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Triboelectrification for Energy Harvesting, Delivery and Tribotronics

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Abstract

In this presentation, I firstly introduce the fundamentals and possible device applications of TENGs, including their basic operation modes. Then the different improvement parameters will be discussed. As main topics, the presenter will present a couple of recent achievements regarding highly robust and efficient TENGs with multifunctional materials, etc. In addition, the presenter will reort transcutaneous ultrasound energy harvesting using capacitive triboelectric technology. A major challenge for implantable medical systems is the inclusion or reliable delivery of electrical power. Ultrasound was used to deliver mechanical energy through skin and liquids and demonstrated that a thin inplantable vibrating triboelectric nanogenerator is able to effectively harvest it. Finally The presenter is going to introduce a 2D materials-based tribotronics for possible future application toward tactile sensors, robots, security, human-machine interfaces, etc. The triboelectric charging behaviors of vaious 2D layered materials including graphene, MoS_2, $MoSe_2$, etc were investigated in order to decide the triboelectric position of each 2D material using the concept of a triboelectric nanogenerator, which provides new insights to utilize 2D materials in triboelectric devices, allowing thin and flexible device fabrication.

1. Introduction

As the Fourth Industrial Revolution comes, emerging technology breakthroughs in a number of fields such as artificial intelligence, quantum computing, biotechnology, The Internet of Things (IoT), and autonomous vehicles become embedded within societies and even human body. Especially, human-machine interaction or so-called multimodal interaction provides the users with multiple modes of interacting with a smart system, which inevitably results in demanding energy consumption. Therefore, many forms of rechargeable battery systems are emerging. However, the cost and labor of charging are increasing, and even the battery exchange during the emergency is technically impossible, in contrast to technological advances. To solve this problem, alternative energy technology that can convert the energy of the surrounding into usable energy for directly charging the battery and developing self-powered platform has appeared, and the application of the technology to convert the mechanical energy triggered from the interaction with the environment into the electrical energy has been highlighted.

Among alternative mechanical energy technologies, triboelectric nanogenerators (TENGs) have been developed as rising energy harvesting devices were first introduced in 2012. Recently, research in TENGs has been prominent due to its relatively high output power. The TENGs based on contact electrification and electrostatic induction physics have been developed as a self-powered platform and powering devices driven by mechanical contact or friction triggered by object movement. Like all energy conversion technologies, TENGs are evaluated by an efficiency that determines possible operate-able application range. The efficiency of TENGs can be affected by two stages; an initial stage in conversion (ISC) is regarding a process that kinetically triggered materials get into contact with opposite materials is followed by instant electrical charge induction along electrodes. The final stage in conversion (FSC) is regarding a circuit efficiency that induced electricity is how efficiently converted to store/use in applications. One of the important factors to influence the ISC can be quantified as the ratio of the amount of induced surface charges to the polarization of materials, and another as the efficiency of the circuit part can be referred to as the FSC. Since the FSC has been sufficiently developed for a long time, more than 90% can be technically realized. However, based on the laws of conservation of energy, given mechanical energy is converted to other energy sources (e.g., light and sound on contact area) rather than electrical energy, resulting in such a low ISC. It determines the energy output spectrum of the TENGs like many alternative energy technologies.

2. Discussions and Conclusion

First, it was necessary to understand the influence on the TENGs output performance according to the level of ferroelectric polarity and its characteristics whether tribonegative or tribopositive. When it comes to analyzing the effect of ferroelectric polarity on the TENGs, one of ferroelectric polymer, poly(vinylidene fluoride-trifluoroethylene) [P(VDF-TrFE)] is a suitable candidate to control its ferroelectric polarity as modulating outermost elements [F or hydrogen (H)] through a certain level of electric field application (poling). As shown in Figure 1, the ferroelectric polarity of the surface was confirmed by Kelvin probe force microscopy (KPFM). By applying a positive potential internally, the outermost atoms were dominated by F atoms, while the outermost atoms were dominated by H atoms when a negative potential was applied. In each case, a region with a positive potential has an electropositive characteristic, whereas a region with a negative potential has an electronegative one. We not only verified that the controlled polarity affects the surface potential at the atomic level but also confirmed its electrical properties of the device at centimeter scale. Consequently, the mechanical-electrical conversion characteristics can be controlled and its efficiency can be enhanced by modulating the polarity of the TENGs materials.

