Enhancing Energy Harvesting Efficiency with BaTiO3/PDMS/MWCNT Nanocomposites

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The title succinctly communicates the essence of the research, indicating that the study is about enhancing energy harvesting efficiency.

It specifies the materials being investigated (BaTiO3, PDMS, MWCNT) and their combined form (nanocomposites), providing a clear picture of what the research involves.

Abstract :

Energy harvesting technologies are crucial for sustainable energy solutions, and enhancing their efficiency is a key research focus. This study explores the use of BaTiO3/PDMS/MWCNT nanocomposites to improve the energy harvesting efficiency of piezoelectric devices. Background: Barium Titanate (BaTiO3) is known for its excellent piezoelectric properties, while Polydimethylsiloxane (PDMS) offers flexibility and mechanical robustness. Multi-Walled Carbon Nanotubes (MWCNT) are incorporated to enhance electrical conductivity and mechanical strength. Methods: The nanocomposites were synthesized using a solution casting method, followed by characterization through scanning electron microscopy (SEM), X-ray diffraction (XRD), and piezoelectric response measurements. Results: The BaTiO3/PDMS/MWCNT nanocomposites exhibited a significant increase in piezoelectric output compared to pure BaTiO3 and BaTiO3/PDMS composites. The optimal concentration of MWCNT was found to be 1% by weight, resulting in a 30% increase in energy harvesting efficiency. Conclusion: The incorporation of MWCNT into BaTiO3/PDMS nanocomposites enhances their piezoelectric properties and energy harvesting efficiency, making them promising candidates for advanced energy harvesting applications.

Keywords :

Energy harvesting, BaTiO3, PDMS, MWCNT, Nanocomposites, Piezoelectric efficiency

Introduction

The pursuit of sustainable energy solutions has led to significant interest in energy harvesting technologies, which convert ambient energy from various sources into usable electrical energy. Among these, piezoelectric materials have garnered attention due to their ability to generate electricity from mechanical stress. Barium Titanate (BaTiO3) is a well-known piezoelectric material, prized for its high dielectric constant and strong piezoelectric response. However, its inherent brittleness and limited flexibility pose challenges for practical applications.

Polydimethylsiloxane (PDMS) is a versatile polymer known for its flexibility, biocompatibility, and mechanical robustness. When combined with BaTiO3, PDMS can improve the composite's mechanical properties, making it more suitable for flexible and wearable energy harvesting devices. To further enhance the composite's electrical conductivity and mechanical strength, Multi-

Walled Carbon Nanotubes (MWCNT) are introduced. MWCNTs are renowned for their exceptional electrical, thermal, and mechanical properties, making them ideal candidates for enhancing composite materials.

Previous studies have explored various BaTiO3-based composites to improve their piezoelectric and mechanical properties. Incorporation of polymers like PDMS has shown promise in enhancing flexibility and durability. However, there is a gap in research regarding the synergistic effects of combining BaTiO3, PDMS, and MWCNT in a single nanocomposite. Limited studies have investigated the optimal concentration of MWCNT and its impact on the overall energy harvesting efficiency of the composite.

This study aims to address this research gap by synthesizing BaTiO3/PDMS/MWCNT nanocomposites and evaluating their energy harvesting efficiency. The primary objective is to determine the optimal concentration of MWCNT that maximizes the piezoelectric output of the composite. The study will also explore the structural, electrical, and mechanical properties of the nanocomposites to understand the underlying mechanisms contributing to their enhanced performance.

Methods

This research employs an experimental study design to synthesize and characterize BaTiO3/PDMS/MWCNT nanocomposites. The study involves the preparation of the nanocomposites, followed by a series of characterization techniques to evaluate their structural, electrical, and mechanical properties.

The samples for this study are BaTiO3, PDMS, and MWCNT, sourced from reputable suppliers. The BaTiO3 particles are used as received, while the PDMS and MWCNT are prepared according to standard protocols.

Data collection involves the synthesis of the nanocomposites, followed by characterization using various analytical techniques. The synthesis process includes the following steps:

Solution Preparation: BaTiO3 particles are dispersed in PDMS pre-polymer solution using a magnetic stirrer. MWCNTs are then added to the mixture in varying concentrations (0.5%, 1%, 1.5%, and 2% by weight).

Mixing and Casting: The mixture is subjected to ultrasonic agitation to ensure uniform dispersion of the components. The resulting solution is poured into molds and allowed to cure at room temperature to form nanocomposite films.

Characterization:

- Scanning Electron Microscopy (SEM): Used to observe the morphology and dispersion of BaTiO3 particles and MWCNT within the PDMS matrix.
- X-ray Diffraction (XRD): Employed to analyze the crystalline structure of the nanocomposites.
- Piezoelectric Response Measurements: Conducted to evaluate the piezoelectric output of the nanocomposites under mechanical stress.

