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THE USE OF PVdF IN ACOUSTIC DEVICES

Griffith Jones

Accusound, 19 Bitteswell Road, Lutterworth, Leics.

INTRODUCTION

Piezo-electric materials have been in use as transducers for musical instruments for many years and, more recently, in ultrasonic applications. Naturally occurring piezo-crystals such as Quartz, Tourmeline and Rochelle salt have led to the development of ceramics with improved piezo-electric properties such as Barium Titanate. These have a randomly aligned crystallite structure which does not exhibit a piezo-electric effect. When the polar axes of these crystals are aligned by the application of an electric field (poling), the resulting ceramic becomes piezo-electric. Being rigid and brittle ceramics have some limitation in application and considerable research has been undertaken to develop other materials, in particular polymers, which can be induced to exhibit piezo-electric properties. Many polar and non-polar polymers come into this category but Kawai [1] showed, in 1969, that PVdF could be activated to a greater extent than any other material then available.

A number of firms are now producing commercially useful versions of PVdF [2] [3]

CHEMISTRY OF PVdF

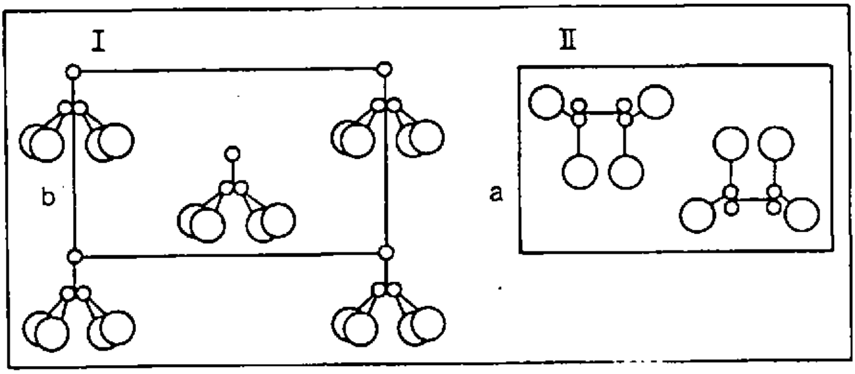

FIG.1 Crystalline structure of forms I(β) and II(α) of PVdF projected on to the a-b plane of the unit cell. Fluorine atoms are shown as large circles, carbon atoms as small circles and hydrogen atoms are omitted.

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PVdF is a long chain polymer with the being $CH_2 - CF_2$. It is about 50% crystalline and there are four crystalline forms. Polar Form I and non-active Form II are the commonest forms and of direct interest. Only Form I exhibits a useful degree of piezo-electricity because its molecular dipoles are orientated normal to the polymer chain axis and parallel to each other. PVdF has been available commercially as a 50% mix of non-polar Form II and an amorphous state. This has been used in the electrical industry mainly as an insulator. Form II can be converted to active Form I by means of stretching and polarising although research is being carried out with other methods of producing commercially useful material.

MANUFACTURE OF PIEZO-ELECTRIC PVdF

The polymeric form is produced from vinylidene fluoride by conventional methods which produces crystalline Form II.

If this material is melt-extruded and uni-axially stretched at around 150° C, it recrystallises as Form I. This forms a film typically of 10-100 microns.

The degree of conversion and the resultant mechanical properties depend on the particular combination of stretch and temperature applied. Although the stretching process produces an alignment of the long-chain molecules in the direction of stretch, it has not resulted in any polarisation of dipoles which is essential for any piezzo-electric effect. This is achieved by applying a high electric field, normally, to the film. Typical conditions are 0.7 MV/cm at 100 C for 1 hour. Subsequent cooling to room temperature results in a stable polarisation which is permanent.

The field may be applied by forming electrodes on the surface of the film by a metallising process or alternatively a corona discharge technique can be employed which gives shorter exposure times and can be used in a continuous process. Films currently available have been subjected to extensive ageing tests at temperatures below 100° C, and have proved to be very stable.

The mechanism suggested for the piezo-electric properties of PVdF, depending as it does on electric dipoles is analogous to ferro-magnetism and can therefore be regarded as ferro-electric. A special issue of "Ferroelectrics" contains more detailed information and a bibliography [4].

ORDER OF MAGNITUDE

In the method of the manufacture of PVdF, the polarising electric field is applied at right angles to the stretch direction. This results in the material having three distinct piezo-electric constants, corresponding to the mutually orthogonal directions 1, 2 and 3. 1 is taken to be the direction of stretch; 3 is the direction of the applied electric field and 2 is mutually perpendicular to 1 and 3.

