GLOBAL RESEARCH IMMERSION PROGRAM FOR YOUNG SCIENTISTS

Grips

Development and Analysis of Hybrid Energy Harvesting Systems: Droplet-based Electricity Generator and TiO2 Nanofiller-Enhanced PVDF-Based Triboelectric Nanogenerators

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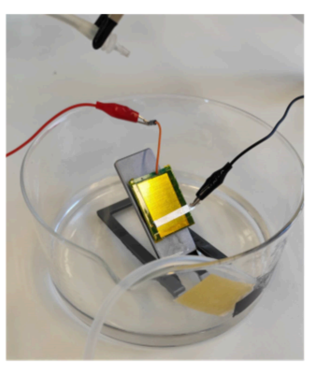
Background

Energy harvesting technologies, such as triboelectric nanogenerators (TENGs) and droplet-based electricity generators (DEGs), offer promising solutions for powering small electronic devices and sensors in remote or inaccessible locations. TENGs utilize the triboelectric effect, where materials become electrically charged after frictional contact and separation, to generate electricity from everyday mechanical movements, making them ideal for applications like wearable electronics and environmental monitoring. DEGs convert mechanical energy from water droplets into electrical energy, which is particularly useful in areas with abundant rainfall or water flow. As the need for sustainable and self-sufficient power sources grows, hybrid systems combining TENGs and DEGs are being developed to capture energy from multiple sources simultaneously, enhancing efficiency and reliability. This research aims to improve the materials and methods used in these hybrid systems to achieve higher energy conversion efficiencies.

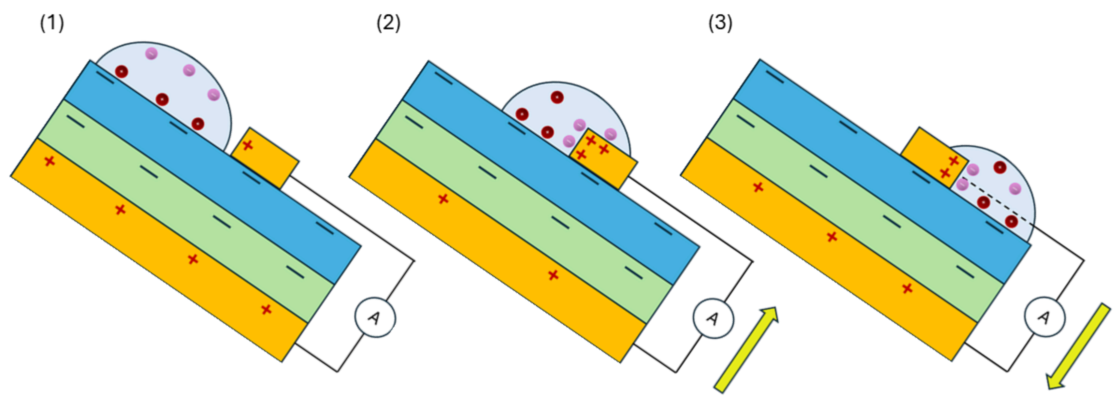
[1]Design of the DEG

I. Introduction

- The device used as our DEG consists of a lower indium tin oxide (ITO) electrode, 2 layers of electret material (the top one being hydrophobic), and an upper aluminum electrode.

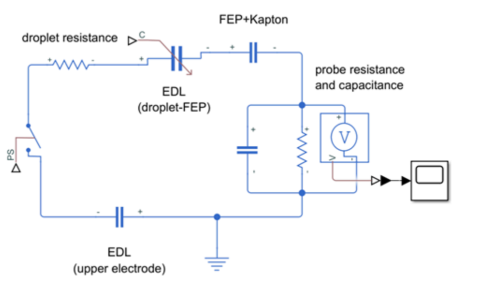


- Working mechanism
  1) When the water droplet hits the upper layer, an electric double layer (EDL) is formed at the water-solid interface.
  2) As the droplet spreads on the aluminum, another EDL is formed, and charges are transferred from the lower electrode to the upper electrode to restore charge balance.
  3) After reaching the maximum contact area with the electrode, charges will transfer back to the lower electrode as the contact area with the upper electrode is reduced. The current direction is reversed.



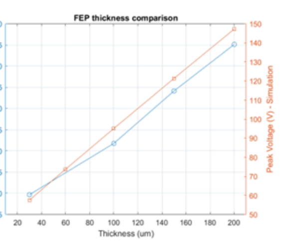
II. Method

- Different thicknesses of FEP have been tested as the upper layer. The intermediate layer, made of Kapton, aims to enhance the output.
- A simulation has been developed according to the equivalent circuit to compare with the experimental results.

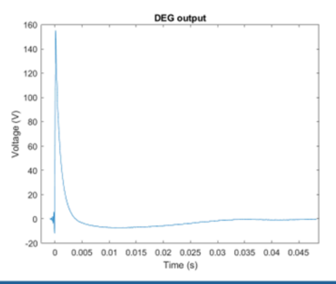


III. Results

- We can compare the simulation and experimental behavior of the output as we change the thickness of FEP. In both cases, output increases with thickness.



- Output waveform for the 200 μm film:



[2]Enhanced Performance of PVDF-TiO2 based TENG

I. Introduction

Polyvinylidene fluoride (PVDF) is known for its intrinsic piezoelectric properties and is used in various types of nanogenerators, including piezoelectric and triboelectric nanogenerators (PNG, TENG). Recent advancements have been focusing on improve the piezoelectric response of PVDF. Previous research showed that adding nanofillers, including nanosheets, nanotubes, nanoparticles, and composite materials can improve the β-phase of PVDF, which demonstrates great piezoelectric properties and has the most crystalline amongst other phases of PVDF, namely, α, γ, δ and ε. This study introduced a method for synthesizing enhanced piezoelectric response PVDF composites by using nano Titanium dioxide (TiO_2) and freeze-drying (FD). The results showed significant improvement in the β-phase of PVDF with enhanced voltage output of fabricated triboelectric nanogenerator (TENG) with a maximum peak-to-peak voltage of 849.2V.

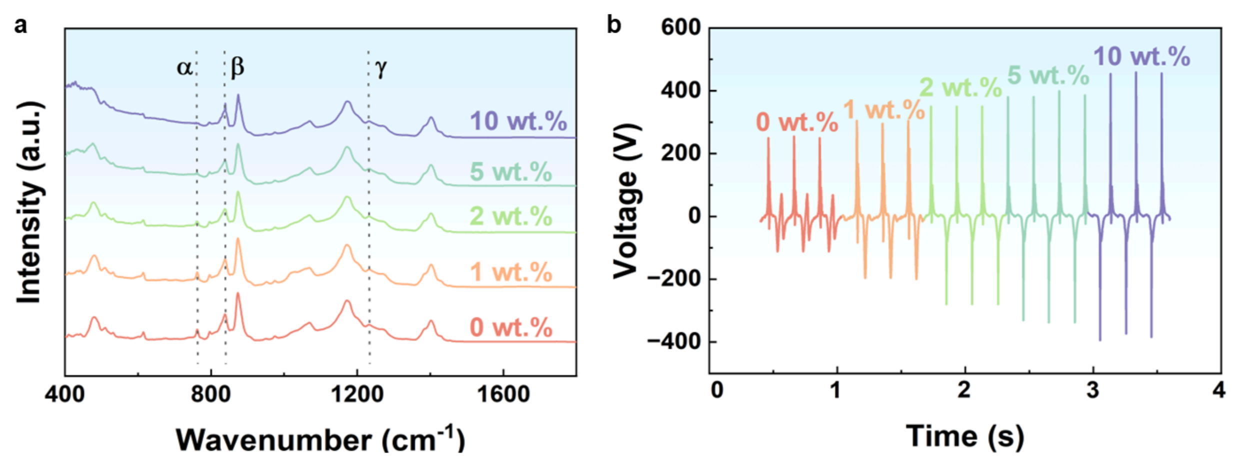
II. Results and Discussion

2.1 Characteristics of Freeze-Drying (FD) induced $PVDF - TiO_2$ Composite Films

Fourier transform infrared spectroscopy (FT-IR) was carried out to analyze the β-phase content in the synthesized material. Among the five crystalline phases of PVDF, β-phase is related to the piezoelectric response of the material, that is, high concentration of β-phase can greatly improve the piezoelectric properties of PVDF. The characteristic bands of α phase are around 530, 615, 765, and 795 cm^{-1}; the characteristic bands of β phase are around 510 and 840 cm^{-1}; and the characteristic bands of γ phase are around 431, 776, 812, and 1233 cm^{-1} [1]. The percentage of β-phase can be calculated using the Gregorio's formula:

$$F(\beta) = \frac{A(\beta)}{\left(\frac{k(\beta)}{k(\alpha)}\right) A(\alpha) + A(\beta)} = \frac{A(\beta)}{1.2623 \times A(\alpha) + A(\beta)}$$

