TENG Structures and Applications in Ocean Environment

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Abstract. TENG is a new potential energy harvesting technology for everyday life, and the ability of TENG to provide renewable energy for small devices is attracting attention in numerous ways. Through special principles, TENG has become an effective blue energy harvesting technology, and energy harvesting in the ocean is one of the areas where this technology is utilized. This article provides information on TENG in oceans including principles, structure, application, and other strategies to improve performance. To optimize the performance of TENG, the most efficient method is designing a new structure. Hence this article focuses on reviewing popular structures and instances. Showing different advantages, the structure designing makes sense in the performance of TENG in the ocean, demonstrating the importance of structure designing in optimization. It is expected that this article can inspire readers to design greater TENG structures. Moreover, the basic information of TENG is able to enhance comprehension of TENG in the ocean.

Keywords: TENG, Blue energy harvesting, Structure designing, Renewable energy, Water wave energy.

1. Introduction

With the development of industry and technology, fossil energy sources, a non-renewable source of energy, have been overused leading to energy shortages. To avoid energy depletion, people need to collect and transform renewable energy to achieve sustainable development. Therefore, different strategies have been devised to harvest renewable energy sources such as wind, solar, water waves and tidal energy. One of the key studies is harvesting blue energy from the oceans [1,2].

The oceans cover 70% of the Earth's surface and contain large magnitudes of energy including forms of tidal energy and water wave energy. Harvesting ocean energy is being widely studied as a promising way to harvest renewable and clean energy. However, the reality of energy harvesting is not as ideal as expected. Nowadays, the most popular strategy is to utilize an electromagnetic generator (EMG), which converts the mechanical energy of water waves into electrical energy by cutting a line of magnetic flux. Devices utilizing EMG are composed of bulky magnets, metal coils and turbines, which are easily eroded by seawater, resulting in costly and low harvesting efficiency in the ocean. The low-frequency oscillation of water waves is difficult to be detected and collected by EMG [3]. Hence, the new strategy TENG is designed to harvest blue energy, which can better fit harvesting of the low-frequency water wave.

TENG converts water wave mechanical energy into electric energy, combining triboelectrification and electrostatic induction together to harvest low entropy energy. Through these two principles, TENG can not only harvest energy during friction, but also utilize that of rotation, vibration, water, and even wind [3]. Therefore, it is a terrific technology to collect especially low-frequency oscillation mechanical energy and convert it toward electrical energy, greatly fitting ocean conditions. Given the promising expectation of TENG, scientists try to enhance the output of TENG by modifying triboelectrification material, optimizing structures, and designing interfaces between materials. In specific, modifying triboelectrification material can include material selection, surface modification, and internal filling. To optimize the structure, scientists generally approach structure fitting different environments by coupling different physical principles or biomimicry technologies. For interfacial design, the strategies include altering surface chemistry, interfacial lubrication, and an increase in interfacial electric field [1]. So far, TENG has been developed as a stable technology with relatively high output to support the battery of small devices in daily life, such as small wearable sensors.

Therefore, it is still important to explore the potential energy harvesting ways to improve and widen the applications in daily life. Within the harvesting ways, the water wave and tide are widely distributed in the ocean, which would be a large magnitude. The effective collection of water wave and tidal energy through TENG technology is an inevitable topic of discussion [4].

In the ocean environment, the most effective way to enhance the working efficiency of TENG is to optimize the structure of TENG, fitting the special point of the ocean and performing better in blue energy harvesting. Hence, this article will focus on reviewing recent TENG structures designed for ocean environments. In addition, principal and normal TENG structures will be introduced. After introducing principles and structures, TENG's application in an ocean environment, including energy harvesting and ocean monitoring, will be mentioned.

