Piezoelectric Plastic Film

Learn about PVDF, a piezoelectric plastic whose uses are limited only by imagination.

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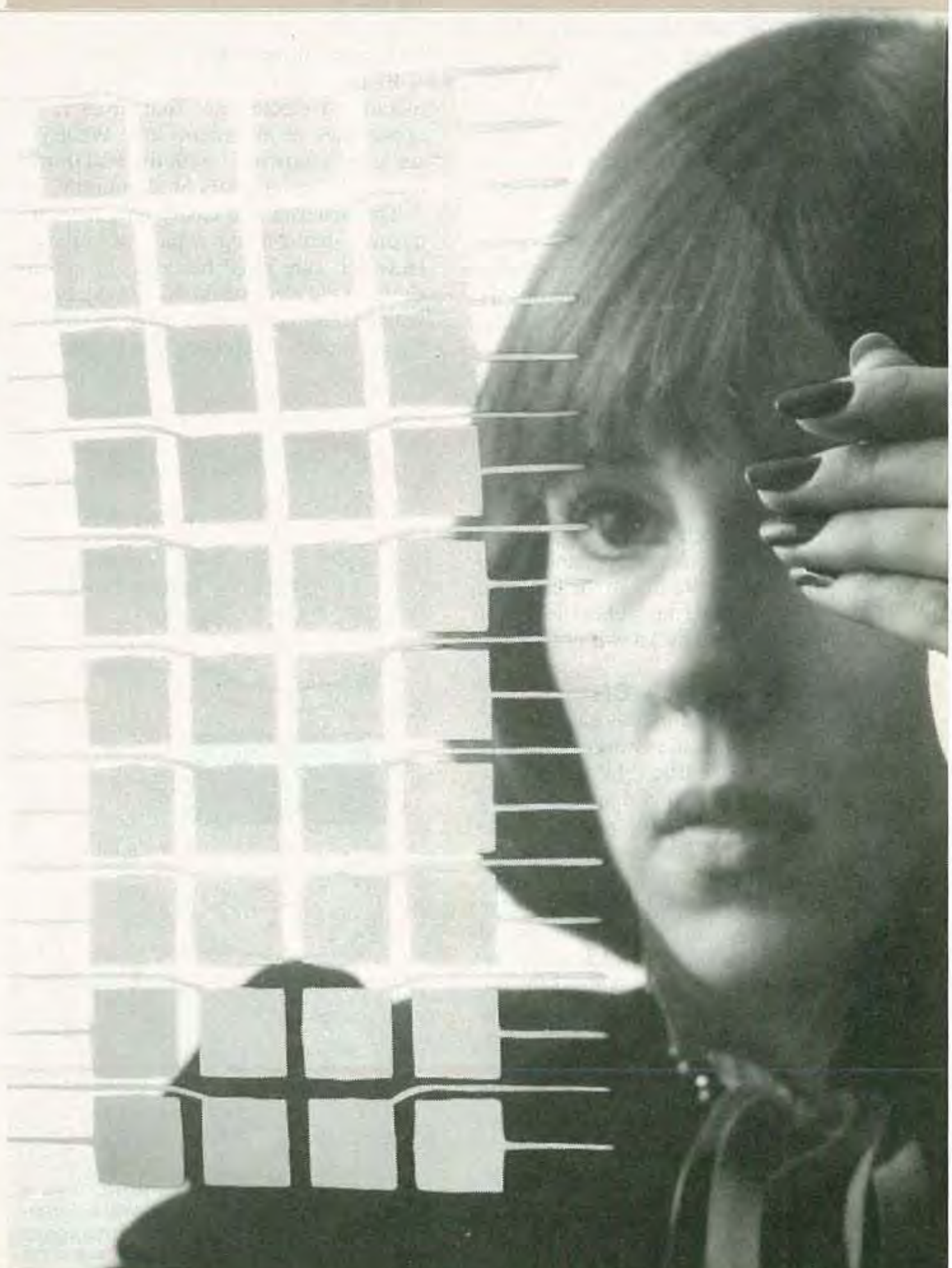

WHILE EXPERIMENTING WITH QUARTZ crystals, French physicists Jacque and Pierre Curie discovered that when such a crystal was exposed to an electric voltage, it would deform. Further, they found that when a quartz crystal was mechanically deformed, it would generate a voltage. They named the phenomenon *piezoelectricity*, which literally means pressure electricity.

Quartz crystal is the best known piezoelectric material, but it is by no means the only one. Other naturally occurring piezoelectric materials include Rochelle salts and tourmeline. Further, many piezoelectric materials have been synthesized. While most of those materials are ceramics, one of the more interesting ones is nothing more than a specially processed plastic sheet or film. Made from *P*oly*V*inyli*D*ene *F*luoride, or PVDF for short, piezoelectric film has properties that make it useful in a variety of applications. In addition, PVDF film is *pyroelectric*; that is, it is capable of transforming thermal energy into electrical energy. That property makes the film useful in applications such as intrusion alarms and proximity switches.