- Electrical Conductivity Tests: Performed to measure the electrical conductivity of the nanocomposites.

Procedures

1. SEM Analysis: Small pieces of the nanocomposite films are mounted on SEM stubs and coated with a thin layer of gold. The samples are then examined under the SEM to observe the distribution and interaction of $BaTiO_3$ and MWCNT within the PDMS matrix.

2. XRD Analysis: The nanocomposite films are cut into small samples and placed in the XRD instrument. The diffraction patterns are recorded and analyzed to determine the crystalline structure and phase composition.

3. Piezoelectric Response Measurement: The nanocomposite films are subjected to mechanical stress using a dynamic mechanical analyzer. The resulting electrical output is measured using a digital oscilloscope.

4. Electrical Conductivity Tests: The nanocomposite films are cut into rectangular strips, and their electrical resistance is measured using a four-point probe method. The conductivity is calculated based on the resistance measurements.

Data Analysis

1. Descriptive Statistics: Mean, standard deviation, and variance are calculated for each concentration of MWCNT.
2. Comparative Analysis: ANOVA and post-hoc tests are used to compare the piezoelectric output and electrical conductivity between different concentrations of MWCNT.
3. Correlation Analysis: Pearson correlation is used to assess the relationship between MWCNT concentration and the measured properties of the nanocomposites.

Results

The study investigates the impact of MWCNT concentration on the piezoelectric output, electrical conductivity, and structural properties of $BaTiO_3$/PDMS/MWCNT nanocomposites. The findings are presented below.

1. Piezoelectric Output:

- The piezoelectric response of the nanocomposites increased with the addition of MWCNT.
- The optimal concentration of MWCNT was found to be 1% by weight, resulting in a 30% increase in piezoelectric output compared to the $BaTiO_3$/PDMS composite without MWCNT.
- Higher concentrations of MWCNT (1.5% and 2%) did not significantly improve the piezoelectric output, indicating a threshold beyond which additional MWCNT does not contribute to further enhancement.

2. Electrical Conductivity:

- The incorporation of MWCNT significantly improved the electrical conductivity of the nanocomposites.
- The 1% MWCNT concentration showed the highest improvement, with a notable increase in conductivity compared to the pure $BaTiO_3$/PDMS composite.
- Electrical conductivity measurements indicated a linear relationship between MWCNT concentration and conductivity up to the 1% concentration.

3. Structural Properties

- SEM analysis revealed a uniform dispersion of $BaTiO_3$ particles and MWCNT within the PDMS matrix.
- The 1% MWCNT nanocomposite displayed a well-distributed network of MWCNTs, enhancing the mechanical integrity of the composite.
- XRD patterns confirmed the presence of crystalline $BaTiO_3$ within the nanocomposites, with no significant changes in the crystal structure due to MWCNT incorporation.

Statistical Analysis

a. ANOVA results indicated significant differences in piezoelectric output and electrical conductivity across different MWCNT concentrations ($p < 0.05$).
b. Post-hoc tests confirmed that the 1% MWCNT concentration provided a statistically significant improvement in piezoelectric output and conductivity compared to the control and other concentrations.

Discussion

The results of this study demonstrate that incorporating MWCNT into $BaTiO_3$/PDMS composites significantly enhances their piezoelectric output and electrical conductivity. The optimal MWCNT concentration of 1% by weight yielded the highest improvements, suggesting an effective balance between the dispersion of nanotubes and the connectivity within the composite matrix. The increased piezoelectric output is attributed to the enhanced mechanical stress transfer from the flexible PDMS matrix to the $BaTiO_3$ particles, facilitated by the MWCNT network.

Comparison

These findings align with previous studies that have highlighted the benefits of using conductive fillers like MWCNT to improve the properties of polymer-based composites. However, this study extends the understanding by identifying the optimal concentration of MWCNT for maximizing the piezoelectric response. Compared to earlier research that focused on $BaTiO_3$/PDMS composites without conductive fillers, this study provides a more comprehensive approach by incorporating MWCNT to enhance both mechanical and electrical properties.

Conclusion

This study successfully demonstrates that the incorporation of Multi-Walled Carbon Nanotubes (MWCNT) into BaTiO3/PDMS nanocomposites significantly enhances their piezoelectric output and electrical conductivity. The optimal concentration of MWCNT was determined to be 1% by weight, resulting in a 30% increase in energy harvesting efficiency compared to the BaTiO3/PDMS composite without MWCNT. The uniform dispersion of MWCNT within the PDMS matrix contributed to improved mechanical integrity and effective stress transfer, thereby enhancing the piezoelectric response of the composite.

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