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

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Introduction
Electroactive polymer 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, transducers, 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 features 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 (P-CNAPB-BODA) polyimide by analyzing the thermally stimulated current (TSC) spectra. Also a discussion of the piezoelectric properties measured in a modified Rheometrics will be addressed.

Experimental
The single wall carbon nanotubes (P-CNAPB-BODA) polyimide nanocomposite was prepared by vacuum-polymerization under vacuum and mechanical shear. The (P-CNAPB-BODA) polyimide was synthesized at a matrix from a diamine, 2,6-di(aminophenyl) benzimidazol (P-CNAPB), and a diamine, 4,4'-diaminodiphenyl ether (BODA). Purified EPOC (High Pressure CO Conversion)-SWNT's were purchased from Carbon Nanotechnologies Inc. and used as received. Surface-modified SWNT's, P2- and P3-SWNT's were obtained from Carbon Nanotechnologies, Inc. and used as received. The composite procedures is described in detail elsewhere [4].

The dielectric constant and the AC conductivity of the pristine polyimide and the SWNT nanocomposite were measured using an HP 4294A Impedance Analyzer and a Novocontrol Resonant System as a function of frequency. The remanent polarization (P0) was measured as a function of temperature, after poling using a Setaram TSC-II.

Piezoelectric strain coefficient, d33, was measured using a modified Rheometrics. The sample was subjected to in-plane stress (1-direction or length direction), P1, resulting in charge, q1, through the film thickness (3-direction or out-of-plane direction). The piezoelectric strain coefficient was calculated according to the following equation below:

\[ d_{33} = \frac{q_1}{\varepsilon_P w} \]  

where w is the width of the sample, l is the length, and t is the thickness. The coefficient d33 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 lower 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% EPOC nanocomposites were much higher. The constant conductivity for a broad range of frequencies for these nanocomposites (P2 and EPOC) indicates that the percolation threshold was exceeded thus rendering the material conductive (see Figure 1). The nanocomposite with SWNTs with minimal acid treatment exhibited higher conductivity, which was consistent with the Raman spectra.

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

The piezoelectric strain coefficients, d33, were measured as a function of temperature for the SWNT nanocomposites. The d33 increased slightly with increasing temperature due to a decrease in the modulus. Figure 2 shows the d33 (at 150°C) normalized by the poling field. The trend of normalized d33 was consistent with that of the normalized remanent polarization (P0). This more conductive SWNTs led to the greater d33 due to the higher dipole orientation resulting from the interfacial polarization of the nanocomposites.

Figure 2. Normalized piezoelectric strain coefficients (d33) of 0.2wt% 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 polyimide nanocomposites. Both conductivity and dielectric constant decreased with increasing wt% nature of the SWNTs caused by acid treatment. The normalized d33 of the SWNT-polyimide nanocomposites increased with decreasing the degree of the acid treatment. The normalized d33 increased with increasing SWNT concentration to show a maximum value at 0.2 wt% of SWNT loading and decreased with further loading of 3wt%SWNT. The trend of the remanent polarization, P0, was consistent with that of d33. 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