

ELECTROSTATIC MICRO POWER GENERATOR FROM LOW FREQUENCY VIBRATION SUCH AS HUMAN MOTION

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Abstract: We developed an electrostatic micro power generator for low frequency energy harvesting applications. This micro power generator consists of a new vibration structure and new electret electrode. The advantage of this micro power generator is the high power generation structure of both the controlled gap between electrodes and long-range moving at low frequency. This generator shows 40μW of power output at very low frequency vibration (2Hz, 0.4G).

Keywords: Power generator, Ball bearing, Low frequency

1. INTRODUCTION

Nowadays, micro power generators that harvest vibration energy and can become power sources for wireless sensors and portable applications are drawing much attention [1-3]. There are three common mechanisms: piezoelectric, electromagnetic, and electrostatic, each of which has various examples reported in literature. The problem that each approach must address is that low frequency vibration such as human motion is only sufficient to generate an extremely low output of power.

To overcome this difficult challenge, we developed a new electrostatic micro power generator that 1) can enable both separation gap control and long-range movement at low frequency, and 2) can increase the number of times power generation (electrostatic induction) is done. To achieve these we developed the following technologies: 1) a micro power generator consisting of microball bearings to roll with the separation gap control and to firmly keep the separation gap (Microactuator using microball bearing has been reported [4]), and 2) a new electret structure to accommodate miniaturization.

2. DESIGN & FABRICATION

2.1 Micro Power Generator for Low Frequency

In Fig. 1 the design of the electrostatic micro power generator is shown. The separated spring and mass manage to vibrate long-range moving (about 2 cm) at low frequency; separated microball bearings manage to keep the gap properly (10-50 μm). This generator consists of fixed parts that have two glass substrates with collector electrodes and moving parts that have proof mass and two Si substrates with new electret structure. This electret structure obtains enough surface potential to be suitable for

miniaturization. A pair of collector electrodes is on the same substrate to keep wiring simple. Microballs which firmly support the moving parts can roll along each deep trench between the glass substrates and silicon substrates.

Reports about current electrostatic micro power generation describe how it is difficult to vibrate at low frequency because only one or two springs keep the moving part moving (several tens Hz. level) [5,6]. Resonance frequency ω_{res} is given by

$$\omega_{res} = (k/m)^{1/2} \quad (1)$$

where k is the spring constant and m is the mass. To vibrate at low resonance frequency, the spring constant needs to be low. On the other hand, a spring with a low spring constant can't retain the moving part well, and can't keep a narrow gap to prevent an electrode break. Therefore, to keep a firm separation

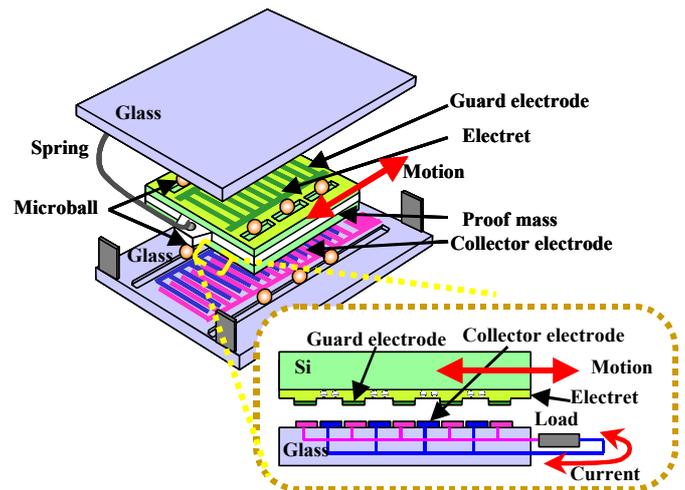


Fig. 1. New structure of electrostatic micro power generator supported on microball bearings. It is possible to apply to low frequency vibration (low spring constant) because it supports a proof mass with microball bearings.

gap, this design has a structure that effectively keeps the separation gap with a microball. This design is not only suitable for good gap control, but also suitable for vibration and long-range movement at low frequency with a spring that has a low spring constant.

2.2 Electret Electrode

Fig. 2 shows the principle of power generation with electrostatic induction [2,7,8]. The electret is a dielectric material that has a quasi-permanent electrical charge. The electrical charge is in the collector electrode facing the electret because of electrostatic induction. When the electret part moves over the other collector electrode from the electrode, electrical charges move the other electrode through the load R as power generation.

Boland et al. show that load-matched output power $P_{optimal}$ of the electret power generator using a rotation model is given by

$$P_{optimal} = \frac{\sigma^2 n \pi r^2 f}{4k_i \epsilon_0 \left(1 + \frac{k_i g}{d}\right)} \quad (2)$$

where σ is charge density, n is the number of electrodes, r is radius, f is frequency, k_i is dielectric constant of electret, ϵ_0 is vacuum permittivity, d is thickness of electret, and g is separation gap [8]. To obtain large power output, 1) high charge density (surface potential), 2) high frequency (the number of charge movements) and 3) narrowing the gap between electrodes are advantageous.

