Electronic Supplementary Material (ESI) for Sustainable Energy & Fuels.

Electronic Supplementary Material

A Synchronous Piezoelectric-Triboelectric-Electromagnetic Hybrid Generator for Harvesting Vibration Energy

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1. Preparation of ZnO-PVDF nanocomposite films

For the preparation of the ZnO-PVDF film, ZnO nanorods were first synthesized by using a hydrothermal method. In the hydrothermal method, Zinc nitrate hexahydrate (50 mM) and Hexamethylenetetramine (75 mM) were used as a precursor. After thoroughly mixing the two, the solution was transferred into a Teflon beaker, which was sealed in an autoclave and kept inside an oven maintained at 95 °C for 4 hr. The prepared nanostructures were later filtered and dried. In the second step, the prepared ZnO nanostructures were added (15 wt.%) into the PVDF solution, which was prepared by dissolving PVDF powder (1 gm) in dimethylformamide solution (10 ml). In order to mix them thoroughly, the solution was ultrasonicated for half an hour. After that, the ZnO-PVDF nanocomposite film was prepared by drop casting the solution on a clean glass substrate and it was kept inside an oven at 90 °C for 1 hr. After cooling down, the substrate containing the film was dipped into deionized water to get the flexible ZnO-PVDF film separated.

2. Output power of the individual units

In order to calculate the output power of the individual units, we measured the voltage drops across the different load resistances which is shown in Fig. S1. We have calculated the instantaneous output power as V^2/R, where V is the voltage drop across the resistor of resistance R. The maximum instantaneous output power obtained is ~21.2 μW at a load resistance of 10 MΩ from the piezoelectric component, ~68.1 μW at a load resistance of 147 MΩ from the triboelectric component. From the electromagnetic (EM) generator, an instantaneous output power of ~5.99 mW at a load resistance of 500Ω was achieved. We have also calculated the power density of the piezoelectric and triboelectric components. For calculating the energy density of the piezoelectric component, we considered the volume of the ZnO-PVDF film, while for the triboelectric component, we considered the surface area of PTFE. And for the electromagnetic component, we took the area of the coil. The value obtained for the piezoelectric nanogenerator is 588.9 $\mu W/cm^3$, for triboelectric is 7.57 $\mu W/cm^2$ and for EM generator is 0.476 mW/cm^2.

