ENERGY HARVESTING USING MICRO ELECTROSTATIC GENERATOR WITH BOTH ENDS BUILD-IN H-BEAM STRUCTURE

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Abstract: In this paper, we present an electrostatic vibration-to-electricity converting generator using an electret. Our prototype generator has two electrodes faced each other, and an electret film between two electrodes. One of the electrodes vibrates in perpendicular direction excited by the environmental vibration and induced charge moves to/from the other electrode. We proposed a model of the generator, estimated the output power and fabricated the prototype generator. The proof mass of the generator is held by four thin beams located in H-shape to keep the proof mass horizontal. The electret was fabricated by the corona charging the CYTOP thin film. With the external vibration of 1090 Hz frequency and 3μm$_{p-p}$ in amplitude, our generator generated 29.3 nW at maximum output power.

Key words: Energy harvesting, Electret, Vibration, Electrostatic

1. INTRODUCTION

Due to the progress of micromachining technologies, many types of sensors have been miniaturized. Also, advances in wireless networking techniques have achieved low power consuming communication. These advantages enabled new applications of wireless sensor networks [1].

Today, various usable energies (e.g. heat, light, vibration etc.) are thrown away in human activities, mechanical systems and so on. Concept of our research is to generate electric energy from these wasted useful energies, such as vibration. Vibration can be found in many places, such as buildings, bridges, automobiles and so on.

Several types of such vibration generators are being studied, and classified into several types: Electromagnetic, Electrostatic and Piezoelectric. In this work, we focused on an electrostatic generator using an electret, since its structure would be compact consisting of MEMS components.

Fig. 1 shows the concept of the generator presented in this work. Two electrodes, the top electrode and the bottom electrode, are faced and the electret is on the bottom electrode. The electret has positive charge and two electrodes have negative charge induced by the electret. By external vibration, the top electrode resonates and the gap between the top electrode and the electret changes. Because the negative charges in both electrodes are induced by the electric field of the electret, the voltage between two electrodes rises and current occurs through the load resistance.

In the model presented in this work, unlike cantilevers, assuming that the top electrode keeps horizontal with the electrets surface. Therefore, the whole area of the electrode is enabled to be used effectively.

