Polarization and Characterization of Piezoelectric Polymers

S3-27

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Abstract:

Piezoelectric materials exhibit an electrical response, such as voltage or charge, in reaction to a mechanical stimuli. The mechanical stimuli can be force, pressure, light, or heat. Therefore, these materials are excellent sensors for various properties. The major disadvantage of state of the art piezoelectric polymers is their lack of utility at elevated temperatures. The objective of this research is to study the feasibility of inducing piezoelectricity in high performance polymer systems. The three aspects of the research include experimental poling, characterization of the capacitance , and demonstration of the use of a piezoelectric polymer as a speaker.

Introduction:

"Piezo" is the Greek word that represents "pressure." Hence, piezoelectricity describes the relationship between pressure and electricity. Piezoelectric materials are those materials that transform mechanical force into an electrical response. The mechanical response may be a force, pressure, light, or heat. Conversely, a piezoelectric material will transform an electrical signal into mechanical motion. The direct and inverse piezoelectric effects are illustrated in Figure 1.1. Piezoelectricity is utilized in a variety of applications as sensors and actuators. One aspect of this research project was to design an amplifier to demonstrate the use of a piezoelectric RAINBOW ceramic wafer as a speaker.

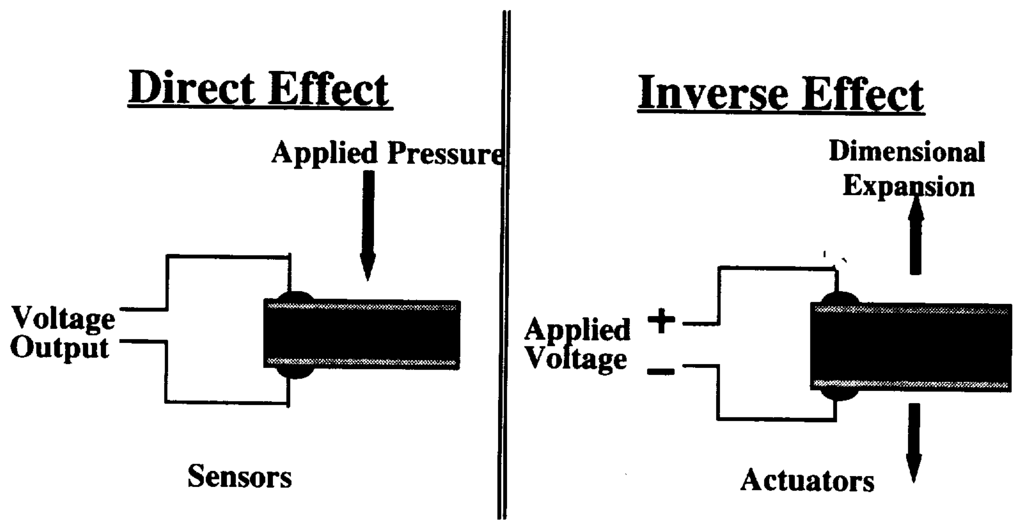

FIGURE 1.1. The direct and inverse effects of piezoelectricity.

Piezoelectricity occurs naturally in some materials or can be induced in polymeric and ceramic materials. Some known materials in which piezoelectricity occurs naturally are quartz and barium titanate. The initiation of piezoelectricity in polymers and ceramics is created through a process called poling. In the poling process, molecular dipoles in the materials are aligned by an external force field. This field may either be mechanical, magnetic, or electrical. In this research, strong electric fields were utilized to pole polymer systems.

Pioneering work in the area of piezoelectric polymers by Kawai [1] in 1969 led to the development of piezoelectric activity in a polarized flouropolymer, polyvinylidene fluoride (PVDF) [2]. Currently PVDF is the only commercially available piezoelectric polymer. A major problem with PVDF as a piezoelectric polymer is that it can not be used at temperatures above 50 degrees Celsius. This is because the dipole alignment induced in the poling process is spontaneously reversed at temperatures significantly above the glass transition temperature (T_g) of the polymer. The glass transition temperature is defined as the temperature region through which the mechanical properties change from those of a brittle glasslike material to those of a flexible rubbery material.

