Effect of ITO Poling Temperature and Silicon Cover on PVDF Sensor

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Abstract. This article examines the influence of poling temperature and cover on PVDF film sensors. The PVDF films were fabricated using the uniaxial stretching method (R=5) at 80°C. A novel ITO poling technique was employed in a vacuum oven, varying temperatures from 80°C to 120°C. The study evaluated the response of PVDF thin film sensors to impact tests involving steel balls of different weights with constant heights. Analysis of the PVDF sensor's output voltage response, considering the elasticity of the supporting material and impact force, revealed that higher poling temperatures and silicon support led to increased output voltage response and sensitivity in the PVDF film sensor.

Keywords: ITO Poling, PVDF sensor, protective, piezoelectric.

1 Introduction

PVDF, or polyvinylidene fluoride, is a polymer that is commonly utilized in electromechanical actuators, piezoelectric sensors, and energy harvesters. Excellent qualities including electroactivity (piezoelectric, pyroelectric, and ferroelectricity), high responsiveness to mechanical stress or strain, good sensitivity, controlled precision, low cost, and simple operation are just a few of the many uses for PVDF [1, 2]. Several advantages of PVDF were highlighted in earlier research, including its high flexibility, low weight, low thermal conductivity, mechanical toughness and strength, and chemical stability. [3, 4]. The PVDF semicrystalline has a complex structure that can represent five different crystalline phase forms (α, β, γ, δ and ε). The α, β, and γ- phases of PVDF (see **Figure 1**) were the most studied and used for various applications. The most important phase of PVDF for application in the engineering field is β-phase [5, 6].

Enhancing the β-phase characteristic of PVDF necessitates a combination of mechanical and poling techniques [7, 8]. Uniaxial and biaxial stretching with a stretching ratio of R>5 and temperatures ranging from 70°C to 90°C can effectively improve the β-phase content during mechanical treatment [6, 9]. Applying an electric field to a non-polar polymer, such as PVDF, to create ferroelectric and piezoelectric properties is known as poling. Poling processes play a crucial role in optimizing the PVDF film sensor's performance. An important factor in this process are temperature, voltage, time, and poling type are critical parameters for β-phase optimization [10, 11]. While further research is needed to determine the optimal parameter values, poling is typically conducted at room temperature. The correlation between the degree

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of crystallinity in PVDF and the poling temperature has been the subject of numerous investigations.

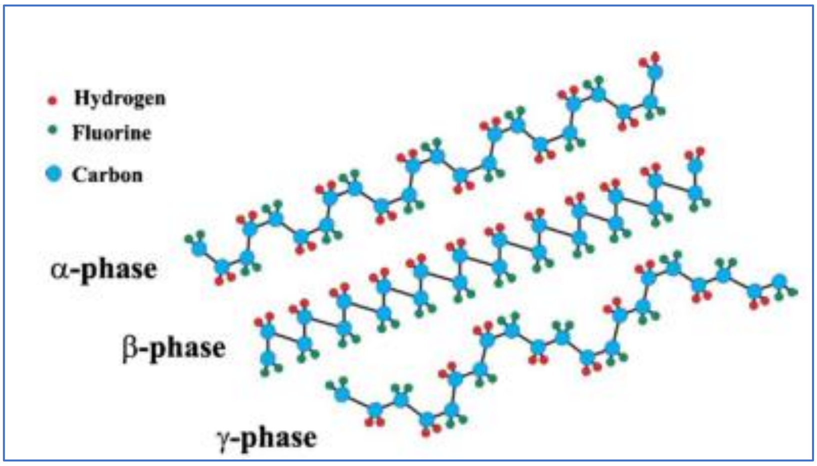


Fig. 1. Schematic illustration of the chain conformation for the α, β,γ phases of PVDF [[5]

The poling temperature significantly affects the properties of PVDF film sensors. Higher poling temperatures can lead to increased dielectric constant and nonpolar-polar transformation in the α phase [12]. They can also enhance the piezoelectric performance by increasing the relative content of the β-phase [13]. The poling time required for dipole alignment decreases with higher temperatures, and a secondary displacement zone may form [14].The dielectric constant and thermal diffusivity increase with the poling field [15]. The dominant phase in PVDF can be determined by the thermal processing conditions, with the β-phase being the most desired for sensors [16]. High electric field poling can further improve the piezoelectric properties of PVDF films[17]. Mechanical treatment and fabrication temperature can also increase the β-fraction and piezoelectric properties of PVDF films[18].