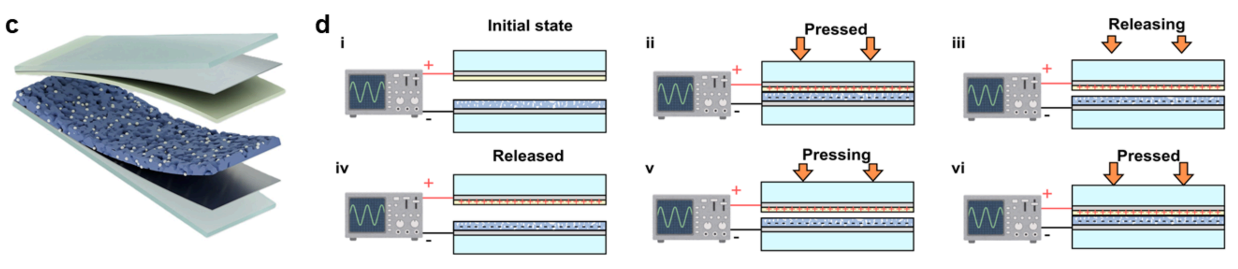
Where $A(\alpha)$ and $A(\beta)$ represent the absorption intensities at wavenumber equals to 765 cm^{-1} and 835 cm^{-1}, respectively. From Fig a, we can see that the FD $PVDF - TiO_2$ composite film displays an increasing content of β-phase as the TiO2 concentration increases, with an maximum of 85.71% with TiO2 reinforcement of 10 wt.%. With increasing concentration of TiO2, there is an obvious suppression of the α peak 765 cm^{-1}, further evidencing the influence of TiO2 to the β phase in PVDF.



(a) FT-IR spectra. **(b)** voltage output of TENG device fabricated using FD $PVDF - TiO_2$ composite film and PA6 membrane.

2.2 Structure and performance of the PVDF based TENG device

In order to test the real life application of the PVDF-TiO2 film, we have fabricated a TENG device using the FD induced PVDF-TiO2 film and a PA6 membrane as its negative and positive friction layer. Fig c shows the schematic of the TENG device. The PA6 membrane was prepared by the phase-inversion using the method reported in [2]. The prepared PA6 film has porous structures and is considered as one of the best positive tribo-materials for TENG. Both membranes were cut into 20mm x 20mm square thin films and placed on the glass substrate, with aluminum electrode between the films and the substrate. The device was tested under a constant impact force of 50N with a working frequency of 5Hz. As shown in Fig b, the TENG exhibit an increasing output voltage along with the increase TiO2 percentage, with a maximum output voltage (V_{OC}) of 459V and peak-to-peak voltage (V_{PP}) of 849.2V at a TiO2 concentration of 10wt%, coinciding with the peak beta-phase of the film illustrated in the previous section.



(c) 3D schematic of the device. **(d)** Working principle of the TENG.

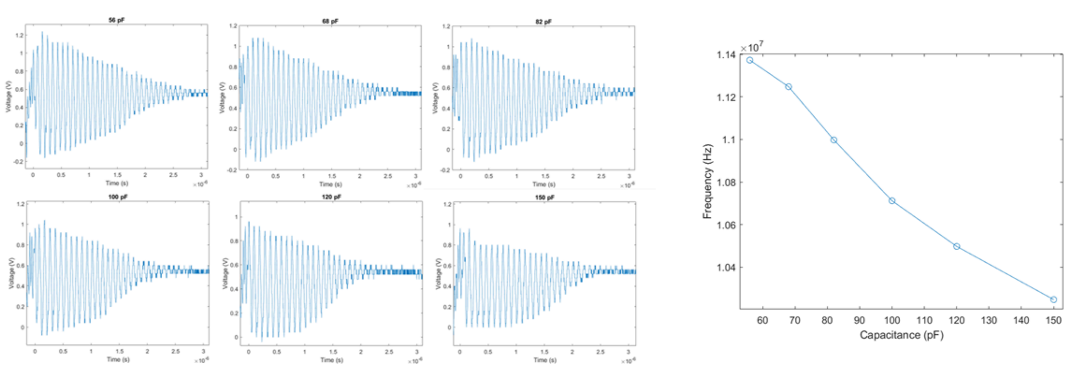
Sensing application

I. Method

- A general sensor will be designed using the DEG, although it could also be done with the TENG.
- Before the output reaches our sensor, it will go through two circuits:
  1) Microswitch: This circuit allows us to get a cleaner and more stable output.
  2) Colpitts oscillator circuit: Transforms the output from the microswitch into a resonance signal.
- By changing the value of one of the capacitances, the signal frequency will change according to an LC circuit equation.

II. Results

- Through an FFT analysis, it is observed that the oscillating frequency changes for each capacitance value.
- Therefore, our system is valid for sensing applications using a capacitive sensor.



Conclusion

In this research, we have successfully demonstrated the applicability of energy harvesting systems using DEGs and PVDF-TiO2-based TENGs for sensor applications. The integration of these technologies results in robust systems capable of powering small devices and sensors, offering opportunities for sustainable energy solutions in remote locations. Future work can focus on assessing efficiency in specific applications, further improving device performance for practical use, and exploring the possibility of powering devices with higher energy demands than sensors.

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