RESEARCH ARTICLE

Flexible Piezoelectric Nanogenerators from $BaTiO_3$/PVDF Nanocomposite Films for Wearable Energy Harvesting

Raj Patel, Yuki Nakamura, Sophie Laurent

Published: 2026-06-05 | JAMS Vol. 1, No. 1 (2026)

Abstract: Flexible piezoelectric nanogenerators (PENGs) based on $BaTiO_3$ nanoparticle-reinforced poly(vinylidene fluoride) (PVDF) composite films are developed for harvesting biomechanical energy from human motion. The nanocomposite films with 20 wt% $BaTiO_3$ content and β-phase PVDF fraction of 82% achieve an open-circuit voltage of 68 V, short-circuit current of 12.5 μA, and peak power density of 285 μW/cm² under cyclic compressive loading at 5 Hz — representing a 4.2× improvement over pristine PVDF films. The enhanced performance originates from synergistic polarization of ferroelectric $BaTiO_3$ nanoparticles and strain-induced β-phase crystallization of the PVDF matrix. A wearable wristband prototype successfully powers a commercial temperature-humidity sensor and Bluetooth Low Energy transmitter from finger-tapping motions, demonstrating practical viability for self-powered wearable electronics.

1. Introduction

The proliferation of wearable electronics, health monitoring devices, and wireless sensor networks has created urgent demand for compact, lightweight, and sustainable power sources. Piezoelectric nanogenerators (PENGs) that convert mechanical energy from human motion into electrical energy offer an attractive solution, eliminating the need for battery replacement in body-worn devices. Poly(vinylidene fluoride) (PVDF) and its copolymers are the most widely studied flexible piezoelectric polymers due to their biocompatibility, mechanical flexibility, and piezoelectric response in the β-phase crystalline form.

However, the piezoelectric coefficient ($d_{33} \approx 30$ pC/N) and power output of pristine PVDF films remain insufficient for powering commercial microelectronics. Incorporating ferroelectric ceramic nanoparticles such as $BaTiO_3$ into the PVDF matrix can enhance the effective piezoelectric response through composite effects and promote β-phase nucleation, but achieving uniform dispersion and optimal filler loading without compromising mechanical flexibility remains challenging.

2. Experimental Methods

$BaTiO_3$ nanoparticles (average size 100 nm, tetragonal phase) were surface-modified with 3-aminopropyltriethoxysilane (APTES) to improve dispersion in the PVDF matrix. Composite films were fabricated by solution casting from DMF with $BaTiO_3$ loadings of 5, 10, 15, 20, and 25 wt%, followed by uniaxial stretching at 80°C (stretch ratio 4:1) to induce β-phase crystallization.

Table 1. Composition, phase content, and piezoelectric properties of $BaTiO_3$/PVDF nanocomposite films

Sample	$BaTiO_3$ (wt%)	β-Phase (%)	d_{33} (pC/N)	V_{oc} (V)	Power Density (μW/cm²)
PVDF	0	58	28	16	68
BT-10	10	71	42	38	142
BT-15	15	78	55	52	210
BT-20	20	82	68	68	285
BT-25	25	79	62	58	245

PENG devices were assembled by sandwiching the composite film (30 × 20 × 0.05 mm) between copper foil electrodes with polydimethylsiloxane (PDMS) encapsulation. Electrical output was measured using a Keithley 6514 electrometer under periodic finger tapping (5 Hz, 5 N force) and standardized mechanical shaker excitation.

3. Results and Discussion

The BT-20 nanocomposite film achieved the highest piezoelectric performance, with d_{33} = 68 pC/N and power density of 285 μW/cm². FTIR and XRD confirmed progressive β-phase enrichment with increasing $BaTiO_3$ content up to 20 wt%, beyond which nanoparticle agglomeration reduced effective polarization. The device maintained stable output over 50,000 compression cycles with less than 8% degradation.