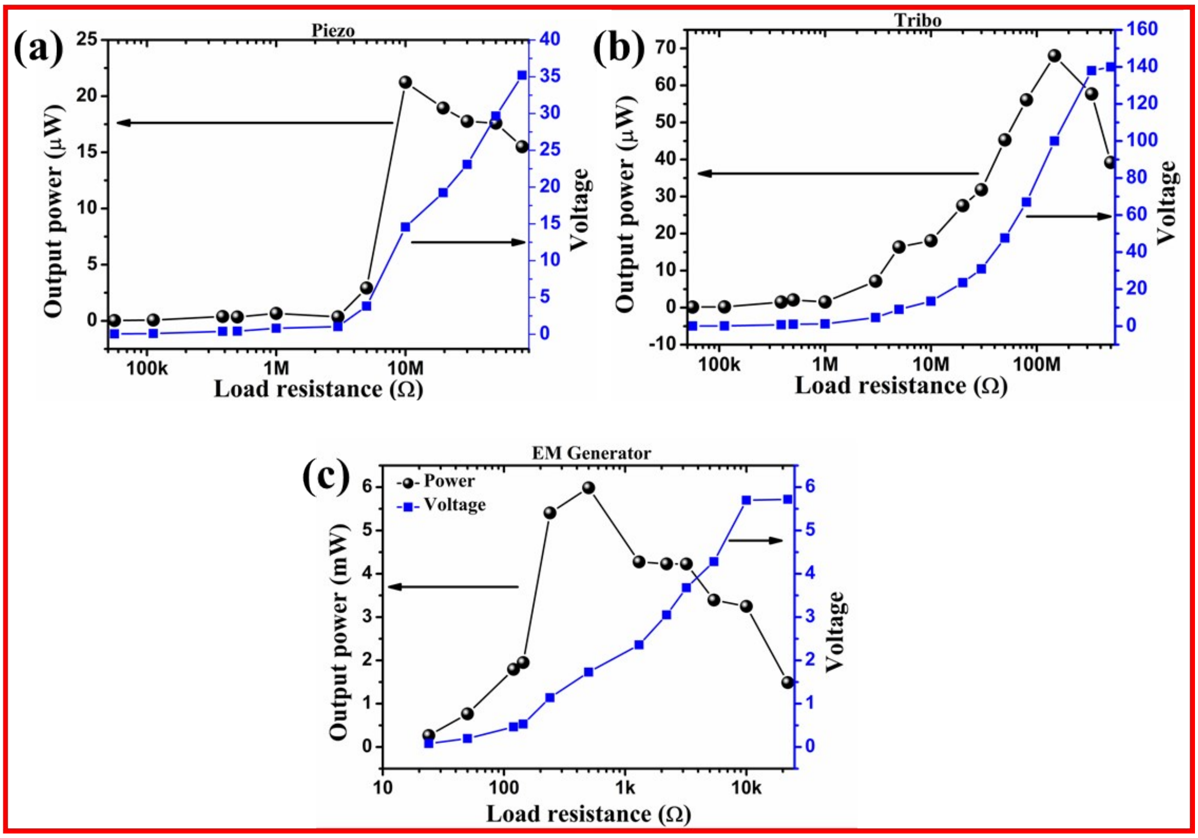

Fig. S1 Voltage drop across different load resistance and calculated output power of (a) piezoelectric unit, (b) triboelectric unit, and (c) electromagnetic unit.

3. Stability test for the hybrid device

We have conducted the stability test for the device. For evaluating the stability of the device, we measured its performance after every seven days for a period of 56 days, and the results are shown in the figure given below. It is evident that the device's performance did not deteriorate over a period of time. It is because of the design of our device, which is based on the contact separation mode. This mode of operation is expected to be much more stable in comparison to sliding mode, where due to rubbing degradation can occur.

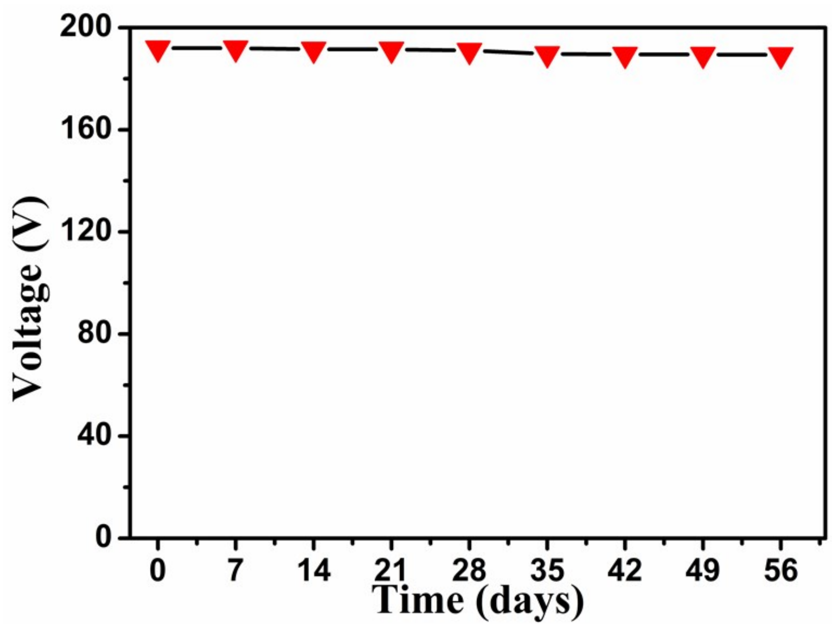

Fig. S2 The output open circuit voltage measured at different time durations.

4. Table of comparison of the performance of the hybrid device

	Device configuration	Piezoelectric generator		Triboelectric generator		Electromagnetic generator		Ref.
		V_{max}	P	V_{max}	P	V_{max}	P	
1	Tribo+EMG	–	–	197 (pp)	15.21 µW	1.08 V	1.23 mW	[1]
2	Tribo+EMG	–	–	10 V	16.19 µW /m²	80 µV	9.09 µW/m²	[2]
3	Tribo+EMG	–	–	2.2 V	0.4 mW/m²	0.8 V	0.8 mW	[3]
4	Tribo+EMG	–	–	80.3 V	–	13.2 V	–	[4]
5	Tribo+EMG	–	–	9.5 V	300 µ W	55 mV RMS	375 µ W	[5]
6	Tribo+EMG	–	–	0.23 V	–	1.8 mV	–	[6]
7	Tribo+EMG	–	–	8 V	3.23 Wm^{-3}	22 V	1.6 mW	[7]
8	Tribo+EMG	–	–	98 V	0.23 mW	4 V	3.4 mW	[8]
9	Tribo+EMG	–	–	51 V	1.7 mW (2 TENGs)	3 V	2.5 mW	[9]
10	Piezo+Tribo+ EMG	6.41 V	41.1 µW	5.1 V	4.6 µW	180 mV	66.5 µW	[10]
11	Tribo+EMG	–	–	240 V	3.4mW (10.8	7.5 V	16.2 mW	[11]
12	Tribo+EMG	–	–	268 V	4.9 mW	4.9V	3.5 mW	[12]
13	Piezo+Tribo+ EMG	35 V	21.2 µW	140 V	68.1 µW	4.8 V	5.99 mW	This work

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