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A Water Resistant Triboelectric Nanogenerator as a Bio-Mechanical Energy Harvester and a Self-powered Pressure Sensor

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1. Abstract

The present work describes a highly reliable water-resistant triboelectric nanogenerator (TENG) made of silicone elastomer and nickel foam as the triboelectric layers. The silicon elastomer acts as a negative triboelectric layer having rough microstructures on its surface. The microstructures on the silicone elastomer were created by cost-effective soft-lithographic techniques using commercial sandpaper. The layers were housed into a PET casing and made to operate in a contact and separation mode TENG device. After the fabrication of the TENG device, the device was packed completely using a transparent polyethylene film. The performance of the TENG device was analyzed under various percentages of relative humidity. The device shows a stable electrical performance with a maximum output of ~370 V/ 6.1 μA with a maximum area power density ~17 mW/m^2 at 1GΩ load resistance. The device has also been used for powering LEDs, charging commercial capacitors and powering wrist watches. The TENG device is then used for scavenging biomechanical energy by placing hand and leg over the device and checked for its electrical responses. Further various ranges of pressure have been applied on the device and analyzed its capability in pressure sensing. The results proved that the TENG device is capable of being working as an active self-powered pressure sensor.

2. Introduction

Energy harvesting from ambient waste mechanical energy has been gaining huge attention in recent days. This is due to the possibility of utilizing the small electric output from the waste mechanical motions and possibly been able to power low power electronic devices. Triboelectric nanogenerators recently emerge as a promising candidate for scavenging waste mechanical energy from wind, tidal, vibrations, pressure and biomechanical movements. Also, the TENGs have the capability of using it as self-powered sensors[1]. To enhance the electrical output of the TENG device, various techniques have been adopted in the recent past, such as creating micro roughness on the surface of the triboelectric layers[2]. This leads to the production of more charge on the layers of the TENG device due to multiple contact points. Other than that TENGs are highly sensitive to humidity and temperature. Herein, we have overcome the humidity issues by packing the device in a polyethylene film and sealed its corners. The device is entirely waterproof and can able to work underwater and various rates of relative humidity. By adopting this type of packing, the performance of the TENG device can be improved or can make it stable in all weather conditions.

3. Results and Discussions

Figure 1 shows the overview of the proposed work from the device fabrication to its application of biomechanical energy scavenging and also works as an active self-powered pressure sensor. The triboelectric layers in the proposed device are nickel foam as positive and silicone elastomer as a negative layer. Aluminum foil is attached at the bottom of the silicone elastomer and works as an electrode. Copper wires are attached at the top and bottom electrodes to draw the electric power. Further, the device is covered with polyethylene and sealed completely under vacuum using a pouch laminator to make a WP-TENG.

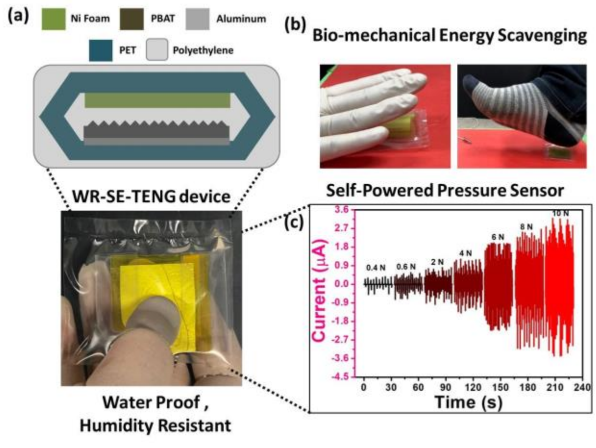

Fig.1 (a) Schematic of water-resistant TENG device with its layers used and the digital photograph shows the fully packed device (b) Biomechanical energy scavenging and (c) self-powered pressure sensing capability of TENG device

Figure 2a and b show the electrical output performance comparison of both the unpacked and packed TENG devices. Both the devices show similar electrical output in the case of voltage as well as current. This proves that the package of TENG device does not affect the performance of the device under humidity and water[3]. The working mechanism of a TENG device is based on contact electrification and electrostatic induction principle. At the initial condition, the top electrode is in contact with the bottom dielectric layer with no flow of electrons in the electrodes. Due to the mechanical motion applied on the device, the layers separate from each other leading towards the occurrence of charge difference across the electrodes. This phenomenon induces the electrons to move from the top electrode to the bottom electrode through the external circuit. This action is responsible for the first half cycle of the electrical output signal. With the further actuating motion on to the device, the layers again move close to each other induces the electrons to flow in the reverse direction, leads to the generation of the second half cycle.

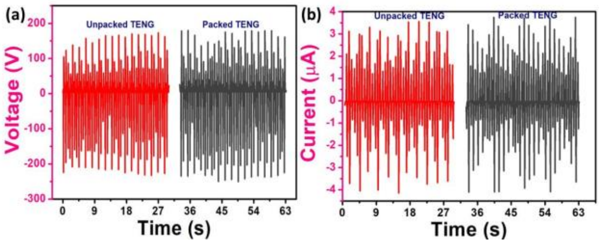

Fig.2 (a) and (b) shows the voltage and current output response of the packed and unpacked TENG device.

The electrical output has to be validated by utilizing the generated electrical power by using the device to powering up LEDs, charging commercial capacitors. The TENG device is connected to a bridge rectifier circuit could charge various ratings of commercial capacitors such as 0.22 µF, 1 µF, 10 µF and 22 µF for a period of 150 s. The capacitor with high rating stores more energy than the capacitor having a high rating, which is shown in Figure 3a. The inset in figure 3a shows the response during the force applying and releasing.

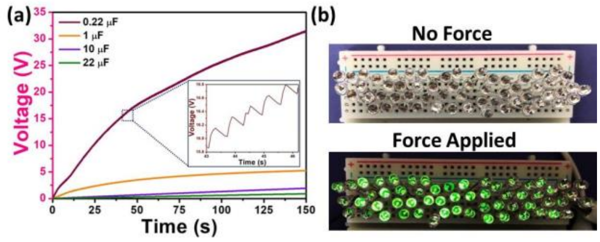

Fig.3 (a) commercial capacitors charging response using the TENG device (b) Glowing 60 green LEDs using the water-resistant TENG

Also, the TENG device was used to glow 60 green LEDs using the same bridge rectifier circuit. When the force applied to the device using a linear motor, the LEDs tends to blink, and during the force released, the LEDs turn off as shown in Figure 3b.

4. Conclusions

In summary, a stable and water resistant TENG device had been fabricated using silicone and nickel as triboelectric layers. The silicone film has been surface modified via a soft lithographic technique using commercial sandpaper. Also, the device was packed using a polyethylene film with the help of sealing on the corners using a pouch laminator. The device shows a maximum electrical output ~370 V/ 6.1 µA with a maximum area power density ~17 mW/m^2 at 1GΩ load resistance. The device performance has also been analyzed by charging commercial capacitors, glowing LEDs, and powering wrist watches. Also, the bio-mechanical energy scavenging analysis had been performed by placing the device and makes hand tapping and leg tapping over the device to scavenge energy from biomechanical motions. The device has also been tested as a self-powered pressure sensor successfully. This proves that the device can be used as an active pressure sensor to be used in harsh environmental conditions.

5. Acknowledgment

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