2. Basic Information of TENG in Ocean

TENG can be effectively and widely utilized in the ocean to conserve the environment. The function of TENG in the ocean can be generally classified into blue energy harvesting and water monitoring [5,6]. For instance, compared to the EMG, the classic technology for harvesting blue energy, TENG has a lighter weight which helps it float on the ocean more easily. The most important is that TENG has extremely high efficiency to converse energy at low frequency and responds to irregular mechanical motion. Therefore, based on tidal waves providing effective utilization of low-frequency mechanical motion, TENG has become an effective energy harvesting technology that perfectly adapts to ocean conditions. Besides, TENG power the sensors which are aimed to monitor the temperature, humidity, and atmosphere pressure to help with the water monitoring in the ocean. Since it is difficult to power the distributed sensor, whose batteries are out of charge, energy harvesting of TENG, making them self-sufficient, becomes to substitutable strategy to solve this problem. From these cases, TENG contributes exclusive value, through the special functions and applications in the ocean to provide new strategies for the renewable-energy area and solve existing problems in the ocean.

2.1. The Principle of TENG

The principle of TENG is the integration of contact electrification and electrostatic induction effect. The contact electrification is based on the theory of the overlapped electron-cloud model. This theory shows that when the distance between atoms is less than the bonding length, electrons can transfer between the atoms. The electrostatic induction effect means that the distribution of electric charge on a given material is influenced by the presence of nearby objects that possess an electric charge. Consequently, the output of TENG is caused by Maxwell's displacement current [1]. Before utilizing TENG, people utilize the electromagnetic generators (EMG). EMG, different from TENG, depends on electromagnetic induction. This principle originated from cutting the magnetic induction line by the coil, generating current. The output is determined by the density of magnetic lines and the volume of metal. Hence, to produce electrical energy more efficiently, the devices have to be composed of heavy and humble magnets, and metal coils, which easily become corrosion in salty water, descending efficiency [5].

Accordingly, when the water waves and tide, mostly irregular and low frequency, hit EMG devices, it is particularly low effective in generating electricity. Instead, once TENG devices receive the irregular, low-frequency oscillation, through electrification and electrostatic induction effect, TENG devices can convert the water wave and tidal mechanical energy to electrical energy effectively. Thus, TENG is a relatively effective strategy to harvest blue energy in the ocean.

2.2. Structure of TENG

The normal TENG has a multilayer structure, as shown in Figure 1a [3]. On the substrate, the PMMA sheet, Cu electrode and PTFE thin film overlap layer by layer. Once the water drops on the device, electrons move between the water and Cu electrode, forming a current. So far, many strategies have been found to optimize TENG efficiency. One of the most important strategies is to adapt to the marine environment. Scientists have applied many corresponding structures and strategies. Recently, the structure of ocean-applied TENG can be roughly divided into core-shell structures, wave structures, and bionic structures [1,7].

The core-shell structure has many advantages, such as light weight, water wave movement resistance, and ease to be integration. Herein, the spherical shell structure of TENG is designed for the ocean environment and this nanogenerator based on a rolling structure and independent frictional layers aims to collect energy from low-frequency fluctuations [8]. The working principle is demonstrated in Figure 1b. The TENG device structure is composed by rolling a Nylon ball into contact with Kapton film in the spherical shell. Due to the light materials, the device is light and can float on the surface of the ocean. Moreover, the structure enables this TENG to have high efficiency within the tide and water wave which the oscillation frequency is low. Through the test, this TENG device provides a maximum current of 1 μA in water waves, which can light 70 LEDs. Liu et al. also designed a core-shell TENG device to enhance the efficiency in the ocean [9]. The structure is shown in Figure 1c, including two semispherical shells made of acrylic. To store elastic potential energy and improve space utilization, multilayered helical semispherical substrates are designed. In addition, to increase swinging motion, blocks are introduced at the end of substrates. The TENG device can therefore have higher efficiency in ocean conditions through this unique structure. The result shows the output power can reach 5.5 mW at 2.5Hz oscillation, which is high enough to provide energy for small electronic devices.

The second popular structure is the wavy structure. The wavy structure can be constructed to collect the impact energy of water wave and tide which has low oscillation frequency. Due to its simple structure and lightweight, the wave-shaped TENG can float on the ocean and easily form a network, making it very suitable for harvesting under ocean conditions. In the early stages, Wen et al. designed a Cu-Kapton-Cu wavy sandwich structure between two PTFEs, achieving outstanding blue energy harvesting efficiency [10]. The structure is shown in Figure 1d. Nowadays, it has been developed a lot. Liang et al. introduced spring into the wavy structure to store elastic energy [11]. As shown in Figure 1e, the structure has 6 sections in different directions, triggered by energy from irregular water waves and tides in different directions. Through the spring, the low-frequency motion of water can be converted into high-frequency vibration, which has higher energy conversion efficiency. Moreover, the spring can also support structure frameworks to ensure contact and friction. Consequently, the wave structure TENG gives an effective idea to improve energy conversion efficiency and act as a great origin which derives countless new strategies like the spring model.

