

Micro Seismic Power Generator Using Electret Polymer Film

Y. Arakawa, Y. Suzuki, and N. Kasagi

Dept. of Mechanical Engineering, The University of Tokyo

7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan

Tel +81-3-5841-6419, Fax +81-3-5800-6999, E-mail arakawa@thtlab.t.u-tokyo.ac.jp

Abstract

In order to meet the increasing demand of power consumption of portable electronic devices, micro power generation attracts much attention. The final goal of the present study is to develop a micro power generator combined with micro thermal engine. Electrostatic induction using electret is adopted as the power generation principle. The characteristic of CYTOP as the electret material was examined and surface charge density up to 0.68 mC/m^2 is obtained. In preliminary experiment, $6 \mu\text{W}$ power generation is achieved with sinusoidal oscillation of 1 mm amplitude at 10 Hz.

Key words: Electret, Seismic generator, Corona charging, CYTOP

1 Introduction

For the last several decades, power consumption of portable electronic devices has been increasing with their performances. Whereas advanced rechargeable batteries such as Li-ion battery are commonly used, their energy density is projected to be far below the future demands. Therefore, micro-scale power generation using fossil fuel is attracting broad interest, since liquid fuel such as methanol and butane possesses 30 - 100 times larger energy density compared with the rechargeable batteries.

Power generation principle in micro scale can be classified into four groups: fuel cell, thermoelectric, thermo photovoltaic, and thermal engine. Among them, thermal engine is expected to have high power generation density [1]. In the present study, a seismic power generator is designed and its prototype is microfabricated, assuming combination with micro thermal engine. Seismic power generators are also expected to be effective for energy harvesting in ubiquitous devices such as "smart tag", since low frequency oscillations exist vastly in environment.

2 Principle of Electret Power Generator

2.1 Electrostatic induction

In macro scale power generators, electromagnetic induction is employed. However, its efficiency is deteriorated in micro scale. In addition, extremely high frequency is needed to

acquire enough output voltage. For instance, it is anticipated that nearly 900,000 rpm is required for 100 W power generator [2]. Moreover, electromagnetic induction needs complicated 3D structures for coils, which is incompatible with conventional MEMS technology. Therefore, electromagnetic induction is not suitable for micro generator. On the other hand, electrostatic induction has desirable features such as simple structure and high output voltage at slow relative speed. For these reasons, we employ electrostatic induction using electret for the power generation principle.

Electret is an dielectric with quasi-permanent charge trapped inside, which generates strong external electrostatic field. Tada [3] developed an rotational electret generator with Teflon FEP, which generates 0.1 mW. Boland et.al. [4] used Teflon AF (Dupont Inc.) as the electret film and developed prototype rotational generator with 8 mm diameter rotor. They obtain 15 mW at 6000 rpm.

2.2 Seismic energy conversion

Since the surface force dominates the body force in micro scale, frictional elements should be avoided. Therefore, we focused on seismic generator where oscillation can be utilized in a simple structure with minimal friction loss if compared with rotation. Suzuki and Tai [5] developed flexible Parylene spring structure having high aspect ratio for this purpose.

2.3 Model of the generator

Model of electret generator is shown in Figure 1 [4,6]. In this simple model, d and σ stand for thickness of electret and surface charge density, respectively. Change in the overlapped area between the top and bottom electrodes A gives change in induced charge at the counter electrode, which leads to output current i . Boland et. al. [4] have shown that with optimal external load, maximum output P_{max} can be calculated as follows:

$$P_{max} = \frac{\sigma^2 \cdot n \cdot A \cdot 2\pi f}{\frac{\epsilon \epsilon_0}{d} \left(\frac{\epsilon g}{d} + 1 \right)}, \quad (1)$$

where n , f , and ϵ are respectively number of poles, frequency of the electrode motion, and relative dielectric constant of the electret film. In Eq. (1), the change rate of the overlapped area is assumed to be constant.

It is found in Eq. (1) that the surface charge density σ , the thickness of electret d and gap g are the important design parameters; output power is proportional to square of σ , and increases with increasing d and decreasing g .

