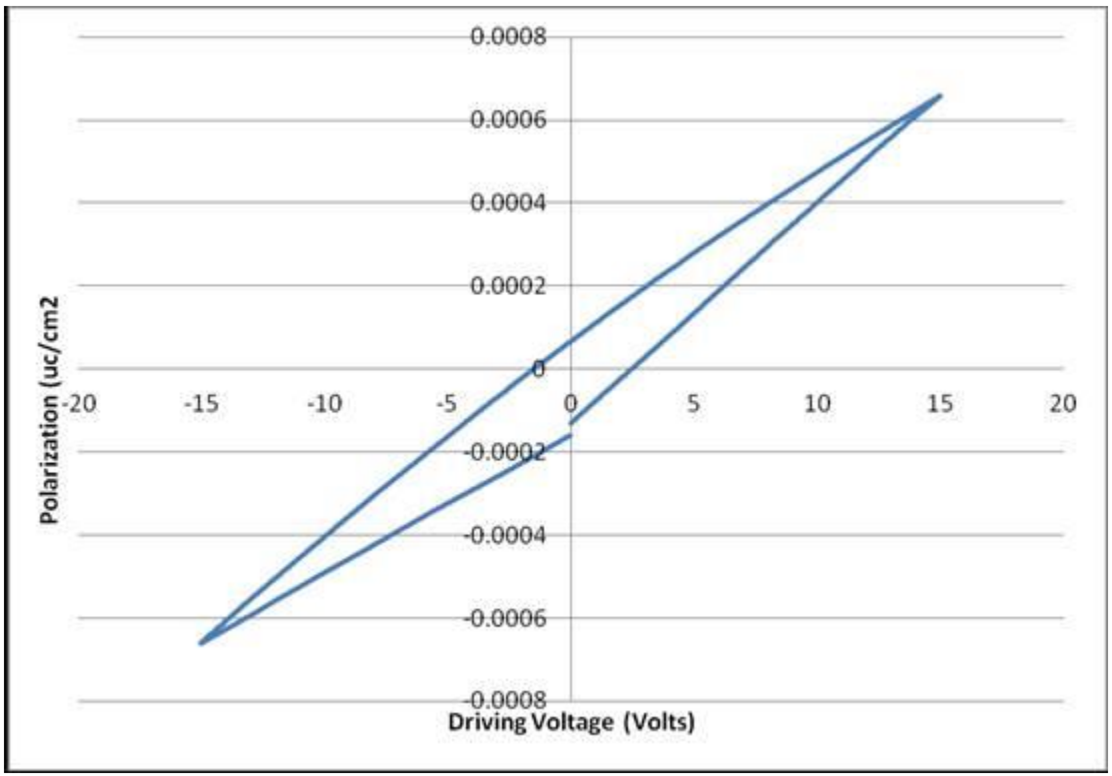


Corona Poling



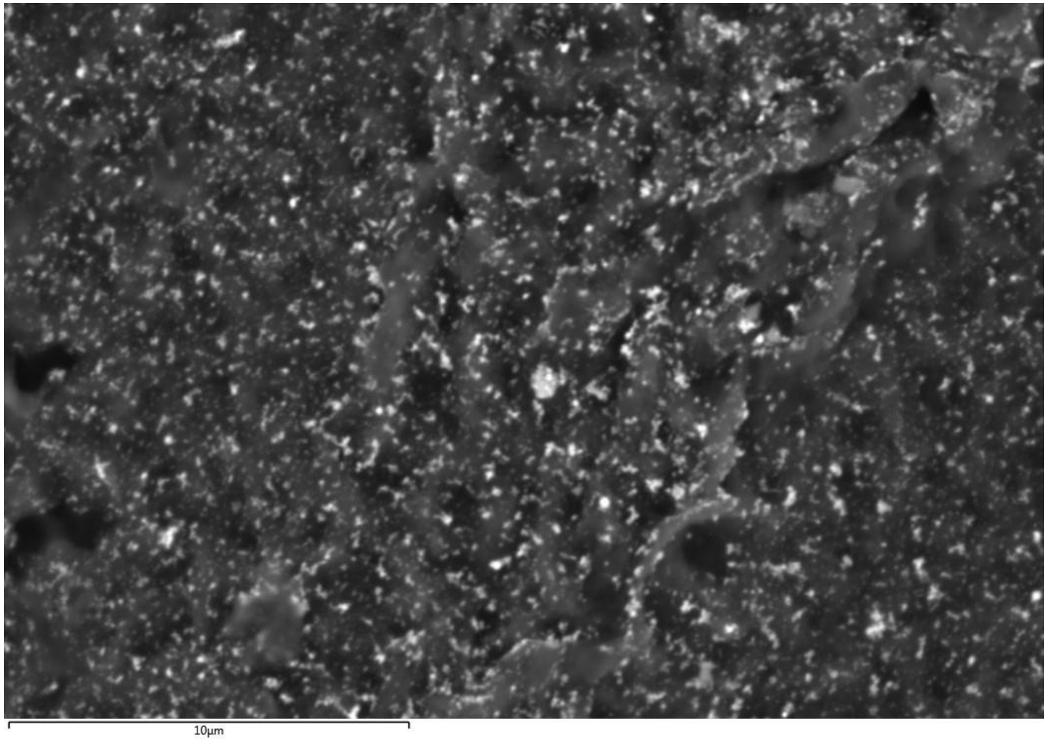
Results

CNT/P(VDF-TrFE)/BaTiO3 (10 w/o) Corona Poled at 2500 V for 20 Minutes
Pr = 61 uC/cm2



Results
SEM CNT/P(VDF)TrFe10/BT10

500X – SEM Image



Piezoelectric Constitutive Equations

- $S_{ij} = s^{E}_{ijkl} T_{kl} + d_{kij} E_k$
- $D_i = d_{ikl} T_{kl} + \varepsilon^{T}_{ik} E_k$

Where:

- S_{ij} = strain components
- T_{ij} = Stress components
- E_k = electric field components
- D_k = displacement components
