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Reviewing the Scope of Triboelectric Nanogenerators as a Feasible Solution and its Applications

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ABSTRACT:- *With the threat of energy scarcity and environmental pollution increasing day by day, it is necessary to develop new and highly efficient technologies for harvesting energy from the environment to be used for the welfare of the society. Many forms of different mechanical energy resources are present in our surroundings - human walking energy, water flow energy, wind energy etc. - are not being used to their full potential and are getting wasted instead of being used to efficiently drive various practical and functional devices, especially small wearable electronics. Though a relatively new technology, triboelectric nanogenerators (TENGs), with their simple working mechanism and easy design, can be used to harvest many forms of waste energy from the environment.*

1. INTRODUCTION

A simple **Nanogenerator** is a type of technology that converts mechanical/thermal energy as produced by small-scale physical change into electricity. There are three types - triboelectric, piezoelectric and pyroelectric nanogenerators. Pyroelectrics are used for gaining energy from thermal sources and piezoelectrics and triboelectrics are used to gain energy from mechanical sources. **Triboelectricity-** is basically a branch or application of contact electrification in which certain materials become electrically charged immediately after separation from a different material with which they were in contact. The triboelectric effect increases if the two materials are rubbed against each other [2]. The material properties including friction, work function, electron affinity and so on, play important roles in TENGs' output performance. Basically, nearly all materials can exhibit triboelectricity. So, pairing the right materials can achieve output in maximum. The triboelectric series is a guidance,[17] in which the capability of a material to gain or lose an electrons is shown as a qualitative indication [2].

A triboelectric nanogenerator (TENG) is a self-powered, feasible solution to convert mechanical energy into electricity and specifically satisfy the increasing demand of the internet of things (IoTs). TENGs can combine the contact electrification and electrostatic induction for energy conversion of mechanical energy into electrical energy to power small-scale electronics including mobile phones and sensors.

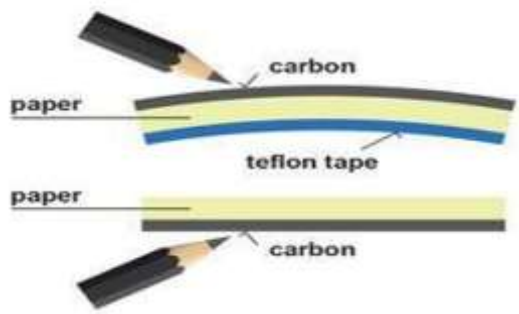
1.1 Why Triboelectricity?

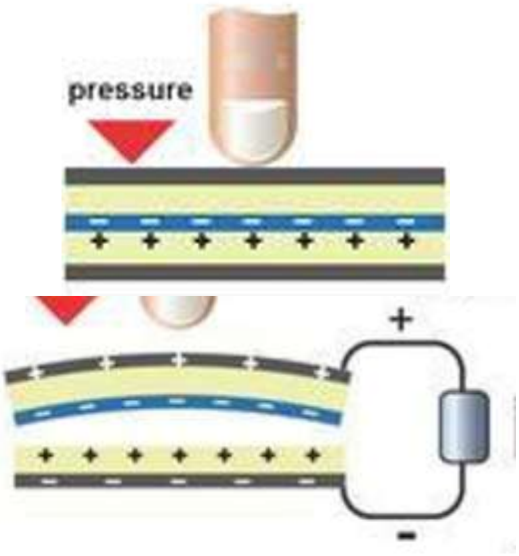
With the modernization of the technology with time, the demand for energy is increasing day by day, it is necessary to find out the new sources of renewable energy. The fossil fuels upon which the maximum energy has been produced till date are going to be depleted soon. A triboelectric nanogenerator (TENG) is new source of energy firstly demonstrated by in Prof. Zhong Lin Wang's group at Georgia Institute of Technology in the year of 2012.

Though a relatively new technology, a triboelectric nanogenerator (TENG) can be used to harvest many forms of energy from the environment which is generally wasted. It's simple design makes it ideal for small wearable electronics. Yet the domain lacks proper research, and newer and improved versions and applications of TENGs are always on the rise.

1.2 Advantages

Triboelectric Nanogenerators (TENGs) are a new source of energy harvesting technology, having high efficiency, easy working mechanism and capable of harvesting Energy from different sources under different conditions. The properties of the triboelectric nanogenerators make them very useful for production of large power. Researchers at EPFL – École polytechnique fédérale de Lausanne Have developed a device that can produce the equivalent of two AA batteries using cardboard, teflon tape and carbon[11]. Contact between the teflon and the paper produces static electricity. The carbon is charged electrically and transmits its potential difference to the capacitor. Every time the capacitor is pressed, it accumulates charge [11].