This research proposes to develop and characterize a novel class of high performance piezoelectric polymers that have several distinct advantages over state of the art materials. These advantages include high temperature stability, high mechanical integrity and utility in the space environment.

The aspect of the research targeted during the LARSS program was to utilize the poling process for polyimide films. This research also included characterizing the capacitance as a function of temperature of unpoled, poled, and poled/clamped polymers and demonstrating the use of a piezoelectric polymer as a speaker.

Poling Polymers:

The process that induces piezoelectricity in polymers is known as poling and is illustrated in Figure 1.2. In the poling process polymers are subjected to electric fields large enough to preferentially orient electrical moments. The normal poling procedure implemented in these experiments consisted of several steps. First a gold electrode with leads was evaporated on each side of the polymer film.

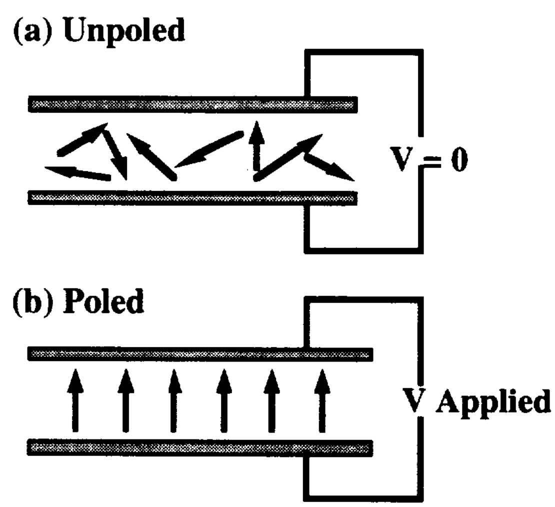

Figure 1.2. Orientation of dipole moments in the polymer during poling.

The electroded film was then attached to the high voltage poling apparatus. The poling set-up is shown in Figure 1.3. It consists of a Trek Model 20/20 High Voltage Amplifier from which a voltage of approximately 3,500 volts was applied across the film. The setup consists of two Fluke 8842A multimeters which monitor the voltage and current during poling.

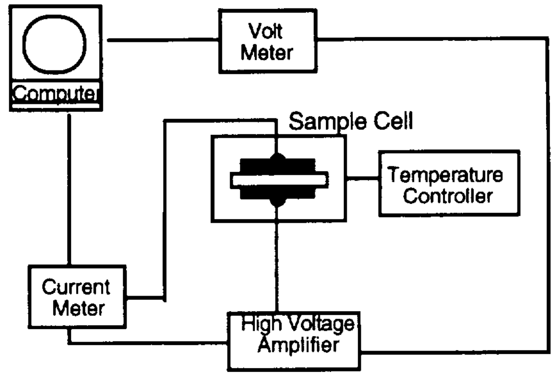

Figure 1.3. Poling set-up

The film was heated at a temperature 10 degrees below the specific polymers' glass transition temperature (T_g), to increase the mobility of the molecular dipoles. Each polymer was poled at a constant time, approximately 5 minutes. After 5 minutes the polymer was taken out of the silicon oil bath and quenched with isopropyl alcohol. It was necessary for cooling to take place with the electric field on in order to freeze in the dipole orientation.

There were three conditions that remained constant during the poling process, the electric field (E_p), temperature (T_p), and poling period (t_p). As shown in Figure 1.4 the polymers were poled for approximately 5 minutes at a constant temperature (approximately 210°C). The voltage was ramped to 3,000V and held constant for the duration of the experiment. The current increased to a value of 1.8μA and leveled off. The large spikes in the current are due to arcing in the polymer.

