Influence of Bipolar Pulse Poling Technique for Piezoelectric Vibration Energy Harvesters using $Pb(Zr,Ti)O_3$ Films on 200 mm SOI Wafers

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Abstract. Piezoelectric vibration energy harvester arrays using $Pb(Zr,Ti)O_3$ thin films on 200 mm SOI wafers were fabricated. In-plane distribution of influence of bipolar pulse poling technique on direct current (DC) power output from the harvesters was investigated. The results indicate that combination poling treatment of DC and bipolar pulse poling increases a piezoelectric property and reduces a dielectric constant. It means that this poling technique improves the figure of merit of sensors and harvesters. Maximum DC power from a harvester treated by DC poling after bipolar pulse poling is about five times larger than a one treated by DC poling only.

1. Introduction

Recently, there have been growing research and development activities of wireless sensor network using MEMS based wireless sensor nodes. Wireless sensor network systems need a large amount of autonomous sensor nodes. Piezoelectric thin films are widely applied to sensor node elements of low power consumption sensors like piezoelectric trigger switches [1,2] and power sources like piezoelectric vibration energy harvesters. High power piezoelectric devices using $Pb(Zr,Ti)O_3$ (PZT) thin films are in demand, but there are few reports on a mass-production technology including a PZT film deposition, fabrication, and poling treatment. In the present study, piezoelectric vibration energy harvester arrays using a PZT film on a 200 mm SOI wafer were fabricated, and in-plane characterization of influence of bipolar pulse poling (BPP) technique [3,4] on piezoelectric and ferroelectric properties was carried out.

2. Experimental procedure

The fabrication process flow is shown in figure 1. $Pb(Zr_{0.52},Ti_{0.48})O_3$ thin films (2 μm, (100)/(001) – oriented) were deposited by an automated sol-gel deposition system, as reported in our previous study [5]. A multilayer of 175 nm Pt/ 15 nm Ti/ 2 μm PZT/ 175 nm Pt/ 15 nm Ti/ 1 μm SiO_2 on a 200 mm SOI wafer was fabricated into piezoelectric vibration energy harvesters through the following process.

First, the top Pt/Ti layer was removed by the reactive ion etching (RIE), and the PZT film was etched by the mixed acid etchant (STEP 1). Next, the bottom Pt/Ti layer and barrier SiO_2 layer were also etched by the RIE (STEP 2). Thirdly, the Au contact pad was deposited by a sputtering and patterned using Au etchant (STEP 3). Then, the patterning of the structural Si layer to the cantilever shape was carried out using a BOSCH etch process (DRIE), and the BOX layer was removed by RIE (STEP 4). Finally, the Si substrate was also removed by DRIE, the BOX layer under the cantilever was etched by RIE from the backside to release the cantilever chips (STEP 5). The fabricated 200 mm SOI wafer is shown in figure 2. Straight cantilevers with a seismic mass were obtained as shown in figure 3.

The waveform for bipolar pulse poling (BPP) is shown in figure 4. Bipolar pulse poling was treated to PZT thin films using a ferroelectric test system (FCE-1, TOYO Corp.). Direct current (DC) poling was applied by constant voltage power equipment (PMC 18-1A, KIKUSUI). When the voltage of the top electrode is higher than that of the bottom electrode, the voltage is defined as positive and vice versa.

3. Results and discussion

3.1. Influence of microfabrications on ferroelectric properties

Influence of process damages on ferroelectric properties was characterized by the double beam laser

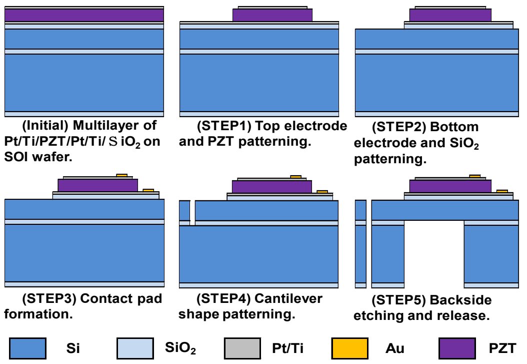

Figure 1. Schematics of the fabrication process for piezoelectric vibration energy harvesters.

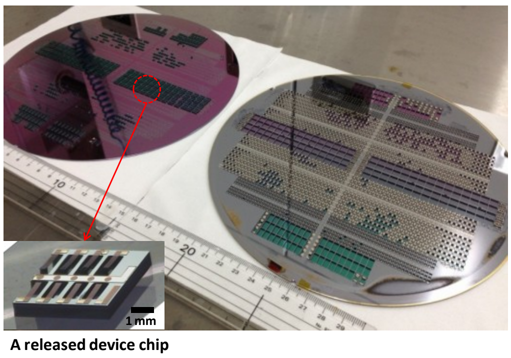

Figure 2. Overall view of the fabricated PZT thin film devices on a 200 mm SOI wafer (right in the figure) and the released device chips on a dummy wafer (left).

