Piezoelectric Carbon Nanotube Tape for use in Sensor Technology

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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 BaTiO3 added to solution to increase piezoelectric response
- Piezoelectric Effect measured using Radiant Technologies Tester
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 μC/cm²
Results

SEM of 0.2 w/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

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
- \( \varepsilon_{ij} \) = 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

Diagram Source: APC Inc.
Orientation of CNT Tape for Piezoelectric Measurements of $d_{33}$

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

<table>
<thead>
<tr>
<th>Material</th>
<th>Dielectric Constant</th>
<th>$d_{33}$ (pm/V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNT/P(VDF-TrFE)</td>
<td>161</td>
<td>70</td>
</tr>
<tr>
<td>P(VDF-TrFE)/BT</td>
<td>204</td>
<td>140</td>
</tr>
<tr>
<td>CNT/P(VDF-TrFE)/BT</td>
<td>76</td>
<td>81</td>
</tr>
</tbody>
</table>

$g_{33} = \frac{d_{33}}{\varepsilon} \ (N/C)$  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