PVDF thin film sensor is sensitive to moisture, chemicals, environment, and mechanical stress, which can damage its efficacy over time. Recent studies mainly focus on investigating how to enhance the piezoelectric response of PVDF film sensors which can be classified into the following techniques (i) modification electrode pattern design for increasing pressure sensitivity, (ii) new processing methods and technologies, (iii) new composite material design (iv) addition of filler such as ionic liquid (IL) [19] or graphene in PVDF [20]. Enhancing the piezoelectric response also means improving its dielectric dan ferroelectric properties [21].

Beyond the techniques mentioned above in designing the PVDF sensors, Y. Jia et al. noted that external conditions such as shock impact, deflection, and strain should be considered [22]. In addition, a previous work reported that the material of the backstop as supporting or cover of the PVDF film sensors may significantly influence the characteristics and performance of PVDF sensors. Thus, this study aims to deepen understanding of (1) the effect of pooling temperature variations in oven vacuum and (2) the influence of rubber and silicon sheets as cover materials on PVDF film sensors by considering the impact forces.

2 Materials and Methods

2.1 Material

In this work, the unstretched commercial PVDF (Kynar®720) with a thickness of 130 mm was purchased from the company. The PVDF film was cut into rectangles with an area of 15 cm x 20 cm and mounted on a uniaxial stretching apparatus. A purpose-built uniaxial stretching apparatus that can move both in two directions (x-y) is placed in the oven chamber with heaters positioned at the top and bottom. The clamps move in opposite directions during the stretching process while the machine shaft is rotated, as shown in **Figure 2.** The PVDF sample was stretched five times (R=5) to its original length at a temperature of 80ºC with a stretching ratio R=5 and controlled by circulating hot air v=0.5 m/s with the stretching rate constant. The final thickness of PVDF films was between 17 and 50 mm, which shows a dependence on stretching parameters (dimension origin of PVDF, speed rate, and temperature).

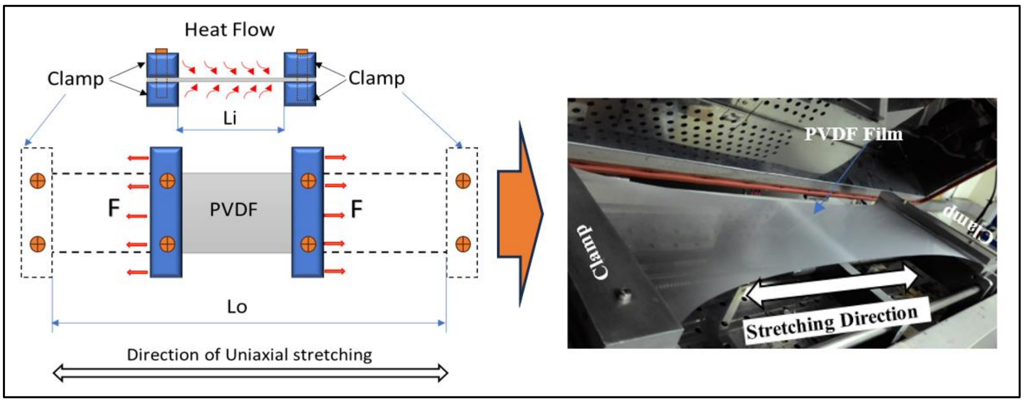


Fig. 2. Schematic illustration uniaxial stretching of the PVDF film.

2.1. Polarization

Polarization is essential for improving the piezoelectric properties of the PVDF film. It includes applying a high electric field to the polymer's molecular dipoles to align them in the appropriate orientation. In this study, thickness poling using ITO glass poling as a conductor was applied in a high electric field of 3 kV/cm for 15 minutes in a vacuum oven at various temperatures of 80ºC to 120ºC is shown in F**igure 3**.

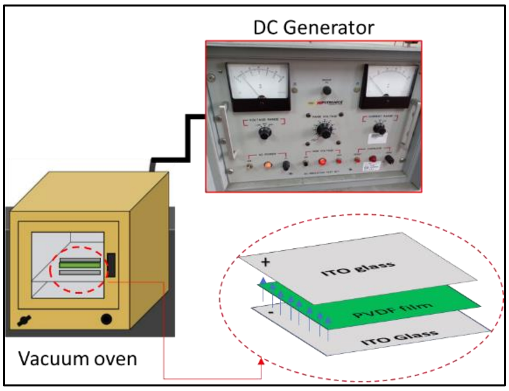


Fig. 3. Thickness poling using ITO glass

3.1. Characterization and Measurement

3.2. Electric Response of PVDF film Sensor

In this study, the response of the PVDF sensor was evaluated by the impact force tests under several conditions of supporting or cover sheet material, namely silicon, rubber, and plate alumni. **Figure 4** illustrates four-configuration trials with cover sheets on both sides of the PVDF film sensor surfaces.

