Electric Field Poling 2GV/m to Improve Piezoelectricity of PVDF Thin Film

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Abstract. Polyvinylidene fluoride (PVDF) is a polymer with unique characteristics i.e. piezoelectric and ferrroelectric properties. Piezoelectric propertiesof PVDF are determined by the fraction of β-phase structure. Several optimization methods have been developed to improve the piezoelectric properties of PVDF. One of our research efforts is to improve the piezoelectricity of PVDF by electric poling with high electric field 2G V/m. The application of high electric field performed on PVDF films with a thickness of 1 μm. Each sample was made with a deep coating method, with annealing temperature 70^0C-110^0C. Based on the XRD characterization, we have obtained value of β-fraction of samples after poling are: 56%, 61%, 77%, 81% and 83%, respectively. Therefore, high electric field poling has been able to improve the piezoelectric properties of PVDF films. The PVDF with good piezoelectric properties are potential can did a tes for piezoelectric sensors and actuators devices.

Keywords: Piezoelectricity, Poling, Polymer, PVDF, β-fraction
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INTRODUCTION

Polyvinylidene fluoride (PVDF) has attracted much attention in the areas of thermoplastic polymer that has the uniqueness of the piezoelectric and ferroelectric properties. These properties are at the origin of various applications, especially in the field of sensor and actuator devices and technologies [1, 2, 3].

Piezoelectric properties of PVDF very dependent on the phase structure, in this case is determined by the β structure of PVDF. The study of the transformation of the structure of PVDF has been widely studied among others by previous researchers. Recently, many research focuses on increasing the amount of the β -phase in PVDF to obtain a good piezoelectric and pyroelectric material [4, 5, 6, 7, 8, 9].

Piezoelectric properties of PVDF films can be improved by performing electric poling. It was shown that poling in intense electric fields under controlled conditions can change the crystalline structure of PVDF from non-

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piezoelectric configurations (α, γ,and δ) to an all-trans (*β*) phase that is responsible for the piezoelectric properties of PVDF [10].

In previous study, we have be enconducted optimization piezoelectric properties of PVDF film by mechanical treatment temperature [11, 12] and found the β fraction of PVDF films reach up to 44%. In this paper, we report the results of studies relating to improve the piezoelectric properties of PVDF films by poling electric field 2G V/m.

Effect of High Electric Field on PVDF Polymer

Phase transformation in PVDF can occur due to the eternal electric field. Electric dipole moment can be directed by an electric field. The process of alignment of the electric dipole moment by the external electric field is called polarization. By apply the external electric field on PVDF film will affect the polarization orientation of the dipole in PVDF film. At first, the electric field is increased by increasing the potential source between two electrodes. When the electric field is reduced to zero, the polarization in the materialis not zero but there is a certain value (Fig.1). It is also called polarization residual.

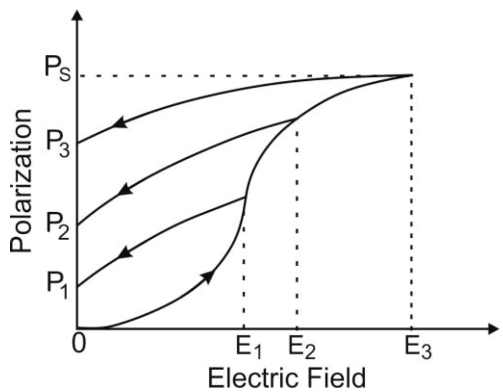

FIGURE 1. The relationship between the external electric field with polarization.

Residual polarization is due to the orientation of the dipole, charge separation and freezing of the charge due to the charge transfer through the electrodes. If the electric field is increased continuously then there is a state in which the polarization becomes zero. This polarization is called the saturation polarization.

Piezoelectric properties associated with changes in the electric dipole polarization, strain-stress, temperature and external electric field as expressed in the equation:

$$dP = \left(\frac{\partial P}{\partial S}\right)_{E=0;T} dS + \left(\frac{\partial P}{\partial T}\right)_{E;S} dT + \chi^{s}\varepsilon_0 dE \quad (1)$$

$$\left(\frac{\partial P}{\partial S}\right)_{E=0;T} = d \quad \text{(Piezoelectric constant)} \quad (2)$$

$$\left(\frac{\partial P}{\partial T}\right)_{E;S} = p' \quad \text{(Ferroelectric constant)} \quad (3)$$

If equations (2) and (3) are substituted into equation (1) and then integrated, obtained:

$$P - P_r = d.(S - S_r) + p'.(T - T_0) + E.\chi^{s}\varepsilon_0 \quad (4)$$

where, P : Polarization, P_r : Residual polarization, d : Piezoelectric constant, S : Strain, S_r : Residual strain, E : Eelectric field, χ^s : Dielectric susceptibility, ε_0 : Dielectric permittivity of vacuum.

EXPERIMENTAL

Electric poling have been conducted using an electrode intended to inject the charge uniformly and its dipole become in the same direction.The description of the poling condition is shown in Fig. 2.