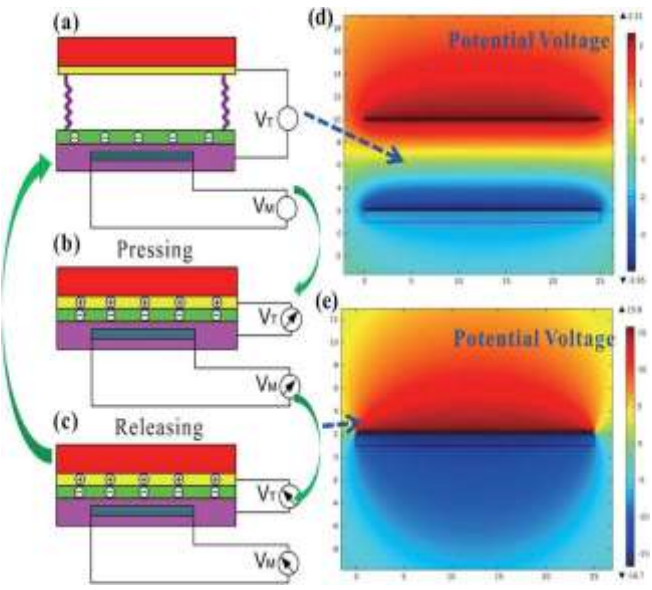




Simple production of current using static charges
Infographic pascal coderay

2. WORKING PRINCIPLES

The TENG follows a mechanism in which, two different triboelectric materials (having opposite polarities) come in contact and then separated or slid against each other which results in the transfer of Electron between the materials, developing electrostatic charges of opposite polarities on the surfaces of the triboelectric materials. The mechanism can be broadly classified into two main movements or motions i.e. sliding motion and vertical contact-separation motion. In sliding type TENG rotating and designs are generally used, whereas in vertical contact separation generally, pressure and vibrations are converted into electricity. The lifespan of vertical contact separation TENG is generally longer than sliding type due to lesser friction damage.



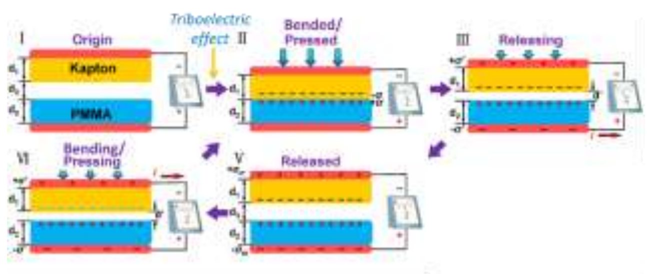
The working principle of the hybrid EMG and TENG: (a) the initial or separation mode; (b) the contact mode for pressing; (c) the contact mode for releasing; (d) the FEA simulation of the potential voltage with a 1 cm gap from the electret PTFE; and (e) the FEA simulation of the triboelectric potential voltage with a small gap.

Credits- Run Huang, Jianxiong Zhu

2.1 Vertical Contact-Separation Mode

This working principle of the triboelectric nanogenerators is described as the cyclic change of the potential difference caused by the periodic separation and re-contact of the opposite triboelectric charges between the inner surfaces of the two sheets. When the two sheets are pressed against each other, the inners surfaces of the two sheets will get into close contact and the charge transfer will begin, by which one side of the surface is left with with positive charges and the other with negative charges. This is the triboelectric effect. On releasing the applied force or pressure, the two surfaces with opposite charges will separate automatically, and these opposite triboelectric charges will be generating an electric field in between and thus inducing a potential difference across the top and bottom electrodes. To screen this potential difference, the electrons are driven to flow from one electrode to the other through an external load. The electricity generated in this process will continue until the potentials of the two electrodes get back to even again. And when the two sheets are pressed towards each other again, the potential difference induced by the triboelectric charges will start reducing to zero, so that the charges which were transferred will flow back, through the external load, to generating another current pulse in the opposite direction. When this periodic mechanical deformation lasts, the alternating current (AC) signals will be continuously generated.

One of the materials which come in contact, needs to be an insulator, so that the triboelectric charges cannot be conducted away but will stick on the inner surface of the sheet. Then AC electricity can be generated by these immobile triboelectric charges through external loads, through cyclic contact and separation.



