A MICRO ELECTRIC POWER GENERATOR
USING A HYBRID SI MICRO CANTILEVER STRUCTURE

Takafumi Suzuki, Sumito Nagasawa, Hiroshi Okamoto and Hiroki Kuwano
Department of Nanomechanics, Tohoku University, Sendai, Japan

Abstract: This paper presents a vibration-driven micro electric power generator using a cantilever consisting of silicon and polymer. Electric power is generated using an electret film by electrostatic induction when the cantilever vibrates. When the electric power generator is small, its resonant frequency is high. It is necessary to make the resonant frequency low without scaling-up the device for matching the environmental vibrations. Therefore we propose to embed a polymer with low Young's modulus in the silicon cantilever. This structure is named Hybrid Silicon Micro Structure (HSMS). The resonant frequency of the HSMS was shifted from 2725 Hz to 1575 Hz.

Key words: Micro electric power generator, Polymer, Hybrid Silicon Micro Structure, Low frequency

1. INTRODUCTION

Energy harvesting techniques are expected to be a key technology for the future maintenance-free ubiquitous network systems. It is expected that by the micro electric power supply, sensor nodes should be maintenance-free since the number of sensors can be large in ubiquitous network. There are several power generating methods for harvesting ambient environment energy, including solar energy systems, thermoelectric generation systems and vibration-based systems. However, it is not any single solution that satisfies all conditions. Solar methods require sufficient light energy. Thermal gradients need sufficient temperature difference. Vibration-based systems need sufficient vibration sources. However vibration sources are generally more accessible. Therefore study on vibration-based systems was chosen.

There are three types of electromechanical transducers by vibration-based systems [1]: electro-magnetic, piezoelectric and electrostatic. Since output of the electromagnetic transducers is typically dependent on volume of magnets, electromagnetic transducers are not suitable for miniaturization. Piezoelectric transducers have an issue that it is difficult for generating electric power to form effective piezoelectric thin-film by MEMS technology. Electrostatic transducers are suitable for the MEMS fabrication and miniaturization since those are the simple structures.

Therefore, we studied a vibration-based micro electric power generator using an electret film by electrostatic induction. When the cantilever is vibrated, the amount of the induced charge on the counter electrode is changed due to the change of the electrode interval. Therefore electric power is generated. The micro electric power generator can convert mechanical vibration energy into electric energy [2] [3]. When the micro electric power generator is vibrated at the resonant frequency of the cantilever, its output becomes the maximum. However, the resonant frequency of electric power generator is high since it is very small. It is desirable to make the resonant frequency low without scale-up the device for matching the environmental vibrations. We propose that polymer which Young's modulus is low is embedded in the silicon cantilever. This is named Hybrid Silicon Micro Structure (HSMS).

2. MICRO ELECTRIC POWER GENERATOR

Figure 1 shows a schematic of the vibration-based micro electric power generator. Electric power is generated using an electret film by electrostatic induction when the Hybrid Silicon Micro Structure is vibrated. Polymer makes it possible to shift resonant frequency to low. Surface area of the free end is large for improving power generation efficiency.
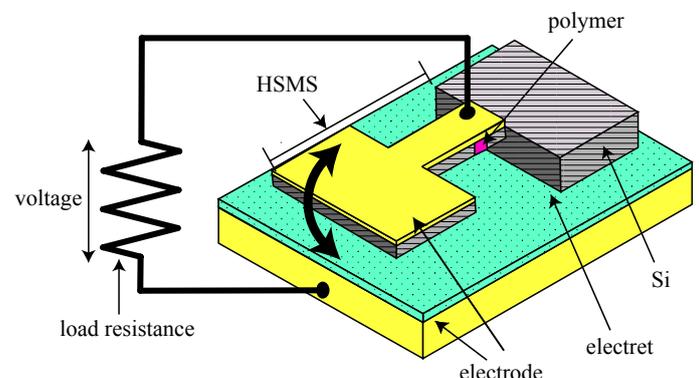

Fig. 1: Schematic diagram of our micro electric power generator.

