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Influence of Various Parameters on the Triboelectric Generation of Bulk Materials

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In this paper we report the study of mechanical energy harvesting of ambient energy based on triboelectric effect. We choose the bulk form of poly-tetrafluoroethylene (PTFE) as electronegative (E-) material and human hand and plywood as the electropositive (E+) materials, respectively making a single electrode based triboelectric generator (TEG). The E+ and E- material were rubbed together to produce a voltage output, which was measured by using a sensitive electrometer. This investigation was carried out for different surface morphology, surface areas of contact, thickness and types of electrode contacts and rubbing frequency. It was observed that sufficient voltage and charge generation was achieved to power low energy devices like LED bulbs, with the highest voltage generation of ~6.2 V for rectangular PTFE sheet, having one surface coated with a thin film of copper for making electrode and other one is made rough using sandpaper, as the E- material and plywood as the E+ material. We observed that the voltage output is influenced by the surface morphology, type of E+ material for the same E- material, frequency of rubbing strokes and frictional area of contact.

Keywords: Triboelectric effect; PTFE; Bulk materials

1 Introduction

Since its first experimental demonstration in the form of Triboelectric Generators (TEG)[1,2] in 2010 and Triboelectric nanogenerators (TENG) in 2012[3], triboelectricity has emerged as a potential and promising candidate for harvesting ambient mechanical energy. Triboelectric effect (TEE) uses a combination of contact electrification (CE), tribology[4,5], where friction between the electronegative (E-) and electropositive (E+) material is used, and electrostatic induction. The choice of E- and E+ material is based on their placing in triboelectric series[6] and polymers have emerged as the suitable material[6-8]. While TENGs have been extensively investigated[9-11]with considerable success, they are also fraught with challenges[8,12] in the form of their lifecycle in real world environment and cost effectiveness. Thus it is worthwhile to investigate TEGs for assessing their suitability for energizing low power devices in the backdrop of these challenges.

Here we report the fabrication of polymer based single electrode (SE)[13] TEGs using bulk form of poly-tetrafluoroethylene (PTFE) as E- and human hand (HH) and plywood as E+ material, respectively. Rectangular PTFE sheets of different frictional surface areas, thickness and type of conducting contacts and surface morphology were used.

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2 Materials and Methods

2.2 Fabrication of TEG

For fabricating the SE[13] TEG, we used rectangular PTFE sheet (E-) of 2 mm thickness of different surface areas and surface morphology. SE TEG was chosen since tapping mechanical ambient energy requires either E- or E+ material to be freewheeling. The electrode on the PTFE sheet were fabricated in two different ways: (a) One side of the PTFE sheet was glued to the Cu sheet of the same surface area using an electrically conducting adhesive (silicone glue) and a Cu wire contact was made (PTFE+Cu glued) as shown in Fig. 1(b) Thin film of Cu was coated on the PTFE sheet of different surface areas using thermal evaporation unit (TEU) and a Cu wire contact was made on the Cu thin film and completely sealed with Teflon tape to prevent any damage to Cu thin film (PTFE+Cu Coat). The Cu wire was connected to positive terminal of the multimeter (Falcon DMM 10) having a least count of 1mV and its other terminal was grounded. E+ material was used for stroking the PTFE sheet at different frequencies. For changing the surface morphology and roughness[14] of the PTFE sheet, its CE face was rubbed with sandpaper (Rough PTFE+Cu Coat) as shown in Fig. 1.

2.3 Vacuum Coating by Thermal Evaporation Method

TEU, manufactured by Technology Application Services, was used for vacuum coating of Cu thin film

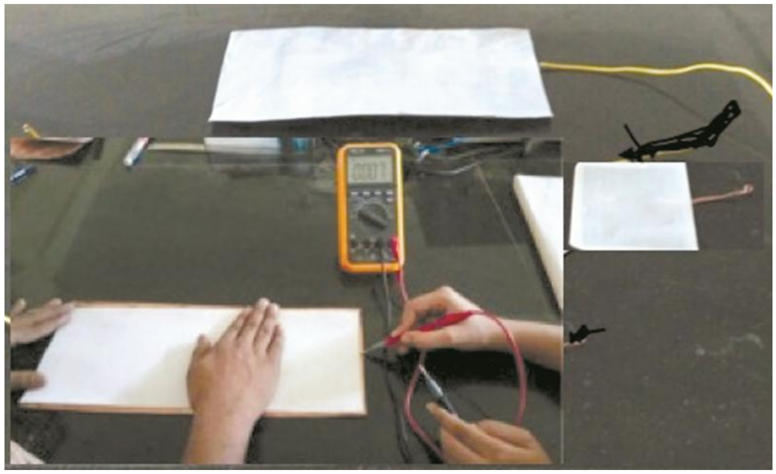

Fig. 1 — (a) TEG made by PTFE sheet glued to Cu sheet and human hand, (b) Rough PTFE sheet coated with thin film of Cu of area 576 cm^2 and 252 cm^2.