For the electret electrode, 1) higher surface potential of electret, and 2) narrower electrode width are important to obtain higher power output from certain vibration energy input. Therefore, we developed a new electret structure that keeps high surface potential with minute electrode width using SiO₂.

Fig. 3 shows (a) a generic electret structure and (b) our new electret structure. The potential difference of

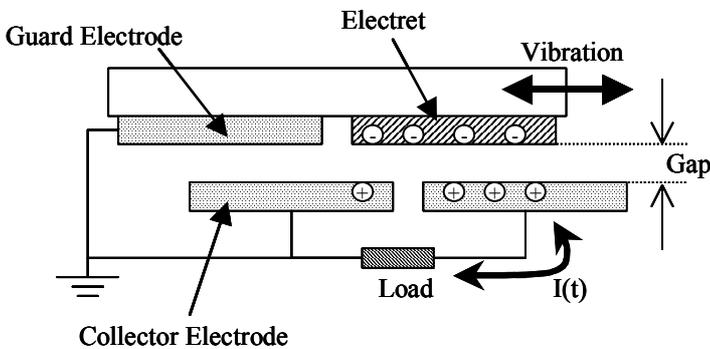


Fig. 2. Schematic of Electrostatic induction power generation using electret principle.

electrodes is necessary to obtain charge movement. For the generic electret structure, patterned SiO₂ on substrate is shown. The area of electret and the area of substrate form the potential difference [2,9]. Our new electret structure has a guard electrode of aluminum on SiO₂ films to form lower surface potential than the electret, and a hollow structure of SiO₂ to prevent charge drifting to the guard electrode.

Fig. 4 shows the surface potential of the each electret structure versus line width. The generic and new electret SiO₂ films are electrically charged by the corona discharge method. For both electret structures, in the case of miniaturization, the surface potential decreases, but the new electret structure has a surface potential high enough to handle electric power generation. Using this new electret structure with high surface potential and narrow electrode width (200 μm), our new electrostatic micro power generator can increase the number of times power generation (electrostatic induction) is done with high surface potential.

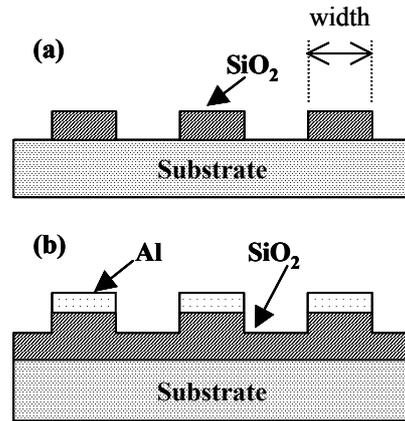


Fig. 3. Cross section of (a) generic electret structure, (b) new electret structure.

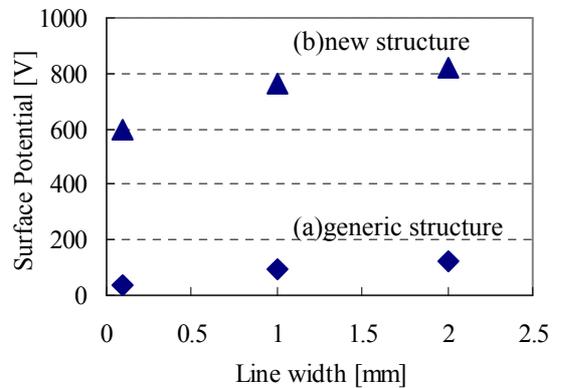


Fig. 4. Relationship between line width of electrets and surface potential.

3. EXPERIMENTAL SECTION

3.1 Experimental Setup

Fig. 5 is a photograph of our prototype. The dimension of the device is 20mm x 45mm, the size of the moving part is 24mm x 27mm. These electrodes keep a 40 μ m gap because of the 140 μ m depth trenches and 320 μ m microballs (Grade 25 (ABMA: American Bearing Manufacturers Association)).

Fig. 6 is a schematic diagram of the experiment setup for power generation. Input vibration was set at 2Hz sine wave, and acceleration was 0.4G (the vibration of human walking motion at the waist). Shaker direction was the same direction as the gravity. Beginning state was the balanced state of the gravity for mass and the restoring force the spring exerts. In order to measure the output power for various external loads, a simple measuring circuit with a voltmeter, two resistances, a capacitor, and two bridge rectifier circuits was employed.