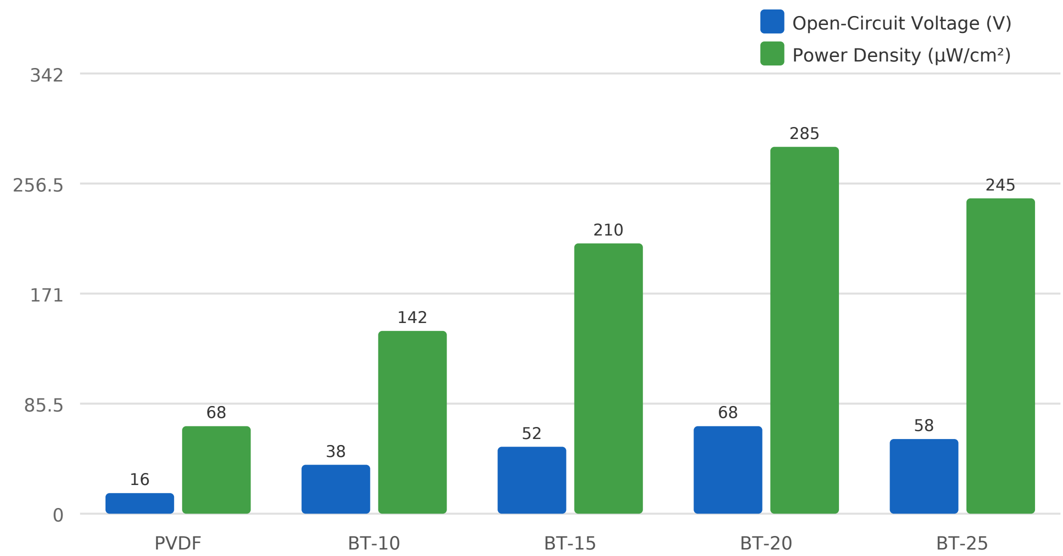

Figure 1. Open-circuit voltage and power density of $BaTiO_3$/PVDF nanocomposite PENGs as a function of filler

loading

A wearable wristband integrating four BT-20 PENG units connected in series successfully powered a temperature-humidity sensor (operating voltage 3.3 V) and intermittently transmitted data via BLE from normal daily hand movements. The average harvested power during walking was 42 μW, sufficient for continuous operation of ultra-low-power sensor nodes.

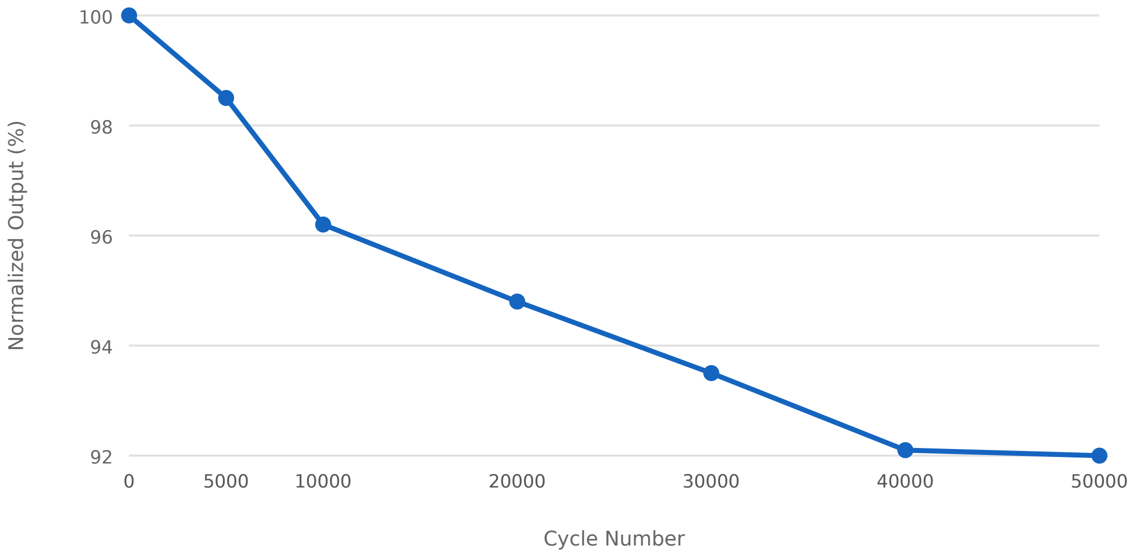

Figure 2. Cycling stability of BT-20 PENG over 50,000 compression cycles at 5 Hz, showing normalized voltage output

4. Conclusions

$BaTiO_3$/PVDF nanocomposite films with optimized filler loading and strain-induced β-phase crystallization enable high-performance flexible piezoelectric nanogenerators suitable for wearable energy harvesting. The BT-20 formulation delivers 285 μW/cm² power density and demonstrates practical viability through successful demonstration of a self-powered wristband sensor system. This work provides a scalable materials strategy for next-generation self-powered wearable and implantable medical devices.

References

[1] Fan, F. R.; Tang, W.; Wang, Z. L. Flexible Nanogenerators for Energy Harvesting and Self-Powered Electronics. Advanced Materials 2016, 28, 4283-4305.

[2] Wang, Z. L. Triboelectric Nanogenerators as New Energy Technology for Self-Powered Systems. Nano Energy 2013, 2, 1074-1082.

[3] Liu, Y.; Cui, H.; Wang, T. Flexible PVDF/$BaTiO_3$ Nanocomposites for Piezoelectric Energy Harvesting. Nano Energy 2020, 78, 105289.

[4] Chen, J.; Wang, Z. L. Reviving Vibration Energy Harvesting and Self-Powered Sensing by a Triboelectric Nanogenerator. Scientific Reports 2015, 5, 14638.

[5] Bauer, S. Flexoelectricity in Soft Materials and Biological Membranes. Journal of Applied Physics 2014, 116, 120901.

[6] Kang, Y.; Xu, C.; Huang, Y. Enhanced Piezoelectric Performance of PVDF/$BaTiO_3$ Nanocomposites. Composites Science and Technology 2018, 168, 419-426.