- d_{kij} = constants of the displacement matrix
- ε_{ij} = constants of electric field matrix

Piezoelectric Response Matrix

For PVDF Materials displacement matrix elements are:

- d_{31}, d_{32}, d_{33}, d_{25} and d_{15}
- The matrix is not fully populated due to the anisotropic nature of PVDF
- d_{ij} for our study: ratio of the strain in the j-axis to electric field applied along i-axis

Figure 1.6 Directions of forces affecting a piezoelectric element

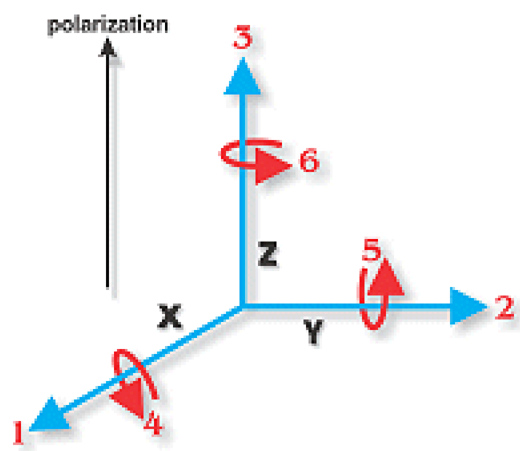


Diagram Source: APC Inc.

