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RAPID COMMUNICATION

Applicability of triboelectric generator over a wide range of temperature

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Abstract
We studied the influence of temperature on the output performance of triboelectric generators (TEGs). PTFE film and aluminum foil are used as the contact materials for the TEG. A high temperature system and a low temperature system were used to conduct measurements of TEG output voltage and current from 300 K to 500 K and from 77 K to 300 K, respectively. Dependence of output performance on temperature was subsequently obtained by statistically analyzing the data as a function of temperature. The performance of the TEG is maximized at around 260 K and degrades at both higher and lower temperatures. A possible mechanism is proposed for explaining the observed phenomenon. Applicability of TEG over a wide range of temperature was confirmed, from as low as 77 K to as high as 500 K, spanning a range of 423 K. Several LEDs connected in series were successfully lit up by TEG as the sole power source at temperatures of 77 K, 300 K and 500 K.

Technological progress in portable electronics, sensor networks, microrobotics etc. significantly changes and improves our quality of living. In the meantime, their mobility, small size and large amount pose serious challenge to the traditional wired power supply. Energy storage devices like batteries and capacitors are the most widely used technologies to meet the demands of these applications [1-4]. However, recharge through traditional power grid is still needed once in a while and this would become very difficult if a large number of such devices are involved. To solve this issue, technologies for in-situ energy harvesting and electricity generation have been widely studied worldwide [5-8] in

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the hope of reducing and eventually eliminating the dependence on traditional power grid.

One recent emerging technology for in-situ energy harvesting comes from a well-known but also unexpected effect: triboelectrification. In this effect, charge separation is achieved through frictional contact between two different materials [9-11]. Often viewed as an adverse effect that may cause fire catching, electrical breakdown or radio communication failure, [12-14] it is only recently seriously considered as a practical option for energy harvesting [15-18] in addition to scientific demonstration [19,20]. This turn of events, however, is very reasonable in the context of the new requirements posed by the miniaturization, portability trend of electronic technology. Ever since its unveil in less than two years ago, the output performance of triboelectric generator (TEG) are dramatically increased to as high as 313 W/m^2 at an estimated efficiency of $\sim$15% [21] and thus demonstrates its great potential of commercial application in the near future. Various questions on how far TEG can go as the solution for in-situ energy harvesting have been asked, including how much more its output power can be enhanced, how small it can be made, how good the durability is etc. It is worth noting that due to its working mechanism, polymer must be at least one of the two contact materials for an efficient TEG [22] and a particular important question concerning this fact is that what is the temperature range that the TEG can work reliably and what are the temperature limits? The objective of this study is to experiment the temperature dependence of the TENG for practical applications.

In this work, simple structured TEGs consisting of PTFE film and aluminum foil as the contact materials are fabricated. TEG output performance from room temperature to 500 K is tested in a chamber equipped with a heater and its output performance from room temperature to 77 K is tested in another chamber equipped with liquid nitrogen cooler. Dependence of output voltage as well as current on temperature is subsequently obtained. Its performance is also tested by powering light emitting diodes (LEDs) at 77 K and 500 K to confirm whether it is still usable under such low and high temperatures.

PTFE film was purchased from DuPont branded as Teflon® PFA that boasts a service temperature from 33 K to 533 K, a melting point of 600 K, a dielectric strength of over 260 kV/mm and great chemical stability. These properties make PTFE film an excellent material for making TEG. The other material was chosen as the aluminum foil due to its excellent conductivity, outstanding thermal and chemical stability (due to its passive oxide layer) and its proven efficiency of electron transfer to polymers like PTFE [23,24]. 2×2 in.^{2} of each material are obtained. One side of PTFE film was coated with 200 nm Cu as the electrode and the other side was kept as purchased. Both sides of aluminum foil were kept as purchased, with one side serving as the contact surface and the other side as the electrode surface. Lead wires were attached to the planar electrode surfaces of PTFE and aluminum foil.

TEG performance was firstly tested in the high temperature chamber as shown by Figure 1(a). The chamber was equipped with a heater, a mechanical feedthrough (push rod), several electrical feedthroughs, vacuum ports and a mechanical pump. Aluminum foil was pasted onto a dielectric cast aluminum bracket fixed onto the heater and the PTFE/Cu film was pasted onto another dielectric cast aluminum bracket fixed onto the push rod. Lead wires were connected to measurement systems via electrical feedthroughs and the push rod was attached to a computer programed linear motor that provided an accurate control of position, speed, acceleration etc. for the mechanical stimulation. To effectively maintain the temperature inside, the chamber was isolated from outer atmosphere and to avoid the pressure difference caused by temperature difference, the chamber was constantly pumped down by a mechanical pump. Output voltage was measured when the TEG was connected in parallel to a 5 MΩ load and output current was measured by directly connecting the TEG to a current amplifier. Measurement was done under the temperatures of 300 K, 340 K, 380 K, 420 K, 460 K and 500 K. At each temperature, two hours′ time for thermal equilibrium were allowed before the TEG was tested for 100 cycles to ensure reproducibility. Part of the output voltage data is shown in Figure 2(a) in red curves and part of the output current data is shown in Figure 2(b) in blue curves. The difference between positive voltage/current and negative voltage/current is a result of asymmetry between press and release action but both show a tendency of decrease with increasing temperature. This is especially obvious for the current output at 500 K, where some of the peaks are submerged under noise signals. To more accurately reflect the dependence relationship, 100 cycles of voltage data at

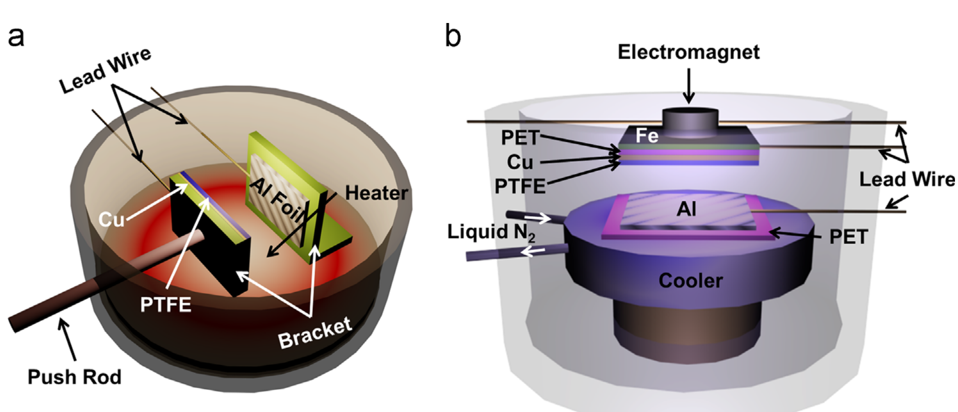

Figure 1 Schematics of the (a) high temperature and (b) low temperature measurement system.