

Separation of the Pyro- and Piezoelectric Response of Electroactive Polymers for Sensor Applications

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Abstract. One of the main problems for the use of ferroelectric materials for sensor applications, especially for tactile sensors, is the separation of the pyro- and piezoelectric response produced by temperature and pressure changes, respectively. We present two different approaches to achieve this goal. The first approach is based on the study of the signal in the frequency domain and uses a signal processing to separate the piezoelectric response from the pyroelectric one. The second approach is based on a double layer configuration of electroactive polymers. In this case, the piezoelectric response is equal in each layer, whereas, the pyroelectric response dominates in the layer exposed to the temperature variations. The pyro- and piezoelectric responses are separated by estimating the difference between the signals of two layers and the signal from one of the layers, correspondingly.

Introduction

Piezoelectric and pyroelectric effects are widely used in the field of sensors and actuators [1, 2]. Many piezoelectric materials also have pyroelectric properties. Further, all pyroelectric materials show piezoelectric response. Synthetic organic polymers containing molecular dipoles in which alignment can be achieved by applying an electrical field (DC) and which produces polarization variation under applied stress exhibit the aforementioned pyro- and piezoelectric properties and are interesting for applications because of its flexibility and easy fabrication of piezo-active films. The organic polymer PVDF is one of the most studied polymer systems that exhibit ferroelectric, pyroelectric and piezoelectric properties [3, 4].

This polymer has great potential as a tactile sensor [5, 6] especially if the piezoelectric and pyroelectric response, i.e. pressure and temperature records are separated [1, 7].

All piezoelectric materials develop an electrical charge produced by mechanical stress. Decay of the electrical charges is determined by the dielectric constant and the internal resistance of the piezo-active film, as well as the input impedance of the interface electronics to which this film is connected [1, 7].

The piezoelectric charge (strain) coefficients predict, for small stress (or strain) levels, the surface charge density originated by external stress. In the charge mode and under conditions approaching a short circuit, the generated charge density is given by Eq.1.

$$D = \frac{Q}{A} = d_{3n} X_n \quad (n = 1,2,3) \quad (1)$$

The mechanical axis n of the applied stress (or strain), by convention, is 1 for length (or stretch) direction, 2 for width (or transverse) direction and 3 for thickness direction. Here D is the surface charge density developed, Q the charge developed, A the conductive electrode area, d_{3n} the appropriate piezoelectric coefficient for the axis of applied stress or strain and X_n the stress applied in the relevant direction.

In the voltage mode, the open-circuit output voltage is given by Eq. 2.

$$V_0 = g_{3n} X_n t, \quad (n=1, 2, 3) \quad (2)$$

Where g_{3n} is the appropriate piezoelectric coefficient for the axis of applied stress, X_n is the applied stress in the n -th direction and t the film thickness.

Pyroelectric materials develop an electric polarization if their temperature is changed and are necessarily piezoelectric.

As these materials absorb thermal energy, they expand or contract, thereby inducing secondary piezoelectric signals. As a piezo film is heated, the dipoles within the film exhibit random motion by thermal agitation. This causes a reduction in the average polarization of the film, generating a charge build up on the film surfaces. The output current is proportional to the rate of temperature change ΔT . Electrical charge Q and voltage produced by temperature increase (or decrease) in a given film of area A and thickness t and permittivity ϵ is determined by the pyroelectric coefficient, ρ , Eq. 3 [7].

$$\begin{cases} Q = \rho \Delta T A \\ V = \frac{\rho t \Delta T}{\epsilon} \end{cases} \quad (3)$$

This article explores the separation of pyro- and piezoelectric electrical response in the signal of a sensor based on ferroelectric β -PVDF polymer. To accomplish this objective the mutual piezo and pyroelectric response emerged in the signal of a single layer sensor is recorded and analysed in the frequency /time domains by means of a signal processing that allows the separation of the signals. The second approach is based on a bilayer arrangement of β -PVDF films. In this case the piezoelectric signal produced by each layer is similar whereas the pyroelectric signal differs in such a manner that the external layer of PVDF film is more sensitive to temperature variations. These facts allow a simpler separation of the piezo and pyroelectric responses.

