Triboelectric Nanogenerators for Self-powered Sensors

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Abstract

Self-powered sensors play an important role in everyday life, and they cover a wide range of topics. These sensors are meant to measure the amount of relevant motion and transform the biomechanical activities into electrical signals using triboelectric nanogenerators (TENGs) since they are sensitive to external stimuli such as pressure, temperature, wetness, and motion. The present advancement of TENGs-based self-powered wearable, implantable, and patchable sensors for healthcare monitoring, human body motion, and medication delivery systems was carefully emphasized in this study. The use of TENG technology to generate electrical energy in real-time using self-powered sensors has been the topic of considerable research among various leading scholars. TENGs have been used in a variety of applications, including biomedical and healthcare physical sensors, wearable devices, biomedical, human-machine interface, chemical and environmental monitoring, smart traffic, smart cities, robotics, and fiber and fabric sensors, among others, as efficient mechanical-to-electric energy conversion technologies. In this evaluation, the progress accomplished by TENG in several areas is extensively reviewed. There will be a discussion on the future of self-powered sensors.

Keywords: Self-powered sensors, Triboelectrification, Implantable and wearable smart textiles, Healthcare monitoring

1. INTRODUCTION

The term “self-powered sensor” refers to a sensor that generates energy when physically engaged without the need for an external power source. It is common knowledge that the majority of today's sensors are passive, meaning they don't give out any signals if they don't have electricity. Second, the sensor's operating power source is self-generated [1,2]. Triboelectric nanogenerator (TENG) is among the breakthrough wearable technologies that have attracted the attention of many researchers due to its considerable impact of self, high output, lightweight, design application, cheap cost, stability and durability, and so on. This is accomplished by taking into account a sensor's active and sleeping phases [3]. A sensor does not need to give out a signal every second in many scenarios, such as environmental monitoring; a signal at a particular interval would suffice. In such cases, the energy collected during the sensor's “sleep” phase might be utilized to power it once it is switched on [4]. This is a long-term operating plan. When it comes to the fast-paced lifestyles of today's working-class individuals, biomedical wearables are particularly relevant.

When travelling between tasks, a substantial amount of the day is spent, and health and fitness are often neglected [5]. Furthermore, the time-consuming procedure of seeing a doctor for a diagnosis, prescription, and treatment causes many individuals to delay visiting a doctor or getting to a clinic until it is absolutely required. As a result, there is a lot of research being done on techniques to monitor a patient's health and communicate real-time data about their health indicators to their physician [6]. In fact, the use of these wearables allows people to take a proactive approach to medicine by monitoring their health own biosignals longitudinally. This is also known as telehealth, and it has grown in popularity as a result of the Internet of Things [5].

Telemedicine is the combination of communication technologies with healthcare, in which technology is utilized to offer healthcare services [7]. Two key tendencies in medical care’s future development are “Smart Medicine” and “Precision Medicine” [8]. Drugs with precise release and slow-release control may improve therapeutic targeting while also increasing patient compliance and lowering drug adverse effects. Another key research direction and objective in the treatment of cancers in the clinic is this. The self-powered drug delivery system (DDS) is a closed-loop device that can actively manage the medication's release quantity and target based on the needs of the human body. Researchers have been

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The grating-structured TENG fabric is shown in Fig. 1(a-b), along with its integration with fiber-shaped dye-sensitized solar cells to create a complete textile-based energy harvesting system [9]. Fig. 1(b) shows large-scale all-textile pressure sensors for monitoring human motion and physiological signals [10]. Significant human body movements are thus needed to trigger device deformation/contact-separation for the production of triboelectricity, as shown in Fig. 1(b). Textile TENGs have shown exceptional superiority in mechanical energy harvesting owing to their ease of fabrication and promising output performance and self-powered sensing because of their ease of manufacture and promising output performance [11]. Fig. 1(d) shows a self-powered pressure and triboelectric sensor for subtle blood pressure monitoring. Reprinted with permission from Ref. [12]. Copyright (2019) John Wiley and Sons. (e) Smart functional socks for multi-sensing and energy harvesting. Reprinted with permission from Ref. [13]. Copyright (2019) American Chemical Society. (f) Membrane based highly stable health monitoring sensors [14]. Copyright (2014) John Wiley and Sons. (g) Nanopatterned textile-based wearable TENG for body motion sensing and charging batteries. Reprinted with permission from Ref. [15]. Copyright (2015) American Chemical Society.

working on a range of self-powered DDSs in recent years since renewable energy and self-powered systems have advanced rapidly.

Herein the progress accomplished by TENG in several areas is reviewed with a discussion on the future of self-powered sensors. This review summarizes various types of TENG-based self-powered sensors for wearable and biomedical applications during their significant development in recent years with different functions and structures.