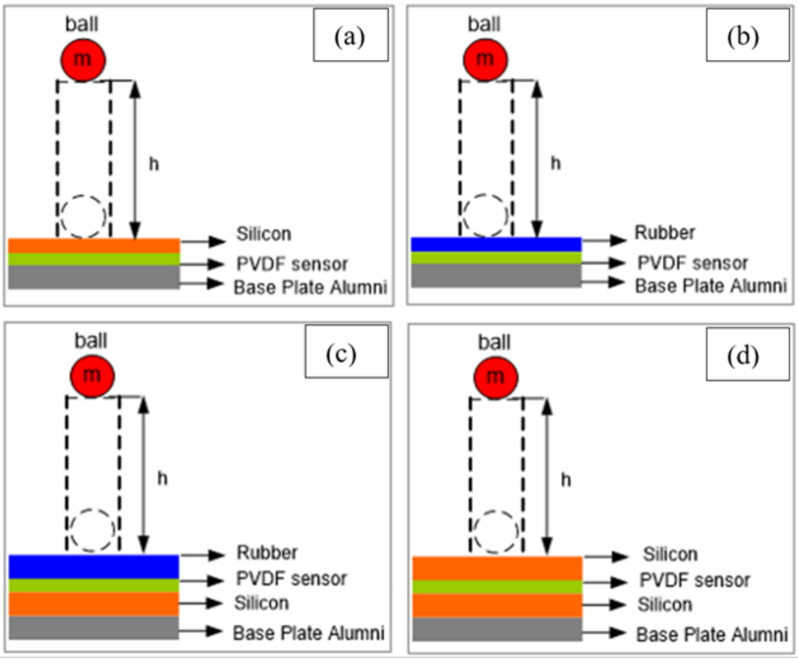


Fig. 4. Impact Force test on PVDF sensor (a) C-1 (b) C-2 (c) C-3 (d) C-4.

Impact force experiments involved dropping a ball from a fixed height (h) onto the upper surface of the cover sensor. Variation in forces was achieved by using different masses for the dropping ball. The average forces exerted on the PVDF sensor's surface during ball impact can be determined using conservation of energy (equation 1) and the work-energy principle equations. (1 to 4) [23].

$$mgh = {}^{1}/_{2}\, mv^2 \tag{1}$$

$$work = Fh = {}^{1}/_{2}\, mv^2 = mgh \tag{2}$$

where m, g, and h represent the mass of the dropping ball, the earth gravity acceleration, and the height distance of the dropping ball from the PVDF film sensor surface. The velocity of dropping ball on surface PVDF can be calculated from the kinetic energy equation, shown in equation 3.

$$v = \sqrt{2gh} \tag{3}$$

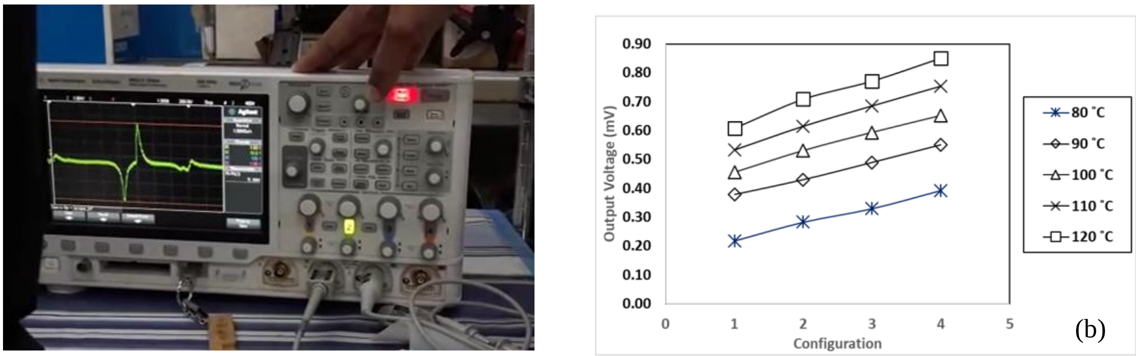
The impact force is

$$F = \frac{{}^{1}/_{2}mv^2}{h} = \frac{mv^2}{2h} \tag{4}$$

3. RESULTS AND DISCUSSION

3.1. Output voltage response

This study considers several factors influencing the output voltage response of the PVDF film sensor, including force or strain magnitude, PVDF film dimensions, sensor properties, and cover material. **Table 1** estimates impact force parameters assuming complete conversion of mechanical energy to impact energy. Thirty tests of varying force (0.961N, 1.935N, and 2.933N) at a constant 0.15m height were conducted on different cover materials. An oscilloscope recorded the output voltage response for four cover material configurations, depicted in **Figure 5(a)**. **Figures 5(b-d)** demonstrate a clear linear relationship between output voltage and applied force. Specifically, configuration C-4 exhibited higher voltage response than others, indicating superior support from silicon (C-4) compared to rubber (C-2 and C-3) under the same impact conditions, likely due to silicon's higher elasticity [22].



