# A Study on Piezoelectric Effect of Gelatin Gel

XIANJIN YANG,* YANYONG JIA, KANGDE YAO, YUFEN WANG, and JITAO MA

Department of Materials Science and Engineering, Tianjin University, Tianjin, 300072, China

## SYNOPSIS

This paper investigated piezoelectricity of the gelatin gel. Polarized infrared and thermal stimulated current experiments provided the proof of the origin of the piezoelectricity-oriented dipoles. Effects of crosslinking, ionic strength, and stress on piezoelectricity were discussed as well. We found that the voltage decreased as the crosslinking time increased, had a minimum value of ionic strength, and increased with the stress, respectively. © 1996 John Wiley & Sons, Inc.

## INTRODUCTION

Recently, stimuli (i.e., pH, temperature, and electric field, etc.) response gels have attracted much attention.[1-4] The polyelectrolytic gels, which can bend under an electric field, will be used as promising actuators to transfer electric energy to mechanical energy.

In contrast to the electric field response gels, there is another kind of gel that can convert mechanical energy to electrical energy. There has been a study[5] on poly(methylacrylic acid) (PMA) gel, which could generate electric potential under a load of 300 g successively.

Since then, no further work has been published in the literature. In considering the application potential of the mechnoelectrical gel, the piezoelectric effect of soft and wet material crosslinked gelatin gel has been investigated here.

## EXPERIMENTAL

### Materials

Biochemical reagent gelatin was obtained from the 3rd Chemicals Manufacturer of Tianijin. Glycerol and formaldehyde were analytical grade.

### Preparation of Gelatin Gel

Gelatin was dissolved in glycerol solution (40 vol %) at 60°C and then injected the solution into a glass mold. Under an 20 V/cm electric field, a gelatin gel via physical crosslinking was formed at room temperature. After being maintained at 10°C for 12 h, it was immersed in a 2% formaldehyde aqueous solution at 10°C for a definite time to form crosslinked network chemically in addition to the original physical network.

### Polarized Infrared Spectra

With a 5DX NICOLET apparatus, polarized infrared (IR) spectra was applied on the gelatin gel. Polarized directions of IR spectra were parallel and vertical to the thickness direction, respectively. Absorbed peaks of some groups were compared in both polarized directions.

### Measurement of Piezoelectric Effect

As the gel was soft and wet, the usual apparatus can not be used to measure the piezoelectricity of it. An instrument (cf. Fig. 1) was set up. A sample of the gelatin gel (25 × 25 × 5 mm) was placed between the electrodes and loaded successively. After amplifying, the signal was recorded.

### Thermal Stimulated Current (TSC) Study

A common experiment apparatus for TSC measurement was used. A cylindrical sample (20 × 5
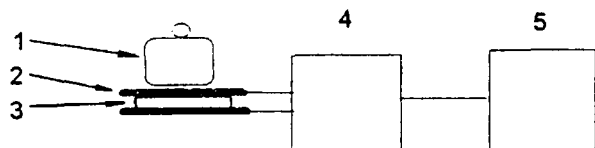
**Figure 1** Instrument for piezoelectricity measurement.

mm) was applied to estimate the TSC spectrum in the span of 26–90°C at a heating rate of 4°C/min. The typical experiment error was ±1°C for the temperature of the maximum current.

## RESULTS AND DISCUSSION

### Piezoelectric Effect of Gelatin Gel

Figure 2 shows the piezoelectric effect of the gelatin gel under a load of 9.8 N successively. The effect may be due to the dipoles orienting.[6] Because the gel was formed in an electric field, some dipoles of gelatin gel were aligned in the electric field direction; thus, the gel was anisotropic. In the case of the stressed sample, the charges induced on the electrodes contacted with the sample were changed; this resulted in piezoelectricity.