Experimental set up

Commercially available 28 μm thick poled β -PVDF (Measurement Specialties Inc.) was electroded by aluminum thermal evaporation. Single and double layer sensors are shown in Figure 1.

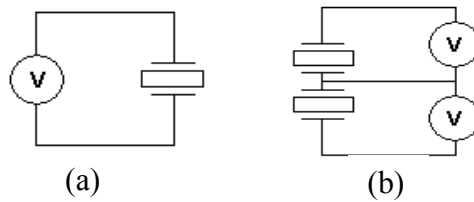


Fig. 1: a) Single and b) double layer sensors measurement circuit.

The signals produced by the applied pressure (piezoelectric signal) and temperature variation (pyroelectric signal) were measured with a Tektronix TDS 303 4B oscilloscope. The pressure and the temperature variations were applied and controlled with home-made setups.

Results and Discussion

Figure 2 shows the voltage produced by a single piezoelectric polymer layer, when a pressure impulse is applied. The maximal response is obtained with a 3ms delay, though the overall response of the single layer sensor extends up to 45ms.

In order to check the pyroelectric response of the same single piezoelectric polymer layer, the voltage produced by a temperature variation of 5°C in 10s was recorded as shown in and analysed,

Figure 3. The radiation source consists of an aluminum plate heated up to 100°C. The polymer layer was placed 2cm above the radiation source and the temperature at its surface is 38°C. In this case a slower variation of the induced voltage is obtained.

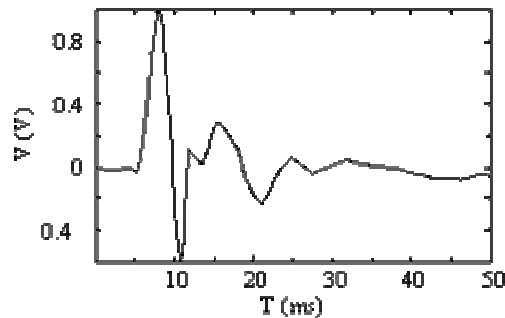


Fig. 2: Voltage produced by a single piezoelectric polymer layer, when a pressure impulse is applied.

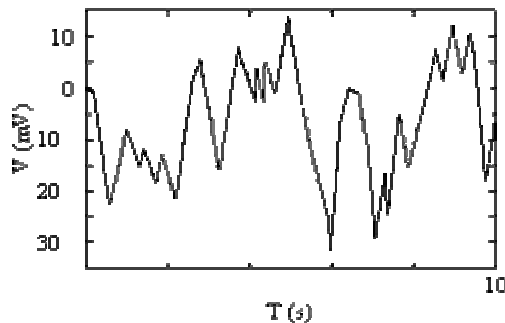


Fig. 3: Voltage produced by a single piezoelectric polymer layer, when placed at 2 cm from a 100 °C hot plate. The temperature at the polymer surface is 38°C.

Figures 4 and 5 show the spectral response of signals shown in Figures 1 and 2 calculated by applying the FFT transform. The spectral response of the material when pressure is applied extends up to 300 Hz. The temperature response, on the other hand, extends up to 2Hz. Due to the different spectral bandwidth of the signals, the separation of the pressure and temperature response is possible by means of filters.

In order to record only the piezoelectric response a band pass filter should be tuned to 200Hz (central frequency) with a bandwidth of 200Hz. Thereby only the 100Hz to 300Hz signals will be present on the filter output. On the other hand, to obtain the pyroelectric response, a low pass filter should be used, that allows output signals from DC up to 2Hz.