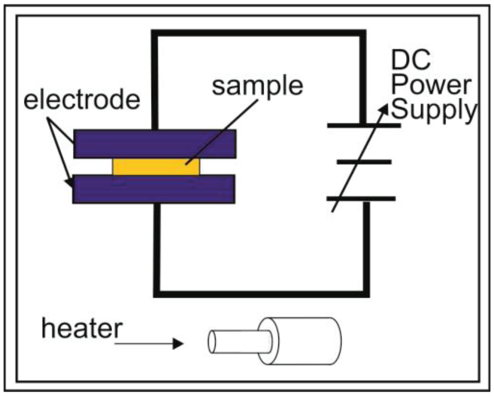

FIGURE 2. Scheme of poling apparatus

For electric poling, the samples of PVDF film were sandwiched between two electrodes and then heated from room temperature to 40^0C. A DC power supply was used to generate the desired electricpotential difference across the electrodes. The voltage applied between the electrodes was gradually increased from 0 to 2 kV will produce an electric field of 2G V/m. The electric field is obtained from equation (5).

$$E = \frac{V}{d} \tag{5}$$

where V is the applied voltage and d is the thickness of the sample (in this work, d = 1μm).

The sample of PVDF films with a thickness of 1 μm have been fabricated using deep coating methods for annealing temperature of 70^0C-110^0C. The poling process have been conducted with poling time of 20 minutes. The characterization of samples are using X-Ray Diffraction.

RESULTS AND DISCUSSIONS

The XRD characterization of PVDF sample before and after poling is shown in Fig. 3 (a) and Figure 3 (b), respectively.

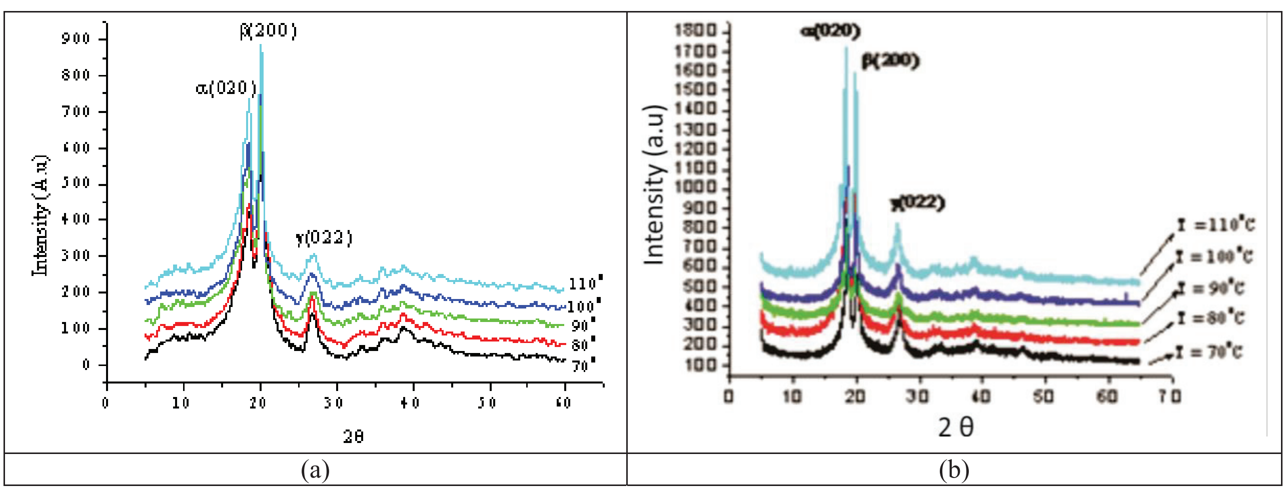

FIGURE 3. Diffraction pattern of the PVDF sample (a) before electric poling and (b) after electric poling

Based on XRD characterization of the samples then conducted the calculations of β fraction of PVDF film sample using equation (6).

$$F(\beta) = \frac{A_\beta}{1.26A_\alpha + A_\beta} x100\% \tag{6}$$

The β fraction of PVDF films for different annealing temperatures before and after poling are expressed in Table 1. As shown in Table1 is very clear that the β fraction of the sample PVDF films increased quite well after electric poling.

TABLE 1. Total β-fraction of PVDF films for temperature variation before and after the poling.

No	Annealing Temperature (^{0}C)	β Fraction (%) Before Poling	β Fraction (%) After Poling
1	70	37	56
2	80	38	61
3	90	44	77
4	100	50	81
5	110	58	83

Although the β-fraction (before and after poling), are proportional to annealing temperature but electric poling is the focus in this article. As shown in Table 1, the β fraction of PVDF increase after poling, this is due to the higher electric field that applied during poling process will induce the non-polar crystal to become polar crystal form, hence more β fraction isgained, and the piezoelectric charge constantis increased [13].

CONCLUSIONS

Electric poling 2G V/m have been done to improve piezoelectric properties of PVDF thin film. Based on XRD characterization obtained that the β fraction of samples increased after poling process. This results indicated that the application of 2G V/m electric field polling has been able to improve the piezoelectric properties of PVDF films significantly.

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