

MEMS ELECTRIC POWER GENERATOR USING A PIEZOELECTRIC PZT THIN FILM CANTILEVER

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Abstract: We propose a micro electric power generator using a piezoelectric PZT thin film cantilever. A piezoelectric PZT micro cantilever generator was fabricated and characterized in this paper. The PZT thin film is deposited by the RF magnetron sputtering. We obtained a good crystalline orientation of PZT (111) direction and the residual polarization was about $16\mu\text{C} / \text{cm}^2$. The device was fabricated by MEMS technique. Dimensions of the cantilever were $1200\ \mu\text{m}$ in length, $600\ \mu\text{m}$ in width and $54\ \mu\text{m}$ in thickness. We characterized the power generation of the device, finally a $418\ \text{pW}$ power generation was achieved at $12\ \text{k}\Omega$.

Key words: micro power generator, PZT thin film, piezoelectric cantilever

1. INTRODUCTION

These days, ubiquitous sensor networks become more and more important systems, for accident prevention, security, medical fields and so on. To realize these network systems, large amount of sensor nodes are needed. Each sensor node requires some features such as sensing environmental measurement, communicating other devices with radio transmission and electrical power suppliers. The most important requirement of them is electrical power supply. Since very large amount of sensor nodes are used for ubiquitous sensor networks, maintenance each battery was hard work. Batteries with no maintenances are needed for ubiquitous sensor networks.

To resolve this issue, micro power generators get a lot of attention. Micro power generators convert some energy such as solar energy, thermal gradients and vibration energy into electric energy. Scavenging energy from the environment, it becomes a semi permanent battery and need no maintenances. But 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. Vibration can be used everywhere and power generation is indefinitely unless the device is not broken.

Our research is aiming at fabrication of the piezoelectric micro power generator for applying ubiquitous networks. In this paper, we made a piezoelectric PZT thin film by RF magnetron sputtering and evaluated its characteristics. We fabricated micro power generator by MEMS techniques, and evaluated characteristics of its frequency responses of mechanical vibration and the electric power generation.

2. STRUCTURE

Fig. 1 shows a schematic diagram of our electric power generation device. The piezoelectric material is on the silicon cantilever. We use lead zirconate titanate (PZT) for the piezoelectric material to convert mechanical vibration energy into electric energy. When the cantilever is bended due to the circumstance vibration, PZT is expand or contract by stress and converts strain energy into electric energy.

PZT is sandwiched by electrodes. The top electrode is made of Au/Cr and bottom electrode is Pt/Ti. To grow up good PZT crystal, Pt layer is very important. The Pt layer helps to get good crystalline orientation of PZT, since a size of Pt crystal lattice is almost same as the PZT crystal lattice. It is called heteroepitaxy effect. SiO_2 is used as a buffer layer to prevent Ti from diffusing Si substrate.

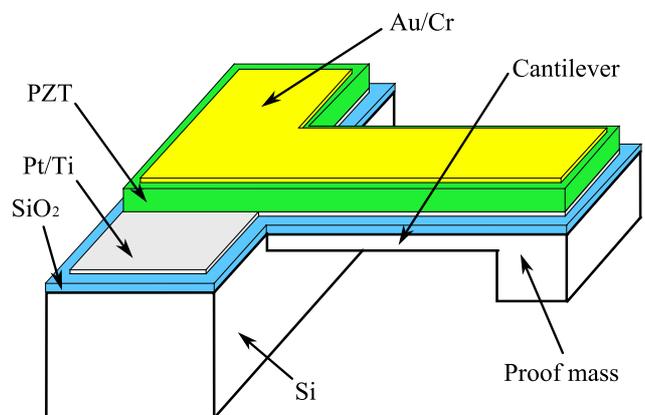


Fig. 1: Schematic diagram of our electric power generation device.

3. EXPERIMENTAL

3.1 PZT deposition

The PZT thin film was deposited by RF magnetron sputtering. The deposition conditions are shown in Table. 1. To optimize the deposition condition, we analyzed the crystalline orientation of the PZT thin film by XRD (X-ray diffraction). The best conditions of deposition parameters were following; temperature was 350 °C, using Ar and O₂ gases and a RF power was 100 W.

After depositing, the PZT thin film was annealed at 700 °C and confirmed the improvement of the crystalline orientation. The effect of the annealing is shown in Fig. 2. PZT (111) orientation is essential for high piezoelectric property and we confirmed the improvement of the orientation by annealing from Fig. 2. As this result, it is necessary to anneal the PZT thin film at 700 °C at least 5 minutes.

Table. 1: Sputtering conditions for the PZT deposition. The best condition was 350 °C, using Ar and O₂, 100W.