In this article, we are going to explore the uses and advantages of PVDF film. Included will be several experiments that you can perform. But first, let's learn a bit more about piezoelectricity, and what gives some materials that property.

The piezoelectric effect

A piezoelectric material is one in which all of the movable electric dipoles are oriented in the same direction. The condition can occur naturally, or it can be induced.

In nature, piezoelectricity occurs in crystals that have a high degree of symmetry. Of the 32 possible crystal structures, 20 are sufficiently symmetrical to give rise to piezoelectric properties. Despite that, relatively few crystal substances have been used in piezoelectric applications. Quartz, the most popular natural piezoelectric material, forms what is termed a triagonal trapezohedral crystal. It has threefold symmetry around its Z or optic axis, which means that if one measures a property at one point around the axis, the same property will repeat at 120° intervals.

In a crystal with strong piezoelectric properties, such as quartz, the electrical dipoles spontaneously align in the same direction; that is, the crystal is naturally polarized. The effect is similar to the alignment of magnetic dipoles in magnetic material. The electrical dipoles are formed by the positive and negative ions (charged atoms) that make up the crystal's molecules. When the crystal is placed under mechanical pressure or stress, the physical distance between the positive and negative ions is altered, causing a voltage to be generated.

Similarly, placing a piezoelectric crystal in an electric field can cause the physical distance between the positive and negative ions to change. Depending on the nature of the piezoelectric material and the external electric field, the material will expand along one axis and contract along the others.

One of the first applications of the piezoelectric effect was in sonar. The Curies experimented with using the piezoelectric effect to locate submerged solid objects. During World War II, the supply of quartz for military sonar could not be guaranteed (most was imported from South America). As a result, researchers began looking for other piezoelectric materials. They found that some ceramics, though not naturally piezoelectric, could be made so by placing them in a strong electric field.

Piezoelectric ceramics do have some drawbacks, however. They are brittle, stiff, and dense, making it impractical to manufacture the ceramics in large sizes or to cut them to complex shapes. Because of that, researchers continued to search for other piezoelectric materials. In the late 1960's, they turned their attention to polymers. By 1969, it was determined that PVDF exhibited the highest degree of piezoelectricity of any known polymer.

Piezoelectricity and PVDF

Polyvinylidene fluoride is a semi-crystalline, high-molecular-weight polymer chain made up of carbon, hydrogen, and fluorine atoms arranged in repeating CH_2–CF_2 units. In its normal, unpolarized state, PVDF thermoplastic has many applications. PVDF pipes, valves, etc., are routinely used to route corrosive chemicals. Extruded PVDF tubing is used to insulate telephone-terminal and computer wiring. PVDF film is used for the "unleaded gasoline only" stickers found on automobiles and for automotive "racing stripes." PVDF resins form the base of a group of premium metal finishes used to beautify and protect metal buildings and structures.

To give the film piezoelectric properties, the electrical dipoles formed by the hydrogen and fluorine atoms of the polymer are aligned in the same direction (through the thickness of the film.) The process includes controlled stretching of the film to achieve the proper mechanical orientation. The film is then polarized by placing it in an intense electric field.

There are many potential applications for PVDF film. Those range from heat and impact detectors, to sound generators, to acoustical pickups for musical instruments. In the remainder of this article, we are going to look at a few but interesting simple applications for the film. We will include several circuits that you can build yourself. If you wish to try some of the circuits but have difficulty locating PVDF film, Pennwalt, which manufactures PVDF piezoelectric film under the brand name of *KYNAR*, offers a small sample of the material and an accompanying 88-page technical manual for $45. To order, contact Pennwalt at: *KYNAR* Piezo Film Department, P.O. Box C, King of Prussia, PA 19406.

Experimenting with PVDF

PVDF film is normally supplied with metallized electrodes. That gives it the appearance of aluminum foil. What you see is a "sandwich" with the PVDF film located between layers of aluminum.

The material can easily be cut to any desired shape using a pair of scissors. However, care must be taken to prevent shorting the electrodes. To be safe, check with an ohmmeter; the resistance between the electrodes should be close to infinite.

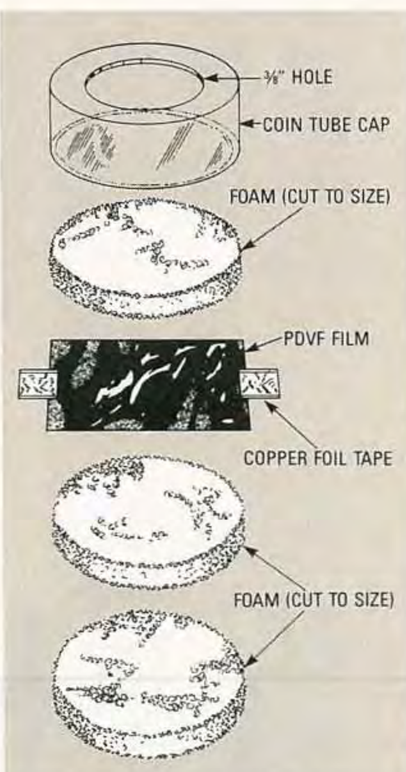

FIG. 1—THIS SIMPLE MICROPHONE uses a plastic coin-tube cap as a form. While performance is satisfactory, frequency response could be improved by curving the surface of the PVDF film.