2. TENG for Self-Powered Sensors

The grating-structured TENG fabric is shown in Fig. 1(a-b), along with its integration with fiber-shaped dye-sensitized solar cells to create a complete textile-based energy harvesting system [9]. Fig. 1(b) shows large-scale all-textile pressure sensors for monitoring human motion and physiological signals [10]. Significant human body movements are thus needed to trigger
health monitoring as self-powered sensors (Fig. 1(f)). The M-TES is a compact and lightweight device that can detect air pressure changes in situations like those depicted when air pressure starts or collapses [14]. After a lengthy period of operation, the device has shown great stability, and increased sensitivity may be predicted when the gadget is further downsized. Seung et al. presented a fabric wearable TENG (W-TENG) with good output performance and mechanical resilience, as shown in Fig. 1(g). W-TENG can use human mechanical energy to drive commercial LEDs and LCD panels. Furthermore, a keyless car entry system based on W-TENG is presented that does not need any external power sources [15].

Fig. 2(a-b) demonstrates the patchable TENG mechanoreceptor-inspired dynamic mechanical perception stimuli hydrogel based for dynamic sensing communicator [16,17]. The construction of a flexible, self-powered ultrasensitive pulse sensor (SUPS) based on a triboelectric active sensor with outstanding output performance, high peak signal-to-noise ratio, ultrasensitivity, and cheap cost is shown in Fig. 2(c) [18]. Without a complicated circuit design, mathematical procedures, or the consequent mistake, the SUPS can immediately acquire a voltage signal that is consistent with the second derivative of a standard pulse signal. Fig. 2(d) demonstrates the creation of active sensors inspired by the eardrum for self-powered cardiovascular and speech recognition systems that can function in several modes for health monitoring and authentication [19]. Self-powered, transparent, stretchy, ultrasensitive, and patchable strain sensors made of multifunctional nanocomposite materials for detecting diverse human activities are shown in Fig. 2(e). For stretchable power sensors, a multi-functional and solution-processable nanocomposite of low-density silver (Ag) nanowires (NWs) with a conductive elastomer was used [20]. To monitor, the skin-inspired TENG-driven self-powered multipurpose sensor is used (Fig. 2(f)). Human physiological signals, such as arterial pulse and voice vibrations. Moreover, an intelligent prosthetic hand, a self-powered pedometer/speedometer, a flexible digital keyboard, and
In recent years, self-powered biomedical devices based on TENG technology have made significant development. Fig. 3(a) shows an implanted TENG for biomechanical energy harvesting in vivo. The output voltage and matching current are driven by the heartbeat of adult pigs. A self-powered wireless transmission system was developed for real-time wireless cardiac monitoring due to its superior in vivo performance [25]. An implanted vagus nerve stimulation device that is battery-free and spontaneously sensitive to stomach movement is shown in Fig. 3(b). A flexible and biocompatible NG is mounted to the surface of the stomach in the vagus nerve stimulation system [26]. A small, flexible, ultrasensitive, and self-powered endocardial pressure sensor (SEPS) for real-time endocardial pressure monitoring is shown in Fig. 3(c). SEPS is based on a TENG, which can convert the conversion of blood flow energy into electricity inside the heart chambers. The device's electric outputs, which might include EP, ventricular fibrillation, and ventricular premature contraction [27], may indicate normal and pathological cardiovascular condition. An implanted symbiotic pacemaker based on an implantable TENG (i-TENG) effectively performs cardiac pacing and sinus arrhythmia correction in a large animal model, as shown in Fig. 3(d). The body and i-TENG-based cardiac pacemaker develop a symbiotic relationship [28]. Sensors for wearable applications that are used in a variety of applications in this sector.

3. CONCLUSIONS

The self-powered TENG-based sensors can collect biological data and serve as power sources for commercial medical sensors, enabling applications in health monitoring and physiological function regulation, such as sensors for heart rate, blood pressure, respiratory rhythm, motion, a power source for drug delivery, nerve stimulation, and more. The in vivo uses of TENGs implantable through biocompatible materials for both health monitoring and illness treatment, as well as the applications of wearable TENGs with varied structures for collecting information.
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on physical parameters, are discussed in this study. Because of its excellent in vivo output and stability, i-TENG might be used to create a self-powered, wireless healthcare monitoring system in addition to implanted medical devices. TENG-based investigations into cell proliferation and differentiation, as well as medication delivery, are also discussed. Despite this advancement, researchers are currently attempting to determine the output performance of self-powered TENG based sensors, as well as their long-term stability, noninvasiveness, and compatibility in hard conditions for human and environmental safety. So far, the materials utilized in self-powered sensors have limits. To lower production costs and make them cheap for commercial and practical usage, fabrication techniques should be streamlined.

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