Designers working with sensor designs based on Measurement Specialties (MEAS) Piezo Film must correctly take into consideration the dipole orientation within the polymer. This is necessary in order to achieve the desired polarity of the piezo film's response to electromechanical excitation. Sensor designers must understand piezo film polarity so that (1) a Piezo Film Sensor (PFS) provides the correct electrical output signal polarity for a given mechanical stimulus, and (2) an applied electrical signal will produce the correct mechanical polarity when applied to a PFS device. This application note will provide the PFS designer with a full understanding of polarity for MEAS Piezo Films.

PIEZO FILM POLARIZATION

Unpoled piezo film is a polymer comprised of many randomly oriented hydrogen (+) and fluorine (-) dipoles as seen in Figure 1(a). The polarization process is used to align the dipoles in an electric field such that a net dipole moment is permanently imparted. Figure 1(b) shows the effect of applying a high DC poling field to the electroded surfaces of a piezo film. It is the polarity of the applied poling voltage which determines the resulting polarity (alignment) of the piezo film's dipole moment. It should be noted that it is the polarity of the applied poling voltage which serves as the standard reference for all discussions of electrical signal polarity.

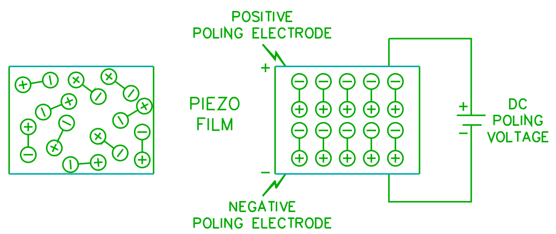

Figure 1

From Figure 1 it can be seen that during polarization, the positive hydrogen atoms are attracted to the negative poling electrode, while the negative fluorine atoms are attracted to the positive poling electrode. After the poling process is completed, a dipole alignment of this same polarity remains intact. The interaction of this remnant dipole moment with time-varying electromechanical stimuli produces the piezo-electric effect. Remember that piezo films respond only to time-varying excitations--static excitation produces no electromechanical response. (However, piezo film can be used in active sensors which sense static events.)

STANDARD AXIS NOTATION

The electromechanical properties of piezo film are anisotropic. That is, the electromechanical responses of the film differ depending on the direction of applied electric field or mechanical stimulus. Any discussions of piezoelectric response in piezo film must accurately account for this directional dependence. In accordance with standard crystallographic notation, a two digit subscript numbering system has been established to denote the relevant piezoelectric constants. The numbering system is based on the numbered axes shown in Figure 2. The figure identifies the length (1), width (2), and thickness (3) axes. For MEAS's uniaxially oriented piezo film, the length (1) axis corresponds to the direction of stretch; the width (2) axis is transverse to the stretch direction.

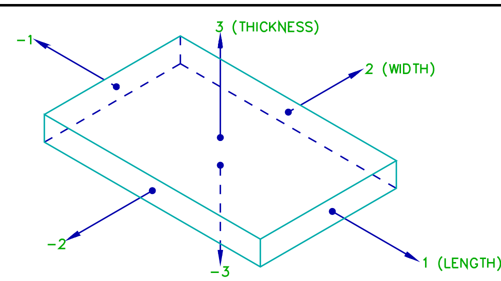

Figure 2

In standard two-subscript notation, the first number indicates the electrical polarization axis while the second number denotes the axis of mechanical stimulation. For MEAS Piezo Film, the polarization is always applied in the thickness (3) axis. This is the result of using the faces of the film as the poling surfaces; the electrical field is thus parallel to the 3-axis.

Mechanical stress or strain can occur in these three defined dimensions. Compressive stress or strain is defined as negative, while tension is positive. Therefore, the piezoelectric strain constant, d_{31}, describes the strain which occurs

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in the 1 (length) direction, when an electric field is applied in the 3 (thickness) direction. Similarly, the piezoelectric stress g_{32}, describes the electric field produced in the 3 (thickness) direction, when a stress is applied in the 2 (width) direction.