3 Fabrication of Polymer Electret and its Properties

3.1 Fabrication of electret

Candidates of dielectric film for electret need to meet the following 3 requirements;

- (1) Compatible with MEMS fabrication technique
- (2) Easy to be formed into thick film
- (3) Having high dielectric strength.

We adopted a fluorocarbon polymer CYTOP (CTL-809M, Asahi Glass Co., Ltd.) as the electret film, since its dielectric strength is 11 kV/0.1mm, which is about five times higher than that of Teflon AF and as high as PTFE. CYTOP can be made with spin coat, and its thickness could be as large as 20 μm by multiple spin-on. It is also easily patterned by O_2 plasma etching.

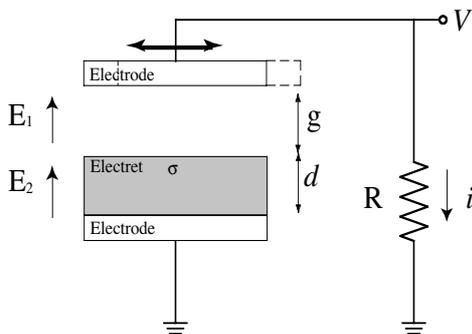


Figure 1. Model of electret generator.

In this research, CYTOP film was charged by corona charging method [7, 8]. As shown in Fig. 2, high negative voltage supplied from DC power source is applied between the needle ($\phi 2\text{mm}$) and the back electrode. The negative ions generated near the needle tip are accelerated by the electric field and encounters the specimen, transferring their charge inside.

The charging was made in atmosphere. The gaps between the needle-to-grid and grid-to-back electrode were chosen as 10 mm and 5 mm, respectively. The HV power source was set to apply constant current of 150 μA , which corresponds to the needle voltage of 7 - 10 kV in voltage. Grid voltage was kept constant at 600 V. The charging temperature and time was respectively set to 80 $^\circ\text{C}$ and 1 hour.

3.2 Charge density and time decay

Since no published data are available for CYTOP as an electret film, its properties need to be clarified. Surface charge density was measured by surface voltmeter (Monroe Electronics, Model 279). CYTOP film was fabricated on 30 mm square copper plate with a thickness of 20 μm films. After fully cured, the CYTOP film was charged by corona charge. Measurements were made in a 10 mm square at the center of the samples. Figure 3 shows the time trace of average charge density. Initial average charge density was 0.68 mC/m^2 with deviation of 0.058 mC/m^2 . This is higher than that of other materials such as Teflon PFA and Teflon AF [8, 9].

4 Power Generating Experiment

As shown in Eq. (1), power output increases with the number of poles n . Therefore, the electrodes were etched into a comb like pattern (Fig. 4). The electrodes were fabricated on 0.7 mm thick glass substrate. Gold layer having 100 nm in thickness was EB deposited with a 10 nm thick chromium adhesion layer. Patterning was carried out with UV lithography.

Although it is desirable to have narrower width for getting larger n , next two conditions define its lower limit.

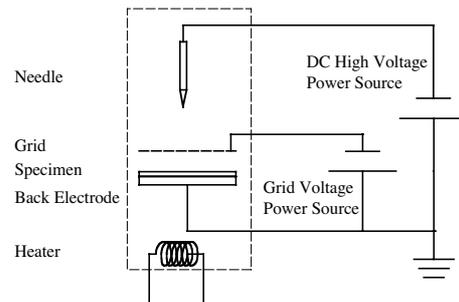


Figure 2. Corona charging setup.

(1) The gap between the electret and the counter electrode should be at least twice as small as the width of the electrode in order to reduce parasitic capacitance, which deteriorate the efficiency. (2) As described later, the charge density is decreased with the width. Therefore, just narrowing the width does not assure increase in output power. Therefore, in the present study, 1 mm is chosen as the width of the electrode.

For the electret chip, electrodes having the same width and gap was prepared on a glass substrate. CYTOP film was then spun and patterned by O₂ plasma using aluminum layer as the etch mask. Finally the CYTOP film was charged with corona charging mentioned previously. Average surface charge density of the patterned electret chip was 0.28 mC/m², which is lower than that of plane CYTOP film. Figure 5 shows the initial surface charge density versus width gap of electret. The charge density is monotonically decreased with decreasing the width. Genda et. al. [10] reported similar results for SiO₂. It is conjectured that the electric field around partially charged electret inhibits further charging.

