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Preparation and Properties of PDMS-Based Triboelectric Nanogenerator

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Abstract

In recent years, the energy crisis and environmental pollution have become more and more serious. A new type of green energy device that converts mechanical energy into electrical energy is needed. Triboelectric Nanogenerator (TENG) came into being. Carbon nanotube (CNT) nanomaterials were doped on polydimethylsiloxane (PDMS) substrates to explore the relationship between doping concentration, load size, two cathode materials and electrical output performance. The charge transfer efficiency is the highest when 1.5 wt% PDMS@CNT film is used as the negative electrode material, Cu is used as the positive electrode, and the applied load is 7 N and 1 Hz. The maximum open circuit voltage is 88.2 V and the maximum short circuit current is 6.3 μA. On this basis, the relationship between microneedle etching density and electrical output performance was investigated by microneedle etching treatment. The results show that the larger the etching density, the higher the electrical output efficiency. However, with the increase of density, the slope of the curve gradually decreases and finally tends to zero.

Keywords

Triboelectric Nanogenerator; PDMS; Doping Concentration; Microneedle Etching; Output Performance.

1. Introduction

In recent years, the problem of environmental pollution caused by the use of fossil fuels has become increasingly serious [1, 2]. In order to accelerate the completion of the goal of "carbon peak, carbon neutrality", promote the construction of a clean, low-carbon, safe and efficient energy system, rational use of resources and protection of the natural environment and the establishment of an environment-friendly society. Under the background of this policy, it is urgent to alleviate the energy crisis, adjust the harmony and stability between human and environment, and carry out more environmentally friendly renewable power sources. Obtaining sustainable energy such as light, wind, heat and mechanical energy from the environment is one of the focuses to solve the energy crisis and environmental pollution [3]. However, these new energy sources still have many shortcomings, such as low efficiency and the risk of destroying biological habitats. And with the improvement of wireless device utilization and environmental awareness, there is an urgent need to develop small batteries and renewable energy to replace limited fossil fuels [4, 5]. Although lithium-ion batteries (LIBs) are widely used in convenient devices such as mobile phones, they are not environmentally friendly and are a self-charging technology. New energy sources are emerging to replace new energy sources. Triboelectric nanogenerator (TENG) is a green energy collection device designed to collect mechanical energy generated by human motion in daily life [6]. TENG is widely used in wearable electronics, biomedical equipment, sensor networks and other fields due to its low price, high efficiency, convenient production, small size and light weight. The generation of TENG is based on the coupling effect of triboelectrification and electrostatic induction [7, 8]. According to the principle of contact and separation, the surface of two triboelectric materials with different polarities generates triboelectric charges due to electron transfer [9]. Therefore, triboelectric materials play an important role in improving the electrical properties of TENG. As one of the triboelectric materials, PDMS has the advantages of high electronegativity, convenient preparation, simplicity, good biocompatibility, high flexibility and low cost [10, 11]. It is the most commonly used material in TENG. In order to improve the output performance of TENG, in addition to selecting materials with large polarity differences or changing the substrate morphology [12], increasing the contact area of materials is also an effective method. The modified PDMS porous structure is prepared by increasing the specific surface area, increasing the effective thickness, and increasing the contact area to improve the performance [13, 14].

2. Membrane Prepared

2.1 Preparation of Smooth PDMS Membrane

The PDMS precursor mixture (the ratio of curing agent to PDMS is 1:10) was prepared and placed on the coating machine for coating. The coating rate was 0.5 mm/s, the horizontal coating was 2 min, and the copper foil was coated. Then it was placed in a vacuum drying oven at 60°C for 30 min, and the membrane was peeled off after drying.

2.2 Preparation of PDMS@CNT Membrane

Firstly, the CNT with a mass of 0.012 g was taken, and the diameter of CNT was 80~90 nm. The CNT was added to the centrifugal tank of the vacuum centrifuge, and the mixed PDMS solution 2.388 g was added to the vacuum centrifuge for 15 min to obtain a uniformly dispersed PDMS mixed solution doped with CNT. Subsequently, the PDMS@CNT mixture was coated on the upper surface of the treated aluminum foil with a coating machine. The coating rate was 5 mm/s and the coating time was 50 s. The PDMS@CNT mixture was taken out and placed on a vacuum drying oven, and cured at 60°C for 1 h. Finally, the PDMS@CNT film was peeled off the aluminum foil. In the same way, 0.024 g of CNT was taken and 2.376 g of mixed PDMS solution was added to prepare a PDMS@CNT composite membrane doped with 1 wt%. Then 0.036 g CNT was added to 2.364 g mixed PDMS solution to prepare 1.5 wt% PDMS film.

2.3 Preparation of Microperforated Membrane

The microneedle roller is selected, and the pattern and density of the microneedle surface are completely transferred to the surface of the friction layer material by rolling drilling on the surface of the PDMS film, so that the actual contact area of the two friction materials in the energy collection process is increased, thereby improving the electrical output efficiency of TENG.

Different densities and the same size of microneedle rollers (400 needles, 800 needles, 1200 needles, 2000 needles, 5000 needles, 7000 needles, 10000 needles) were used. After etching the cured PDMS film with microneedles, a negative friction layer material complementary to the surface structure of the microneedle roller was obtained. It is worth noting that the conventional copper foil thickness does not meet the needs of experimental operation. Here, four layers of 15 μm copper foil are uniformly compounded.

The cured PDMS film doped with 1.5 wt % CNT was divided into seven pieces of the same size, and then etched on the surface of PDMS with different specifications of microneedle rollers to make seven kinds of microhole arrays with different densities. The number of needles was 800, 1200, 2000, 5000, 7000, 10000, respectively. It is worth noting that in order to avoid the microneedle penetrating the PDMS film, the PDMS film is made to be 2 mm thick, and the length of the microneedle is 0.5 mm, which avoids the influence of the penetrating film on the overall output performance of TENG. In the study of preparing doped graphene and zinc oxide, it was found that the optimum thickness of PDMS film was 2 mm, so it was reasonable to choose 2 mm thickness. Finally, the PDMS membrane was stripped of the silicon template to obtain a variety of microporous array membranes with different densities. The specific operation is shown in Fig. 1.

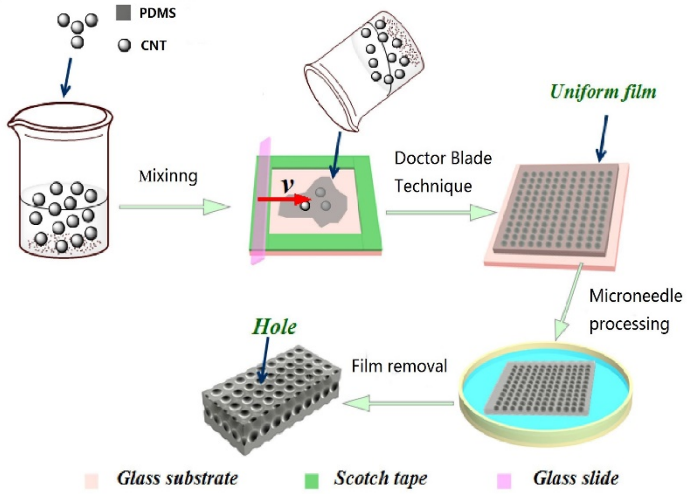

Fig 1. Preparation flowchart of microporous PDMS membranes

2.4 Assembly of PDMS @ CNT Anode TENG

In order to facilitate the test, an independent friction layer mode was adopted, and copper foil was selected as the cathode material. Firstly, the copper foil was cut into two pieces of 60×40 mm^2, and the copper foil was directly fixed to the 40×200 mm^2 PVC plate with double-sided adhesive as the friction electrode, and then the aluminum foil was compounded with the prepared pure PDMS film and fixed. As a friction negative electrode, two wires are used to connect the copper foil with the digital multimeter to control the periodic friction of the friction negative electrode between the two copper foils, and the load is 4 N. With the accumulation of charge, the maximum open circuit voltage of TENG is 14 V, and the short circuit current is 2.48 μA. The preparation flow chart is shown in Fig. 2.

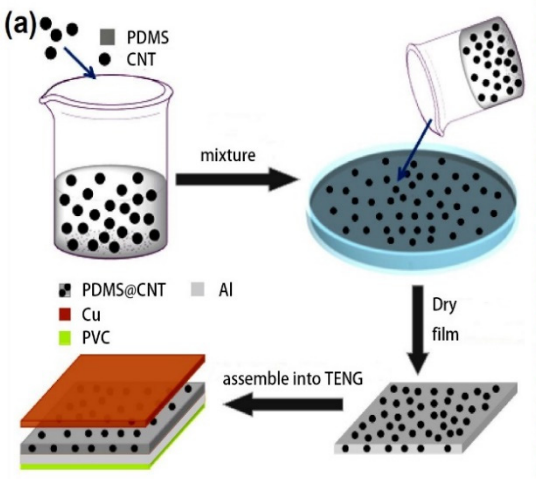

Fig 2. TENG assembly process

3. Result and Discussion

3.1 The Relationship between Doping Concentration and Electrical Output of PDMS@CNT Film

The open circuit voltage and short circuit current of 0.5 wt% PDMS@CNT film were measured to be 32 V and 4.06 μA, respectively, which were 3 times and 1.68 times higher than those of PDMS film. The change of the structure in the film has a great influence on TENG. The doping of CNT improves the electrical output of TENG obviously, and CNT improves the dielectric properties of PDMS greatly.

The PDMS@CNT film with 1 wt% was taken, and the same treatment method, the same circuit connection method, the applied load was 4 N, the same friction frequency, the open circuit voltage was 68 V, and the maximum output current was 5.32 μA, which was 5 times higher than the PDMS film voltage and 2.3 times higher than the current. The peak voltage of 1.5 wt% is 79.6 V, and the maximum output current is 5.45 μA, which is 6.5 times higher than the pure PDMS voltage and 2.42 times higher than the current. If it is connected to the rectifier bridge, it can light up sixteen 2 V LED lights. The maximum voltage of 2 wt% is 61.2 V, and the maximum output current is 5.28 μA, which is 4.8 times higher than that of pure PDMS. The current is increased by 2.1 times. The electrical output performance of TENG with PDMS@CNT as friction negative electrode has been greatly improved. The reason for this phenomenon is that doping CNT changes the dielectric properties of the film and increases the amount of charge transfer on the whole circuit [15]. The relationship between the doping concentration of CNT and the voltage and current of TENG increases first and then decreases, and 1.5wt% of the four concentrations is close to the optimal value. The open circuit voltage of different doping concentrations is shown in Fig. 3.

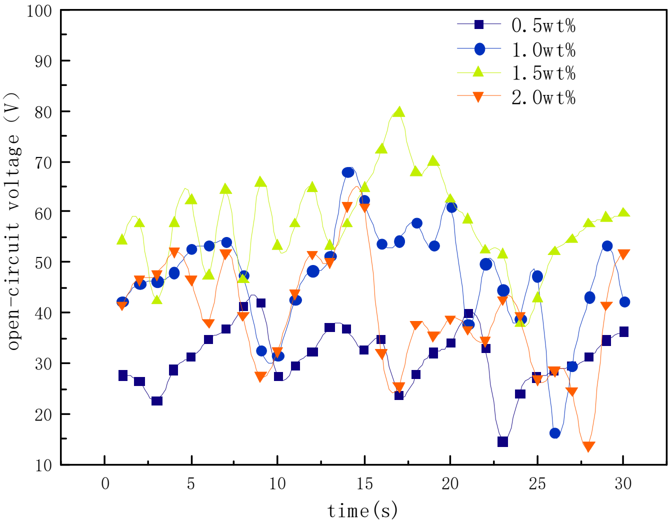

Fig 3. Open circuit voltages with different doping concentrations

3.2 The Effect of Changing the Cathode Material on the Electrical Output Performance of TENG

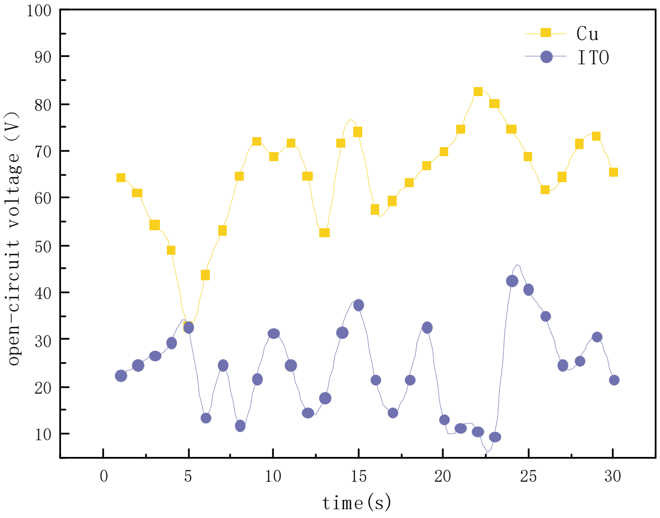

Fig 4. Open circuit voltages for two frictional cathode materials

In order to improve the electrical output performance of TENG, the friction layer material with large electronegativity difference should be selected from the current theoretical aspects, so as to make the electrical output performance higher, such as PDMS-Al and PDMS-ITO. Here, the independent friction layer mode of TENG is still used for the experiment. The aluminum foil and PDMS@CNT film doped with 1.5 wt% are fixed on the PVC plate with double-sided adhesive. The positive electrode is tin-doped indium oxide (ITO) film. The maximum open circuit voltage is 42.6 V and the maximum short circuit current is 4.6 μA. Since the conductivity of copper is stronger than that of ITO, the free charge flowing through copper per unit time is higher than that of ITO, and the output voltage of copper as positive electrode is large [16]. The TENG open circuit voltage of two different cathode materials is shown in Fig. 4.

3.3 The Effect of Load on the Electrical Output Performance of TENG Doped with CNT

In the independent friction layer mode, Cu is the positive electrode and Al is the negative electrode conductive material. TENG doped with 1.5 wt % CNT, a pressure sensor is attached to the back of the PVC plate with a friction negative electrode, and the force is presented in the form of a signal lamp. Two lights represent 1 N load, four lights represent 2 N, and so on. With the increase of load, it was found that the electrical output of PDMS composite membrane increased first and then remained unchanged with the increase of load.

When the load is 1 N, the open-circuit voltage and short-circuit current reach 21.6 V and 3.2 μA, respectively.When the load is 3 N, the open-circuit voltage and short-circuit current reach 66.5 V and 4.63 μA, respectively.When the load is adjusted to 5 N, the open-circuit voltage and short-circuit current reach 72.6 V and 5.94 μA, respectively.When the load is 7 N, the open-circuit voltage is 88.2 V and the short-circuit current is 6.3 μA.After 7 N, it begins to flatten out, if it is connected to the rectifier bridge. It can light up eighteen 2 V LED lamps. The open circuit voltage and short circuit current reach 72.6 V and 4.86 μA at 10 N, respectively. The reason for this phenomenon is that the contact area between the two friction surfaces increases with the increase of the force. When the force exceeds 7 N, the contact area tends to be saturated and this phenomenon no longer increases.

3.4 Effect of Etching Density on Electrical Output Performance

The independent friction layer mode of TENG is adopted and copper foil is selected as the cathode material. Since the etching density is only a physical change and does not change the internal structure of PDMS, the etching density experiment only needs to be doped with CNT. On this basis, the best doped 1.5 wt% PDMS@CNT film was selected, and then 1.5 wt% PDMS@CNT doped with microneedle etching was used as the friction negative electrode, and Al was used as the conductive material and fixed. Two wires were used to connect the copper foil and the multimeter, and a load of 7 N and 1 Hz was applied to it. The open circuit voltage and short circuit current obtained are shown in Fig. 5.

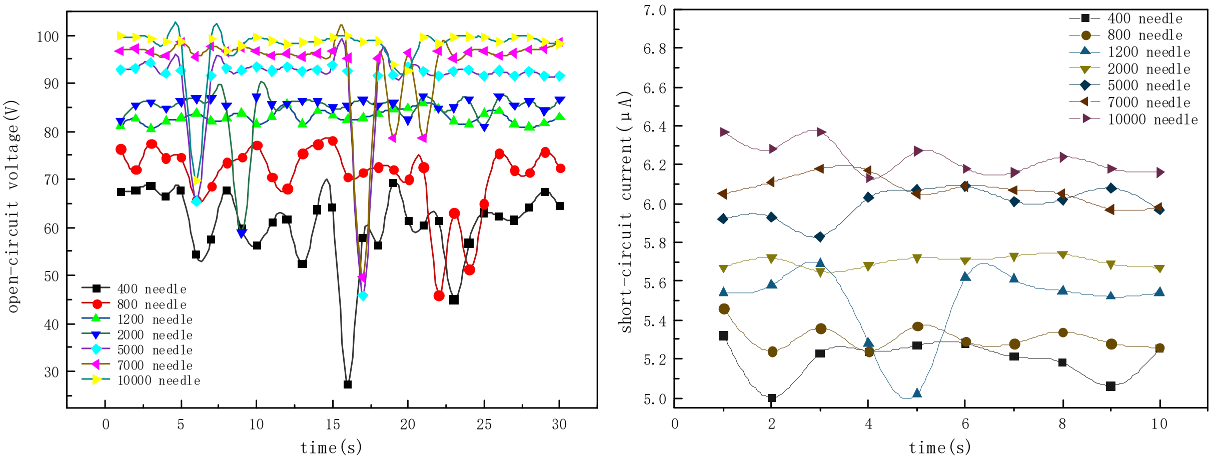

Fig 5. Etch density vs. voltage/current diagram

As the number of needles increases, its electrical output performance also gradually increases, but its increasing trend is getting weaker and weaker, and finally tends to zero. The relationship curve is shown in Fig. 6. The maximum output voltage is 99.8 V when the etching density is 10000 needles. If the external rectifier bridge, can light twenty 2 V LED lights.

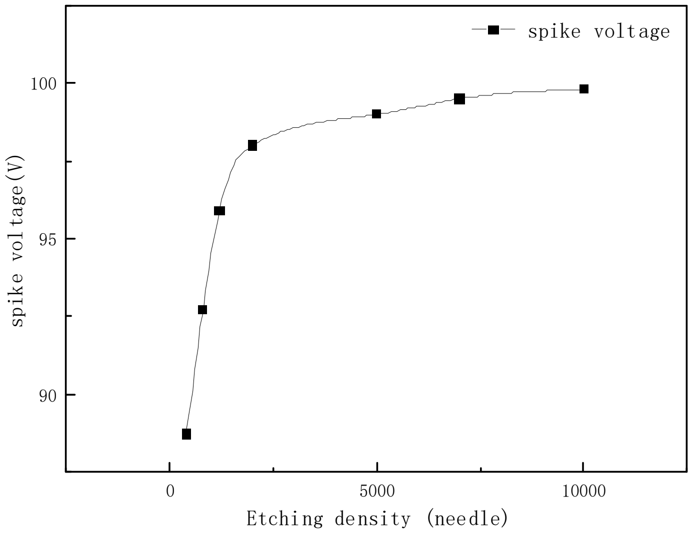

Fig 6. Voltage vs. etch density diagram

4. Conclusion

A triboelectric nanogenerator that can collect radial mechanical energy was prepared through experiments. Pure PDMS film and PDMS@CNT film were prepared. The effects of two different cathode materials, doping concentration and load size on PDMS@CNT film were tested. The PDMS@CNT film was etched by a microneedle roller and its law was explored. When doping 1.5 wt% PDMS@CNT as the negative electrode, CNT has a greater improvement in the electrical output performance of PDMS membrane. The optimal cathode material is Cu, the optimal load is 7 N, the measured open circuit voltage is 88.2 V, and the short circuit current is 6.3 μA. As the micropore area increases, its electrical output performance also increases. However, due to the influence of the interface, this relationship is not linear, but a curve that grows upward and the slope approaches zero. It can be seen from the experimental results that the performance of TENG is significantly improved by chemical treatment of PDMS film and surface etching treatment. This irregular mechanical energy collection device can be realized, which is of great significance and role in environmental energy crisis and environmental pollution.

Acknowledgments

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