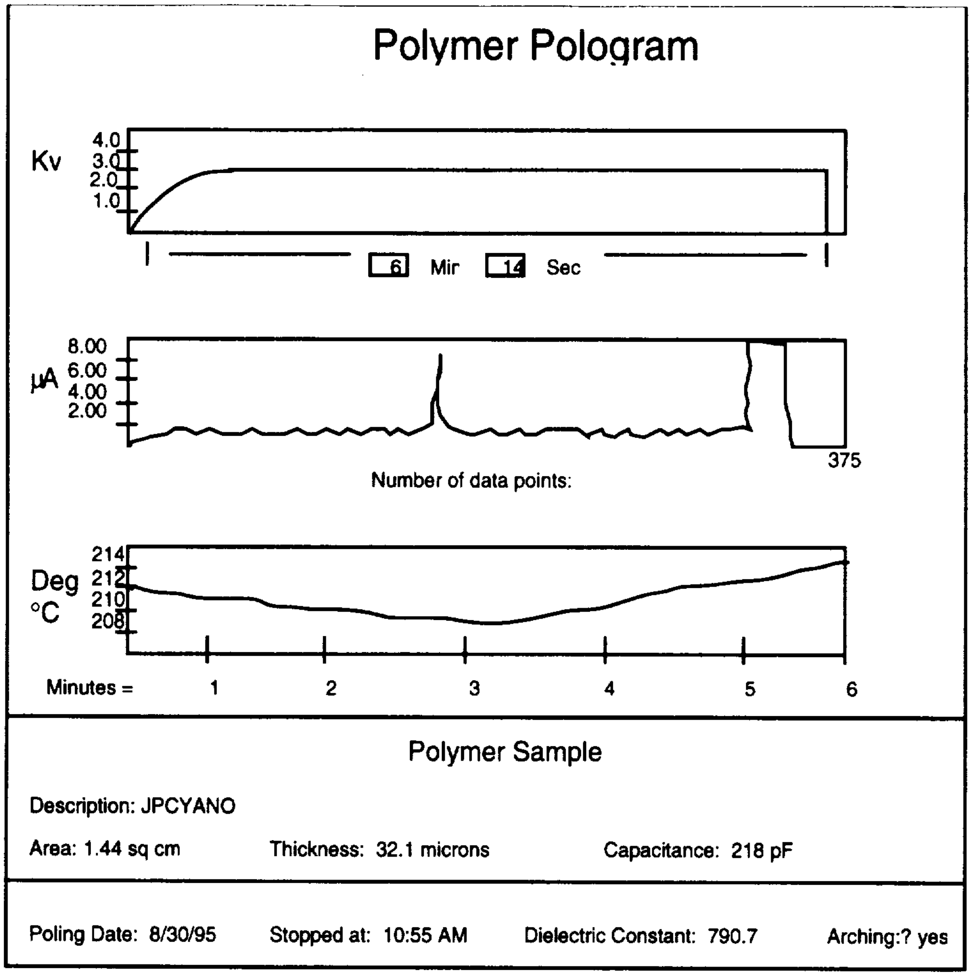

Figure 1.4. Pologram for a polyimide

Characterization of Capacitance Properties:

One method for characterizing materials is to evaluate their capacitance as a function of temperature. In this research a technique called parallel plate capacitance was used. Parallel plate capacitance measurements are taken by applying an electric field across a dielectric medium to measure its polarization. The polymer is the dielectric and the electrodes are the parallel plates, as shown in Figure 1.5.

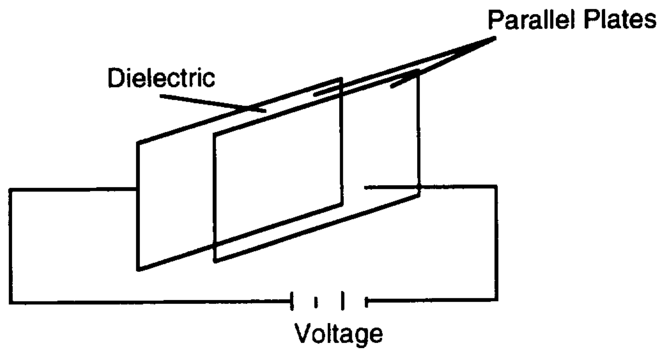

Figure 1.5. Parallel Plate Capacitance

From the capacitance measurements the dielectric constant, k, can be calculated using equation 1.1.

$$k = \frac{Cd}{A\varepsilon_o} \qquad (1.1)$$

where
- d = thickness between polymer plates
- ε_o = permittivity of free space and is equal to 8.854×10^{-12}F/m
- A = area of the parallel plates
- C = capacitance of the polymer

Various steps were taken to compare capacitance as a function of temperature of the polyimide shown below in Figure 1.6.

