Triboelectric effect in energy harvesting

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Abstract. With the development of wearable technology, much research has been undertaken in the field of flexible and stretchable electronics for use in interactive attire. The challenging problem wearable technology faces is the ability to provide energy whilst keeping the end-product comfortable, light, ergonomic and nonintrusive. Energy harvesting, or energy scavenging as it is also known, is the process by which ambient energy is captured and converted into electric energy. The triboelectric effect converts mechanical energy into electrical energy based on the coupling effect of triboelectrification and electrostatic induction and is utilized as the basis for triboelectric generators (TEG). TEG’s are promising for energy harvesting due their high output power and efficiency in conjunction with simple and economical production. Due to the wide availability of materials and ease of integration, in order to produce the triboelectric effect such functional materials are effective for wearable energy harvesting systems. Flexible TEG’s can be built and embedded into attire, although a thorough understanding of the underlying principle of how TEG’s operate needs to be comprehended for the development and in incorporation in smart technical textiles. This paper presents results associated with TEG’S and discusses their suitability for energy harvesting in textiles structures.

1. Introduction

In recent years, research has advanced into wearable energy harvesters due to an increase in low power consumption and nanoelectronic wearable devices [1, 2]. Energy harvesting, or energy scavenging, is the process by which waste energy captured from the ambient environment and human movement is converted into electric energy replacing the need for traditional means of power supplies, like batteries, which are limited in capacity [3] and constantly need replacing resulting in high maintenance cost [4, 5].

The generation of electric energy from mechanical energy can be from different mechanisms such as piezoelectric and triboelectric nanogenerators. Even though the development of piezoelectric generators has proven to be effective, its limitations have directed research into triboelectric nanogenerators [6] producing a high output power with great efficiency, in conjunction with its simple and economical production [7, 8, 9].

Triboelectricity converts mechanical energy into electricity [10, 11] coupling triboelectrification and electrostatic induction. Electrostatic induction is the phenomenon of electrification by contact of two objects that become spontaneously charged. The general concept of TEG’s is that when two
materials come into contact there is a charge transfer, one membrane becomes positively charged and the other negatively charged creating an electronic potential difference (EPD) with the presence of an air gap. The cause of electrostatic induction is still not well understood [12].

For this paper we concentrated on dielectric-dielectric sliding mode TEG’s fabricated from identical material, polyamide 6 (PA6) and polytetrafluoroethylene (PTFE) TEGs, with different contact areas. A series of experiments were completed for the following samples; sample 1 of dimensions 30x30mm, sample 2, 40x30mm, sample 3, 50x30mm and sample 4, 60x30mm with a vertical center force of 9.8N and at a speed of 0.02m/s. Although, previous research states the triboelectric phenomenon exists only when two different materials come into contact, the experiments identified a substantial EPD for two identical materials as proven by Apodaca et al. [13]. In addition, it was observed that the EPD occurs when the top component slides inwards, following the non contact phase.

2. Previous Research
Previous research has demonstrated that although TEG’s produce a large voltage, they have a high internal resistance resulting in a low output current. [1]. Wang et al. [10] built a sliding mode triboelectric nanogenerator (TENG) of dimensions 71mm x 50mm using polyamide 6,6 and polytetrafluoroethylene (PTFE) films with surface etched nanowires on glass substrates. The TEG produced an open circuit voltage up to \( \sim 1300V \) and a short circuit current density of 4.1mA/m\(^2\) with a peak power density of 5.3W/m\(^2\) which was used as a direct power supply to light up a series of LED’s.

Yang et al. [14] developed a single electrode based sliding mode TENG using PTFE with surface-etched nanoparticles and an aluminium (Al) electrode. The TENG produced an open circuit voltage up to 1100V, a short-circuit current density of 6mA/m\(^2\), and a maximum power density of 350mW/m\(^2\) with a load of 100M\(\Omega\), which was used to drive 100 green-light-emitting diodes (LEDs).