### Polarized Infrared Spectra

Attenated total reflection (ATR) IR spectra (cf. Fig. 3) show that the characteristic peaks of $-C=O$ of the $-CONH$ (1638.0 cm$^{-1}$) and $-C-N$ of the $-CONH$ (1413 cm$^{-1}$) exhibit different intensities when applied 0 and 90 degree polarized IR spectra. In the direction parallel to the thickness (Fig. 3, curve a), these groups had stronger peaks than that in the other direction (Fig. 3, curve b). According to the theory of the polarized IR spectra,[7] it may be said that the $-CONH$ dipoles of the gelatin gel were oriented in the thickness direction. The di-
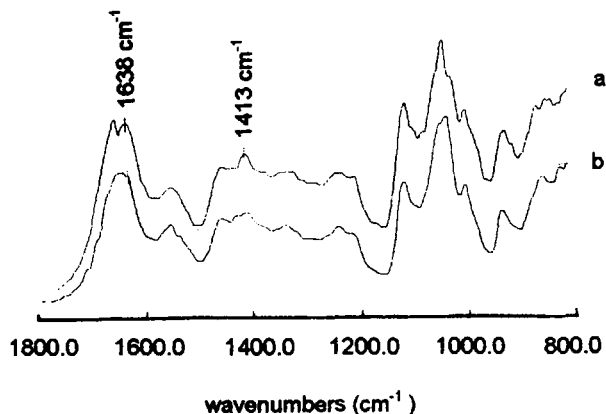


**Figure 3** Polarized IR spectra of the gelatin gel.

chroic ratios (R) were calculated as 1.37 and 1.62, respectively.

### TSC Study

Figure 4 demonstrates that there are two bands in opposition in the TSC thermogram. At 52°C, there is a slight negative peak; perhaps it is due to the embedded charges migrating to the electrodes directly. A large peak occurs at 63°C in positive direction, and the current is in the 10$^{-9}$ order of magnitude. Deorientation of the $-CONH$ dipoles may contribute to the peak.

### Influence Effects of Piezoelectricity

#### Crosslinking

The voltage (gained when samples were loaded with 9.8 N) versus the crosslinking time was displayed (cf. Fig. 5). Data reveal that the voltage decreased as the crosslinking time increased. This may be interpreted using the theory of dimensional effect.[8] The theory considers a film containing N dipoles of
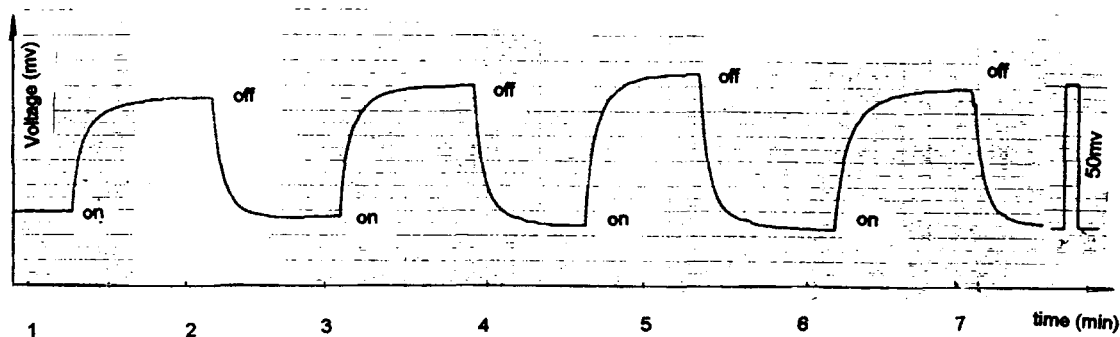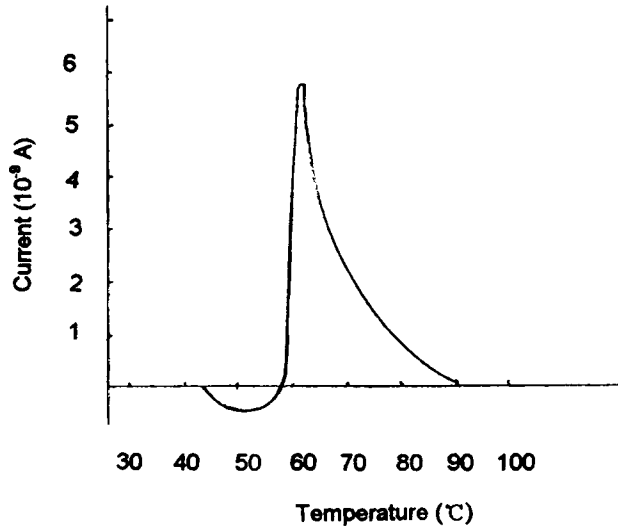


