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PZT Acoustic Energy Harvester Proposed for Use in MEMS/IC Integrated Systems

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1. Introduction

Approaching physical limits for miniaturization of advanced integrated circuits seem to start requesting further additional values for those integrated circuits. Recently, integration of CMOS and micro electro mechanical systems (MEMS) to increase the values of these devices has been strongly demanded. This is so called “More than Moore” concept. It was also pointed out that one of the advantageous devices are those which can operate independently from the outer power circuits. The key for this concept is to realize micro power sources integrable on the CMOS chips. The Ishida’s group proposed to integrate a power generator with an antenna on CMOS chips, and it generates power by receiving alternate magnetic fields. However, if the chip is located where magnetic field is difficult to penetrate, it will not function. For example, it is impossible to feed power to the CMOS chip in a human body or in a metallic container. On the other hand, Pb(Zr,Ti)O_3 (PZT), have been reported to have superior ferroelectricity and piezoelectricity [2]-[4].

In this paper, we propose to integrate a PZT energy harvester on the chip, and it can receive the power from an acoustic field, which can make it possible to supply power to the CMOS chip even if it is in a place which is magnetically shielded. We report on the performances of a PZT piezoelectric energy harvester fabricated on a silicon substrate.

2. Concept of MEMS/IC integrated system with acoustic energy harvester.

Figure 1 describes a concept of an intelligent system on a silicon substrate where CMOS circuits, MEMS sensors, actuators, and an energy harvester are integrated. The energy harvester is expected to function as the power source for these devices. Since the power given to the PZT acoustic energy harvester is through sound waves, it can operate where sound can be penetrated while electromagnetic field is not easy to penetrate.

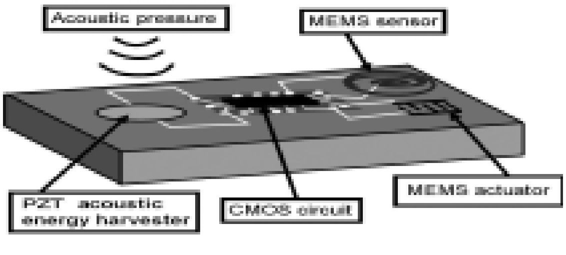

Fig. 1 Concept for integrated MEMS/IC system

3. Design of the acoustic energy harvester

The device structure investigated here is conceptually shown in Fig. 2. A piezoelectric capacitor with the diaphragm structure of Al/PZT/Pt/Ti was formed on a 1.5 μm-thick SiO_2. The hole underneath the diaphragm was fabricated using the silicon micro processes. The hole under the diaphragm and the smaller hole form so called Helmholtz resonator, which is used to enhance the resonance vibration of the diaphragm. The principle of power generation of this device is as follows. When the sound pressure is applied from the upper direction of the device, the diaphragm vibrates resulting in the distortion of the diaphragm of the PZT piezoelectric capacitor. The distorted PZT capacitor generates voltage difference between the two electrodes. This way, the electrical power is generated. The diaphragm of the piezoelectric capacitor has the structure of Al/PZT/Pt/Ti/SiO_2. The thicknesses of those films are, Al 100 nm, PZT 1.0 μm, P t 100 nm, Ti 100 nm, SiO_2 1.5 μm, and the total thickness of the diaphragm was 2.8 μm. Two kinds of devices with two different diaphragm diameters of 1500 μm and 2000 μm were fabricated. The resonant frequencies of those devices were designed to be approximately 6 kHz using the finite element method.

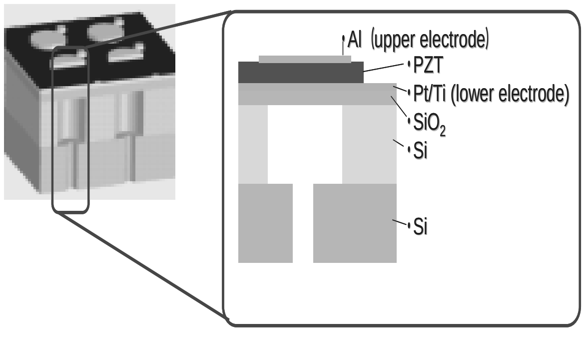

Fig. 2 Structure of diaphragm and Helmholtz resonator

4. Device fabrication processes

Figure 3 shows the device fabrication processes used here. The Si substrate of 300 μm in thickness with a 1.5 μm-thick SiO_2 film was prepared. The Pt/Ti layer was deposited using sputter to form the lower electrode (Fig. 3A). The 1 μm-thick PZT thin film was deposited using the sol-gel method (Fig. 3B). The PZT was patterned by wet etching using BHF (Fig. 3C). The Al for the top electrode was thermally deposited. The top electrode patterns were defined using photolithography and wet etching (Fig. 3D).

The cavity was formed by etching the silicon substrate from the backside with an ICP dry etcher (Fig. 3E). Finally, a silicon wafer with a bottleneck hole was bonded from the back of the chip. This way, the Helmholtz resonator was fabricated (Fig. 3F).