Figure 2 shows characteristic features of the Hybrid Silicon Micro Structure. We propose this method for matching the environmental vibrations.

We chose CYTOP (CTL-809M, Asahi Glass Co., Ltd.) as the polymer for the HSMS and as the electret for micro electric power generator. CYTOP is suitable for MEMS fabrication processes and effective for bonding capability for silicon. Tsutsumino *et al.* discovered that CYTOP as the electret, an amorphous perfluoro-polymer [3] [4]. CYTOP is a better electret material than Teflon AF with higher charge density.

3. THEORETICAL ANALYSIS OF HSMS

ANSYS modal analysis was used to predict the resonant frequency and ANSYS frequency analysis was used to simulate amplitudes. Figure 3 shows model of the HSMS and the silicon micro structure. CYTOP is depicted with different color. The silicon micro structure is made of silicon only and That is same shape as HSMS. Table 1 shows the result of the modal analysis. Figure 4 shows the result of the frequency analysis. Input amplitude is 500 nm_{p-p}. The ANSYS analysis is demonstrated that the HSMS makes it possible to shift the resonant frequency to low.
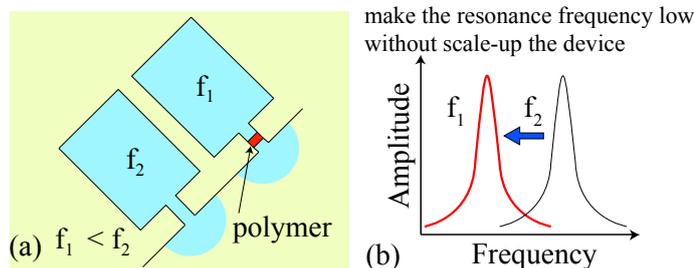

Fig. 2: Characteristic feature of the Hybrid Silicon Micro Structure.
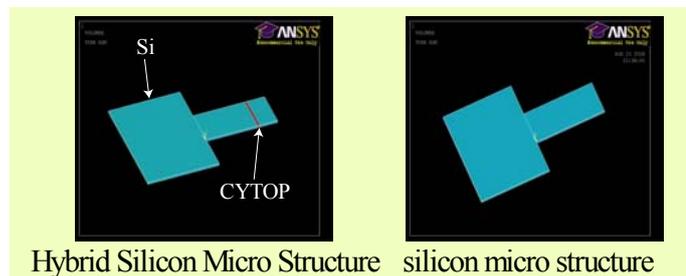

Fig. 3: Model of HSMS and silicon micro structure.

Table 1: Resonant frequencies of the HSMS and the silicon micro structure.

	Resonant frequency (Hz)
HSMS	1571
silicon micro structure	2742

4. FABRICATION

4.1 Electrode using the Hybrid Silicon Micro Structure fabrication

The micro electric power generator consists of two parts, electrode using the HSMS and an opposite electrode with an electret. The fabrication of electrode using the HSMS is explained in this section.

This is realized by MEMS techniques. Figure 5 shows the process chart for fabricating an electrode using the HSMS. SiO$_2$ layer is formed on the Si substrate by the wet thermal oxidization and wet etching (a). To make a trench, Si substrate is etched by DRIE (b). CYTOP as a polymer material is poured into the trench and spincoated (c). Aluminum is evaporated and patterned as the metal mask (d). CYTOP is etched by O$_2$ plasma with RF power of 50 W for 35 minutes (e). The cantilever is released by DRIE (f), (g). Finally the top electrode Au/Cr film (200 nm in thickness) is formed by sputtering (h).
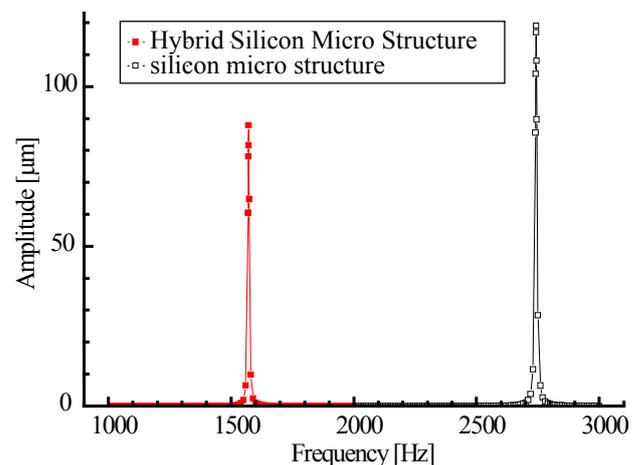