Experimental condition	Parameters
Deposition temperature	50 / 350 / 500 °C
Gas	Ar / Ar, O ₂
RF power	50 / 100 / 200 W
Anneal time at 700 °C	0 / 5 / 10 / 30 min

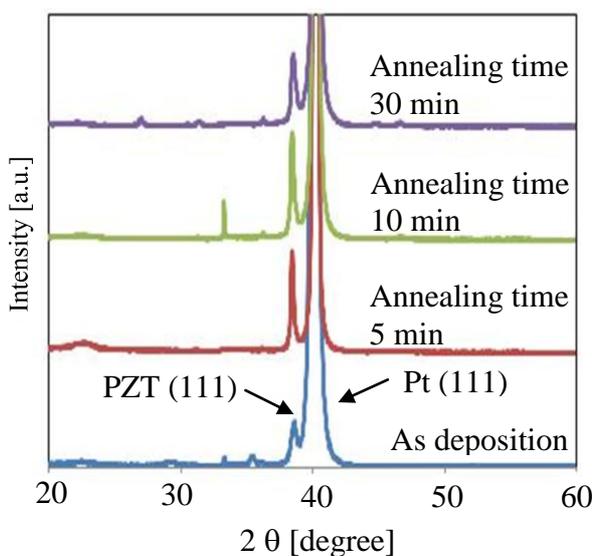


Fig. 2 : A diagram of the result of PZT crystalline orientation annealing at 700 °C.

3.2 PE hysteresis loops

To evaluate PE hysteresis loops of PZT thin films, we use the Toyo Corporation's Q / V conversion system (Model 6256 Rev C). Fig. 3 shows an experimental setup for evaluating PE hysteresis loops. Function generator applies a triangular wave to piezoelectric materials with a pre amp and then the same electric charge is obtained to both the sample capacitor and the reference capacitor through the influence of virtual ground effect. Measuring electric charge of the reference capacitor, we can know the sample capacitor charge, because their charges are equal. A post amplifier amplifies signal voltage and finally we can measure PE hysteresis loops by an oscilloscope.

Fig. 4 shows PE hysteresis loops of the fabricated PZT thin film. We got the residual polarization as 16 μC / cm².

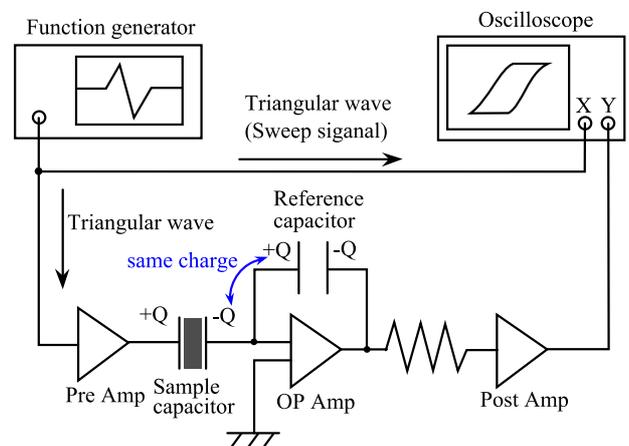


Fig. 3 : Experimental setup for evaluating P-E hysteresis loops.

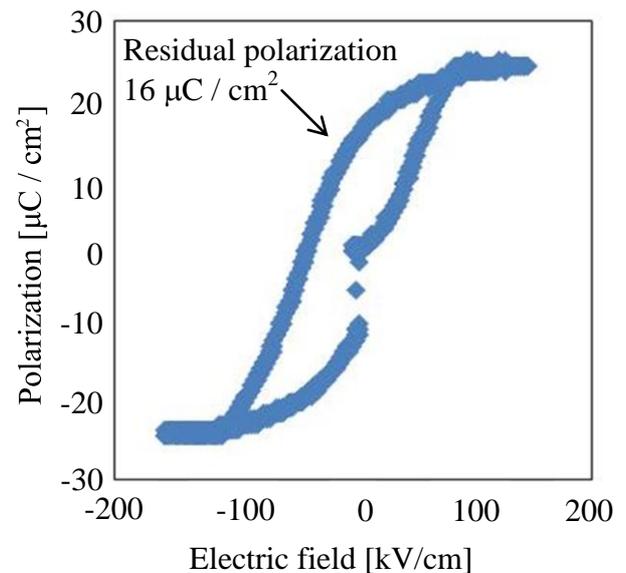


Fig. 4 : Hysteresis loop of the PZT thin film. The residual polarization was 16 μC / cm².

