Enhancement of the Triboelectrification Using Artificial Surface Charges

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ABSTRACT Triboelectrification is a novel technology to harvest electricity from unexploited environmental energy. Its efficiency depends on the area, morphology and charges on the in-contact surfaces. Many studies are carried out in order to increase the efficiency of the triboelectric generators by increasing the surface area or varying the morphology but the charge density is not properly focused until date. Herein, we will discuss the effect of the artificial charges induced on the in-contact surface. For that purpose, plasma treatment was used to increase the surface charge density of the in-contact surface. The increment in the charge density actually helped us to increase the efficiency of triboelectric generator even without changing the dimensions of the device. The output power was increased up to two folds as compared to the untreated device. At the end, we also charged the capacitor in order to compare the charge storing efficiencies of both devices. We found that the untreated device and the plasma treated device (15 min and 30 min) stored voltages up to 6 V, 9 V and 12 V respectively. This type of study will surely support the researchers to enhance the triboelectric current generation efficiency even without increasing the size of the device.

INDEX TERMS Plasma treatment, triboelectric generators, energy harvesting.

I. INTRODUCTION

In recent years, energy harvesting has developed as one of the major technologies due to the rapid growth of novel technology in portable and wearable electronics. Energy harvesting is the method wherein the untapped ambient environmental energies are converted into electric energy in order to power electronic devices and wireless sensor networks at small scale [1]. This ambient environmental energy is present in different forms such as solar, wind, thermal, kinetic and potential energies. The amount of generated energy depends on both technology and the energy generating device and it ranges typically from small scale such as piezoelectric generators, reverse electrowetting or electrophoresis phenomenon, pyroelectric generators to large scale including solar cell panels and wind turbines. Energy harvesting is valuable as it is substituting conventional energy generation techniques from fossil fuels that might be jeopardy for human civilization in near future. Moreover, it also swaps the heavy, periodic washing, high maintenance cost and health concerned batteries [2], [3]. Typically, nano-generators are getting famous in the last decade due to the recent advent of Internet-of-Things era with mobile electronic devices [4]. Therefore, different energy nano-generators have been designed such as piezoelectric [5]–[8], triboelectric [9]–[27], electric double layer modulation methods [28]–[32], and reversal of famous electrowetting phenomenon [33]–[35]. It is also known that these methods may provide solutions for the Internet-of-Things devices and limited lifetime of batteries in portable electronics [4].

Typically, piezoelectric generators have increasing attention in order to harvest energy from the pressure applied due to the man’s weight while walking, stretching or bending motions, vibrational motions of a moving car, the impact of
raining water droplets, etc. This method of energy harvesting is economical with simple design but energy magnitude limitation causes the research directed towards the triboelectric nanogenerators [3]. First triboelectric nanogenerator was proposed by Z. L. Wang in 2012 [9], claiming that it is an efficient device at low frequency, economical, light weighted, many working configurations/modes and cheap materials as compared to piezoelectric materials [5], [9]. Recently, we have also successfully demonstrated some triboelectric nanogenerators to scavenge electricity from the water droplets, human hair, human skin and bubbles inside the water [4], [12], [15], [17]. Moreover, the researchers have fabricated triboelectric generator (TEG) by using the material, polytetrafluoroethylene (PTFE) and polyamide 6 (PA 6) [3]. The PTFE TEG produced maximum voltage of 1000 V whereas PA 6 TEG produced maximum voltage of 800 V. Authors in [18] reported a nanocomposite material system as a triboelectric active material. They achieved a boosting power-generating performance with ferroelectric composite-based triboelectric nanogenerator (TNG). Authors in [20] developed slidable and bendable microstructures (fish-scale-like) by extending the triboelectric interfaces. The fabricated triboelectric nanogenerators (TENGs) generated 470 V output voltage and 45 μA/cm² current density. A low-cost duplication method was developed in order to fabricate the bendable and slidable microstructures. Usually, the efficiency of a triboelectric generator was enhanced by either using many folds to increase the contact area, by using nano-structured surfaces, or by changing the tribomaterials. However, until now, surface charge density is not properly discussed as it can be efficiently used to increase the harvested energy. In this communication, we are going to increase the surface embedded charge density for increasing the efficiency of the triboelectric generator. Here, we successfully increased the power generation by introducing artificial surface charges by plasma treatment up to two folds as compared to the untreated device.

II. EXPERIMENTATION

For the experiment, copper was deposited on the substrates as an electrode. We had used PTFE polymer and copper electrode as negatively and positively polarized triboelectric materials respectively. The negative polarized triboelectric material was first spin coated on top of layer of copper at 500 rpm for 30 sec and at 1000 rpm for 130 sec. The amount of PTFE that was spin coated on copper layer was 1 ml.

After that, the sample was cured at 180 °C for about 1.5 hour in a conventional oven (IncuMax CV 250, Amerex Instruments). Fig. 1 illustrates the schematic of the device with proper dimensions (25 × 76 mm). A micro water droplet was also used in this experiment to check the wettability and surface energies of the sample. PTFE surface was exposed to plasma gas (Argon) for introducing more negative embedded surface charges in order to increase the efficiency of the triboelectric generator. The plasma settings were as follows: amount of gas released was 1 L (30 min), gas exposure time was 4 s and plasma power was 20 W. Gas pressure and gas flow rate were 30 mTorr and 30 cm³/min respectively. Load resistor (1.2 MΩ) was connected to measure the output current using a Keithley digital multimeter (DMM 2420). Next, using I²R, power was calculated. Schematic of the experiment for measuring the current is also shown in the Fig. 2.