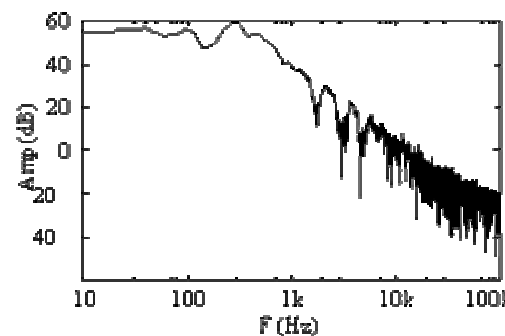


Fig. 4: Spectral response of a single piezoelectric polymer layer, when a pressure impulse is applied.

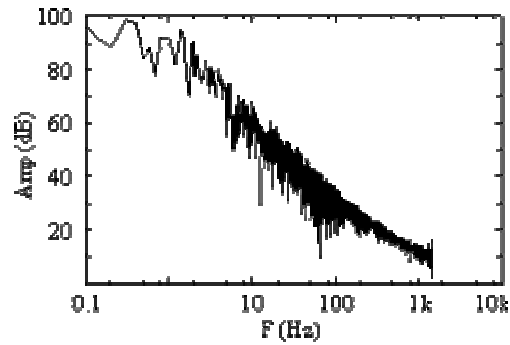


Fig. 5: Spectral response of a single piezoelectric polymer layer, when placed at 2 cm from a 100 °C hot plate. The temperature at the polymer surface is 38°C.

In the following the results of a bilayer arrangement will be presented. Figure 6 shows the voltages produced by two superimposed layers, when a pressure impulse is applied. The piezoelectric voltage response, when the force is applied to the upper layer, is similar for both layers excepting for a phase shift of approximated 0.5ms.

For the pyroelectric signal of the bilayer, Figure 7 shows the voltage produced when the sensor is placed at 2cm from a 100°C hot plate. The temperature at the top polymer surface is 38°C. In this case, whereas the layer receiving the radiation suffers variations consistent to the signal measured for a single layer sensor, the second layer shows two times smaller amplitude variations. Thus, in the case of a double layer configuration, the piezoelectric and pyroelectric responses can be independently recorded as follows: whereas the piezoelectric signal can be directly obtained from the lower layer, the pyroelectric signal will be obtained by subtracting the signals of the two layers.

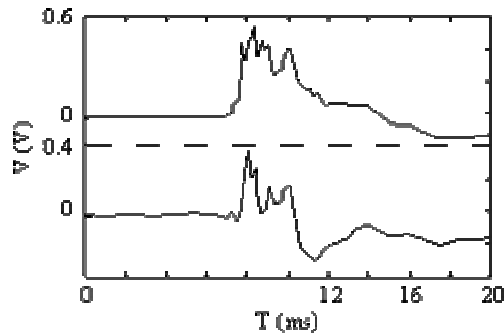


Fig. 6: Voltages produced by two superimposed piezoelectric polymer layers, when a pressure impulse is applied (above: upper layer; below: lower layer).

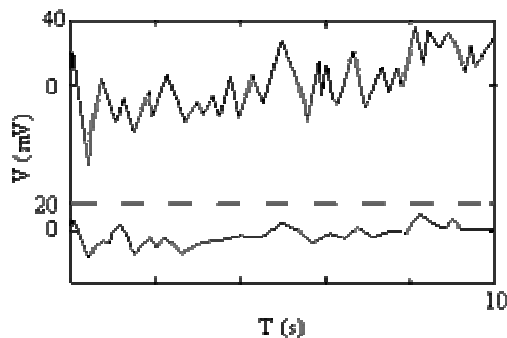


Fig. 7: Voltage produced by two superimposed piezoelectric polymer layers, when placed at 2 cm from a 100 °C hot plate. The temperature at the polymer surface receiving the heat is 38°C.

Conclusion

Two measurement methods using single and double arrangements of polymer layers were investigated. Both methods allow the separation of the piezoelectric and pyroelectric response. In the case of a single layer arrangement, more electronics and more complex, with filters tuned at different frequencies, is required in order to separate both signals.

In the case of a double layer sensor, the sensor preparation is more complex but the electronic is simpler: the pyroelectric effect is obtained from the difference between the signal from the two layers and the piezoelectric effect can be directly obtained from the lower layer.

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