**Figure 2** Piezoelectricity of the gelatin gel.

**Figure 4**  Thermal stimulated current thermogram of the unpolarized gelatin gel.



**Figure 5**  Effect of crosslinking on piezoelectricity.

moment $\mu$ aligned in one direction. The remnant polarization of such a film may be given by

$$Pr = N\mu\langle\cos\theta\rangle/AI \qquad (1)$$

where $\langle\cos\theta\rangle$ is the orientation coefficient of dipoles, $A$ represents the electrode, area and $I$ is the thickness. The total charge amount is as follows:

$$Q = PrA = N\mu\langle\cos\theta\rangle/I \qquad (2)$$

The dimensional effect assumes that when the film is deformed, $N\mu\langle\cos\theta\rangle$ does not change. In this case, piezoelectric activity is proportional to the variation in thickness.

Along with the enhanced crosslinking time, the gel became more rigid. When the same load was applied, the change in the thickness was reduced; that is to say, $I$ was larger in eq. (2), so the charges induced on the electrodes declined. As a result, the voltage between the electrodes decreased with an increase in crosslinking time.

*Ionic Strength*

Figure 6 indicates the curve of voltage (recorded when loading 9.8 N on samples) against the ionic strength. It was obvious that at ionic strength, $I$ = 0.15$M$/L, the voltage had a minimum value. Perhaps it was the charges embedded in the network that played an important role. At $I$ = 0.15$M$/L, the piezoelectricity originated from the dipoles compensated by the ions of electrolyte diffusing into the gelatin gel, and the detectable voltage was about
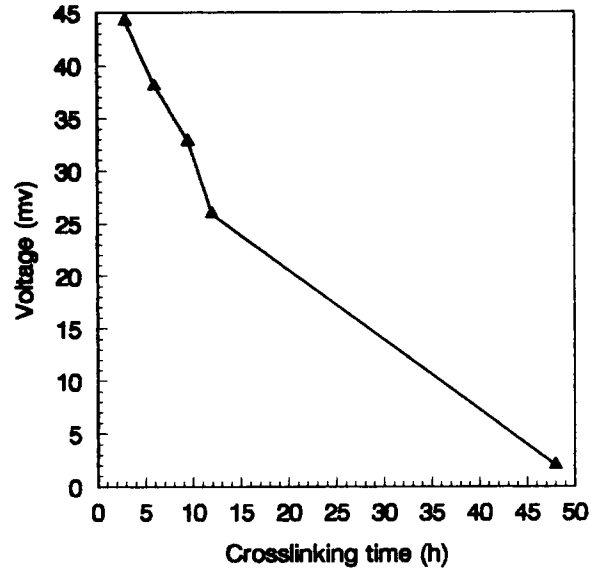
zero. Meanwhile, with the ionic strength raised, the piezoelectricity of the gelatin gel originated chiefly from the charges embedded in the network.