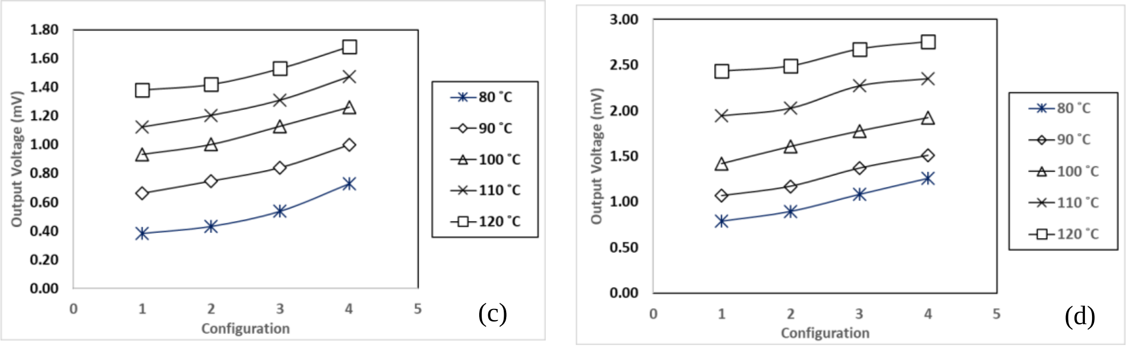


Fig. 5. Output response voltage of PVDF Force sensor on configuration supported as a function of poling temperature in oven (a) sample of peak-to-peak output voltage signal (b) Force = 0.961N (c) Force = 1.935N (d) Force = 2.933N.

Table 1. Impact force for measurement test

Mass (kg)	Diameter ball (m)	Height Object (m)	Impact Force (N)
0.0083	0.0127	0.15	0.961
0.0237	0.018	0.15	1.935
0.0439	0.022	0.15	2.933

The performance of the PVDF film sensor can be identified from the sensitivity, which is related to the content of the β-phase fraction and the degree of crystallinity [24]. The sensitivity of the PVDF film sensor can also be defined as the output electricity divided by the input impact force (η=V/N) [6, 25]. **Figure 6** shows the result of impact force testing 30 times applied on a sample case of poling temperature at T=80ºC, the stretching ratio of R=5, and the impact force of 1.935 N. As shown in Figure 6, the C-4 configuration supporting material cover on the PVDF film sensor exhibited the best performance of the output sensitivity than the other configurations, C-1, C-2, and C-3.

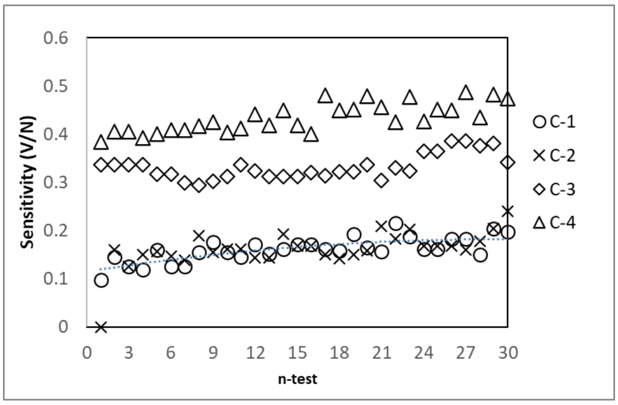


Fig. 6. (a) The fraction of β-phase and degree of crystallinity (b) Data of sensitivity from impact force testing of PVDF film sensor

4. Conclusions

This study successfully utilized uniaxial stretching and temperature variation in ITO polling methods. It examined the impact of different supporting materials on the sensor's sensitivity through impact force tests. Results revealed that increasing the poling temperature led to higher output voltage responses. The best output voltage and sensitivity were achieved when ITO poling at 120°C and employing silicon-PVDF-silicon as the supporting material. The exceptional physical properties of silicon likely contributed to the significant enhancement in the PVDF film sensor's output signal response. This research aims to serve as a blueprint for cost-effective manufacturing of commercially viable PVDF film sensors.

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