MECHANICAL EXCITATION OF PIEZO FILM

The polarity of a piezo film electrical signal resulting from a mechanical excitation is easily determined by noting the relevant piezoelectric "g" (stress) constant. Compressional (negative) stress in the thickness (3) direction, $T < 0$, causes an open-circuit voltage to appear across the electroded film surfaces with a polarity which is opposite that of the poling voltage. It should be noted that this voltage polarity is opposite that for piezo-ceramic materials and is the result of fundamental differences in piezoelectricity in the two materials. Figure 3 illustrates the effects of compressional excitation.

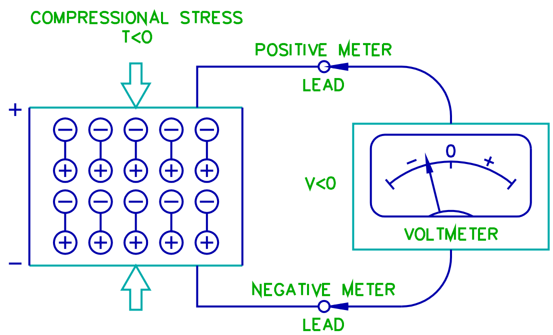

Figure 3

From Figure 3, since the applied compression is in the thickness (3) direction, the g_{33} constant verifies the correct open-circuit voltage polarity:

$$v = -g_{33}Tt \qquad (1)$$

where

- v = resulting open-circuit voltage
- g_{33} = piezoelectric stress constant ($g_{33} < 0$)
- T = applied stress ($T < 0$ for compression)
- t = thickness of piezo film

Since compressional stress is negative in standard crystallographic notation, and since g_{33} is negative for piezo film, then the voltage v is also negative (opposite polarity of the poling voltage).

Since the g_{31} and g_{32} constants for piezo film are positive, stretching (positive stressing) a piezo film in the length (1) or width (2) directions, causes an open-circuit voltage to appear across the electroded film surfaces which also has opposite polarity of the poling voltage. Figure 4 summarizes these mechanical excitation results. In the figure, the "meter" boxes represent any two-lead measuring instrument (voltmeter, oscilloscope, amplifier, etc.). It can be seen that the measuring instrument is connected to the piezo film with the same polarity as the film's poling voltage (standard reference polarity). The arrows represent the direction of stress (either compression, $T < 0$, or tension, $T > 0$). The voltage "v" represents the voltage developed across the piezo film electrodes in response to the mechanical stimulus.

THERMAL EXCITATION

Heating or cooling piezo film causes thermal expansion or contraction, resulting in an indirect pyroelectric response. One can determine the correct polarity of an output voltage signal due to a change in temperature by reviewing the pyroelectric "p" constant for piezo film. The open-circuit voltage developed across the electrodes of a piezo film when subjected to a change in temperature, is given by:

$$v = pt\Delta T/\varepsilon \qquad (2)$$

where

- v = open-circuit voltage developed
- p = piezo film pyroelectric constant, ($p > 0$)
- ΔT = change in temperature
- ε = dielectric permitivity of piezo film
- t = piezo film thickness

It can be seen from (2) that heating piezo film causes a positive voltage, (cooling piezo film causes a negative open-circuit voltage) to be developed across the electroded surfaces.

ELECTRICAL EXCITATION

To investigate a piezo film's mechanical reaction to an electrical excitation, one need only look at the piezoelectric "d" (strain or charge) constants. The strain (Δx/x) produced by an applied voltage is given by:

$$S = dv/t \qquad (3)$$

where

S = strain (Δx/x)
d = piezoelectric strain (or charge) constant
v = applied voltage same polarity as poling voltage)
t = thickness of piezo film

Since d_{33} is negative for piezo film, a positive time-varying applied voltage produces a negative strain (i.e., the film gets thinner). Obviously then, a negative input voltage causes piezo film to get both longer and wider (since $d_{31} > 0$ and $d_{32} > 0$).