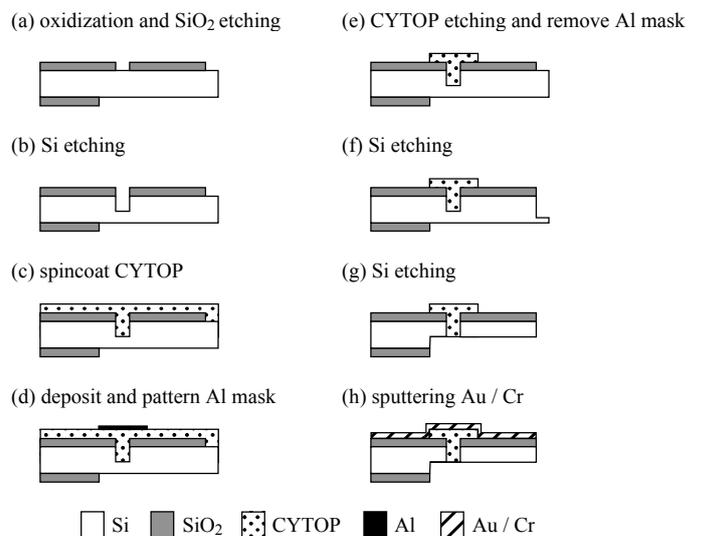*Fig. 4: Simulation of frequency characteristic.*

Fig. 5: Process chart for fabrication an electrode using the HSMS.

Figure 6 shows the Hybrid Silicon Micro Structure and this design. The HSMS having a trench filled with CYTOP with 50 μm in depth, 50 μm in length is 1000 μm in width, 3000 μm in length and 50 μm in thickness.

4.2 Elctret fabrication

CYTOP was employed as a dielectric material for an electret. An Au/Cr thin film having 220 nm in thickness was deposited on a Si substrate using the RF magnetron sputtering. Then, CYTOP was spincoated and soft-baked at 100 °C for 15 minutes. This process is repeated 3 times to obtain a 6 μm-thick film. Finally, the CYTOP film is fully cured at 185 °C for 90 minutes. Thereafter, the CYTOP film was charged by a corona discharge. Figure 7 shows the corona discharge setup [5]. Discharge voltage is -3.15 kV. Grid voltage is -300 V. Charging time was 2 minutes. After charging, the average surface voltage was about -270 V. Figure 8 shows the surface potential distribution.
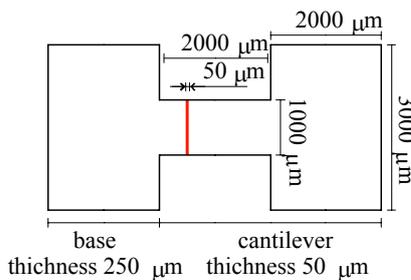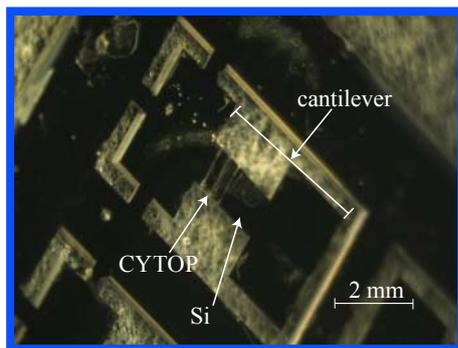

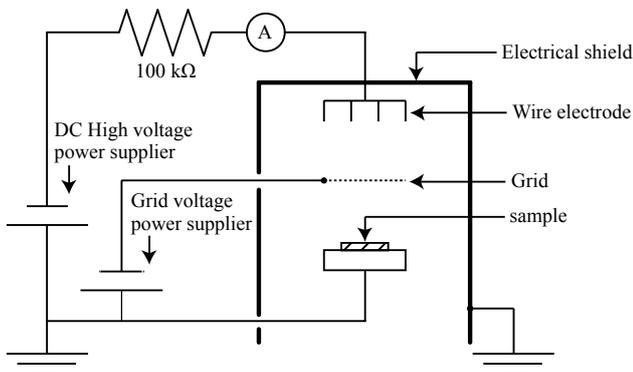*Fig. 6: The HSMS and this design.*

Fig. 7: Corona discharge setup.