The third strategy to design TENG structures to fit ocean environment is, inspired by nature, biomimicry. Normally, through observing and analyzing physical structures of animal tissues or organs, researchers mimic corresponding structures with outstanding mechanical and hydrodynamic properties, such as the fin of fishes, the scale of butterflies, and wings of birds, to make TENG easier to collect and convert mechanical energy of water wave. For instance, a biomimetic fin-shaped device TENG can enhance efficiency [12]. In this structure, a cone hollow wedge-shaped, lightweight, can transmit the mechanical energy of a wave to TENG effectively. When the surge hits the fin-shaped device, the fin-shaped device is easy to get into motion. In the process of motion, TENG produces electric energy, which is a particular four alternating current peaks in one cycle of motion. The working principle is shown in Figure 1f. Hence, the biomimetic fin-shaped device performs as a motion-transmitting device to optimize the efficiency of TENG. Other biomimetic structures are also designed. For instance, a butterfly-shaped TENG designed by Lei et al. can better absorb the mechanical energy from waves and tides and convert it into electric energy more effectively [13].

Generally, TENG devices harvest blue energy in the form of a TENG device network floating on the surface of the ocean. The structure of TENG in the ocean should be designed considering the weight, network, and moist environment. So far, through a long development, the output of TENG network can reach around 1.15MW per km2, which can serve as a power source for many small devices. Consequently, it is still expected to be optimized to support more applications.

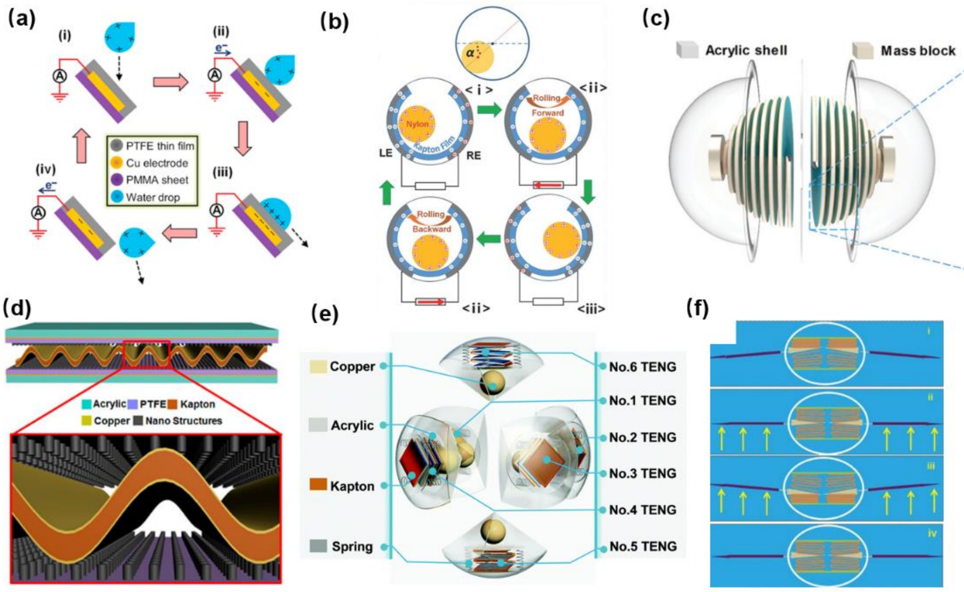

Figure 1. (a)Structure and scheme of normal TENG (b) Working principle of rolling structure and independent frictional layers TENG (c) Structure of TENG device consisting of two acrylic semispherical shells from Liu (d) illustration of classic wave structure TENG (e)Working principals of wave-structure based TENG (f)Working principle of fin-structure [3, 8-12]

