# Controlling Porous Structure of PVDF-TrFE Films via Microwave-Synthesized ZnO with Tunable Morphologies for Improved Piezoelectric Output

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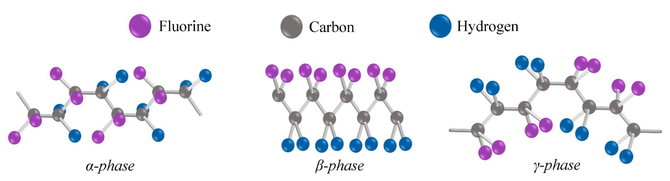
## Abstract

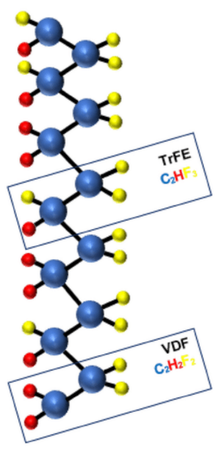
The conversion of mechanical energy into electrical energy via piezoelectric nanogenerators (PENGs) has emerged as a promising approach for powering next-generation self-sustainable electronic devices, including wearable sensors and portable electronics. PENGs operate based on the direct piezoelectric effect, wherein mechanical stress applied to a piezoelectric material induces electrical polarization, thereby generating a measurable voltage or current. Among various piezoelectric materials, poly(vinylidene fluoride-co-trifluoroethylene) (PVDF-TrFE) copolymers are particularly attractive due to their mechanical flexibility and processability. In this study, we aim to enhance the piezoelectric performance of PVDF-TrFE based PENGs by introducing a porous microstructure, which is achieved by incorporating ZnO nanoparticles. The ZnO nanoparticles are synthesized via a high temperature and high pressure microwave-assisted hydrothermal method. By tuning the pH of the precursor solution, the morphology of the ZnO particles can be controlled from hexagonal rods to other geometries, which subsequently determines the pore morphology of PVDF-TrFE after selective HCl etching. We demonstrate the critical role of ZnO morphology in defining the resultant porous structure of PVDF-TrFE, and we systematically investigate how these pore structures influence the piezoelectric output performance of the PENGs.

## Introduction

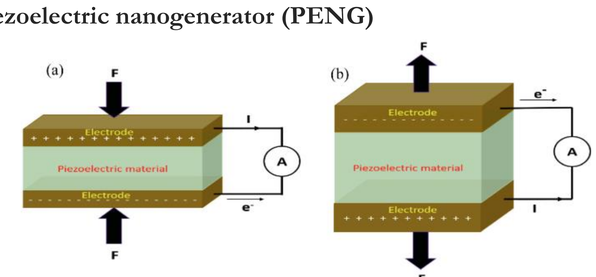
➢ Structure of PVDF in different phase




➢ Structure of PVDF-TrFE

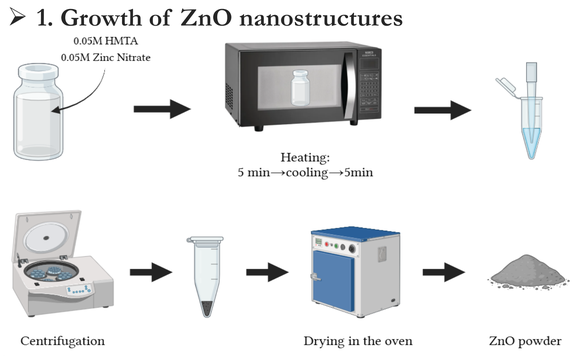



➢ Piezoelectric nanogenerator (PENG)