5. EXPERIMENT

Figure 9 shows the experimental setup for the electric power generator. In order to make the electric power generator, the electrode using the cantilever was placed on the electret and fixed. The electric power generator was vibrated at various frequencies by the vibration exciter and measured the output voltages by an oscilloscope. And the displacement was measured by a laser vibration measure.

Air gap was 200 μm. Input amplitude was 500 nm_{p-p}. Load resistance was 1 MΩ. Surface potential of the electret is about -270 V. Figure 10 shows the output voltage versus frequency.
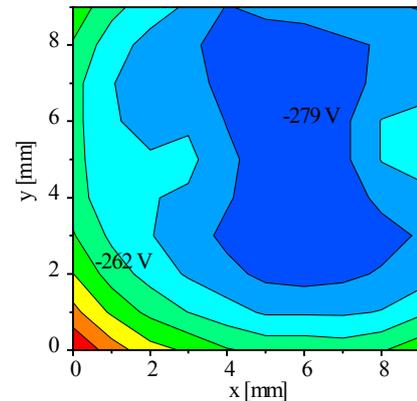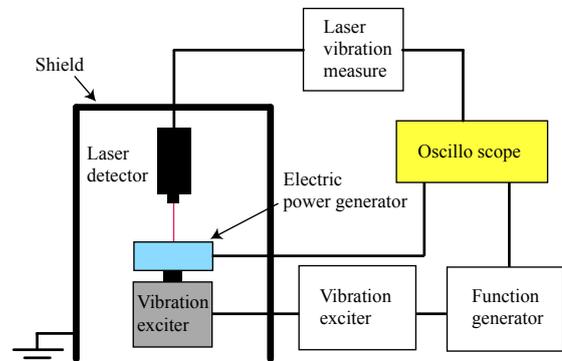

Fig. 8: Surface potential distribution.
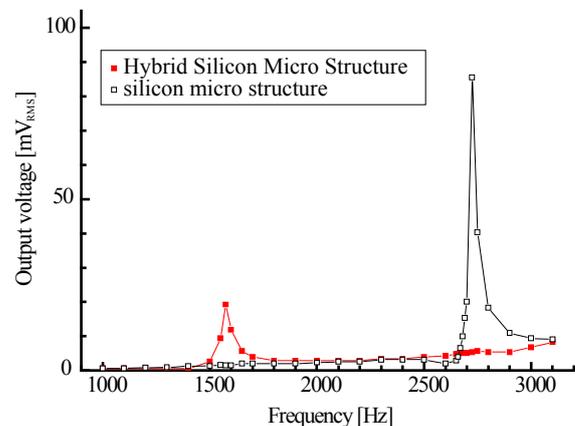

Fig. 9: Experimental setup.

Fig. 10: Output voltage versus frequency.

The maximum RMS value of the HSMS was 19.2 mV_{RMS} at 1575 Hz when the amplitude of the HSMS was 34.8 μm_{p-p}. Contrastively the maximum RMS value of the silicon micro structure was 85.6 mV_{RMS} at 2725 Hz when the amplitude of the silicon micro structure was 107.0 μm_{p-p}.

Figure 11 shows the output power of the HSMS versus load resistance at 1575 Hz. Figure 12 shows the output power of the silicon micro structure versus load resistance at 2725 Hz. Both input amplitudes were 500 nm. The maximum output power of the HSMS was 1.79 nW_{p-p} at 660 kΩ. The maximum output power of the silicon micro structure was 54.4 nW_{p-p} at 330 kΩ.