Results

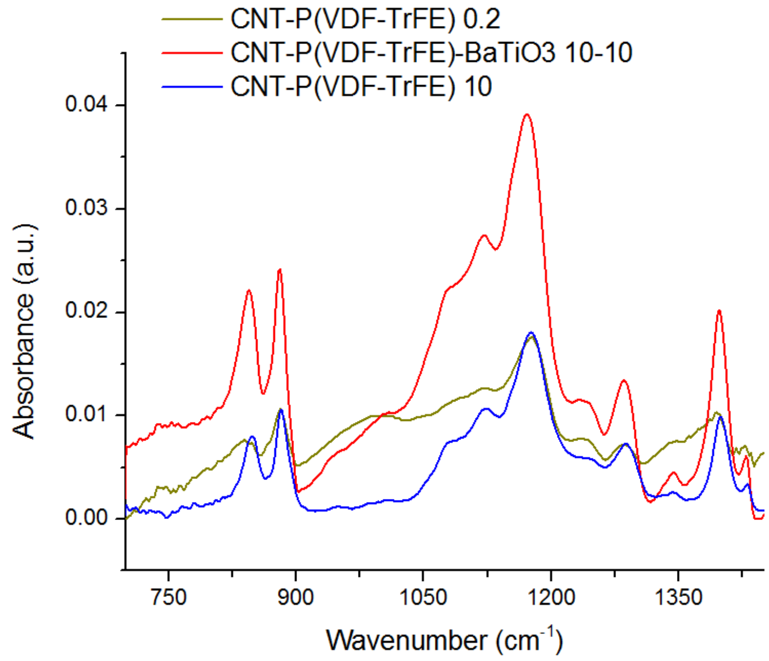
Orientation of CNT Tape for Piezoelectric Measurements of d33

Apply voltage along 3 direction and Measure Response along 3 direction

Results

- CNT/P(VDF-TrFE)/BT showed d33 of 140 pm/V
- Lit shows values from 1 – 34 pm/V
- Differences not only due to material but also sample thickness and polarization voltage
- Thin films with high voltage show highest values
- CNT/P(VDF-TrFE) films had d33 of 70 pm/V compared to 32-35 pm/V for pure P(VDF-TrFE) commercial film
- Due to Maxwell-Wagner-Sillars polarization – buildup of charges at interface of materials of different conductivity
- Dielectric constant of CNT/P(VDF-TrFE) was 161
- Lit values approximately 16 – These only had small w/o cnts (0.1 or less)
- These tapes had a tensile strength of 120 MPa and Young's Modulus of 17.8 GPa (Lit values of 68 MPa strength and 1.4 GPa Young's Modulus)

Results
FTIR Data



Beta Phase Wavenumbers: 840 and 1280

Results

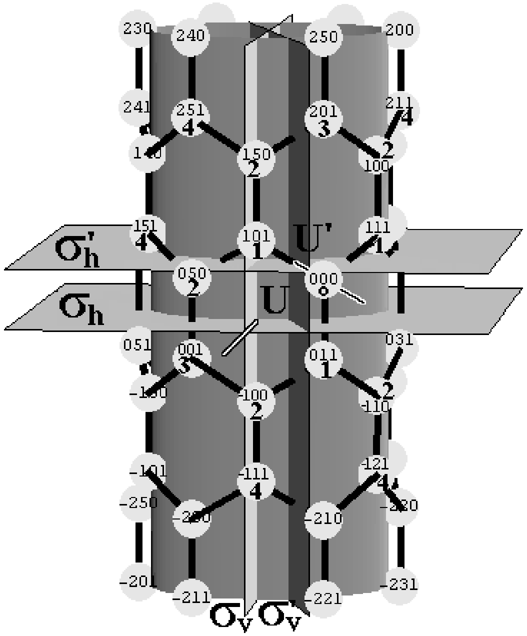
Material	Dielectric Constant	d_{33} (pm/V)
CNT/P(VDF-TrFE)	161	70
P(VDF-TrFE)/BT	204	140
CNT/P(VDF-TrFE)/BT	76	81

$g_{33}=d_{33}/\varepsilon$ (N/C) This gives idea of sensor value

Last material is only one with value > 1 so should be investigated further; also PZT as additive should be investigated

Future Work

- Achiral SWCNTs show mirror symmetries



Inducing Piezoelectricity in CNTS

- Theoretically, it is possible to induce piezoelectric effect in CNTS
- Break mirror symmetry by adsorbing ions on one end or side of CNTS – Will try ion implantation
- Will try potassium initially on one end of vertical array
- Draw into CNT sheets and reinforce with BMI: Previous testing showed Tensile Strength of 3.8 GPa and Thermal Conductivity of 40 W/m K
- Also will take sheets and ion implant one side
- Test for Piezoelectric Effect