3.3 Fabrication process

The device was fabricated by MEMS techniques [1]. Fabrication process is shown in Fig. 5. SiO₂ layer is formed on a Si <100> substrate by the wet thermal oxidization (a). Then, SiO₂ was patterned by BHF as the shape of the micro cantilever. PZT/Pt/Ti layers are deposited by RF magnetron sputtering (c). These layers were dry etched by fast atom beam (FAB) using SF₆ gases (d). PZT layer was formed only on the top of the cantilever, and Pt/Ti layer was formed as a bottom electrode. To enhance the PZT crystalline orientation, it was annealed at 700 °C. Then, the top electrodes Au/Cr was formed by RF magnetron sputtering and shaped by a lift off process (e). After all, the cantilever was patterned by ICP-RIE (f). From the front side, we decide thickness of the cantilever and from the back-side, the micro cantilever was released and shaped the proof mass.

The fabricated device is shown in Fig. 6. The cantilever had 1200 μm in length, 600 μm in width and 54 μm in the electrode.

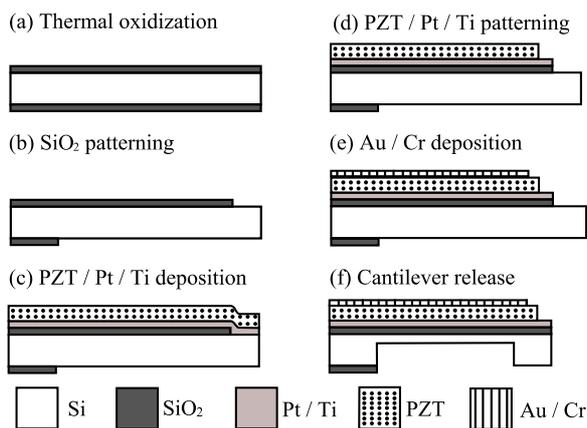


Fig. 5 : Fabrication processes.

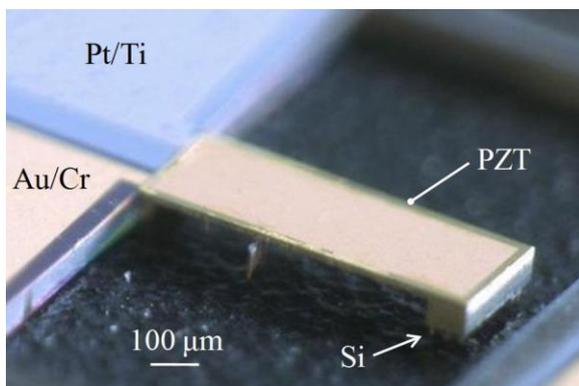


Fig. 6 : Photo of the fabricated micro cantilever. The cantilever has 1200 μm in length, 600 μm in width and 54 μm in thickness. The proof mass size is 200 μm in length, 600 μm in width, 150 μm in depth, about 0.42 mg.

3.4 Mechanical vibration characteristics

Fig. 7 shows the experimental setup for evaluating mechanical characteristics of the micro cantilever. A function generator produced sin wave and applied this AC voltage to the shaker as an input signal of the excite vibration. Using the shaker, the base to which the micro cantilever was fixed got vibration and then the micro cantilever tip vibrated. We use a laser displacement sensor for measuring cantilever tip displacement. The displacement measuring signal was treated by a signal processor, and finally indicated on a display.

Fig. 8 shows mechanical characteristics of fabricated micro cantilever. The resonance frequency was about 8.81 kHz. Base displacement was about 400 nm, and cantilever tip displacement was 3.5 μm at resonance frequency.

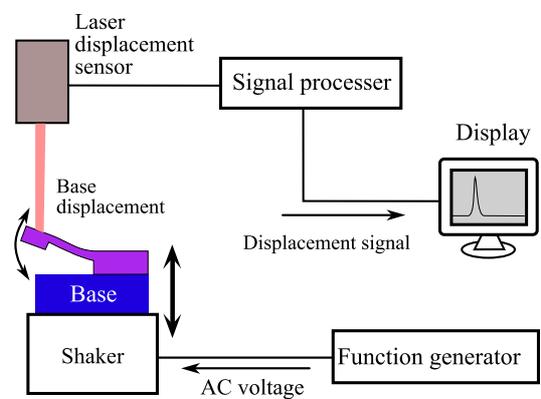


Fig. 7 : Experimental setup for evaluating of the micro cantilever's mechanical characteristics. A shaker excites and we measure cantilever's tip displacement by a laser displacement sensor.

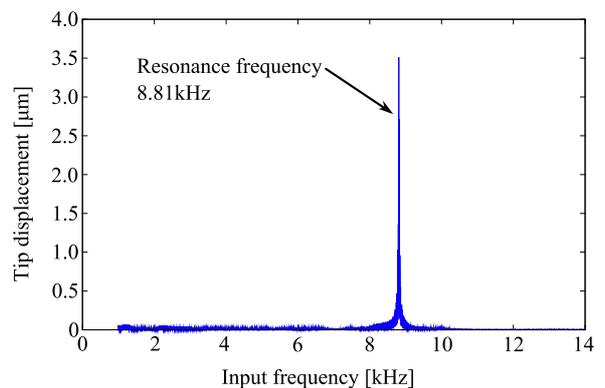


Fig. 8 : Mechanical characteristics of the fabricated micro cantilever. The displacement of the base was about 400nm, and cantilever tip displacement was 3.5 μm. The resonance frequency was about 8.81 kHz.