The working principle of the sliding mode is based on keeping one component steady and sliding the second component outward until there is no contact between the two components, then inward where the two components come into full contact and EPD is 0. Wang et al. [10] and Yang et al. [14] demonstrate the generation of the EPD when the top component of the TENG slides outwards, defining the larger the displacement between the two components, the greater the EPD.

3. Experimental section
The dielectric-dielectric triboelectric devices consist of an upper and lower component. Each component constitutes of an acrylic substrate, an aluminum electrode and a PA6 and PTFE electrification layer. Lead wires connected the electrodes to the oscilloscope Agilent Technologies DSO3102A for measurements, refer to figure 1. The two components were vertically aligned with the bottom component stabilized and the top component unrestrained to slide in the lateral plane.

**Figure 1.** Experimental set up.
4. Results and discussion
At a speed of 0.02m/s, the TEG completes a cycle where the components fully overlap then fully separate. As a result of a small area of friction, the surface of one component of the TEG gains positive charges whilst the other gains negative charges producing a potential difference.

The maximum open circuit voltages (Voc) produced for the PA6 TEG samples 1, 2, 3 and 4 were 320V, 360V, 700V and 800V respectively, refer to figure 2. The maximum Voc for the PTFE TEG samples 1, 2, 3 and 4 were 800V, 700V, 700V and 1000V respectively, refer to figure 3. The EPD produced was non uniform therefore standard deviation was applied to the data set where the average was calculated to gain a more accurate depiction of the EPD. The PA6 TEG samples 1, 2, 3 and 4 produced an average Voc of approximately 170V, 180V, 650V and 730V. The PTFE TEG samples 1, 2, 3 and 4 produced an average Voc of approximately 410V, 650V, 660V and 880V. Figure 4 presents the mean Voc produced for the four samples of the PA6 and PTFE TEG. Figure 5 presents the mean Voc produced for the four samples correlating the output with the polymers of the TEG’s.

![Figure 2. PA6 TEG Maximum Voc](image-url)

(a) Sample 1: 30mmx30mm (b) Sample 2: 30mmx40mm (c) Sample 3: 30mmx50mm (d) Sample 4: 30mmx60mm.
Figure 3. PTFE TEG Maximum $V_{oc}$ (a) Sample 1: 30mmx30mm (b) Sample 2: 30mmx40mm (c) Sample 3: 30mmx50mm (d) Sample 4: 30mmx60mm.

Figure 4. Mean $V_{oc}$ produced for the four samples (a) PA6 TEG (b) PTFE TEG.
Figure 5. $V_{oc}$ produced for PA6 and PTFE (a) Sample 1: 30mm x 30mm (b) Sample 2: 40mm x 30mm (c) Sample 3: 50mm x 30mm (d) Sample 4: 60mm x 30mm.

It can be observed that by applying standard deviation to the data sets the average EPD produced differs substantially to the maximum $V_{oc}$. Analyzing the maximum average it shows that by increasing the contact area of the TEG the $V_{oc}$ increases refer to figure 4, although the correlation between the generated $V_{oc}$ and the relative increase of the contact area of the TEG is not succinct.

We can make a reasonable assumption that the surface roughness for each membrane differs. The range of the $V_{oc}$ produced by the PA6 and PTFE TEG from sample 1 to sample 4 is comparable proving that the triboelectric effect is dependent on the surface area. Figure 5 clearly depicts this concept and the $V_{oc}$ produced for samples 3 and 4 as the average output for the two TEGs is relatively close.

5. Conclusion
It can be concluded that an EPD is produced for dielectric-dielectric TEGs with identical membranes. At a speed of 0.2m/s and with a vertical force of 9.8N, the PA6 TEG produced a maximum open
circuit voltage of 800V and the PTFE TEG 1000V. The Voc produced by the TEGs is dependent on the contact area of the TEG in distinction to the electrification membranes used to fabricate the TEG. This becomes distinct when the contact area increases and the average Voc produced for the two TEGs is comparable. This research can be further extended into the fabrication of triboelectric fibres in order to produce triboelectric textiles that can be used for attire, where a large contact area is available, to harvest energy to power wearable devices.

6. References
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