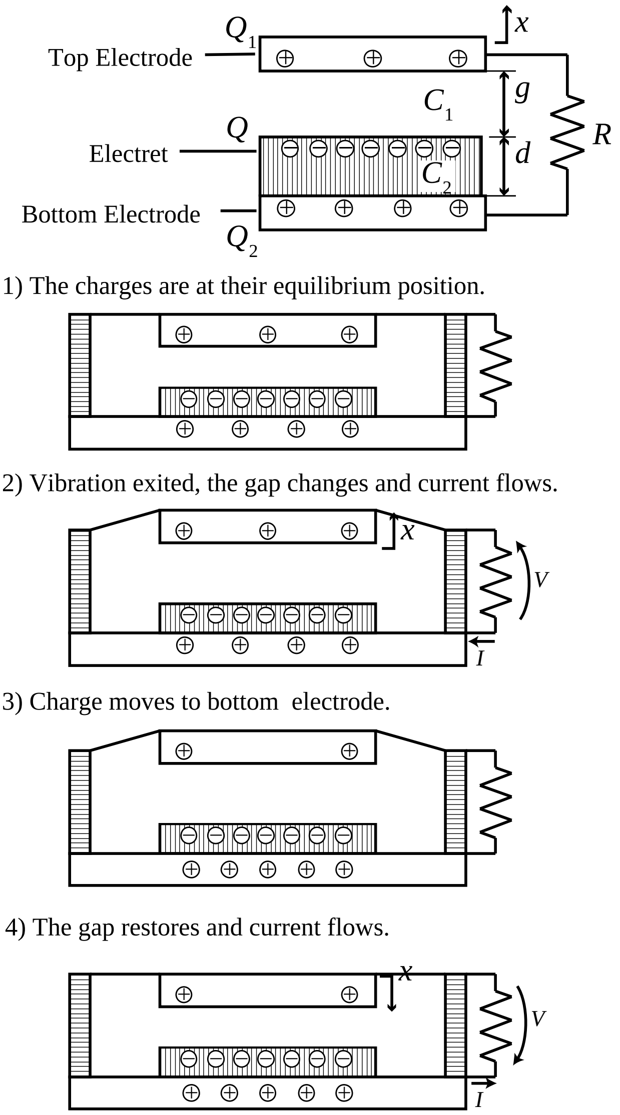

Fig. 1: The model of the generator presented in this work

To generate efficiently, larger amplitude and higher frequency of the top electrode are necessary. There are many kind of vibration sources are available, but most of its frequency are lower than several kilohertz. Therefore, large amplitude is absolutely imperative, which means that the resonance frequency of the top electrode should be in this range. To fulfill this requirement, we designed a structure with a proof mass and four thin beams. We fabricated the prototype of our generator and performed generating experiment.

2. FABRICATING THE GENERATOR

2.1 Prototype generator

Fig. 2 shows a schematic of our prototype generator. The proof mass and the beams of the top electrode are fabricated by the bulk silicon etching. To keep the proof mass horizontal, the proof mass is held by 4 beams located in "H" shape. The electret film is fabricated on another 2 cm square silicon wafer. These two structures are piled up on copper bottom electrode.

2.2 Fabricating Electret

As an electret material, we chose CYTOP (CTL-809M, Asahi Glass co.). CYTOP can exhibit high surface potential and its fabrication process is compatible with MEMS process since it can easily be patterned with O_2 plasma etching [2].

First, CYTOP was spincoated 200 μm in thick on 2 cm square silicon wafer and soft baked at 100 °C for 10 minutes. This process can be repeated until getting arbitrary thickness. Fig. 3 shows the relationship between repeating count and CYTOP film thickness. After repeating, the CYTOP film was hard baked at 185 °C for 90 minutes. In this present study, spincoat was repeated for three times and the film thickness was 5.64 μm.

The corona charging was used to charge the CYTOP film. The setup of the corona charging system is shown in Fig. 4. CYTOP charging condition was 4.35 kV of the high voltage, 300 V of the charge control power source and 30 sec of charging time. The distribution of the electrets surface potential is shown in Fig. 5. The surface potential was 252 V at an average.

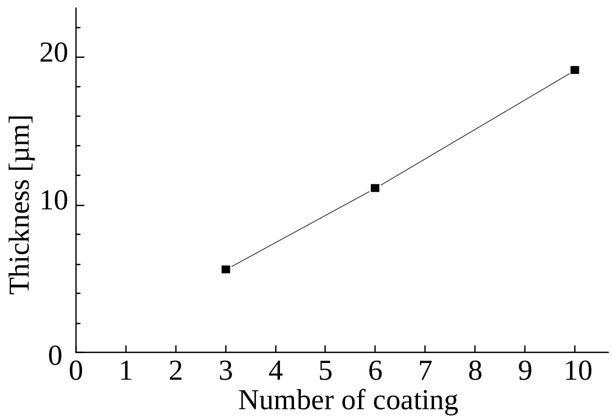

Fig. 3: Relationship between number of spincoating and the thickness of CYTOP film.