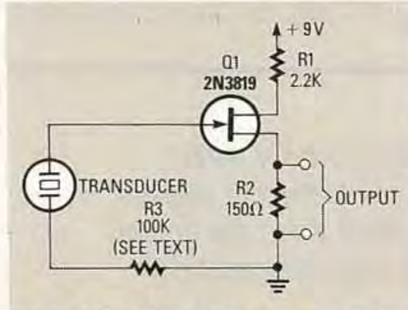

FIG. 2—A VOLTAGE FOLLOWER is used to buffer the output of the microphone for input to an audio amplifier.

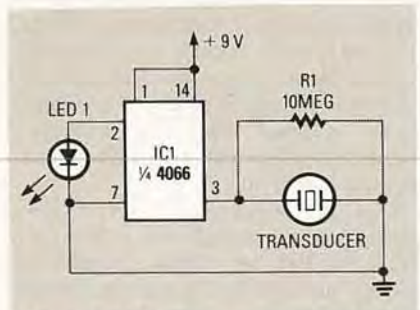

FIG. 3—PVDF FILM will generate a voltage when subjected to mechanical stress. That property can be demonstrated using the circuit shown here. When the PVDF film is tapped, the LED will light.

You'll need to devise some means of making connections to the metallized electrodes. One way is to use short lengths of copper-foil tape; that tape is normally used to make or repair PC boards. The tape uses an electrically conductive adhesive, making connection to the foil simple. If you purchase your sample from Pennwalt, the material is supplied with a set of special connectors.

We made a simple microphone using the scheme shown in Fig. 1. The "form" was an end cap from a plastic coin tube. A ⅜-inch hole was drilled in the center of the cap. The PVDF film was sandwiched between pieces of lightweight foam as shown. Using shielded cable to reduce noise, the copper tape leads were then connected to the voltage follower of Fig. 2; that circuit was used to buffer the output voltage of the film for input to an audio amplifier.

Note that that design is extremely simple and is intended only to demonstrate how the film could be used as a microphone. While performance is acceptable, the frequency response of the flat film is not very good. However, frequency response could be improved by curving the film's surface. In fact, it is possible to design a PVDF microphone that has a flat frequency response over an extremely wide range. PVDF film itself is an extremely broad-band material that will respond to frequencies from near DC to the GHz range.

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PIEZOELECTRIC FILM

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It is also simple to make a speaker using the film. Use a cardboard mailing tube as a form. Wrap the tube in a layer of lightweight foam. Then wrap the film around the tube/foam. Secure the ends of the film with ordinary cellophane tape. Be sure not to overlap the ends of the film or you will short out your "speaker." Connect the film to a signal source and listen. What you will hear is the higher audio frequencies of the signal.

The film will also respond, of course, to direct mechanical pressure. That means that the film can be used for applications ranging from a simple touch plate to impact monitors to tactile sensors for robots (R-E Robot builders take note!). PVDF can withstand impacts of up to several hundred G's without losing its piezoelectric characteristics.

The circuit in Fig. 3 shows how the film could be used in a touch-plate circuit. Tapping the film will cause the LED to light. For best results, mount the film in such a way that there is sufficient clearance for the film to flex. Perhaps the best approach would be to mount the film on a pair of ¼-inch plastic spacers using ordinary contact cement.

As mentioned, in addition to its piezoelectric properties, PVDF is also pyroelectric. If the temperature of the film is raised, a voltage is produced. As the film cools, voltage reduces linearly. Note that at temperatures greater than 50°C, the pyroelectric activity is permanently reduced. At temperatures greater than 120°C, the film's piezoelectric properties are permanently impaired.

To demonstrate the film's pyroelectric properties, connect the film directly to the input of a high-impedance voltmeter or oscilloscope. Breathe on the film, and watch the response. For a more dramatic response, try shinning a desk lamp on the film, or waving a lit cigarette in front of the film. PVDF is so sensitive that it can be used to detect the body heat of a person from as far as 50 feet away.

Applications

PVDF applications under investigation or showing potential include:

- a disposable blood-pressure cuff
- tone generators
- acoustical pickups for musical instruments
- engine noise/vibration sensors
- intrusion-detection systems
- signature-verification systems
- fluid-flow monitors
- and many, many others

Other applications are sure to be developed because PVDF film's use is limited only by human imagination. **R-E**