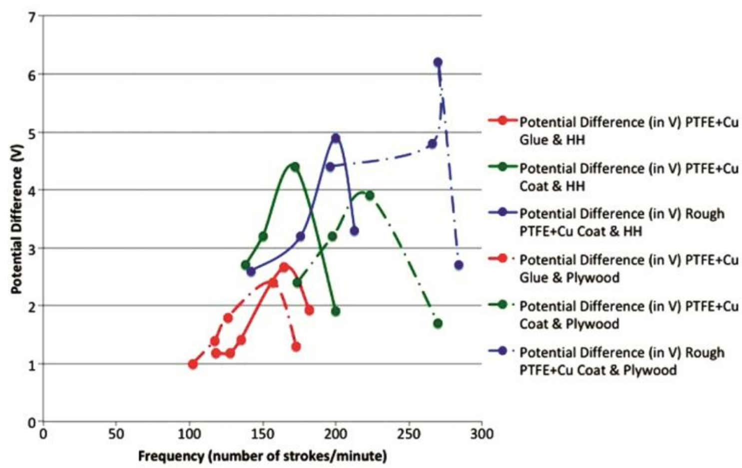

Fig. 2 — Variation of potential difference (V) with frequency (strokes/minute) for PTFE+Cu glued, PTFE+Cu Coat and Rough PTFE+Cu Coat as E- and Human hand (HH) and Plywood as E+, respectively.

on PTFE sheet. TEU had two types of vacuum pumps; a diffusion pump (10^{-2} to 10^{-6} torr) and a rotary vane pump (1 to 10^{-3} torr) acting as a backing pump. Pirani gauge (0.5 to 10^{-3} torr) and Penning gauge ($10^{-3}$to 10^{-6} torr) were used to note the pressure. Cu was placed in a boat at the bottom and PTFE was placed as a substrate at the top inside the vacuum chamber. Cu was electrically heated beyond its melting point producing some vapour stream which reached the substrate and stuck to it as a coating or thin film.

3 Results and Discussion

Theoretical studies[15] have given the expression for the displacement current density for TEG/TENG as

$$J_D = \frac{\partial D_x}{\partial t} = \frac{\partial \sigma_I(x,t)}{\partial t} = \sigma \frac{dx}{dt} \frac{\left(\frac{d_1}{\varepsilon_{r1}}+\frac{d_2}{\varepsilon_{r2}}\right)}{\left(\frac{d_1}{\varepsilon_{r1}}+\frac{d_2}{\varepsilon_{r2}}+x(t)\right)^2} \quad \ldots (1)$$

where D_x is the electric displacement vector, $\sigma_I(x,t) = \frac{\sigma x(t)}{\left(\frac{d_1}{\varepsilon_{r1}}+\frac{d_2}{\varepsilon_{r2}}+x(t)\right)}$, σ is the triboelectricity induced surface charge density across each dielectric due to CE, d_1 and d_2 are the thickness and ε_{r1}, ε_{r2} are the relative dielectric permittivity (dielectric constants) of dielectric 1 and 2, respectively and *x(t)* is the time dependent separation between them. Thus the displacement current density is proportional to the charge density on the dielectric surface and the speed at which the dielectrics are being separated or contacted i.e. frequency of rubbing. From the above theoretical formalism the following results can be understood.

The variation of voltage generated as a function of frequency *i.e.* number of strokes per minute for TEG fabricated with PTFE sheet as E- and HH and Plywood as E+, respectively, for all the three cases viz. PTFE+Cu glued, PTFE+Cu Coat and Rough