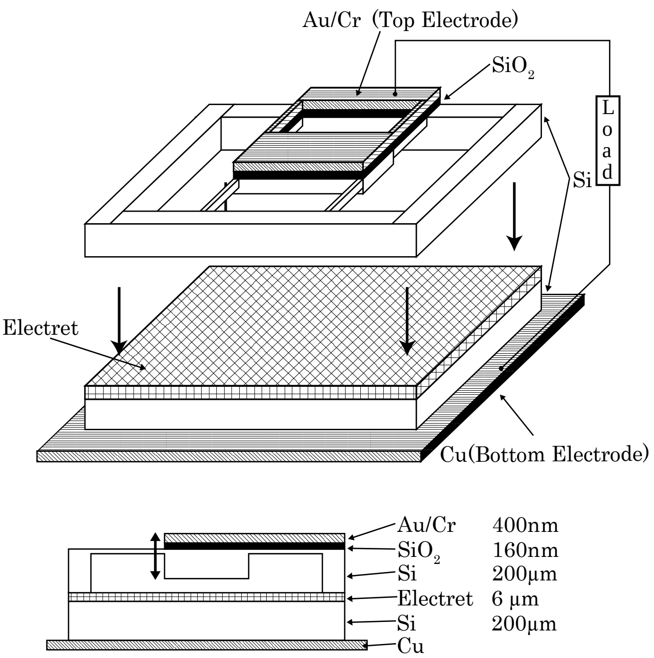

Fig. 2: Schematic of the prototype generator

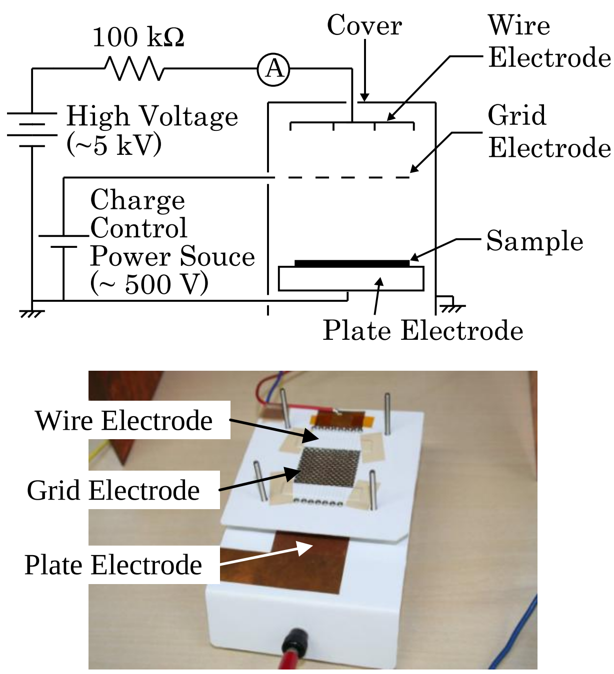

Fig. 4: Schematic and picture of corona charging system.

2.3 Fabricating the top electrode

The fabricating process chart is shown in Fig.6. First, a photoresist (AZ-5214E) was patterned on a 2 cm square silicon wafer. Next, SiO_2 and Au/Cr was sputtered, and by removing the photoresist, SiO_2 and Au/Cr was patterned. Then, the silicon wafer was etched by the ICP-RIE for once on front side, and twice on back side. As mentioned above, it is preferable that the resonance frequency of the generator is low. In our prototype generator, the thickness of the proof mass was designed thicker than the four beams for bringing down the resonance frequency. The fabricated top electrode is shown in Fig. 7.

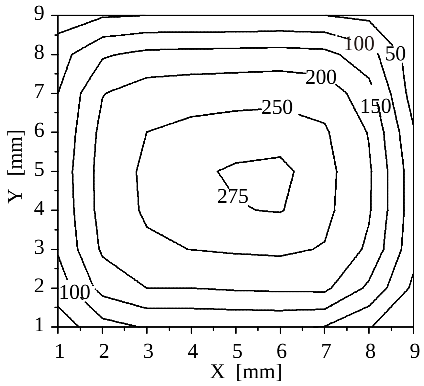

Fig. 5: Distribution of the surface potential of electret (unit: Volt)

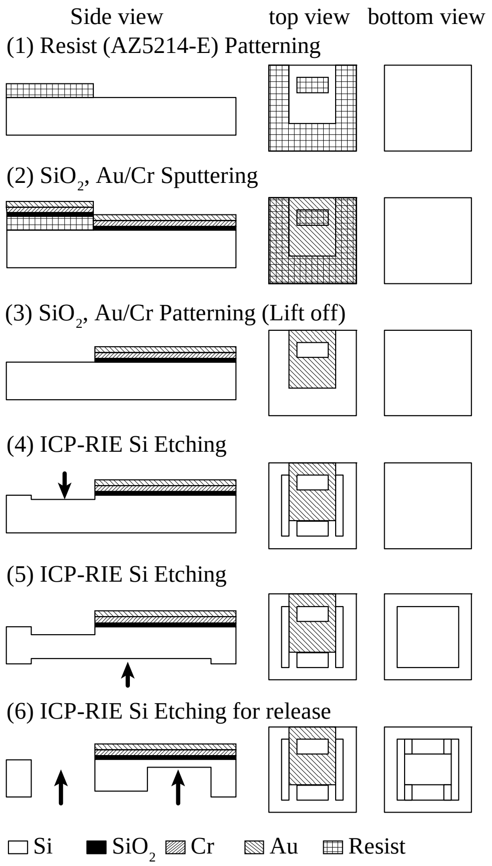

Fig. 6: Fabrication chart of the top electrode.