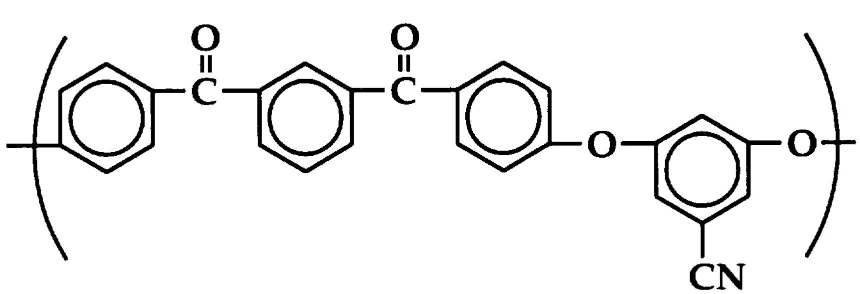

Figure 1.6. Chemical structure of JPCYANO polyimide.

A Data Precision Capacitance meter model 938 was used to measure capacitance in a Blue M mechanical convection oven model OV-472A-3. Measurements were taken at 10° C intervals starting at room temperature and ending at 211°C for an unpoled sample. This sample was poled at 210°C for approximately 6 minutes and quenched with isopropyl alcohol. The capacitance of the unpoled sample was then measured over the same temperature range. The capacitance measurements of the unpoled and poled samples were used to calculate the dielectric constant as a funtion of temperature using equation 1.1.

Capacitance measurements as a function of temperature were taken for the polyimide JPCYANO shown in Figure 1.6. This polymer contains a highly polar cyano group (CN) which should preferentially align with the electric field during poling. In order to characterize the difference poling makes in the dielectric properties of a polymer, the capacitance was measured for both poled and unpoled samples of JPCYANO. As shown in Figure 1.7, the dielectric constant increases with increasing temperature for both samples. This rise in dielectric constant is due to an increase in molecular mobility which occurs as the viscosity of the polymer decreases at increasingly higher temperatures. The dielectric constant is a measure of the polarizability of a material. The unpoled sample has a higher dielectric constant at temperatures well below the glass transition temperature than the poled sample because in the poled sample all of the molecular dipoles are have already been polarized in the poling process.

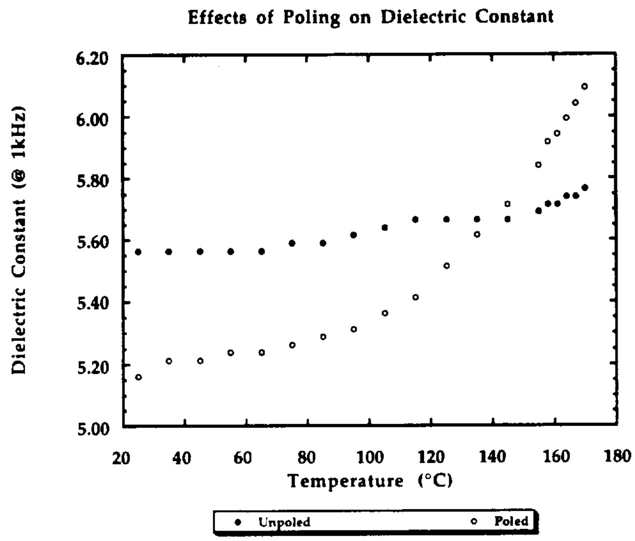

Figure 1.7. Dielectric constant as a function of temperature.