Setup for preliminary power generation experiment is shown in Fig 6. Both counter electrode and electret chips were fixed to stages for precise alignment. Electret chip was moved

in the horizontal direction using electrodynamic shaker (Labworks Inc., ET-140). Gap between the electret and the counter electrodes was set to about 300 μm. Amplitude of the shaker was measured by laser displacement meter (Keyence Inc., LC-2440) and kept constant at 1 mm.

Figure 7 shows the power output versus the external load at 10 Hz oscillation. At 1 GΩ, 6 μW power generation is achieved with 200 V_{p-p} voltage output. The experimental data are in good

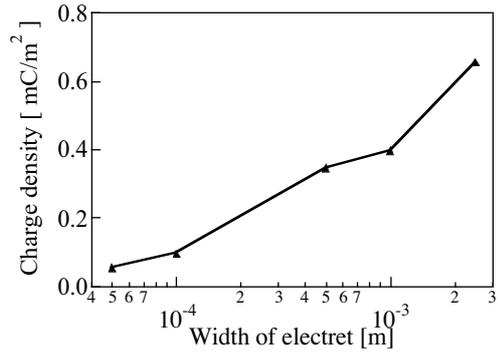
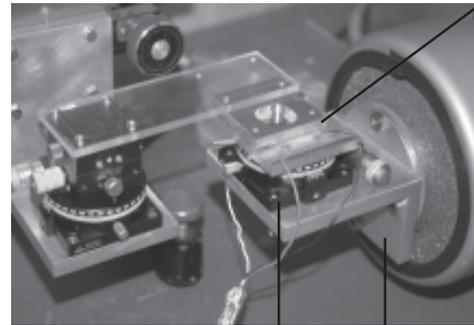


Figure 5. Effect of the width of electret.

Patterned film fixed to 6 degree of freedom stage



Electrode chip on rotation stage Shaker

Figure 6. Experimental setup.

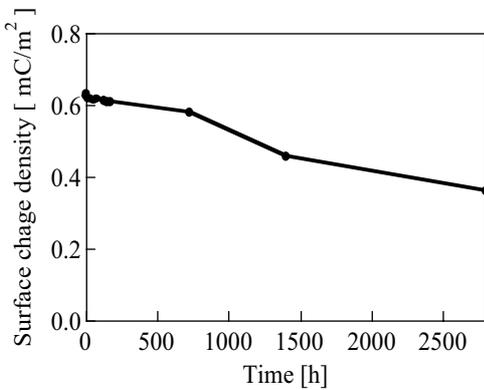


Figure 3. Time trace of mean surface charge density.

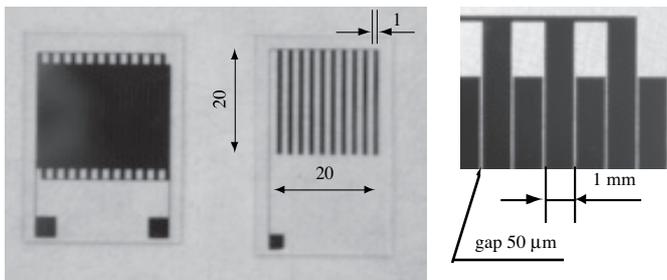


Figure 4. Patterned counter electrode(left), electret (middle), and close-up view of the counter electrode (right).

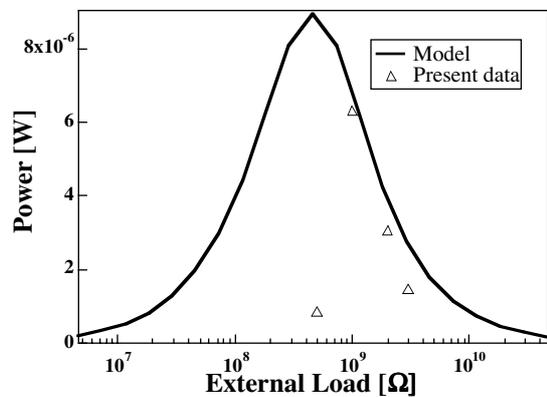


Figure 7. Power output versus external load.

