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Performance Improvement of PVDF-Based Piezoelectric Energy Harvesters Using Flash Light Annealing

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1. Introduction

The rapid growth in demand for standalone wireless sensors and wearable electronic devices has highlighted the limitations of traditional battery-based power supplies, particularly regarding size, operational lifespan, and performance degradation. Energy harvesters, which convert ambient waste energy into electricity, are viewed as a potential solution to these challenges. Among the various types, piezoelectric energy harvesters have attracted considerable attention due to their high energy conversion efficiency and simple design. Polyvinylidene Fluoride (PVDF), a lead-free piezoelectric material, is particularly promising due to its environmental friendliness, mechanical stability, and flexibility, making it suitable for use in various applications, including wearable and implantable devices. However, the lower piezoelectric performance of PVDF compared to ceramic materials has been a limiting factor. This study explores the use of flash light annealing to enhance the β-phase content in PVDF, thereby improving its piezoelectric properties and energy harvesting performance.

2. Methods and Results

PVDF films were prepared using a spin-coating process to achieve a uniform thickness of 8 μm, followed by a flash light annealing process to induce crystallization, as shown in Fig.1. The flash light annealing was conducted with a fixed pulse duration of 1.5 milliseconds, while the applied voltage was varied between 200 V and 400 V to optimize the β-phase formation. The β-phase content in the PVDF films was quantified using Fourier Transform Infrared (FTIR) spectroscopy. The analysis revealed that the β-phase content peaked at 76.5 % when a 300 V voltage was applied, while higher voltages resulted in a decrease in β-phase content due to the phase transition from β-phase to α-phase. Compared to traditional high-temperature annealing, which typically requires prolonged exposure to heat, flash light annealing significantly reduced the processing time to milliseconds while achieving comparable or even superior crystallization. The flexible piezoelectric energy devices were fabricated at the optimized condition as shown in Fig. 2 and tested for their electrical output under repeated bending deformations.

It was noted from Fig. 3 that the devices demonstrated stable performance, generating a maximum open-circuit voltage of 0.21 V and a short-circuit current of 102 nA, with no significant degradation observed over multiple cycles.

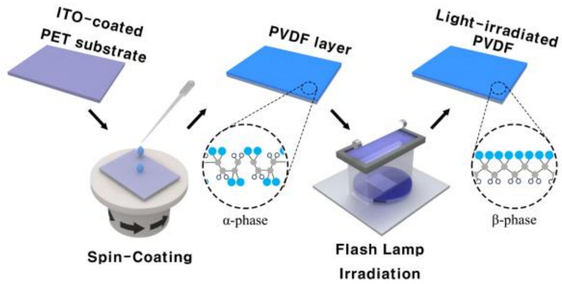

Fig. 1. Schematic diagrams illustrating the enhancement process of the β-phase contents in PVDF films via flash light irradiation.

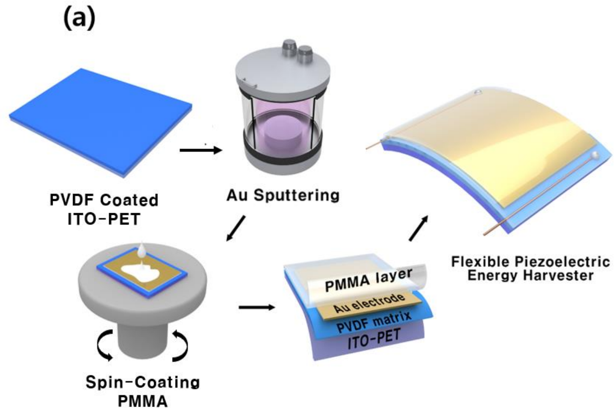

Fig. 2. Schematic illustrations showing the fabrication process of the flexible piezoelectric energy harvester based on flash lamp irradiated PVDF films.

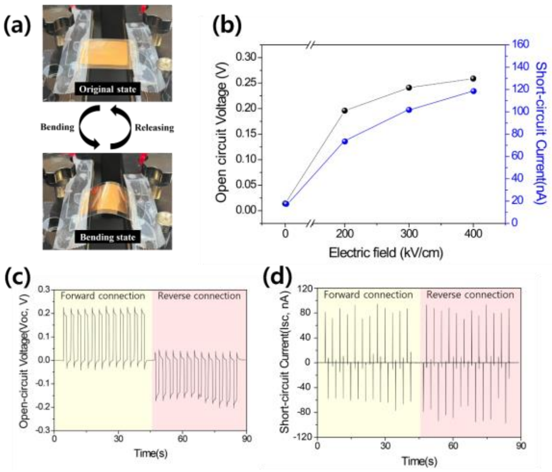

Fig. 3. (a) Photographs of the flexible piezoelectric energy harvester in bending and original states. (b) Open-circuit voltage and short-circuit current measured from the energy devices after poling process at 200, 300, and 400 kV/cm. (c,d) Open-circuit voltage (c) and short-circuit current (d) measured under forward and reverse connections, respectively.

3. Conclusions

This study successfully demonstrated that flash light annealing is an effective technique for enhancing the piezoelectric properties of PVDF-based energy harvesters. By optimizing the annealing voltage, the β-phase content was maximized, resulting in improved energy conversion efficiency. The process not only shortens the overall processing time compared to conventional method but also maintains high-performance characteristics, making it a promising alternative for the large-scale fabrication of flexible energy harvesters. Further research into the optimization of other flash light annealing parameters, such as pulse duration and interval, could lead to even greater improvements in device performance.

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