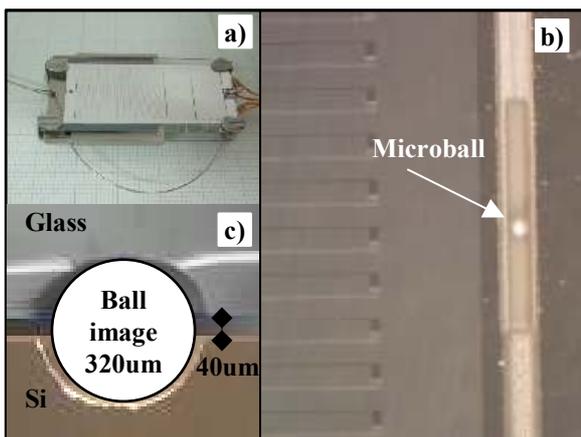


Fig. 5. a) Microphotograph of the prototype, b) expanded view, c) cross section image

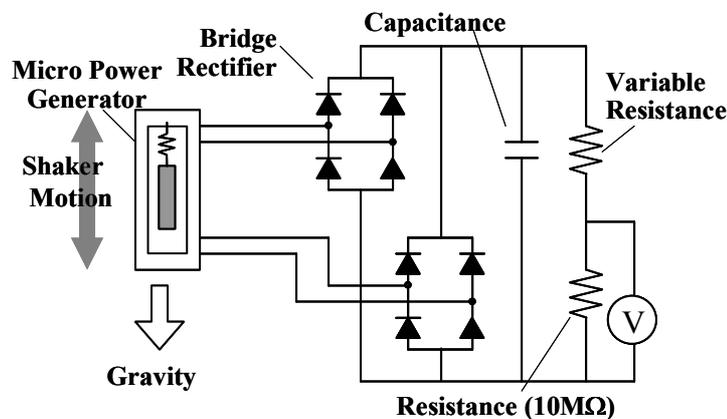


Fig. 6. Schematic diagram of experiment setup for power generation.

3.2 Power Generation Experiment

Fig. 7 shows the output power versus the external load R . Maximum output power of 40 μ W is obtained at $R = 7\text{M}\Omega$. Fig. 8 shows the time trace of the output voltage for a pair of collector electrodes without measuring circuit. The output voltage shows two large power generations in a period (0.5sec). It shows that the moving part vibrates (accelerates and decelerates) with input vibration (one reciprocating motion per period) and generates electric power. With a measuring circuit, the calculation of the power output is done by adding these two pairs of output.

Fig. 9 shows the frequency response of the generator output. The generator shows maximum power output at 6Hz resonant frequency. Our vibration system can vibrate comparatively better at a low resonance frequency than a high resonance frequency. Therefore, power output is possible at a low frequency of 2Hz.

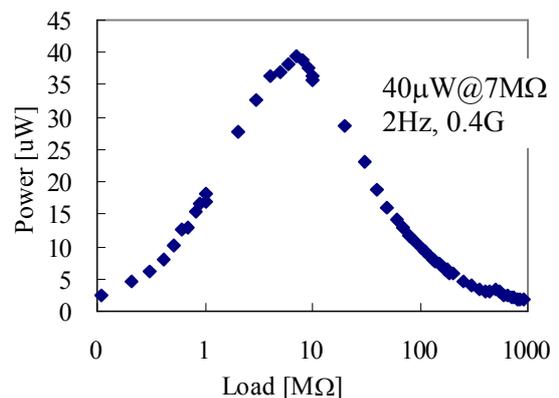


Fig. 7. Output power versus external load R .

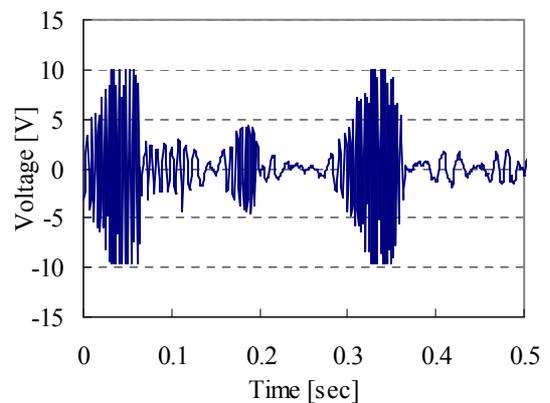


Fig. 8. Time trace of the output voltage for a pair of collector electrode without circuit (a period)

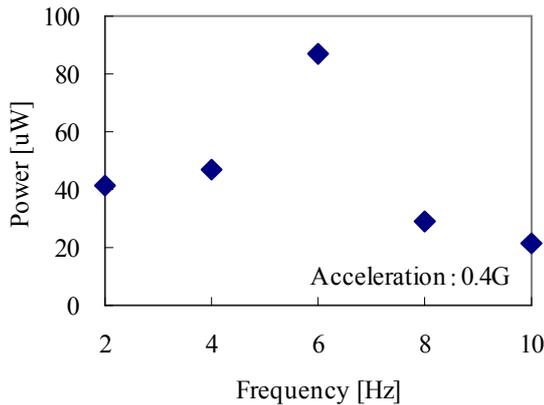


Fig. 9. Frequency response of the generator output (0.4G, R=optimum load)

4. SUMMARY

We developed an electrostatic micro power generator for low frequency energy harvesting applications. This generator shows 40µW of power output at very low frequency vibration (2Hz). Technologies we developed are: 1) a micro power generator consisting of microball bearings to roll with the separation gap control and to keep separation gap constant, and 2) a new electret structure to accommodate miniaturization. The advantage of our design is the high power generation structure of both the controlled gap between electrodes and long-range moving, and the high surface potential electret structure.

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