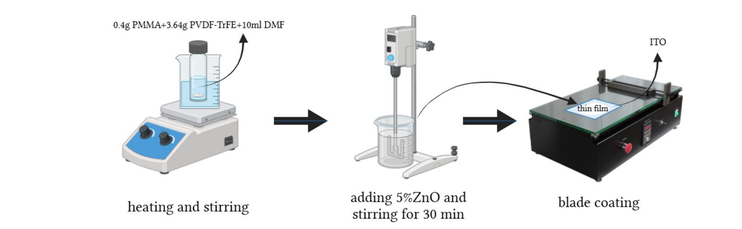



## Experimental procedure

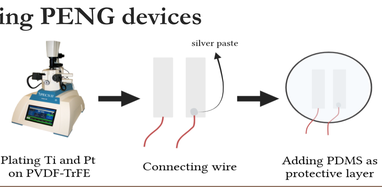
➢ 1. Growth of ZnO nanostructures

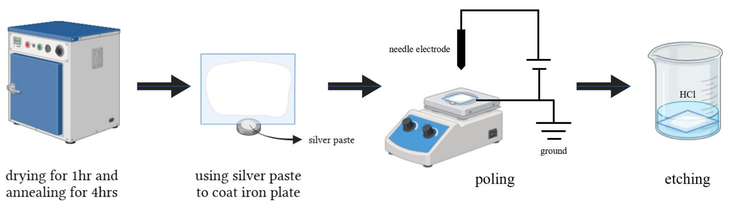



➢ 2. Preparation of PVDF-TrFE/ZnO cpmposite film




➢ 3. Making PENG devices



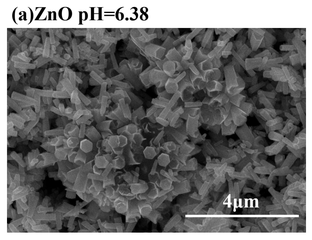




## Result & Discussion

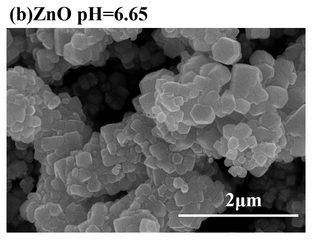
### Surface Morphology

➢ SEM image

(a)ZnO pH=6.38



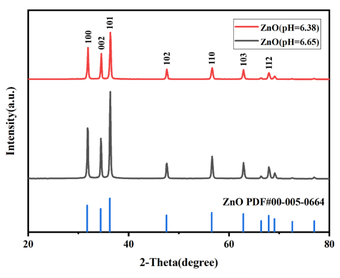

(b)ZnO pH=6.65



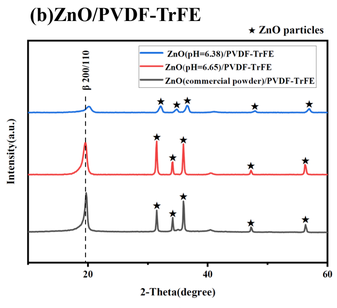

### Characterization

➢ XRD analysis

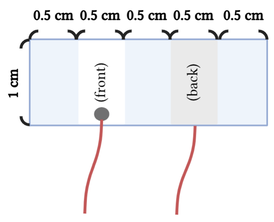
(a)ZnO powder



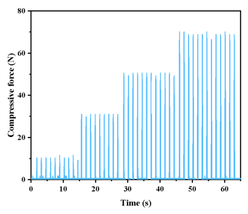

(b)ZnO/PVDF-TrFE




➢ PENG device

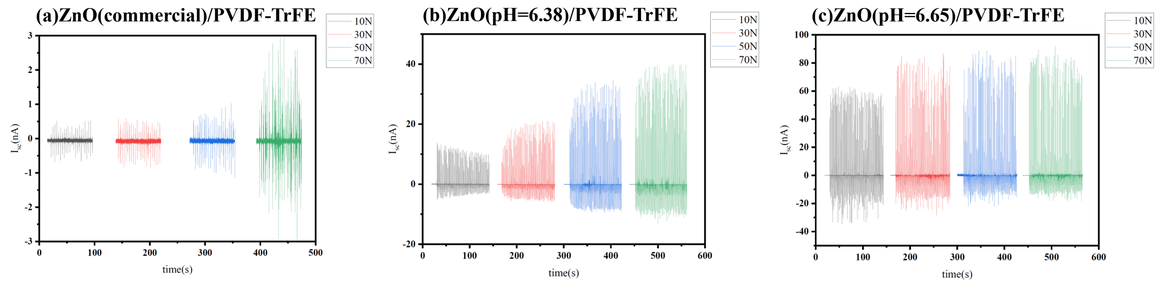



➢ Applied force

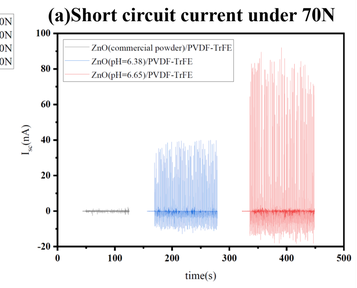



### PENG

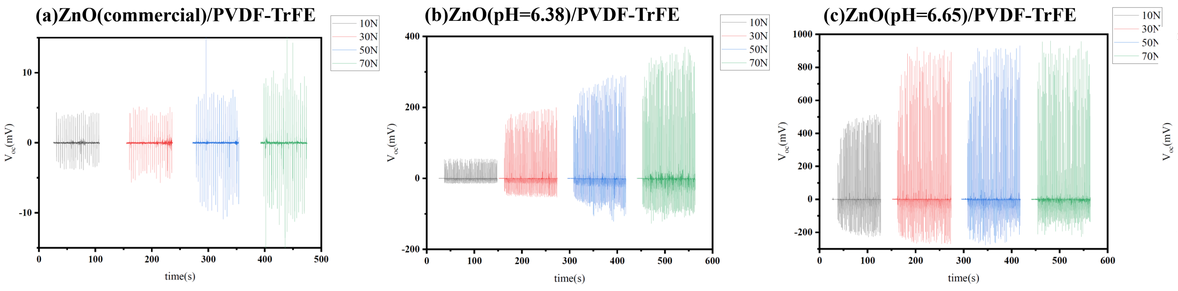
➢ Short circuit current of the PENG

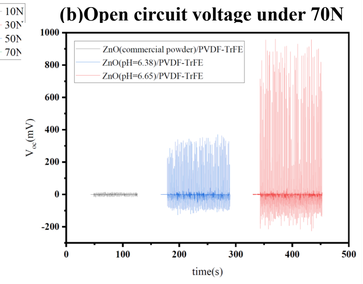



➢ Comparison



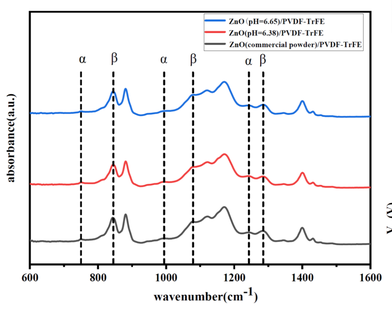

➢ Open circuit voltage of the PENG



