STACKING ELECTRETS FOR ELECTROSTATIC VIBRATION ENERGY HARVESTERS

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Abstract: We have established a new method using a stacked electrets system to increase output power of electrostatic vibration energy harvesters. This method enabled one to increase the total surface charge density and the surface potential of the electrets system as a sum of those of multiple electrets stacked. As a result, the output power of the electrostatic vibration energy harvesters was increased almost proportionally to the square of the surface potential from about 2 to 120 nW by increasing the number of the electrets stacked from 1 to 3.

Keywords: energy harvester, electret, output power

INTRODUCTION

Energy harvesting that converts surrounding energy such as vibration, heat, light, and temperature gradient to electricity is expected to play an important role in ubiquitous networks including mobile phone, PC, and sensor networks, as well as consumer electronics, and artificial organs. Especially, ubiquitous sensor networks become more and more important systems for accident prevention, security, medicine, energy and materials savings, and so on. To realize these network systems, a large number of sensor nodes are essential. Each sensor node requires some features such as sensing environmental measurement and communication with other devices via autonomous wireless radio transmission. And one of the most important requirements is an electrical power supply. Generally, wireless systems are desirable for these applications since wired systems are costly and inconvenient. Two candidates for a wireless power supply are batteries and energy harvesters. Energy harvesters are more promising because they do not need replacement and charging unlike batteries.

The energy harvesters are devices which scavenge energy from the environment. Among micro energy harvesting, vibration-driven power generation is one of those considered viable [1-9]. Solar energy is not always available if the sun light cannot arrive. A case of thermal gradients, it is difficult to maintain enough thermal gradients because the device size is very small. We choose vibration energy for a micro power generation source of sensor node. Vibration can be used everywhere and power generation is permanently until the devices are broken.

An electrets (EL) is a dielectric that produces a permanent electric field in its surrounding space, owing to an implanted charge or, in some cases, an internal charge polarization. Since the discovery [10,11], the EL has been used widely for devices such as polymer microphones [12]. In the burgeoning field of microenergy harvesting [13,14], the EL has attracted renewed interest as a material for electromechanical energy conversion [15–20]. The principle behind the EL-based electromechanical transducer is straightforward as shown in Fig. 1: Because of lines of electric force from the surface of the EL due to its permanent charge, it induces an opposite-sign countercharge on the surface of the working electrodes. When the EL moves, the countercharge moves from one working electrode to the other one and generate an electric current in the circuit. The reverse process of converting electrical energy to mechanical energy works also in this fashion.

Though being promising, EL energy harvesting needs to increase its output power before practical applications. Therefore, the purpose of this study is to establish new method enabling one to increase the output power for the electrostatic vibration energy harvesters using the EL.

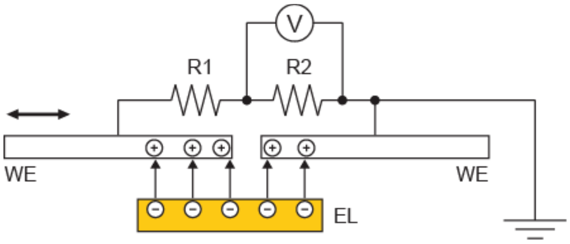

Figure 1. Schematic of the electrostatic vibration energy harvesting setup. R1 and R2 stand for load resistances of 50 MΩ and 500 kΩ,respectively. WE and EL stand for working electrode and single or stacking electrets, respectively.

EXPERIMENTAL

In this work we prepared the ELs by implanting negative charges into a polytetrafluoroethylene (PTFE) sheet (10 mm × 10 mm × 50 μm) using a corona discharge process as shown in Fig. 2. Breakdown voltage of about -2 kV was applied to induce electric breakdown in the air. Surface potential of the single electrets were controlled by fixing the acceleration voltage to be -600 V. A new type of an EL system named stacking electrets (SEL) was fabricated by stacking the multiple ELs along the surface normal as shown in Fig. 3(b) and (c). Viewing the SEL as one unit, total charge amount stored in the SEL should be sum of those of the each EL. Consequently, the number of lines of electric force arising from the surface of the SEL increases. As amount of induced charge on the working electrodes is proportional to the number of lines of electric force, increase in the number of lines of electric force should increase the intensity of a current generated by vibration.