2.3. Ocean Area Application of TENG

In the ocean area, so far, TENG mainly has two applications. The first application is forming a TENG network to harvest blue energy, The second is to provide self-power charge for monitoring sensors to monitor the ocean environment. The first is harvesting blue energy. Since ocean resources cover 71% of the globe, the water wave energy and tidal energy are vast enough to relieve energy issues if people can utilize them. TENG, with the function of low entropy energy harvesting, is a proper strategy to perform as a power provider for small devices, which in total are great magnitudes of power. In the area of harvesting blue energy, researchers are trying to elevate the conversion efficiency. The low-frequency oscillation wave mechanical energy, from the ocean, results in descended conversion efficiency in traditional methods. At that time, TENG provided a nice solution to deal with the problems. Scientists construct TENG networks to collect water wave and tidal energy in the ocean, and then transport collected energy into power to support small devices in daily life. Nowadays, though the harvested energy has been utilized in devices, scientists are still exploring more efficient strategies to construct the TENG network to further improve conversion efficiency. It is expected to become a more reliable renewable energy source.

The second application in the ocean is helping with ocean monitoring (See Figure 2). TENG network provides a self-power system for monitoring devices especially that of surrounding islands without people which is inconvenient for people to change the battery. Since the ocean covers a large area including many areas with rare people which need to be monitored, the self-power system becomes especially important. The TENG network is designed to satisfy the power needs of devices. For instance, the MH-TENG networks float in the ocean area surrounding an island [14]. The framework for a self-powered uninhabited island monitoring system is shown. Through a designed semispherical TENG network, water wave energy is converted into electric energy. The generated power is allocated by the management system on the island, which forms functional circuits to support monitor devices working. These two applications of TENG are commonly utilized in ocean areas. Owing to the limited output, TENG cannot be used in other applications in the ocean area, scientists are still exploring the applications in the ocean.

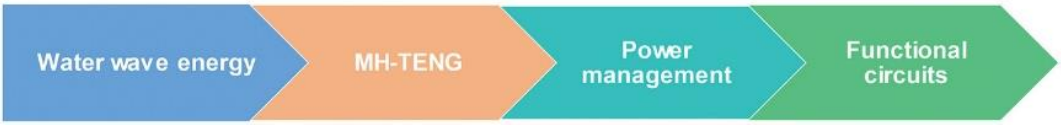

Figure 2. Cycle of monitoring [14]

2.4. Other Strategy to Enhance Performance of TENG

Scientists also try to find other strategies to enhance the performance of TENG in the ocean. The two frequently used methods are changing material and coupling with EMG. Researchers try to find proper and highly efficient materials on TENG to enhance contact electrification and electrostatic induction effects, such as TPU and PTFE. Through material exploration, the performance of TENG can be further optimized. On the other hand, EMG is being tried to coupling with TENG to construct a network to harvest blue energy in the ocean. The result is worth being expected. Though there is still a long way to optimize blue energy harvesting until it can be utilized in daily life devices, TENG in the ocean has been put to use in energy harvesting and ocean monitoring. The TENG networks floating near inhabited islands have constructed self-powered systems to charge monitoring sensors in a wide range of sea areas, helping people to monitor and even explore new areas in the ocean.

3. Conclusion

Compared with low entropy energy, TENG is a particular energy conversion technology to solve the lack of energy issues. Especially, in the ocean, because of the special principle, TENG is a greatly effective strategy to harvest low-frequency wave and tide mechanical energy, which is difficult for other technologies. Hence, at least so far, TENG is unalterable in energy harvesting in the ocean, making it important in blue energy harvesting. Scientists also make efforts to develop ocean TENG networks. Plenty of structures are designed, which are generally classified into core-shell structures, wave structures, and bionic structures to adapt ocean environment. These structures have achieved great results. In summary, TENG, in a new era, is a potential and special technology that can relieve energy issues. However, some problems are still waiting to be solved. The most important problem is the not high enough output, which is limited by the scale of the network. If people can overcome the output problems and construct a TENG network with highly efficient materials and structures, it is hoped that TENG can provide energy for more devices in the ocean area. Consequently, it is absolutely a potential technology in blue energy harvesting.

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