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Mechanical-Electrical Action (Microphones)

The most relevant constant here is probably that in the 1 direction where the relationship E=gS obtains where:

E = the induced electric field

S = the applied mechanical stress

g = piezo-electric stress constant in 1 direction.

now $E = \frac{V}{t}$

where V = the induced voltage

t = thickness of the film

and $S = \frac{F}{t \times w}$

where F = the applied force

W = width of the film

for a typical film of cross-section 1 cm x 50 micron and an applied force of 1 Newton g may be taken as 0.2 V m/N

$$\text{which gives } V = \frac{gFt}{txw} = \frac{gF}{w}$$

$$= \frac{0.2 \times 1}{0.01}$$

$$= 20 \text{ volts}$$

A useful voltage if stresses around 1 Newton can be produced by acoustic pressure fields!

Electrical-Mechanical Action

The piezo-electric constant for conversion of electrical energy to mechanical energy 'd' is defined by means of the relationship

$$S = d\,E$$

where S = relative strain i.e. $\frac{\Delta l}{l}$

E = applied electric field

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d = piezo-electric strain constant

l = length of film

therefore $l = \frac{l d V}{t}$

Typically V = 100 volts

l = 01 m

t = 50 microns

d = 20 pc/N = 20 x 10

therefore $l = \frac{0.1 \times 20 \times 10 \quad \times 100}{50 \times 10}$

$= 4 \mu m$

In neither of these cases can the longitudinal stressing of a film be applied directly to acoustic applications in such devices as microphones or speakers. Bending of films, however, does produce longitudinal stresses and this principle has been used by manufacturers to produce useable devices.

MEASUREMENT OF PIEZO-ELECTRIC CONSTANT

Because of the anisotropic nature of PVdF, the practical measurement of the three piezo-electric constants is quite difficult and is discussed with examples in the paper by Holmes-Siedle, Wilson and Verral [2]. Figure 2 shows the apparatus developed at Fulmer Research Institute.

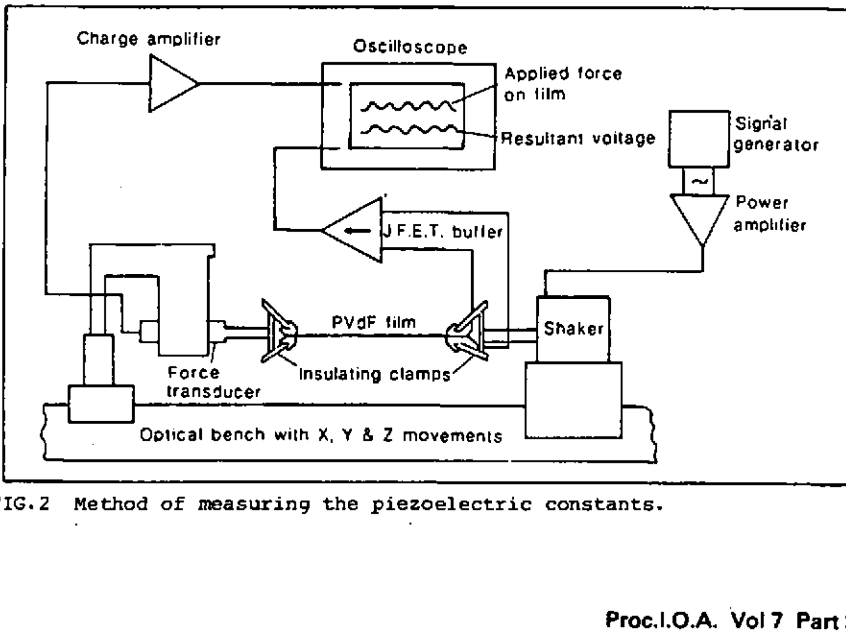

FIG.2 Method of measuring the piezoelectric constants.

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USE OF PVdF IN PRACTICAL DEVICES

Physical Advantages

PVdF has many advantages over ceramic material not the least being that, as it is usually in the form of thin film, it can conform to a curved surface such as the sound board of a musical instrument or when attached to human skin. The low mass and density of the film make it ideally suited to the reception and transmission of ultra high frequencies in fluids. Since the PVdF is a damping medium its frequency response is broad and flat and, particularly in the audio range, is limited only by the resonance of the physical support of the film. The acoustic impedance of PVdF is similar to that of fluids and because the PVdF film can be produced by a continuous process it is available in large areas and thus acoustic power can be transmitted into or received from a large volume of a fluid. Figure 3 gives a comparison of piezo-electric and pyroelectric constants.

MATERIAL	PIEZOELECTRIC CONSTANTS		PYROELECTRIC COEFFICIENT
	d_{31} pC/N	g_{31} Vm/N	p_3 $\mu C/m^2K$
PVDF	20	0.14	28
PZT-5	171	.011	60-500
$BaTiO_3$	78	.005	200
QUARTZ	2	.05	—
TGS	—	—	350

FIG.3 Comparison of piezoelectric and pyroelectric properties of PVdF ceramics.

Electrical Connections

Although the polarisation takes place throughout the PVdF, intimate electrical connection is essential over both surfaces of the thin film. This is normally done by means of a metallisation using such metals as aluminium, gold, nickel, chromium, vanadium, zinc, titanium and even stainless steel. Various combinations of these non-reactive metals are used for specific purposes depending on the design of the device and the environment in which it will be used.