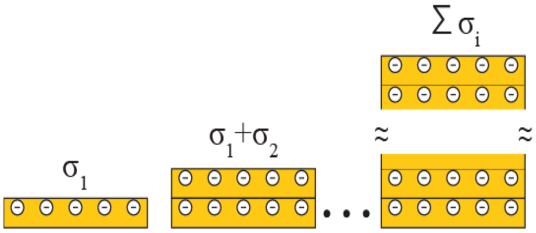

Figure 2. Cross-sectional schematic of the single electret and the stacking electrets. The surface charge density is shown on each stacking electrets.

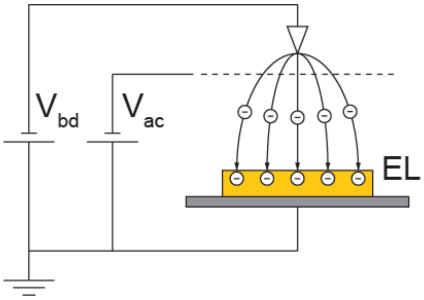

Figure 3. Schematic of the corona discharge. V_{bd}, V_{ac}, EL stands for breakdown voltage, acceleration voltage, and an electret, respectively.

The number of lines of electric force was evaluated by measuring surface potential of the SEL using an electrostatic voltmeter (TREK Inc, Model 344). During the measurements, distance between the probe of the voltmeter and the surface of the SEL was set to be less than 5 mm for accuracy. The output power P of the electrostatic vibration energy harvesters composed of the SEL and working electrodes (see Fig. 1) was calculated from

$$P = \frac{V_{avg}^2}{R} \qquad (1)$$

where R and V_{avg} are total load resistance (R1 + R2, 50.5 MΩ) and average voltage drop at the load resistances.

RESULTS

Figure 4 shows the surface potential as a function of the number n of the electrets stacked for the SEL. As the fitting straight line shows, absolute values of the surface potential increased almost linearly from 250 to 930 V with increase n from 1 to 3. This indicated that the number of lines of electric force available for the electrostatic vibration energy harvesting was increased almost linearly by simply stacking the electrets.

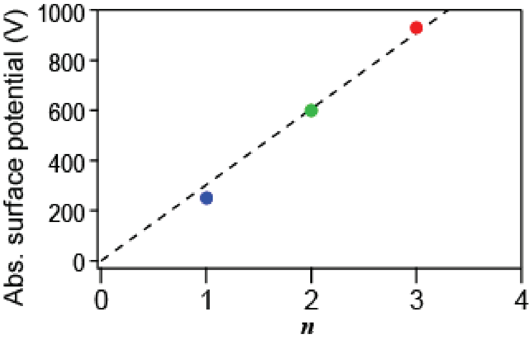

Figure 4. Absolute surface potential as a function of number of the stacking electrets n. n = 1 corresponds to a single electret.

The electrostatic vibration energy harvesting was implemented using the experimental conditions; amplitude, frequency, and acceleration of vibration were 2.5 mm, 20 Hz, and 19.6 m/s^2, respectively. The vibration was applied externally by a commercial shaker. Distance between the working electrodes and the SEL was fixed to be 250 μm. Figure 5 shows the output voltage for the SEL for n = 1 to 3. Though the shape was asymmetric, the output voltage oscillated at the same frequency with the applied vibration frequency. The output voltage increased with increasing the number of the stacked ELs for the SEL, and average output voltage V_{avg} was minimum (0.30 V) and maximum (2.46 V) for n = 1 and 3 respectively. The output power of the energy harvester was calculated from the obtained V_{avg} and equation (2), and plotted as a function of the surface voltage of the SEL (Fig. 6). Numbers on each data point corresponds to the number of the electrets stacked. The output power of the SEL electrostatic vibration energy harvesters increased from 2 nW for $n = 1$ to 120 nW for $n = 3$. As the fitting line indicates, the increase was almost quadratically. Slight deviation of the output power from the fitting line may be attributed to the change in the surface potential of the stacked ELs susceptible to humidity in the air.