VERIFYING A PIEZO FILM'S POLARITY

The correct polarity for a piezo film's response to excitation can be easily determined by reviewing the relevant piezoelectric or pyroelectric equations (1-3)and noting the sign of the excitation and piezoelectric constant. Tables 1-3 summarize these results in a convenient format for the PFS device designer. It is often necessary to determine or verify the correct polarity (i.e., determine which side is positive) for a piezo film or PFS device.

To verify the correct polarity of a piezo film, one can connect a two-lead voltage measuring instrument (voltmeter, oscilloscope, etc.) to the piezo film electrodes. When the positive lead of the instrument is connected to the positive side of the piezo film (the side which connected to the positive side of the poling voltage), the polarity of the voltage developed across the film (v) will be as shown in the tables for the mechanical and thermal stimuli noted. Although any of the tests in the tables can be used to determine the polarity of a piezo film, a thermal test is probably the most convenient and reliable. By simply breathing on the piezo film, a positive voltage will be noted when the positive lead of the meter device is connected to the positive side of the piezo film (as shown in Figure 4).

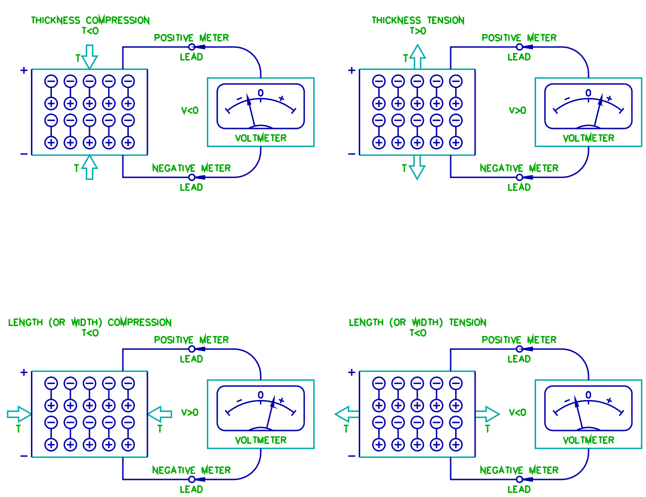

Figure 4

SUMMARY OF VOLTAGE POLARITIES* PRODUCED FROM MECHANICAL EXCITATION OF PIEZO FILM (T = STRESS)

Excitation Dimension	Compression (T < 0) Produces:	Tension (T > 0) Produces:
Length (1)	v > 0	v < 0
Width (2)	v > 0	v < 0
Thickness (3)	v < 0	v > 0

Table 1

SUMMARY OF VOLTAGE POLARITY* PROPERTIES PRODUCED FROM THERMAL EXCITATION OF PIEZO FILM (Δ T = TEMPERATURE CHANGE)

Excitation Dimension	Cooling (Δ T < 0) Produces:	Heating (Δ T > 0) Produces:
Volume	v < 0	v > 0

Table 2

SUMMARY OF VOLTAGE POLARITIES* PRODUCED FROM ELECTRICAL EXCITATION OF PIEZO FILM

Mechanical Dimension	Negative Input Voltage (v < 0) Produces:	Positive Input Voltage (v > 0) Produces:
Thickness, t	Δt > 0, gets thicker	Δ t < 0, gets thinner
Length, l	Δl < 0, gets shorter	Δ l > 0, gets longer
Width, w	Δw < 0, gets narrower	Δw > 0, gets wider

Table 3

* Voltage polarity is specified with reference to the polarity of the voltage used to polarize the piezo film (poling voltage). Using this convention, the positive side is labeled on all MEAS Piezo Film Sheets. The labeled (positive) side of a MEAS Piezo Film Sheet is therefore the side which was used as the positive electrode during polarization.

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