Efficient Energy Harvesting Using Biomaterials: Fabrication of a ZnO-Modified Eggshell Membrane and Cotton Based Piezo-Tribo Hybrid Generator

Addanki, Meghana (School: Dr. Ronald E. McNair Academic High School)

The ever-increasing global energy demand—particularly for small, portable, and wearable electronics and self-powered systems—necessitates the development of sustainable energy sources. Mechanical energy nanogenerators (MENGs), which include piezoelectric nanogenerators (PENGs) and triboelectric nanogenerators (TENGs), offer promise but face challenges: PENGs often use toxic, brittle materials like lead zirconate titanate (PZT), while TENGs are sensitive to environmental conditions and yield low energy outputs. To address these challenges, the objective of this research was to develop a high-output hybrid piezo–tribo nanogenerator (HNG) using natural biomaterials—eggshell membrane (ESM) and cotton—modified with zinc oxide (ZnO). The HNG features an arch-shaped configuration, comprising two ZnO-modified, biomaterial-based PENGs to increase strain in the upper PENG and enable contact–separation mode. Tribopositive ESM served as the base PENG, while tribonegative cotton served as the upper arch PENG. PENGs of each biomaterial were fabricated, and both ESM and mercerized cotton were modified with varying concentrations of ZnO (10–30%). Through systematic performance evaluation, it was found that 30% w/w ZnO yielded peak voltages of 7.55 V (cotton) and 7.10 V (ESM). Optimized PENGs were then assembled into final 5 × 3 cm HNGs, and the average Vpp was found to be 20.47 ± 2.20 V with a VRMS of 6.82 V under weight-drop testing conditions (1 kg, 3 cm drop height, 5 Hz). Under forceful finger tapping (~10 N, 3 Hz), the HNG achieved a peak output of 33.29 V. Furthermore, the HNG achieved a power density of 26.4 μW/cm² at a load resistance of 5 MO. Overall, the bio-based HNG serves as a sustainable and promising alternative to nonrenewable energy sources and conventional MENGs.

Awards Won: