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Triboelectric Nanogenerator Using Lithium Niobate Thin Film

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Abstract. We present a triboelectric nanogenerator (TENG) using a lithium niobate thin film, as one of the triboelectric pairs which was grown on a silicon substrate by laser molecule beam epitaxy (LMBE). The designed TENG has the advantages of simple structure, easy fabrication, small size (1.1*1.0*0.15 cm^3). An open-circuit voltage of 136 V and a short-circuit current of 8.40 μA have been achieved. The maximum output power is 307.5μW under the load resistance of 10MΩ. This is the first time to use lithium niobate thin film as one of the friction pair, which may make it possible to expand the application of triboelectric nanogenerator to optical field.

1. Introduction

As the aggravation of the environmental pollution and energy crisis, it is urgent to develop green energy sources. Since mechanical energy is very common and stable in our daily life, lots of research has been done to develop new methods and devices that can harvest mechanical energy. In 2012, Wang et al. invented triboelectric nanogenerator (TENG) [1] which was based on the conjunction of contact electrification and electrostatic induction. It can harvest many forms of mechanical energy, such as vibrational energy [2] and biomechanical energy [3]. TENG can generate electrical output when two materials with different friction polarities contact and separate from each other. Due to its low cost, easy fabrication, small size, lightweight and high power output, TENG has been proved to be a powerful means to convert mechanical energy into electricity.

It is crucial to develop rational structure to improve the output characteristic, especially to develop TENG with new fractional materials. Here, we demonstrate a new fractional material, lithium niobate thin film (LNTF). As a typical piezoelectric and pyroelectric material, lithium niobate is widely used in optical and material fields [4, 5]. Using LNTF as one of the tribo-pairs may make it possible to expand the application of TENG to optical or material field. Continuous periodic output is achieved when LNTF contacts and separates with micro-structured PDMS from black silicon mold. The resistive load characteristics of the TENG is also investigated.

2. Results and discussion

Working as the attached-electrode contact-mode, a TENG includes two layers as sketched in figure 1. A PDMS film with a thickness of 180 μm is selected to be one of the triboelectric layers because it is easy to gain electrons [6]. A black silicon [7] fabricated by a femtosecond laser is used as a mold to fabricate micro-structured PDMS. Served as an electrode, an aluminum foil is fixed on the PDMS by ordinary adhesive tape. The other layer is an iron doped LNTF which was grown on a highly doped silicon substrate by laser molecule beam epitaxy (LMBE) method. The silicon substrate serves as the other electrode to accumulate induced charges. The size of the TENG is 1.1*1.0*0.15 cm^3.

Figure 1. Structure of the triboelectric nanogenerator (TENG)

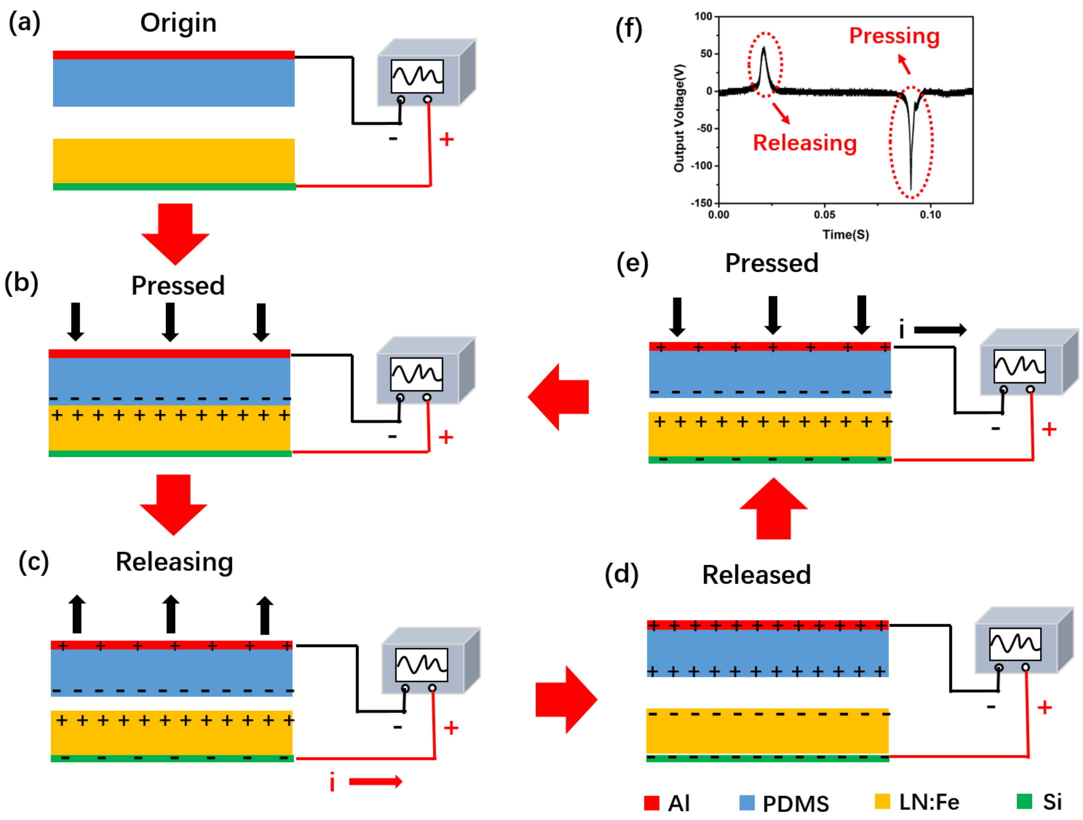

Figure 2. Working principle of the TENG using a LNTF. (a) original state with a fixed distance. (b) The friction pairs generate triboelectric charges when compressive force is applied. (c) Positive signal is generated while withdrawing the compressive force. (d) The system reaches electrical equilibrium. (e) Negative signal is generated when compressive force is applied again. (f) Open-circuit voltage during one cycle.

The TENG is based on the conjunction of contact electrification and electrostatic induction. In the beginning, the LNTF is separated from the PDMS film at a fixed distance. There are no triboelectric charges on the friction pairs and no charges transfer between the electrodes, which means no current flow (Figure 2(a)). By applying compressive force with a vibration platform, the LNTF starts to contact with the PDMS film. Because of the contact electrification, the electrons are transferred from the LNTF to the PDMS film since it is much easier for PDMS to gain electrons. As a result, the opposite triboelectric charges with the same density are generated on the inner surfaces of the LNTF and the PDMS film (Figure 2(b)). As the compressive force is withdrawn, the LNTF starts to separate from the PDMS film, leading to a potential difference between them. In order to screen this potential difference, the electrons will flow from the Al electrode to the Si electrode (Figure 2(c)) generating a positive signal in the external circuit (Figure 2(f)). When the system reaches electrical equilibrium, there will be no signal. (Figure 2(d)). When the compressive force is applied again, it will build a reversed potential difference, which will drive the inductive electrons to flow in the opposite direction (Figure 2(e)), and thus generates a negative signal in the external circuit (Figure 2(f)). Then, the LNTF and the PDMS film are in contact again with no signal output (Figure 2(b)). This is one cycle of the electricity generation process.

The output measurement is investigated with a separation distance of 1.5 mm and a vibration frequency of 9.0 Hz. The periodic compressive force with variable frequency and amplitude is achieved by a connection of a waveform generator (Agilent 33120A), a power amplifier (SINOCERA YE5872A), and a vibration platform (SINOCERA JZK-10). The output voltage and current are measured by an oscilloscope (Tektronix DPO4054). Figure 3(a) demonstrates an open-circuit voltage of 136 V measured by a high voltage differential probe (Tektronix THDP0100). Figure 3(b) shows a short-circuit current of 8.4 μA measured with a low value resistor of 24 kΩ. Both the voltage and current signals are very steady, which indicates the stability of the TENG.

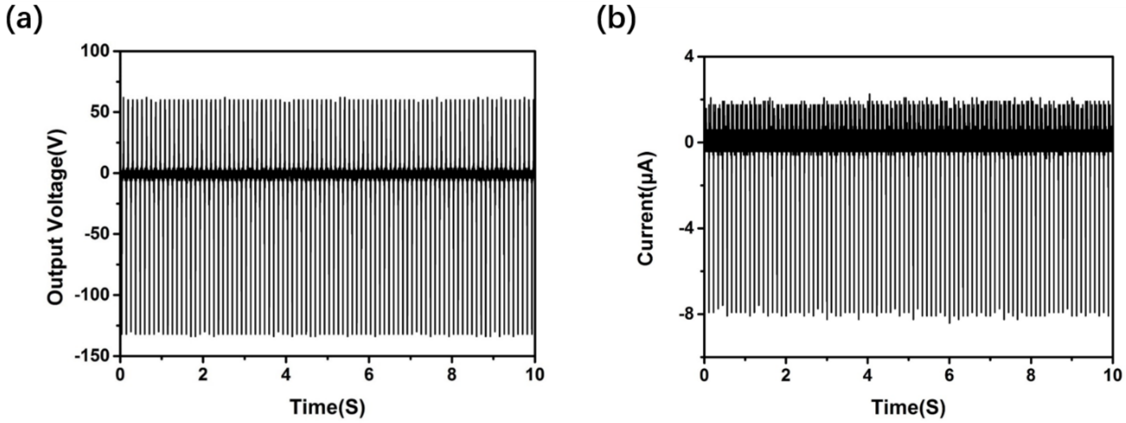

Figure 3. output characteristics. (a) open-circuit voltage, (b) short-circuit current.

As for practical applications, the electrical output to external devices varies a lot due to the matching between the external load and the TENG. In order to investigate the optimum resistive load, we have measured the voltage output under different external resistive load from 1.00 MΩ to 100 MΩ, as sketched in figure 4(a). When the resistance is very small, the influence to the real charge transfer is not obvious, the external current is nearly short-circuit current. As the resistor increases, it starts to affect the charge transfer rate dramatically, resulting in a rapid drop of the current. When the resistance is large enough, there will be nearly no charge transfer between two electrodes, and the voltage will approach to open-circuit voltage. The dependence of output power curves on the resistance is shown in figure 4(b). The power reaches its maximum value when the external resistance is equal to the internal resistance of the TENG. With a load resistance of 10 MΩ, the TENG gives the maximum power output of 307.5 μW, corresponding to a power density of 280 μW/cm^2.

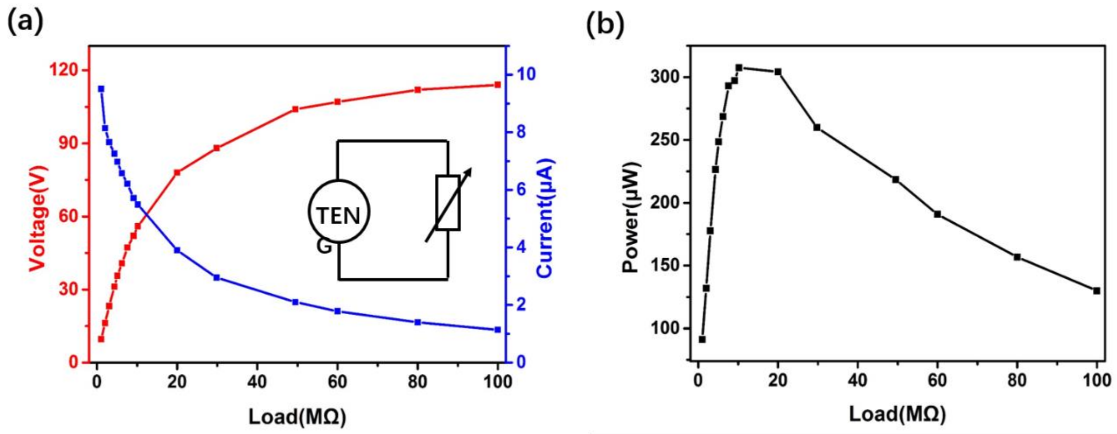

Figure 4. Resistive load characteristics. (a) peak voltage and current as a function of external load resistance. (b) instantaneous power output as a function of external load resistance.

3. Conclusions

In summary, we present a triboelectric nanogenerator based on a brand new fraction material, LNTF. This device is stable, easily fabricated and low cost. The volume of the device is 1.1*1.0*0.15cm^3. It can provide an open-circuit voltage of 136V and a short circuit current of 8.4μA. When the load resistance is 10 MΩ, the TENG can give a maximum power output of 307.5 μW. This work shows the possibility of using lithium niobate as a new friction material of TENG to convert mechanical energy into electricity energy, which may expand the application fields of TENG.

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