6. DISCUSSION

We demonstrated that the resonant frequency was shifted to low. However, comparing output power of the micro power generator using the HSMS with that of the micro power generator using the silicon micro structure, the number of reasons can be given for low output power of that using the HSMS. Firstly, amplitude of the HSMS was low since damping ratio of that was rather high. It would be necessary to attach a mass to free end. Secondly, output power is dependent on input frequency. Basically, the charge variation per unit time is current.

However, it is the most important for generating the electric power to operate the micro electric power generator around its resonant frequency.

7. CONCLUSION

This paper presented the design, simulation, fabrication and experiment of a micro electric power generator using the Hybrid Silicon Micro Structure. The HSMS enabled lower resonant frequency without scaling-up the device. The prototype micro electric power generator fabricated by the MEMS technologies generated 1.79 nW_{p-p} at 1575 Hz and 660 kΩ. The experimental resonant frequency was in a good agreement with the results of the ANSYS modal analysis.

In the future, it will be necessary to develop a micro electric power generator that covers the wide band of environmental vibrations. We are working toward a further understanding of the micro electric power generator.

Fig. 11: Output power versus load resistance at f = 1575 Hz.

Fig. 12: Output power versus load resistance at f = 2725 Hz

REFERENCES

[1]   Roundy S, Leland E S, Baker J, Carleton E, Reilly E, Lai E, Otis B, Rabaey J M, Sundararajan V, Wright P K 2005 Improving Power Output for Vibration-Based Energy Scavengers *IEEE Pervasive Computing* **4** 28-36

[2]   His-wen Lo, Rus Whang, Yu-Chang Tai 2007 A Simple Micro Electret Power Generator *Technical Digest MEMS 2007 (Kobe, Japan, 21-25 January 2007)* 859-862

[3]   Tsutsumino T, Suzuki Y, Kasagi N, Kashiwagi K, Morizawa Y 2006 Efficiency Evaluation of Micro Seismic Electret Power Generator *Technical Digest 23rd Sensor Symposium* 521-524

[4]   Arakawa Y, Kasagi N, Suzuki Y 2004 Micro Seismic Power Generator Using Electret Polymer Film *Technical Digest National Symposium on Power and Energy Systems* 37-38

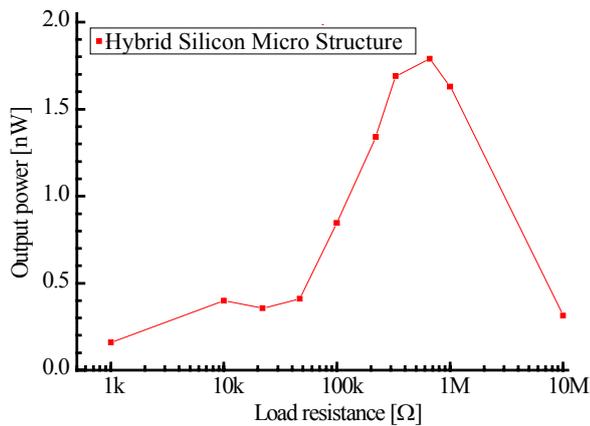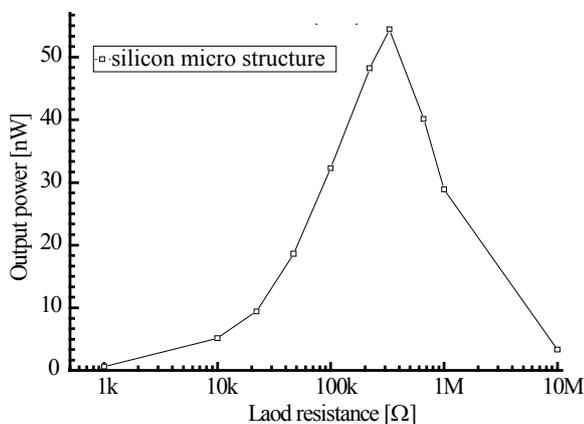[5]   Genda T 2003 Study of High Power Micro-Motor and Generator Using Electret *Doctoral dissertation of Tohoku University*