*Stress*

The piezoelectricity as a function of load is shown in Figure 7. This result shows that the curve includes two stages. At the early stage, voltage increased with the load. It is thought that the gel exhibits elasticity in this range, strain was proportional to the stress, and thickness ($I$) of the gelatin gel declined while
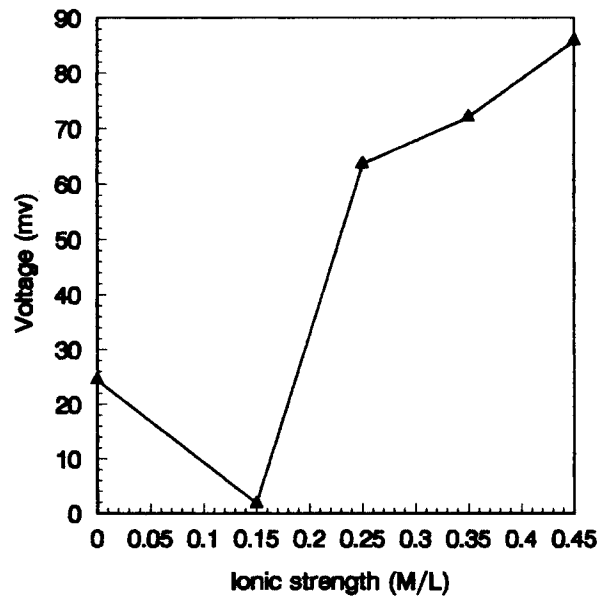


**Figure 6**  Effect of ionic strength on piezoelectricity.
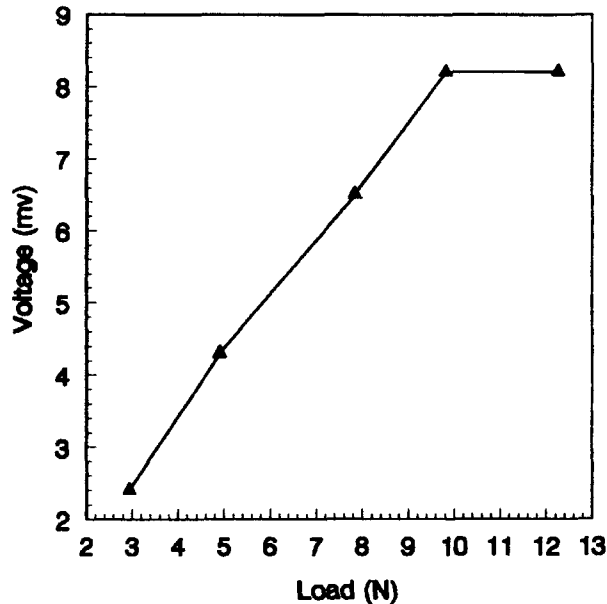
**Figure 7** Effect of stress on piezoelectricity.

the stress was enhanced. According to eq. (2), an increased voltage should be obtained. When the load is larger than 9.8 N, the gel surpassed the elastic regime, and the voltage remained constant.

## CONCLUSIONS

There was piezoelectricity in the gelatin gel. Here, oriented dipoles contributed to the origin of the pi-ezoelectricity; if charges were embedded in the network, they also had something to do with the piezo-electricity. Items related to the strain of the gelatin gel influence the piezoelectricity.

## REFERENCES

1. M. Suzuki, *Biorheology,* **23**, 274 (1986).
2. D. De Rossi, K. Kajiwara, Y. Osada, and A. Yamauchi, Eds., *Polymer Gels, Fundamentals and Biomedical Applications,* Plenum Press, New York, 1991.
3. D. De Rossi, M. Suzuki, Y. Osada, and P. Morasso, *J. Intel. Mater. Syst. Struct.,* **3**, 75 (1992).
4. T. Hirai, H. Nemoto, M. Hirai, and S. Harashi, *J. Appl. Polym. Sci.,* **53**, 79 (1994).
5. Y. Osada and R. Kisi, *Chem. Eng. Suppl. (Jpn),* **31**, 189 (1987).
6. G. Sessler, D. K. DasGupta, A. S. Dereggi, W. Eisenmenger, T. Frukawa, J. A. Giacometti, and R. Gerhard-Mithaupt, *IEEE Trans. Elec. Insulation,* **27**, 873 (1992).
7. D. Y. Shen, *IR Applied in Polymer Research,* Science Press, Beijing, 1982, Chap. 7.
8. T. Furukawa, *Proc. 5th Int. Symp. Electrets,* 1985, p. 883.