Vertical contact-separation mode of triboelectric nanogenerator

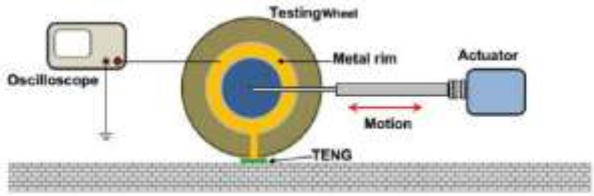
Credit- Wikipedia, Wanngsh05

2.2 Lateral Sliding Mode

In the original position, the two polymeric surfaces fully overlap and intimately contact with each other. Because of the large difference in the ability to attract electrons, the triboelectrification will leave one surface with net positive charges and the other with net negative charges with equal density. Once the top plate with the positively charged surface starts to slide outward, the in-plane charge separation is initiated due to the decrease in contact surface area. The separated charges will generate an electric field pointing from the right to the left almost parallel to the plates, inducing a higher potential at the top electrode. This potential difference will drive a current flow from the top electrode to the bottom electrode in order to generate an electric potential drop that cancels the tribo-charge-induced potential. Because the vertical distance between the electrode layer and the tribo-charged polymeric surface is negligible compared to the lateral charge separation distance, the amount of the transferred charges on the electrodes is approximately equal to the amount of the charges separated during the sliding motion. Thus with every sliding process the current flow keeps increasing, until the top plate fully slides out of the bottom plate and the tribo-charged surfaces are entirely separated. The measured current should be determined by the rate at which the two plates are being slid apart. Subsequently, when the top plate is reverted to slide backwards, the separated charges begins to get in contact again but no annihilation due to the insulator nature of the polymer materials. The redundant transferred charges on the electrodes will flow back through the external load with the increase of the contact area, in order to keep the electrostatic equilibrium. This contributes to a current flow from the bottom to the top electrode, along with the second half cycle of sliding. Once the two plates reach the overlapping position, the charged surfaces get into fully contact again and with that, there will be no transferred charges left on the electrode, and the device returns to the initial state. In this entire cycle, the processes of sliding outwards and inwards are symmetric, so a pair of symmetric alternating current peaks should be expected.

3. APPLICATIONS

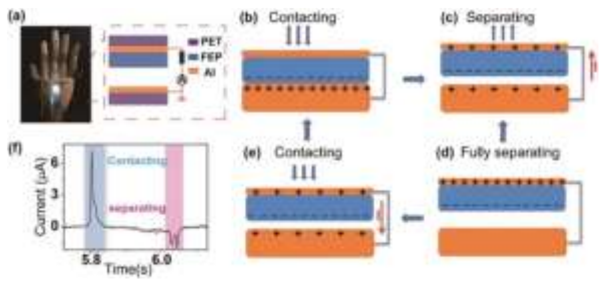
A single electrode TENG can be used to harvest the braking energy in vehicles. In case of rolling tires on the ground, the maximum energy loss is due to friction and that energy can be harvested by using a TENG. When a triboelectric material (PDMS) comes in contact with the ground, transfer of electrons take place between the PDMS plate and the ground due to triboelectric effect which is shown in figure. Due to continuous rotation of the wheel, there is a non-equilibrium of charges on the surface which leads to the generation of current [2]. It is observed that the electric output from the TENG on wheel increased with the increase in rotation speed of the wheel and the load. A disc-based design of the braking system can be used in automobiles. Waste energy can be harvested during the braking action of a vehicle using the contact and non-contact modes of braking pads having opposite tribo-polarities. The energy was harvested using the principles of triboelectric effect and electrostatic induction process. Efficiency is high in non-contact mode due to reduced friction. Efficiency was found to be directly proportional to rotational speed and inversely proportional to the distance between the discs [2].



Schematic setup of characterising of the friction energy scavenging ability of the TENG from a rolling wheel [2]

3.1 TENG driven by Magnetic force and fingertip pressure

TENG driven by Magnetic force and fingertip pressure Taghavi et al. designed a typical contact key based TENG, driven by the magnetic force and fingertip pressure mechanism which is shown in fig below. when finger pressure is applied on the upper part, causing the upper pair of materials to come in contact. When the pressure is removed, due to magnetic force the lower part is pushed upwards causing the contact of the lower pair of materials. Hence the contact and separation leads to charge transfer between the materials, resulting in the flow of current. A seesaw structured TENG can be operated under different speeds and magnetic force [2]. Magnetically coupled contact mechanism is used to reduce the wear of the material. Rubber sponges were used for long-term stability of the TENG electrodes. The sponges, characterised by high density were more resilient, elastic, better at resisting shocks, and were less prone to damage during high speeds. The discs were provided with the permanent magnets on the side of each disc due to which a non-contact magnetic force acts between the discs [2].