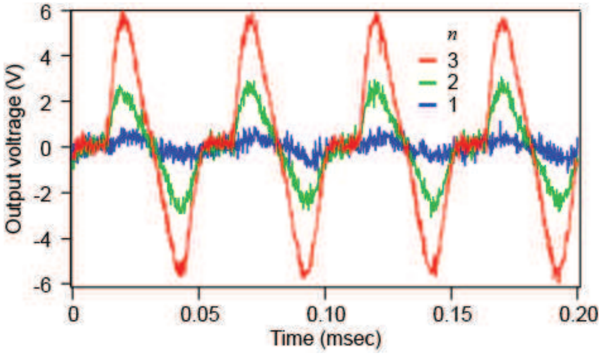

Figure 5. Output voltage of the SEL for n = 1 to 3 as a function of time.

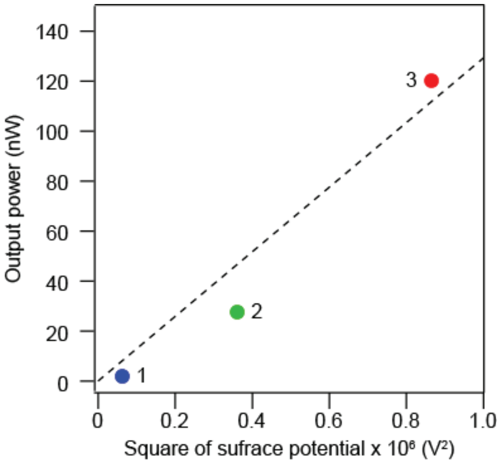

Figure 6. Output power as a function of square of the surface potential. Numbers on each data point corresponds to the number of the stacking electrets.

DISCUSSION

Gauss's law tells us that intensity of an electric field E, which is proportional to the number of lines of electric force, near a uniformly charged sheet such as the EL is

$$E = \frac{\sigma}{2\varepsilon_0}, \qquad (2)$$

where σ and ε_0 are surface charge density and dielectric constant of vacuum, respectively. As the surface potential is proportional to an electric field, stacking identically charged ELs with the same σ has to increase the surface potential of the SEL proportionally to n.

Theoretical maximum output voltage $P_{\max}$ of the electrostatic vibration energy harvesters shown in Fig. 1 is [16]

$$P_{\max} = \frac{\sigma^2 \cdot Af}{4\dfrac{\varepsilon\varepsilon_0}{d}\left(\dfrac{\varepsilon g}{d}+1\right)}, \qquad (3)$$

where A, ε, d are surface area, dielectric constant, and thickness of the SEL, respectively. g and f are gap distance between the SEL and the working electrodes and vibration frequency, respectively. As mentioned above, surface potential is proportional to σ. Thus equation (3) predicts that the output power in this study increases proportionally to square of the surface potential of the SEL.

Both of linear increase shown in Fig. 4 and quadratic increase shown in Fig. 6 agreed with the theoretical considerations above. Thus increase in the output power of the electrostatic vibration energy harvesters in this study should be ascribed to increase in the surface charge density of the SEL by increasing n, which is the number of the stacked ELs.

CONCLUSION

In conclusion, we have established a new method using ELs system named stacking electrets to increase output power of the electrostatic vibration energy harvesters. We constructed the SEL by stacking multiple ELs. The total surface charge density of the SEL is sum of the surface charge density of each EL stacked. Absolute values of the surface potential of the SEL increased almost linearly from 250 V to 930 V by increasing n from 1 to 3. Consequently, the output power of the electrostatic vibration energy harvesters increased from 2 to 120 nW quadratically to the surface potential. The simplicity of the method should be highly beneficial to further improve the output power of the electrostatic vibration energy harvesters.

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