3. EXPERIMENT

3.1 Experimental setup

Our experimental setup is shown in Fig. 8. A shaker (PET-05-05A, IMV co.) vibrates according to the input sign wave generated by a function generator (33220A, Agilent co.). The prototype device was held in atmosphere.

To measure the gap between the top electrode and the electret, the displacement of both the shaker and the top electrode were measured by a laser doppler vibrometer (LV-1710, Ono Sokki co.). The gap was calculated by subtracting two measured displacements using the shaker input signal as a synchronizing signal. The output voltage was obtained by measuring the terminal voltage of the load resistance. The picture of the experimental setup is shown in Fig. 9.

3.2 Experiments

As the first experiment, the generator was shaken with 400 $nm_{p\text{-}p}$ of the shaker amplitude, 1080 Hz of the frequency and 470 kΩ of load resistance. The output voltage and the relative displacement of the top electrode are shown in Fig. 10. The maximum output voltage was 27.6 mV and the relative amplitude of the top electrode was 6.57 $\mu m_{p\text{-}p}$.

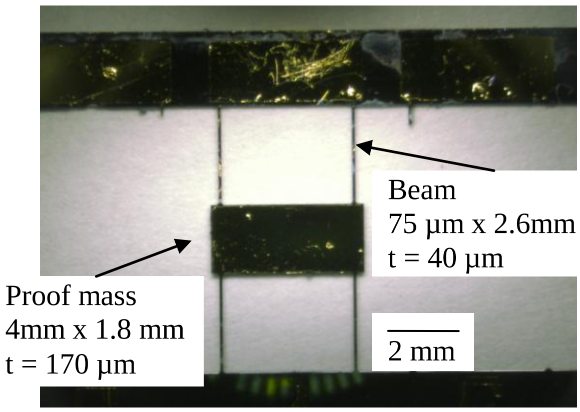

Fig. 7: Picture of the top electrode

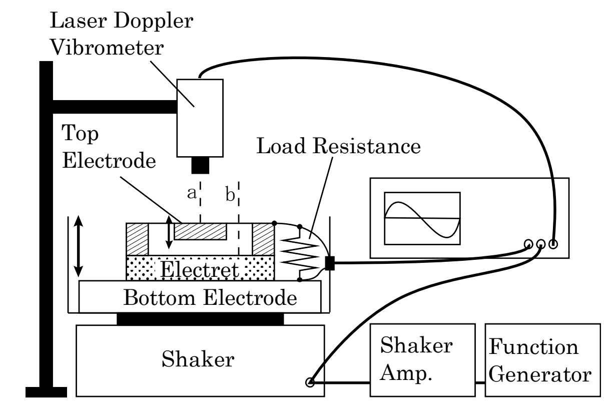

Fig. 8: Schematic of the experimental setup

Next, the frequency characteristics were measured for 700 Hz to 1500 Hz. The result is shown in Fig. 11. The maximum output power 2.31 nW was measured when the frequency was 1090 Hz. As the third experiment, we measured the relationship between the load resistance and the output power, shown in Fig. 12. The maximum output power 2.42 nW was measured when the load resistance was 660 kΩ. Finally, the shaker amplitude was set to 3μm$_{p-p}$, and the maximum output power was 29.3 nW. The conditions and its results are shown in Table 1.

4. DISUCUSSION

From the experiments, the resonance frequency was measured as 1090 Hz. To generate electric power more efficient, the resonance frequency should be lower than the present results. Changing the beam structure to more elastic one improves the energy convert efficiency. Also, the maximum output power of 29.3 nW is much lower than general sensors consuming power. Increasing the surface charge density of the electrets and increasing the amplitude of the top electrode can increase the output power.