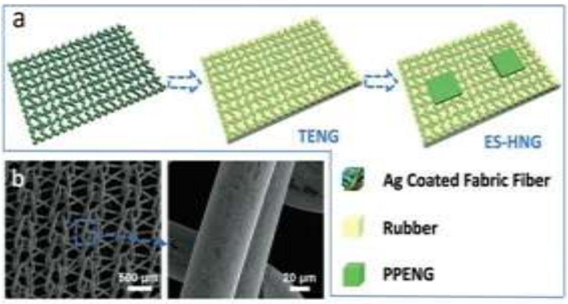


Fig(a) shows the physical model of the triboelectric nanogenerator and its placement on the artificial hand. Fig(b), (c), (d) and (e) show the cycle of charging and discharging. Fig(f) shows a graph, of the current readings obtained from the process [2].

3.2 Textile TENGs as Self-Powered Health Monitors

Textile-based TENGs possess merits such as good air permeability, flexibility and large-scale production, which makes them very suitable for wearable applications. Textile-based TENGs have been applied to serve as self-powered sensors for healthcare such as detection of respiration and sleep monitoring [8].

Textile TENGs can be categorized into two types according to device structure. One type is that the TENG is a fabric woven by one or two kinds of triboelectric fibres. The other type is that the TENG uses two whole pieces of textile as the substrates or triboelectric layers. Prospects include integrating triboelectric nanogenerators with pacemakers to reduce the risk of battery replacement. As researchers have demonstrated in numerous applications, TENGs have been applied for health monitoring such as for instance heartbeat and breathing detection [8].



Fig(a) shows a normal textile being placed with TENGs creating a hybrid nanogenerator (HNG)

Fig(b) shows a microscopic image of the HNG.

© *Wiley-VCH Verlag* [8]

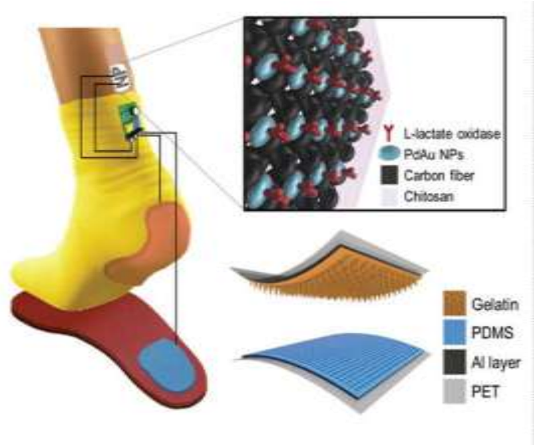
3.3 Non-Textile TENGs as Self-Powered Health Monitors

Most of the reported TENG-based health monitors are non-textile, and they are generally either mounted on the skin or on clothes. Some of the non-textile TENG-based self-powered health monitors have only one sensing ability, while others have multiple. Some examples:

Monitoring muscle/body motion such as joint motion, biceps exercises and abdominal respiration has wide applications in postoperative rehabilitation, sport and fitness management. The motion of the muscle or body has relatively large displacement, and thereby is relatively easy for TENGs to detect [8].

In contrast, heartbeat and pulse have relatively small amplitudes, and that requires the sensors to possess high pressure sensitivity and low detection limit in order to obtain the information of heartbeats and pulses.

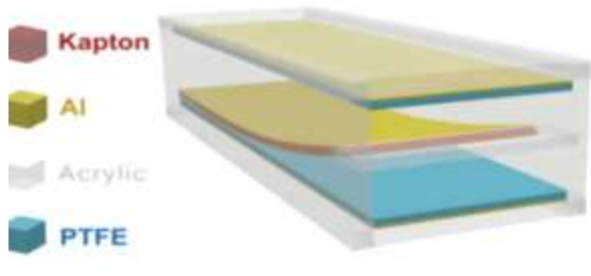
TENGs have also been applied to monitor voice and act as hearing aids. Monitoring voice can not only pick up spoken sounds in noisy environments but could also be important in vocal rehabilitation [8].



