# The Effect of Single Wall Carbon Nanotubes on the Dipole Orientation and Piezoelectric Properties of Polymeric Nanocomposites

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## Introduction

Electroactive polymeric materials have been studied extensively during the last two decades for use in a variety of applications including electromechanical sensors and actuators, ultrasonic transducers, loudspeakers, sonars, medical devices, prosthetics, artificial muscles, and devices for vibration and noise control [1,2]. As compared to electroactive ceramics and shape memory alloys, electroactive polymeric materials offer a unique combination of qualities because they are lightweight, conformable, and tough. Recently, we have developed a series of amorphous piezoelectric polyimides containing polar functional groups based on molecular design and computational chemistry, for potential use as sensors in high temperature applications [3].

In this presentation, we report the effect of types and concentrations of SWNT on the dipole orientation of the (β-CN)APB/ODPA polyimide by analyzing the thermally stimulated current (TSC) spectra. Also a discussion of the piezoelectric properties measured using a modified Rheovibron will be addressed.

## Experimental

The single wall carbon nanotube/(β-CN)APB-ODPA polyimide (SWNT/polyimide) nanocomposite was prepared by *in-situ* polymerization under sonication and mechanical shear. The (β-CN)APB/ODPA polyimide was synthesized as a matrix from a diamine, 2,6-bis(3-aminophenoxy) benzonitrile ((β-CN)APB), and a dianhydride, 4,4'-oxydiphthalic anhydride (ODPA). Purified HiPCO (High-Pressure CO Conversion)-SWNTs were purchased from Carbon Nanotechnologies, Inc. and used as received. Surface-modified SWNTs, P2- and P3-SWNTs were obtained from Carbon Solution, Inc. and used as received. The complete synthetic procedure is described in detail elsewhere [4].

The dielectric constant and the AC conductivity of the pristine polyimide and the SWNT nanocomposites were measured using an HP 4291A impedance analyzer and a Novocontrol system as a function of frequency. The remanent polarization ($P_r$) was measured as a function of temperature, after poling using a Setaram TSC-II.

Piezoelectric strain coefficient, $d_{31}$, was measured using a modified Rheovibron. The sample was subjected to in-plane stress (1-direction or length direction), $F/wt$, resulting in charge, $q$, through the film thickness (3-direction or out-of-plane direction). The piezoelectric strain coefficient was calculated according to the following equation below:

$$d_{31} = \frac{(q/wl)}{(F/wt)} \tag{1}$$

where $w$ is the width of the sample, $l$ is the length, and $t$ is the thickness. The coefficient $d_{31}$ was measured at 1 Hz and as a function of temperature from 25 °C to 150 °C.

## Results and discussion

The AC electrical conductivities of the pristine polyimide and the 0.2wt% P3 nanocomposite were linear as a function of frequency on a logarithmic scale. This linear correspondence is typical for insulators and indicates that the percolation threshold for the P3-SWNT was not achieved at this concentration. In contrast, the AC conductivities of 0.2wt% P2 and 0.2wt% HiPCO nanocomposites were much higher. The constant conductivity for a broad range of frequencies for these nanocomposites (P2 and HiPCO) indicates that the percolation threshold was exceeded thus rendering the materials conductive (see Figure 1). The nanocomposite with SWNTs with minimal acid treatment exhibited higher conductivities, which was consistent with the Raman spectra.

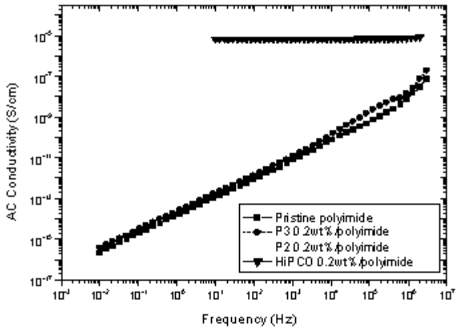

**Figure 1.** AC conductivities of 0.2wt% SWNT/polyimide nanocomposites.

The piezoelectric strain coefficients, $d_{31}$, were measured as a function of temperature for the SWNT nanocomposites. The $d_{31}$ increased slightly with increasing temperature due to a decrease in the modulus. Figure 2 shows the $d_{31}$ (at 150 °C) normalized by the poling field. The trend of normalized $d_{31}$ was consistent with that of the normalized remanent polarization ($P_r$). The more conductive SWNTs led to the greater $d_{31}$ due to the higher dipole orientation resulting from the interfacial polarization of the nanocomposites.

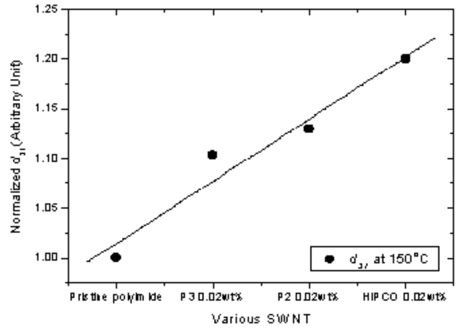

**Figure 2.** Normalized piezoelectric strain coefficients ($d_{31}$) of 0.02wt% SWNT/polyimide nanocomposites at 150°C.

## Conclusions

This study shows the effect of the SWNT type and concentration on the dipole orientation and piezoelectric properties of the electroactive polymide nanocomposites. Both conductivity and dielectric constant decreased with decreasing $sp^2$ nature of the SWNTs caused by acid treatment. The normalized $d_{31}$ of the SWNT/polyimide nanocomposites increased with decreasing the degree of the acid treatment. The normalized $d_{31}$ increased with increasing SWNT concentration to show a maximum value at 0.1 wt% of SWNT loading and decreased with further loading of P3-SWNTs. The trend of the remanent polarization, $P_r$, was consistent with that of $d_{31}$. From the cyclic piezoelectric measurement at a high temperature, it was found that the SWNT nanocomposites possess very thermally stable piezoelectric properties, applicable for high temperature devices.

## References

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