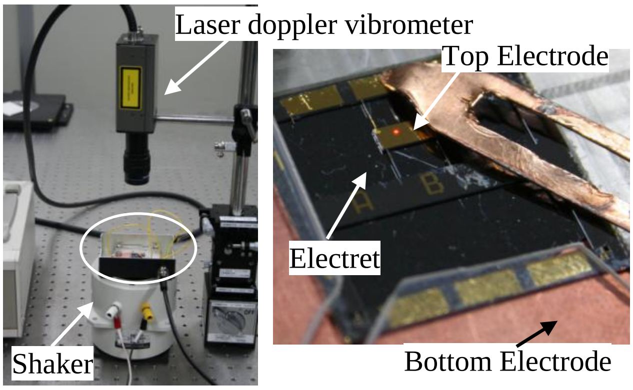

Fig. 9: Picture of the experimental setup

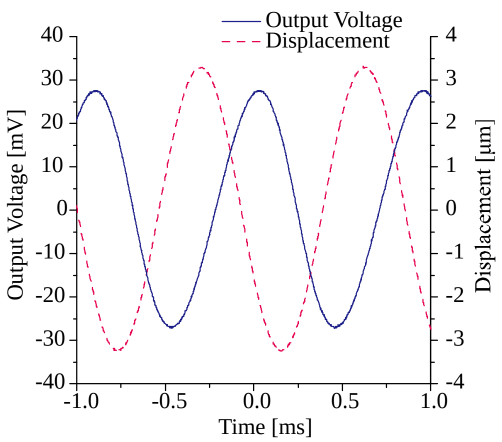

Fig. 10: The waveform of the output and the relative displacement of the top electrode.

5. CONCLUSION

In this work, we investigated an electret micro generator using the H-shaped beam structure, and from experiments we obtained following conclusions:

1. By the corona charging the CYTOP film, 252 V of the average surface potential of the electret was measured.
2. Our prototype generated the maximum output power of 29.3 nW at 1090 Hz of shaker frequency, 3μm of shaker amplitude and 660 kΩ of the load resistance.

REFERENCES

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "Wireless sensor networks: a survey," Computer Networks 38, pp.393-422 (2002)

[2] T. Tsutsumino, Y. Suzuki, N. Kasagi, K.Kashiwagi and Y. Morizawa, Micro Seismic Electret Generator for Energy Harvesting, PowerMEMS2006, pp.279-282.

[3] T. Genda, Study of High Power Micro-Motor and Generator Using Electret, 2003, Doctoral dissertation of Tohoku University.

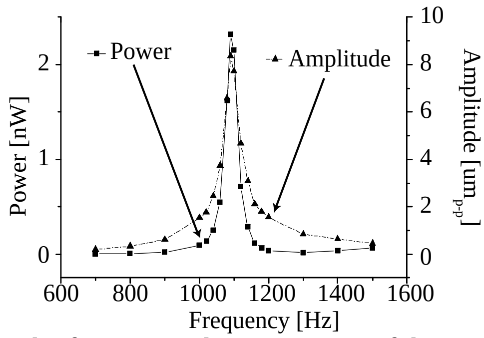

Fig. 11: The frequency characteristics of the generator.

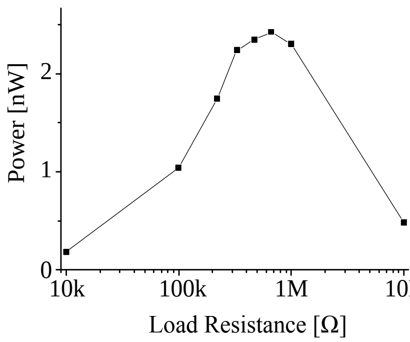

Fig. 12: The relationship between load resistance and the output power.

Table 1: Experiment conditions and its results

No.	Shaker Amplitude	Load Resistance	Max. Output
1	400 nm$_{p-p}$	470 kΩ	2.31 nW
2	400 nm$_{p-p}$	660 kΩ	2.42 nW
3	3.0 μm$_{p-p}$	660 kΩ	29.30 nW