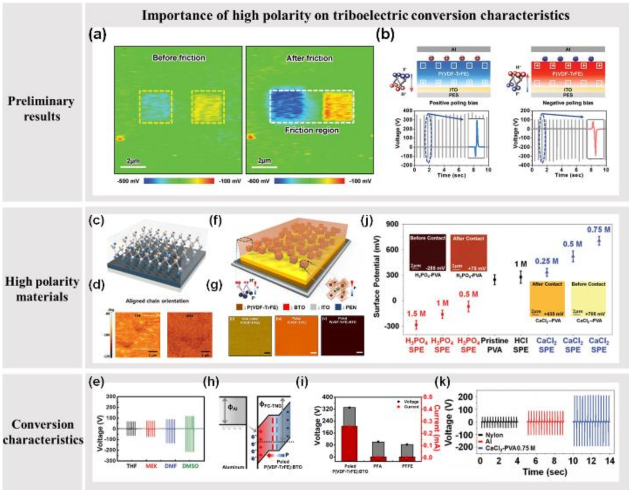

Fig. 1 Schematics showing the importance of polarity for the triboelectric conversion characteristics. (a) Induced polarization on ferroelectrics characterized by KPFM, and (b) TENGs tuned as electropositive/electronegative ferroelectric polarity and electrical output characteristics. (c) Well aligned polymer chain based TENGs, and (d) the impact on surface charge density characteristics depending on the chain length. (e) Conversion characteristics trend depending on the polarity of polymer. (f) Nanocomposite structure capable of excessive polarity, and (g) controlled surface charge density through the level of polarity with its (h) working principle and (i) superior conversion characteristics beyond current TENGs materials. (j) Electrolyte based TENGs materials controlled triboelectric charge, and (k) the electrical conversion characteristics.

We have understood the surface chemistry characteristics of polymers due to the chain lengths depending on the type of solvent in the polymer synthesis process. Taking advantage of this strategy, we understood high conversion characteristics of TENGs with given high electropositive/electronegative polymers. When it comes to the conversion characteristics, it is necessary to analyze the surface charge density of the present material before and after the contact with the counterpart materials. Through the contact potential difference (CPD) analysis strategy, the controlled electropositive (tribopositive)/electronegative (tribonegative) characteristics were studied and verified at the atomic level. In addition, it was confirmed experimentally by fabricating a macro-scale TENGs device with a centimeter size, and its current output characteristic was improved by about 75% by controlling the polarity of the solvent (Figures 1c-e). We verified the effect of polymer chain length on the degree of orientation uniformity of polarity, and as a result, the quantitative correlation between the energy conversion characteristics and the polarity of the polymer [1].

In previous studies, excessive polarity has been achieved through physically embedding techniques through composite structures, but studies have also been conducted to chemically control excessive polarity. Through a simple chemical doping process, the intrinsic polarity of polyvinylalcohol (PVA), a well-known electrolyte substance, has been exceeded. We have realized the highly excessive polarity characteristics through the combination of various ion pairs and concentration control to modulate the polarization of neutral PVA material, and have developed the relatively tribonegative/tribopositive characteristic control technology [2]. These controlled polarity properties were verified by KPFM analysis and they acted as active materials of TENGs by depositing them on the substrate (Figure 1j). Therefore, we experimentally confirmed the mechanical-electrical conversion efficiency was improved even at the macro-level scale (Figure 1k). This approach is groundbreaking to develop a system of excessive polarity by chemical doping technology and to be applicable to TENGs because of the advantage that it is possible to introduce broad material groups through surface chemistry technology. This study opens the possibility of the unexplored materials to become active TENGs materials that have not yet been discovered.

In addition, the presenter will reort transcutaneous ultrasound energy harvesting using capacitive triboelectric technology. A major challenge for implantable medical systems is the inclusion or reliable delivery of electrical power [2]. Ultrasound was used to deliver mechanical energy through skin and liquids and demonstrated that a thin inplantable vibrating triboelectric nanogenerator is able to effectively harvest it. Finally The presenter is going to introduce a 2D materials-based tribotronics for possible future application toward tactile sensors, robots, security, human-machine interfaces, etc [3]. The triboelectric charging behaviors of vaious 2D layered materials including graphene, MoS_2, $MoSe_2$, etc were investigated in order to decide the triboelectric position of each 2D material using the concept of a triboelectric nanogenerator, which provides new insights to utilize 2D materials in triboelectric devices, allowing thin and flexible device fabrication.

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