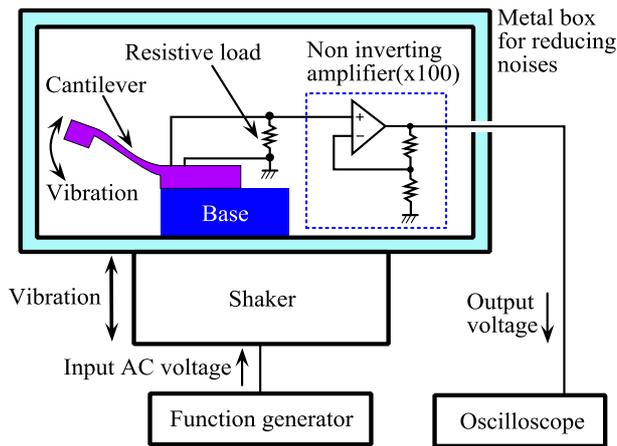


Fig. 9: Experimental setup of power generation. The micro cantilever was vibrated by a shaker and generates energy. With a non inverting amplifier, output power was measured by an oscilloscope.

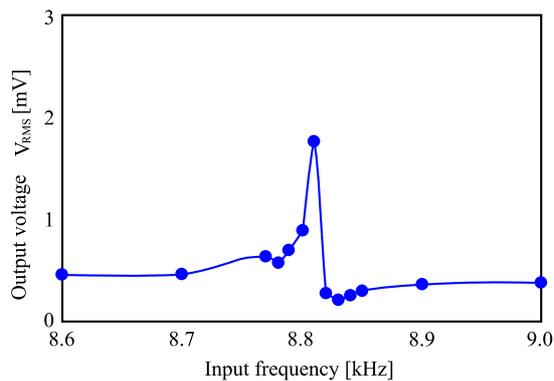


Fig. 10: Output voltage vs. input frequency of mechanical vibration. Maximum output voltage was 2.5 mV when the input frequency was 8.81 kHz.

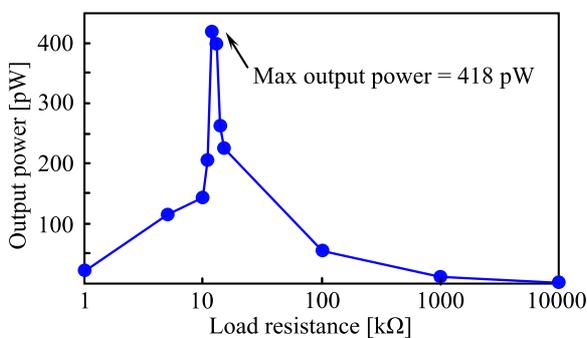


Fig. 11: Result of the impedance matching. Changing the road resistance from 1 kΩ to 1 MΩ, output power was measured.

3.5 Power generation

Fig. 9 shows the experimental setup for power generation. The function generator produced sin wave and applied this AC voltage to shaker as an input signal of the excite vibration. The micro cantilever is covered by a metal case for reducing electric noises. When the cantilever was bended by vibration energy, this device generated electric power and applies voltage to the resistive road. We measured its voltage with a non-inverting amplifier, and observed voltage with an oscilloscope.

Fig. 10 shows output voltage vs. input frequency. The maximum output voltage was about 2.5 mV when the input frequency was 8.81 kHz. Fig. 11 was results of the impedance matching. Changing the road resistance from 1 kΩ to 1 MΩ, we measured output power. We got the maximum output power of 418 pW when the road resistance was 12kΩ.

4. DISCUSSION

The fabricated cantilever resonance frequency was 8.81 kHz, we got the maximum electric output at 8.81 kHz. From the result of the impedance matching, our micro power generator can generate about 400pW of electrical energy. But this output power is smaller than other reported power of the generator [2]. To improve output power of our micro generator, it is important that we fabricate more effective PZT thin films.

5. CONCLUSION

We propose the micro electric power generator using the piezoelectric PZT thin film cantilever for ubiquitous networks. We fabricated the piezoelectric PZT micro cantilever generator by MEMS techniques. The PZT thin film was deposited by RF magnetron sputtering. We obtained good crystalline orientation of PZT (111) direction and the residual polarization was about 16 $\mu\text{C} / \text{cm}^2$. The cantilever had 1200 μm in length, 600 μm in width and 54 μm in thickness. We characterized power generation of the device, and finally a 418 pW power generation was achieved at 12 kΩ. To improve the micro power generator more efficiency, better PZT thin films are required as a future work.

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