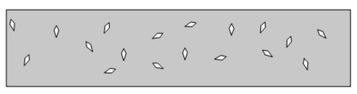

### Molecular Structure

➢ FT-IR spectra

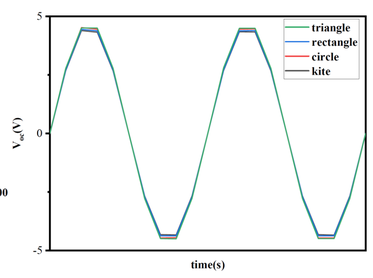



### Comsol-Simulation

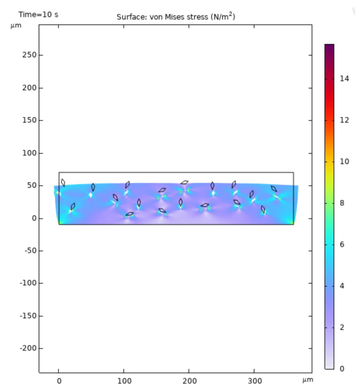
➢ Kite-shaped pores



➢ $V_{oc}$ output simulation

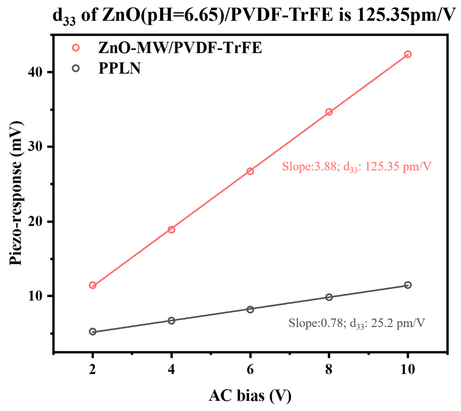



➢ Compressive stress simulation

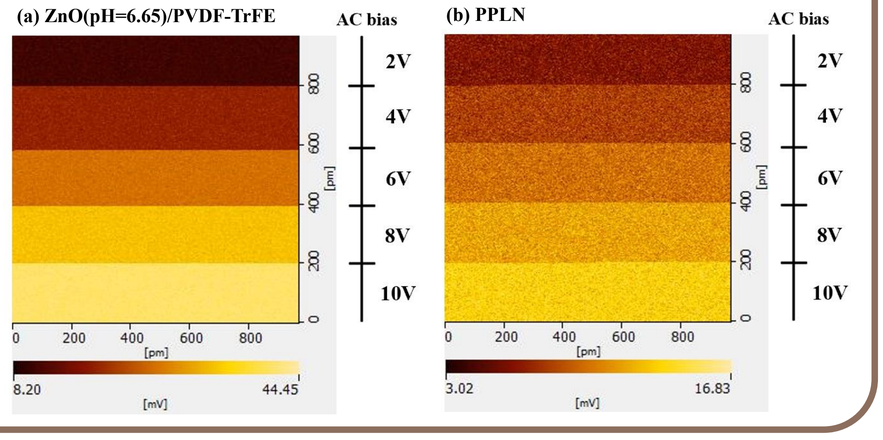



### AFM analysis

➢ Piezo-response




➢ PFM respond amplitude




## Conclusion

By adjusting the pH of the precursor solution, the morphology of ZnO nanoparticles can be effectively tuned. Incorporating ZnO nanoparticles with different morphologies into PVDF-TrFE films alters the resulting porous structure, which significantly influences the piezoelectric output performance. As a result, PVDF-TrFE-based piezoelectric nanogenerators fabricated using ZnO synthesized at higher pH values exhibit enhanced efficiency in converting mechanical energy into electrical energy, with the $d_{33}$ piezoelectric coefficient reaching as high as 125.35 pm/V.