Demonstration of Piezoelectric Effect:

The final phase of the LARSS research project was to demonstrate the use of a PLZT ceramic RAINBOW wafer, as a speaker. In order for the speaker to amplify signals from the piezoelectric ceramic, a step-gain amplifier was created. The following materials were utilized in the assembly of the amplifier: a printed circuit board which contained a 10 k potentiometer, an LM386 amplifier chip, capacitors with values of 100 micro-F,250 micro-F, 10 micro-F, .05 micro-F disk, and resistors with values of 1.2 kilo ohms, 600 ohms, and 10 ohms. Additional parts included a 9 volt battery holder, chasis (bud box), a four position wafer switch, and a terminal switch.

The design was assembled in the following manner: first the printed circuit board was configured using the necessary components. The circuit diagram is shown in Figure 1.6. The second step was to draw the layout of the bud box, place screw holes where necessary, and cut out necessary holes. All of the materials were then placed in the bud box. The leads were then attached to the PLZT ceramic RAINBOW wafer and the amplifier. The bud box was closed and the leads from the headset were attached to the screws on the outside of the bud box.

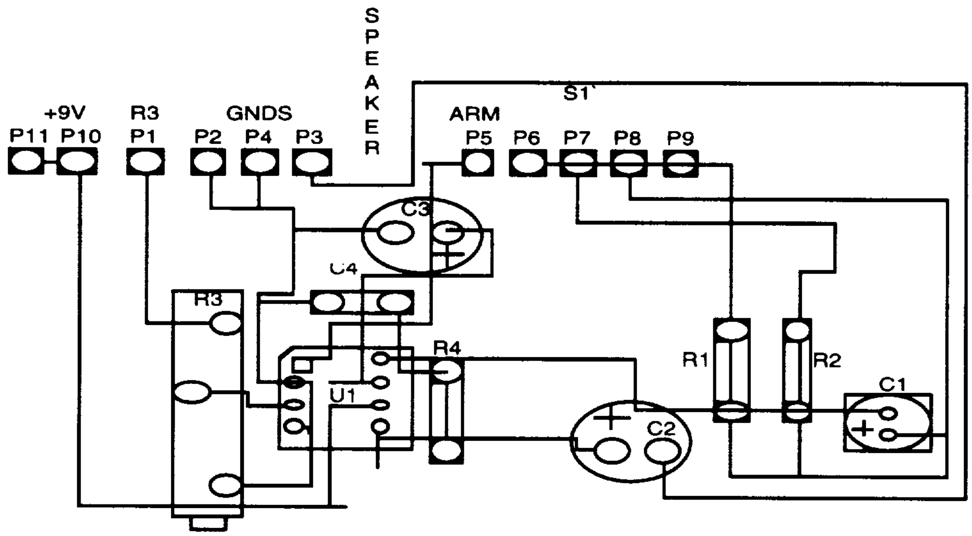

Figure 1.7. Circuit diagram for printed circuit board.

The frequency signals from the headset were sent through the amplifier to the PLZT ceramic rainbow. The amplifier buffed or made the sound clear. The sound then traveled to the ceramic where the vibrations caused the ceramic to pulsate producing music. The piezoelectric ceramic also acted as a microphone when the cycle was reversed. External noise was input directly into the ceramic and sent through the amplifier. The external noise traveled to the headset where the sound was recorded. The overall quality of the speaker was excellent.

Conclusions:

The process of using parallel plate capacitance was successfully completed by applying an electric field of approximately 10°C below the glass transition temperature across the polymers. From the graph of capacitance as a function of temperature, it was observed that the capacitance increased with an increase in temperature due to increase in molecular mobility. The final aspect of the summer research was to use a piezoelectric RAINBOW ceramic as a speaker. A step-gain amplifier was created in order to construct a circuit that would use the piezoelectric RAINBOW ceramic, PLZT, as a speaker.

References

1. Kawai, Jpn. J. Appl Phys., 8, 975 (1969).
2. M.G. Broadhurst and G.T. Davis, Ferroelectrics, 60, 3 (1984).