Schematic diagram showing a triboelectric nanogenerator-based lactate sensor. (© Wiley-VCH Verlag) [8]

3.4 Flexible power sources for lighting light emitting diodes (LEDs)

After the invention of TENGs, a significant amount of research has proved them to be largely adaptable to be utilized as a source of energy to light up LEDs. Yang et al. fabricated a triboelectric generator (TEG) that scavenges wind flow-induced mechanical energy. As illustrated in figure below the TEG consists of two PTFE films (Polytetrafluoroethylene), Al electrodes, Kapton films, and an acrylic tube [1]. When wind pressure is applied onto the PTFE film, it constantly vibrates and touches and separates from the Al electrodes, hence producing an AC (Alternating signal current) as its output. The researchers found that, if more cells were integrated in a parallel fashion then the intensity of the alternating current increases. And the total output current can be increased to about 150 μA by paralleling 10 cells. The integrated cells can simultaneously drive 10 LEDs for providing effective illumination in the dark environment [1].



The breakdown of a TENG used to power LEDs [1]

3.5 Biomedical Applications

Since there is a broad range of materials selections, we can take into account the output ability, flexibility, biocompatibility and cost of the device, which make TENG an ideal candidate for biomedical applications. Several research groups have employed high-performance flexible and/or implantable TENGs for harvesting mechanical energy derived from the human motions or in vivo physiological movements [6]. Together with the PENGs, TENGs are becoming most promising biomechanical energy harvester and providing great chance for building self-powered biomedical systems By specific structural design, these devices can be very sensitive to detect small scale mechanical motions (e.g. the vibration of carotid artery caused by phonation and bloodstream) [6]. For example, pacemakers are being integrated with triboelectric nanogenerators. They work on the vibration energy caused by the above mentioned carotid artery, enough for it to generate electricity sufficient enough to run a pacemaker, all and completely from the mechanical and vibrational energy from the heart itself. This results is a virtually endless battery, which in turn lowers the need for operating procedures on the patient, lowering the risk.

4. CONCLUSION

As wearable electronics and other flexible sensors are widely used in daily life, self-powered systems are fundamental components. To realize this goal, various new energy-scavenging techniques have been exploited, such as solar cells, thermoelectric cells, and piezoelectric nanogenerators. As compared with these energy harvesters, the TENG as a new power-generating technology has many prominent advantages including high power density, high energy conversion efficiency, low cost, and easy fabrication. However, some potential issues still need to be solved. First, fundamental mechanism of contact electrification has not been clarified. Second, triboelectric materials are susceptible to mechanical wear. To realize large-scale applications, researchers need to fabricate new materials with stable and durable characteristics. Third, because of obvious effects of external environments on output performances of TENG, it is important to develop effective packing technology to protect these devices.

4.1 Improvements required before wide scale industrial applications

(i) Improving the performances of flexible TENG.

A vast amount of advanced materials would be good choices, such as graphene, 38, 39carbon nanotube, 40 and nano-Ag ink.41 it is found that nanoscale roughness on graphene can increase the surface charges, which can improve the output power of the TENG. Besides the materials, novel structural designs still need to be optimized to improve device durability and output stability, such as sponge structure, grating structure, and wavy structure [9].

(ii) Improving the charge density

Triboelectric nanogenerators have long been considered as a complimentary technology to electromagnetic generators, however due to the critical issue of not providing sufficient charge density, TENGs are still unable to provide large power output which in turn affects its applications and customer usage as a whole. To counteract this, researchers have developed, a TENG model which is self-sustaining and it utilizes part of the energy output from itself to improve its charge density, pushing the boundaries of generating current from triboelectric nanogenerators to the next stage. Some fundamental mechanisms have been established, but no substantial conclusion has been proposed. It is important to understand the corresponding mechanisms for designing new high-performance TENGs.

(iii) Conjunction of TENGs with other technologies

Integration of TENG with other power generators to fabricate hybrid energy cells. The hybrid energy cells could enhance the output performances of the TENG and solve some key problems when facing different functional requirements in human life. This sort of hybridisation has not been thoroughly explored yet [7].

4.2 Popularity

The table given below indicates the contribution of different countries to the area of PENGs. Based on the Scopus database, more than twenty nine countries have at least one published paper based on the new concept of PENGs [10]. The United States of America and China have presented the highest number of published papers in this field, respectively. After USA and China, South Korea, India, and Taiwan have shown significant contributions to the area of PENGs, respectively. [10]

A world map showing publications in the field of triboelectric nanogenerators (2012-2016) [10]

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