Any of the standard methods of metallisation may be used and patterns of electrodes may be produced by masking or etching. Alternatively, the film may be screen printed with conductive inks. This gives a very simple method of producing patterns of electrodes.

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The criteria for a satisfactory coating are:

(a) Satisfactory adhesion to the PVdF

(b) Resistance to physical handling such as bending

(c) Reliable electrical connections to the conductive coating

The first two criteria are fairly simply satisfied but the third is a much more difficult proposition especially in a production item. Temporary connections for prototype development work can be made using conductive rubber (Figure 4a), conductive epoxy (Figure 4b) and conductive adhesives (Figure 4c) but they have various problems in terms of stability, and the techniques for solving these problems on a production basis are not generally available.

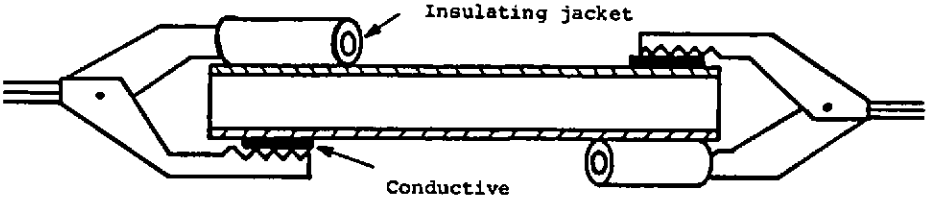

FIG.4a

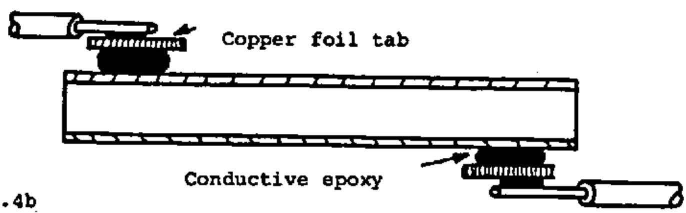

FIG.4b

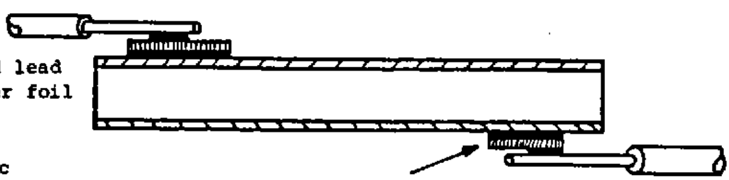

FIG.4c

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Advantages and Disadvantages of PVdF

Holmes-Siedle [2] list general advantages and disadvantages of PVdF as follows:-

PVdF and inorganic piezo-electrics differ strongly as engineering materials. The following are some major advantages of PVdF over inorganics:

(1) Very thin, self-supporting, pinhole free films are easily produced.

(2) Areas up to 1 square metre are easily produced.

(3) Laminates can be made easily.

(4) Electrodes can be produced on the foils in a virtually unlimited variety of patterns.

(5) The polymer is very flexible and tough, and hence can be moulded or stretched to conform to a surface.

(6) The polymer is very resistant to chemical attack.

(8) Strong resonances are unlikely.

Some disadvantages naturally follow from the organic structure:

(1) The material is soft.

(2) The firm attachment of electrodes to the smooth, mobile surface may be difficult.

(3) Unlike monocrystals, efficient resonator structures are not feasible.

(4) The foil operates efficiently only in the length extension mode.

(5) The stiffness of the material is low compared to ceramic.

(6) The stability of the electrical response of film material is lower than for ceramics (i.e. ageing can cause changes in response).

(7) The temperature coefficient of the piezo-electric response of the material is high and the Curie point (at which response disappears) is relatively low. Penwalt [3] list a total of 117 devices, using PVdF and of these the following are relevant to sound reinforcement.

Microphones
Telephone microphones
Noise cancelling microphones
Telephone operator headset
Voice verification

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Audio Speakers

Stereophonic tweeters
Headset speakers
Earphones
Acoustic couplers
Phonographic cartridges

Contact microphones for musical instruments
Acoustic delay lines

A number of devices or photographs will be on show during the conference and a contact microphone designed and manufactured by the author of this summary will be demonstrated.

[1] H. Kawai "The Piezo-electricity of Polyvinylidene Fluoride" Japan J. Applied Physics 945 (1969).

[2] A. G. Holmes-Siedle, P. D. Wilson, Fulmer Research Institute. Stoke Poges, Slough.
A. P. Verral, Yarsley Technical Centre, The Street, Ashtead.

[3] Kynor Technical Manual Penwalt Corporation. 900 First,ave., P.O. Box C, King of Prussia, Pennsylvania 19406.

[4] "Ferroelectrics" 32. (1-4) (1981).