

Abstract

A study on nature-inspired multifunctional polymeric composites for piezoelectric energy harvester, real time triboelectric sensors and lead-free ultrasound transducer

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With the growing energy crisis, there is a rising global interest in using renewable energy sources like solar, tidal, wind, rainwater and various biomechanical movements to cut carbon emissions and achieve carbon neutrality. Regarding green energy production, self-powered energy harvesting devices using multifunctional polymeric composites have attracted significant attention in recent years. The main goal of this research is to design polymeric composite based, self-powered devices by utilizing piezoelectric and triboelectric effects, either through the use of naturally available materials or by designing a bio-inspired device structure. Many studies explored piezoelectric nanogenerators (PENGs), but few have examined natural dopants in polymers for multifaceted nanocomposites. With this in concern, naturally available mud volcano clay from the Andaman and Nicobar Islands, India, was used to develop two cost effective and biocompatible PENGs for mechanical energy harvesting and body motion sensing. Clay nanoparticles (NPs) of two different sizes were produced through nanostructuring using mortar-pestle and ball milling methods and then incorporated into electroactive PVDF. A comparative study was done to evaluate the characteristics of the composites and output performance of PENGs made with each type of NPs. The PENGs showed high power densities and notable piezoelectric coefficients under hand-applied force, where PENG with ball-milled clay delivered better performance due to their smaller NP size.

Ultrasound transducers (USTs), also operating on piezoelectric effect, have traditionally relied on lead based single crystals, posing environmental risks while polymer composite-based USTs remain largely underexplored. Owing to this fact, a study was conducted on developing a lead free, high frequency UST using PVDF-TrFE based piezoelectric composite combined with a transition metal hydroxide. Using a pulse-echo test, a peak-to-peak output voltage of 5.19 V was obtained, along with a notable -6 dB bandwidth of 51.22 MHz (102.4%) with a high central frequency. Thus, the UST broadens the scope of non-invasive medical diagnostics and non-destructive testing in industrial applications.

Rainfall is one of the most widely explored renewable energy sources, offering a valuable form of mechanical energy by converting the waste kinetic energy of falling raindrops into electricity before they reach the ground. Based on this concept a real-time, bio-inspired triboelectric acid rain sensor has been fabricated, operating through solid-liquid interface contact electrification. Drawing inspiration from the micro-patterns on petunia flower petals, a template-sacrifice technique was employed to create the micro structured triboelectric polymeric membrane. The microstructures enhanced charge transfer, hydrophobicity and contact-separation, resulting in a high sensitivity of 34.4 V/kPa and a high contact angle of 135.8°. The improved hydrophobicity of the triboelectric nanogenerator (TENG) due to its rough surface has been explained by the Wenzel wetting model. Besides harvesting energy from raindrops, the TENG also enabled real-time pH monitoring of rainwater, allowing early warning of potential environmental hazards. In today's use-and-throw culture, developing sustainable and reusable technologies has become challenging. Therefore, a waste-based TENG was designed utilizing polystyrene (non-biodegradable polymer) from packaging waste and cellulose fibre from discarded banana pseudostems, promoting the waste-to-energy concept. This TENG with unique butterfly shape, can capture energy from irregular breezes in the environment, including wind gusts generated by passing vehicles and can also detect over-speeding of vehicles, assisting in road safety. It was found to generate an output voltage of 389 V (under an 11.7 N periodic force), with high stored energy during capacitor charging and excellent sensitivity.

The developed polymeric composite based self-powered nanogenerators, provide sustainable green energy harvesting and wearable sensor abilities. Meanwhile, the lead-free piezoelectric UST pave the way for accurate, non-invasive medical diagnostics, enhancing healthcare outcomes. Together, these three types of devices deliver comprehensive harvesting, sensing and diagnostic solutions, aligning with the advancements in the human-machine interface era.

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