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Development of Piezoelectric Nanogenerator Using PU-PVDF Polymer Blend for Efficient Energy Harvesting

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Abstract: ***Flexible and lightweight energy-harvesting materials are essential for the next generation of self-powered electronic devices. This study reports the fabrication and characterization of a polyvinylidene fluoride (PVDF) and polyurethane (PU) blend-based piezoelectric nanogenerator (PENG) using the solvent casting technique. PVDF offers good piezoelectricity but is brittle in nature, whereas PU imparts elasticity and mechanical toughness. PVDF:PU composites of varying compositions (90:10, 80:20, 70:30, and 60:40) were synthesized and analyzed with the help of Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Diffraction (XRD), and Thermogravimetric/Differential Thermal Analysis (TGA/DTA). 90:10 PVDF–PU blend had the largest β-phase fraction, improved thermal stability, and best electrical performance, showing an open-circuit voltage of 5.58 V and a current output of 5.56 µA. Capacitor charge tests validated its ability to retain the charged energy. PVDF/PU nanocomposite showed remarkable flexibility and efficiency, suitable for wearable and self-powered electronics.***

Keywords: PVDF, Polyurethane, Piezoelectric nanogenerator, β-phase, Energy harvesting

1. Introduction

Over the past few years, the need for sustainable and adaptive energy sources has risen because of the growing popularity of portable and wearable electronic devices. Traditional batteries are fixed in their lifespan and pose environmental issues, leading researchers to investigate self-sustained energy systems. Piezoelectric nanogenerators (PENGs) are advanced devices that transform mechanical energy from vibrations, movement, and pressure into electrical energy, and therefore are perfectly suited for self-powered power generation.

Of piezoelectric materials, polyvinylidene fluoride (PVDF) is extensively employed because of its high piezoelectricity and ferroelectricity. Its intrinsic brittleness, however, restricts its elasticity and mechanical resilience. To circumvent this limitation, polyurethane (PU), a flexible, elastic, and tough polymer, is mixed with PVDF to enhance its elasticity and mechanical reliability without greatly sacrificing piezoelectricity.

The current research is centered on the development of PVDF/PU blend films using a straightforward solvent casting method and their characterization by FTIR, XRD, and TGA/DTA testing. The objective is to maximize the PVDF–PU ratio for optimum β-phase development and enhanced piezoelectric operation for energy-harvesting applications.

2. Experimental Details

2.1 Materials

Polyvinylidene fluoride (PVDF, Sigma-Aldrich), polyurethane (PU, Desmopan), and N,N-dimethylformamide (DMF, Merck) were employed without purification. The chemicals used were of analytical grade.

2.2. PVDF/PU Film Fabrication

Homogeneous PVDF film was prepared by dissolving 2 g PVDF in 20 mL DMF and stirring at 55 °C for 12 hours. The homogeneous solution was cast on a Petri dish and dried at 80 °C for 2 hours to form a clear PVDF film.

For PVDF–PU composites, PVDF and PU were separately dissolved in DMF, stirred for 5 hours, and subsequently blended together under constant stirring at 55 °C for 12 hours to achieve blends with different weight ratios (90:10, 80:20, 70:30, and 60:40). The blended solution was cast onto Petri dishes and dried at 80 °C for 2 hours to produce smooth, flexible composite films.

2.3 Characterization Techniques

- \tFTIR Analysis: Employed to determine functional groups and establish the existence of the β-phase in PVDF/PU blends.
- \tXRD Analysis: Employed to identify the crystalline structure and the influence of the PU content on the β-phase of PVDF.
- \tTGA/DTA Analysis: Conducted to analyze the thermal stability and decomposition properties of the composites.
- \tElectrical Output Measurement: Electrical performance of the nanogenerator was measured with an oscilloscope under periodic mechanical stimulation (4 Hz, 20 N).

3. Results and Discussion

3.1 FTIR Analysis

FTIR spectra of PVDF and PVDF/PU composites revealed characteristic absorption peaks for the α-phase (761 cm^{-1}) and β-phase (840 cm^{-1}) of PVDF. Increasing the intensity of the β-phase peak with addition of PU suggests increased dipole alignment and better electroactive phase formation. The

PVDF/PU (90:10) composition had the highest fraction of the β-phase (~89%), as opposed to 85% for pure PVDF, establishing that a small proportion of PU enhances the nucleation of the β-phase.

3.2 XRD Analysis

XRD analysis showed that the pure PVDF showed a prominent peak at $2\theta \approx 20.6°$, which is characteristic of the β-phase crystalline structure. In the PVDF/PU composites, the β-phase peak became more intense and sharper at a ratio of 90:10, while peaks around 18.3° and 26.5° due to α-phases were drastically decreased. This established that addition of PU increases the content and crystallinity of the β-phase and thus enhances piezoelectric properties. But more than 20% PU disrupted chain alignment, decreasing crystallinity.

3.3 Thermal Analysis (TGA/DTA)

Pure PVDF was shown by TGA analysis to degrade at 436 °C, whereas the PVDF/PU (90:10) blend exhibited better thermal stability with a degradation temperature of 471 °C. The better stability is attributed to strong intermolecular interactions between PVDF and PU chains. A greater amount of PU slightly raised the degradation temperature even higher (to ~484 °C) owing to the formation of the char layer that shields the polymer from thermal decomposition.

3.4 Piezoelectric Output Performance

The electrical measurements showed that the highest open-circuit voltage (5.58 V) and short-circuit current (5.56 μA) were obtained by PVDF/PU (90:10) composite film under 4 Hz frequency and 20 N mechanical excitation. Pure PVDF generated just 0.64 V and 0.65 μA. The improved performance of the 90:10 blend is credited to enhanced β-phase content and mechanical flexibility, promoting efficient stress transfer and dipole orientation. Capacitor-charging tests revealed that a 1 μF capacitor was charged to 1.5 V in 60 seconds, which verified effective energy storage performance.

4. Conclusion

The PVDF/PU nanocomposite films were successfully prepared by the solvent casting process and analyzed by FTIR, XRD, and TGA/DTA. Incorporation of PU enhanced the flexibility, thermal stability, and piezoelectric characteristics of PVDF. The 90:10 PVDF–PU blend showed the optimal balance of β-phase content and electrical properties, generating an open-circuit voltage of 5.58 V and a current of 5.56 μA. The results show that the PVDF/PU blend is an efficient material for flexible, wearable, and self-powered energy-harvesting devices.

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