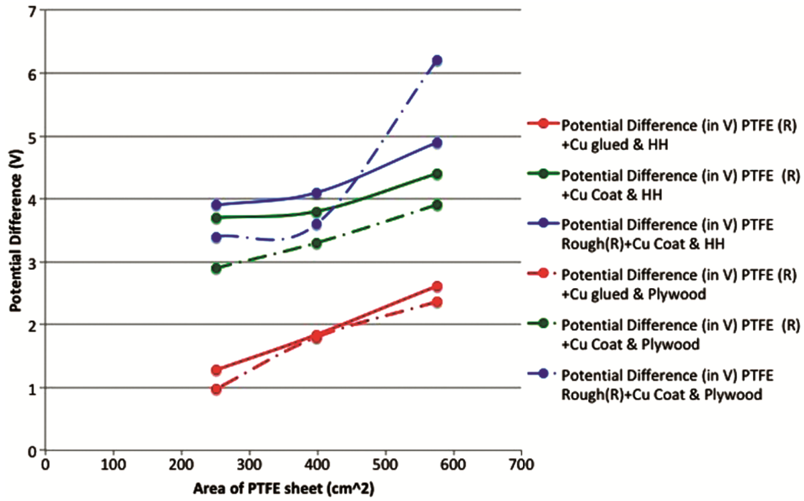

Fig. 3 — Variation of potential difference (V) with frictional surface area (cm^2) for PTFE+Cu glued, PTFE+Cu Coat and Rough PTFE+Cu Coat as E- and Human hand (HH) and Plywood as E+, respectively.

PTFE+Cu Coat is shown in Fig. 2. It is clear that as the frequency increases the voltage also increases reaching a maximum value after which it starts decreasing. Thus there is saturation in the value of voltage generated because with increase in the frequency, the cycle of tribology, CE and electrostatic induction reaches an optimal efficiency beyond which charge accumulation on the electrode as a function of time starts decreasing.This defines a frequency range for TEG operation to obtain optimal voltage generation.

As can be seen from Eq. (1) that voltage generation of TEG is dependent on the surface area of contact. Hence as we increased the surface area of PTFE sheet from 252 cm^2 to 399 cm^2 and finally to 576 cm^2, the voltage generation also increased for all the three cases *viz*. PTFE+Cu glued, PTFE+Cu Coat and Rough PTFE+Cu Coat as shown in Fig. 3. Also the combination of PTFE and HH for all the cases gave highest voltage output except for 576 cm^2 surface area, where the combination of Rough PTFE+Cu Coat with plywood gave the highest voltage output of 6.2 V as shown in Fig. 3. This is due to the fact that as the surface area of PTFE sheet increases, plywood, being of the same shape and area, provided maximum frictional area as compared to HH. Thus the shape and area of the two triboelectric surfaces also play an important role in the designing of TEGs. Further Rough PTFE+Cu Coat TEG gave maximum voltage output for all the three surface areas of contact since making the contact surface of PTFE course increased the frictional area of contact between PTFE and E+ material thus further increasing the voltage output. These voltages and frequency in the range of ~ 1 - 5 Hz (Fig. 2) are sufficient to power Ferroelectric Liquid Crystal (FLC) displays and LEDs as reported in earlier studies[1,2].

The resistivity of Cu thin film does not change appreciably from its bulk value till the mean free path of the electrons (~few hundred nanometers) becomes comparable to the thickness of the Cu thin film[16,17]. Thus the resistivity of the Cu thin film coated on the PTFE sheet using above method, typically having a thickness ~ few μm to few hundred nm, remains roughly constant. Hence for the same surface area and resistivity, we decreased the thickness of Cu from bulk value (~0.5 mm) to a few μm - few hundred nm, thus decreasing its resistance and hence increasing its voltage output as can be seen from Figs 2 and 3. The crystalline nature and uniformity of Cu thin film was ascertained from the clear peaks obtained in X-ray Diffraction (XRD) and its electrical conductivity, checked using multimeter, was found to be uniform.

4 Conclusion

The TEGs designed and fabricated in the present study, using bulk form of the polymers, are robust, economical, easy to fabricate, have considerable lifetime in real world environment and hence offer promise for being further investigated for future application. The polymers chosen, being part of our daily life, provide ample opportunity for exploiting TEE for energy generation like conveyor belts, walking on wooden flooring, insulating curtains and flaps, keyboards and touch screens amongst others. All the TEGs fabricated gave an output between 1.0 V

(PTFE+ Cu glued and plywood) and 6.2 V (Rough PTFE+Cu Coat and plywood), which is sufficient to energize LED bulbs, display devices using liquid crystals, charging hand-held electronic devices amongst others. Coating PTFE sheet with Cu thin film and grazing its CE surface using sand paper improved the voltage output of TEG thus showing promise for further improvement in voltage generation by choosing different surface morphology and area and thickness and type of electrode contacts.

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