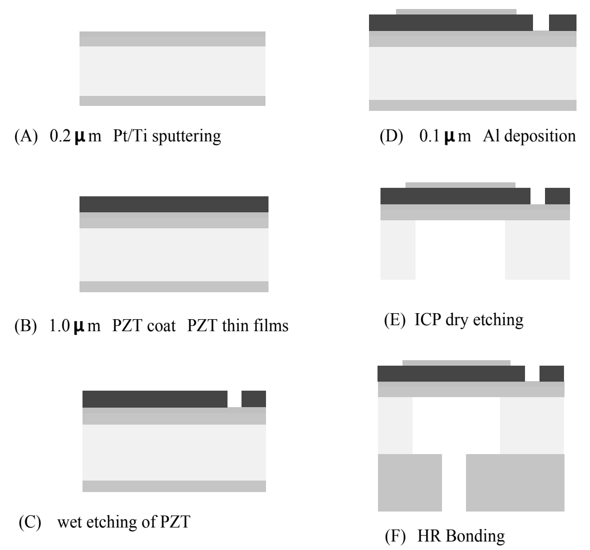

Fig. 3 Device fabrication processes

5. Device characterizations

The following measurements for the fabricated devices were performed (Fig. 4). A sine wave ac-signal at the resonance frequency generated by the function generator was amplified, and was transmitted to the speaker. The output impedance of the harvesters was measured to be 549 Ω. Thus, the load resistance value used in this experiment for the both devices was selected to be 549 Ω, which ensured the maximum power was delivered to the load. The voltage difference at the load resistor was measured to obtain the power delivered to the load. To calibrate the sound pressure applied to the power MEMS device, a standard microphone (B & K, Inc.) was situated next to the energy harvester (power MEMS). The sound pressure of approximately 100 dB at the resonance frequencies 6.02 kHz and 5.72 kHz was irradiated to the devices. The generated electric power was calculated from the measured voltages.

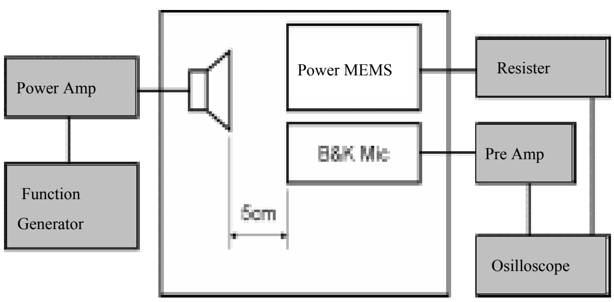

Fig. 4 Experimental setup for generated power measurements

Figure 5 shows the measured relationships between the power delivered to the load and the sound pressure. The resonant frequencies were 6.02 kHz, and 5.72 kHz for the devices with the diaphragm diameter 1500 μm and 2000 μm. It should be noted that the power generated by the device with the smaller diameter, 1500 μm was 2.2 nW, while that of the device with the diameter, 2000 μm was 1.0 nW.

Horowitz et. al. [5] have already reported a power MEMS which has almost the similar structure and similar dimensions to the devices investigated here. But their PZT film thickness is much thinner than the PZT films investigated here. Their device generated the power approximately 0.006 pW at the sound pressure of 100 dB, which seems much smaller than the power generated by the devices investigated here.

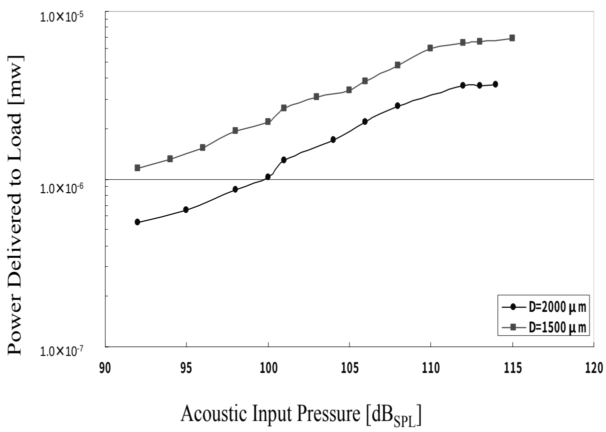

Fig. 5 The relationships between the power delivered to the load resistance, 549 Ω for the power device with the diameter, diameter D of 1500 μm and 2000 μm, respectively.

6. Conclusions

The energy harvester with the PZT thin film with the thickness of 1 μm deposited using the sol-gel method was fabricated and characterized. The output impedance of the fabricated device was 549 Ω, and the resonant frequencies were 6.02 kHz, and 5.72 kHz for the devices with the diaphragm diameters of 1500 μm and 2000 μm. The power generated to the 549 Ω load resistance was 2.2 nW for the device with the diameter of 1500 μm at the sound 100 dB at the resonant frequencies, and that with the diameter of 2000 μm was 1.0 nW. It is believed that this energy harvester may be a candidate for a power source for intelligent integrated systems.

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