Table 1. Case study of electret seismic generator.

	charge density	number of poles	gap	frequency	amplitude	power
unit	mC/m ²		μm	Hz	mm	W
Present	0.28	10	300	10	1	6μW
Case 1	1.1	200	20	2000	0.3	0.5W
Case 2	1.1	200	20	10	1	30mW

accordance with the model prediction [4] except at 500 MΩ. This fact encourages us to predict power output of generator having higher performance.

5 Performance Prediction

We have predicted the performance of the generator for two cases using the model [4] as shown in Table 1. In Case 1, power generator combined with micro thermal engine having 0.5 W generation is assumed. Amplitude and frequency are assumed to be 0.3 mm and 2 kHz, respectively. Then, charge density of 1.1 mC/m² is required, despite the small electrode width. In Case 2, lower frequency is assumed for energy harvesting applications. If the same charge density is realized, 30 mW power generation is possible at the frequency of 10 Hz, which is enough to operate most mobile electronic devices.

6 Conclusion

With a view to develop a micro seismic electret power generator, we have studied CYTOP for electret materials. Preliminary power generation experiment was also conducted using MEMS fabricated electrode chips. Following conclusion can be derived.

- (1) CYTOP is proved to be good electret material. Maximum 0.68 mC/m² charge density is achieved by a corona charging method.
- (2) At the low oscillation frequency of 10 Hz with 1 mm amplitude, power output of 6 μW was obtained.
- (3) The model prediction is in reasonable agreement with the experimental data. It is shown that 0.5 W power generation could be possible with 0.3 mm oscillation at 2 kHz.

Acknowledgment

This work was supported through the Grant-in-Aid for Young Scientists A (No. 14702028) by the Ministry of Education, Science, Culture and Sports (MEXT).

Reference

- [1] S. A. Jacobson, and A. H. Epstein, "An Informal Survey of Power MEMS," ISMME2003, Tsuchiura, pp. 513-520.
- [2] H. Kanebako and F. Sato, "Development of Ultra High Speed Micro-Generator for Ultra Micro Gas Turbine," 9th Nat. Symp. Power and Energy Systems, Tokyo, pp. 33-36, (in Japanese).
- [3] Y. Tada, "Theoretical Characteristics of Generalized Electret Generator, Using Polymer Film Electrets," IEEE Trans. Electrical Insulation, Vol. 21, 1986, pp. 457-464.
- [4] J. Boland, C.-H. Chao, Y. Suzuki, and T.-C. Tai, "Micro Electret Power Generator," Proc. 16th IEEE Int. Conf. MEMS2003, Kyoto, 2003, pp. 538-541.
- [5] Y. Suzuki, and Y.-C. Tai, "Micromachined high-aspect-ratio parylene beam and its application to low-frequency seismometer," Proc. 16th IEEE Int. Conf. MEMS2003, Kyoto, 2003, pp. 486-489.
- [6] G. M. Sessler, Electrets, Laplacian Press, 1998.
- [7] G. F. L. Ferreira and M. T. Figueiredo, "Corona Charging of Electrets," IEEE Trans. Electrical Insulation, Vol. 27, 1992, pp. 719-737.
- [8] Z.-F. Xia, H. Ding, G.-M. Yang, T.-J. Lu, and X.-M. Sun, "Constant-current Corona Charging of Teflon PFA," IEEE Trans. Electrical Insulation, Vol. 26, 1991, pp. 35-41.
- [9] T. Y. Hsu, W. H. Hsieh, Y.-C. Tai, and K. Furutani, "A Thin Film Teflon Electret Technology for Microphone Applications," A Solid State Sensor, Actuator and Microsystems Workshop, Hilton Head, 1996, pp. 235-238.
- [10] T. Genda, S. Tanaka, and M. Esashi, "Charging Method of Micro-patterned Electret for High Power Electret Motor and Generator," PowerMEMS2003, Makuhari, pp. 77-80.