III. RESULTS AND DISCUSSIONS

Copper is positioned above PTFE in the triboelectric series. Therefore, when these triboelectric materials come in contact with each other, then electrons will tend to move from copper towards the polymer causing tribo positive charges on copper and tribo negative charges on the polymer. The charge travel between two surfaces is due to the difference in electron affinities. As a result, triboelectric charges can be used to induce electric current when continuous repeated contact and de-contact of these materials is performed, and it is possible only when this triboeffect is combined with electrostatic induction phenomenon by fabricating electrodes on the back side of these materials. Here, we have considered PTFE as it forms high hydrophobic layer, generates greater number of negative charges as compared to other materials, and generates higher efficiency [4]. Also, we have considered copper as it is commonly available and cheap as compared to other materials [21].

Fig. 3 represents the schematic of the working mechanism. Proposed nanogenerator is comprised of one copper-deposited substrate while other has a layer of PTFE. At first, triboelectric charges are not generated (Fig. 3(a)). When two glass substrates come in contact, the polymer gains negative charges (as placed below the copper in triboelectric series) while copper gains positive charges as shown in
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FIGURE 3. Working mechanism of proposed electrification device (a) First state of the device. The right section represents the device structure (b) No signal is appeared during the first contact (c) Negative signal is generated on subsequent releasing, demonstrating the current flow (d) The current again drops to zero when two surfaces are entirely released and (e) A positive signal is produced on subsequent pressing, demonstrating the current flow in opposite direction. By collecting the generated signals due to subsequently contact and decontact, energy can be harvested.

FIGURE 4. Single signal of output current.

Fig. 3(b). When the two substrates are separated from each other, potential difference is created due to triboelectrification (Fig. 3(c)), thus causing the current to flow. When the two substrates are completely separated from each other (Fig. 3(d)), no current will flow until the substrates are forced to come in contact again. On pressing the two substrates again (Fig. 3(e)), current flows in opposite direction until the induced charges neutralized. Thus, continuous contact and de-contact procedures are performed to generate triboelectric signals.

Average tapping frequency was approximately 4.5 Hz. Generated single signal of output current is shown in Fig. 4. Fig. 5(a) represents the generated current for the electrification device before the plasma treatment and after introducing the artificial surface charges with the help of plasma treatment, (two samples were treated at different exposure times). The (15 min and 30 min) plasma exposure devices produced maximum peak-to-peak current of 0.85 µA and 1 µA and the untreated device produced 0.7 µA. The output current is not stable due to the variations in tapping frequency. But, we were taking the average power/energy of around 500 tapping events and found repeated results in multiple experiments. The calculated average powers due to single contact were 0.3 µW, 0.45 µW and 0.6 µW, for the electrifying devices before plasma treatment, plasma treated exposure time of 15 min and plasma treated exposure time of 30 min respectively as shown in Fig. 5(b). Here, output power is different because of triboelectric charges on the surface. Since, induced surface charges increase the energy harvesting efficiency of the device.

Therefore, as expected the plasma treatment would considerably enhance (approximately 2 folds) the output efficiency of the device. Fig. 6 depicts the generated output power with respect to different resistances.

The proposed generator was then utilized for charging a capacitor (1 µF), that was coupled to a rectifying circuit. Fig. 7 illustrates the charging curve. Only 80 s were required for complete capacitor charging. Inset photos in Fig. 7 shows the serial LED lightening with the help of the proposed electrifying device. It is shown in the figure that the brightness of the LEDs with the device that has artificial induced surface charges is greater than that of the pre-treated device where there were no induced charges.
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At the end, a micro water droplet was also used to check the wettability of the sample, ultimately demonstrated the variation in tribocharge density on the polymer surface [36]. Before plasma treatment, the droplet in Fig. 8(a) had the contact angle of 112° depicting that it is highly hydrophobic surface and has very little surface charges. But when artificial charges were embedded on the PTFE surface, the contact angle was around 95° (Fig. 8(b)), portraying that the surface tribocharge density increased. Actually, the variation in wetting properties describes that after plasma treatment, some more electronegative ions/charges were sprinkled on the polymer surface that are used to enhance the efficiency of tribo-electrifying device. Here, contact angle and hydrophobicity is decreased after performing argon plasma treatment. This is mainly because of triboelectric charge enhancement i.e. increase in surface negative ions to attract ions from water. This is also demonstrated before [28]. The surface becomes hydrophilic after the treatment. The comparison of current study with other type of TENG is shown in Table 1.

We had also checked the stability of triboelectric nanogenerator by measuring the current after few days of plasma treatment (30 min). Fig. 9 depicts the current generated after 4 days of treatment whereas Fig. 10 shows the current generated after 1 week of treatment. It can be seen that the current is reduced slightly, assuring the stability of TENG.

We had also calculated maximum dissipated power by the triboelectric nanogenerator before and after plasma treatment. Before plasma treatment, maximum dissipated power was 30 μW. After plasma treatment of 15 min, maximum dissipated power was 67.5 μW and after plasma treatment of 30 min, maximum dissipated power was 120 μW.
We have used argon gas for plasma treatment as it was available here and has low cost as compared to others (He, Ne). The gases with fluorine concentrations like CF4, SF6 were not available. As we have to enhance the triboelectrification using plasma treatment, so that plasma gas is to be used which is available and also increase the efficiency. We have performed treatment for 15 min and 30 min time as more time can damage the polymer layer.

IV. CONCLUSION

We introduced artificial charges by plasma treatment on the contacting surfaces in order to increase the charge densities on the in-contact surfaces. The overall efficiency and the contacting surfaces in order to increase the charge densities of both devices. We found that the untreated device and plasma treated device (15 min and 30 min) stored voltages up to 6 V, 9 V and 12 V respectively. This type of study will surely help the researchers to enhance the triboelectric current generation efficiency even without increasing the size of the device.

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