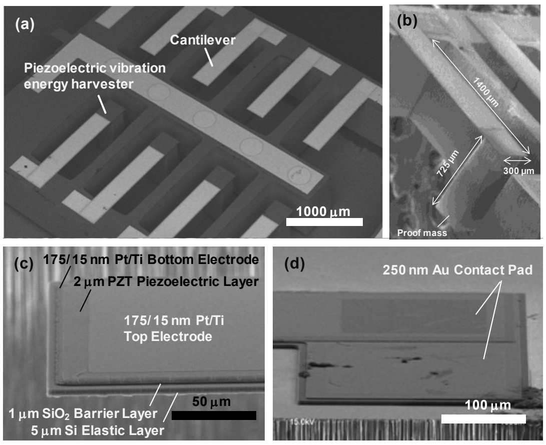

Figure 3. SEM images of the (a) fabricated piezoelectric thin film device array, (b) harvester, (c) tip and (d) base of a cantilever.

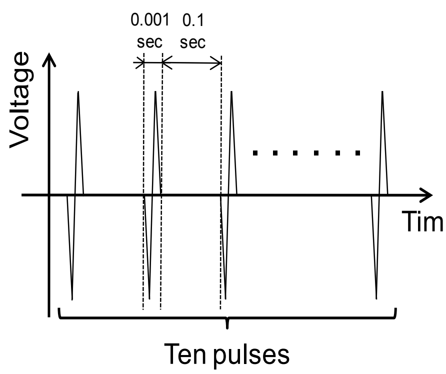

Figure 4. The waveform for bipolar pulse poling.

interferometer system with the ferroelectricity measurement module (TF 2000E, aixACCT SYSTEMS GMBH). Figure 5 shows the *P-V* hysteresis curve measured at 40 V and 1 kHz after STEP 1 and 5. Figure 6 shows the variation in positive and negative remanent polarizations with the progress of the fabrication process. Bipolar pulse poling amplitude was 90 V. Significant degradation was not observed after the fabrication, but the unbiased estimate of the variance of properties was increased after BPP from ±0.5 to ±3.1 μC/cm^2. It appears that any chemical reactions occurred at an interface between the Pt/Ti electrode and PZT film during plasma processes such as STEP 1 and 2 [6].

3.2. Influence of poling conditions on piezoelectric properties
Figure 7 shows the transverse piezoelectric constant $-d_{31}$ and dielectric constant of as a function of DC poling time. A harvester treated by 110 V BPP before DC poling was compared with an unpoled one. The transverse piezoelectric constant was estimated by the calculation using the value of the measured tip displacement of the microcantilever actuated by small AC voltages (±1 V) [7]. The result indicates that a combination poling treatment of DC and bipolar pulse poling increased the $-d_{31}$ from 45 to 60 pmV^{-1}, and reduced a dielectric constant ε from 1400 to 900. It means that this poling technique doubled the figure of merit of sensors and harvesters like a g-constant (= $-d_{31}\varepsilon^{-1}$). Figure 8 shows the estimated $-d_{31}$ before and after 110 V BPP as an in-plane distribution on a 200 mm wafer. The $-d_{31}$ was increased from 33±13 to 65±8 pmV^{-1} after the combination poling.

3.3. Direct current output power from piezoelectric vibration energy harvesters treated by bipolar pulse poling
Direct current output power from a harvester in the mechanical resonance at the vibration of 9.8 ms^{-2} was measured using a shaker, an AC-DC conversion circuit and an oscilloscope shown in figure 9. Harvesters were treated in three different ways, (1) DC poling only (+15 V, 10 sec), (2) 90 V BPP only, and (3) DC poling (+15 V, 2 sec) after 90 V BPP. The result shown in figure 10 indicates that the effect of poling treatment showed different dependency on the position in a wafer. The difference of dependency appears associated with the distribution of plasma damages. Direct current output power from a harvester located between the radius from 60 to 90 mm treated by BPP and DC poling is about five times larger than a one treated by DC poling only. It seems that the effect of the increase of the g-constant increased electro-mechanical conversion efficiency above.

4. Conclusions
Piezoelectric thin film devices using a PZT film on 200 mm SOI wafers were fabricated, and influence of the bipolar pulse poling on piezoelectric and ferroelectric properties of the devices was

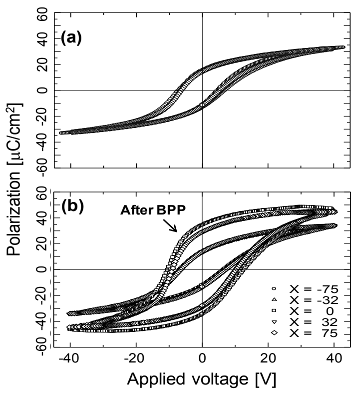

Figure 5. The variation in *P-V* hysteresis curves of five points within a range of the 150 mm diameter after fabrication (a) step 1 and (b) step 5. X in the figure means distance [mm] from the wafer center.

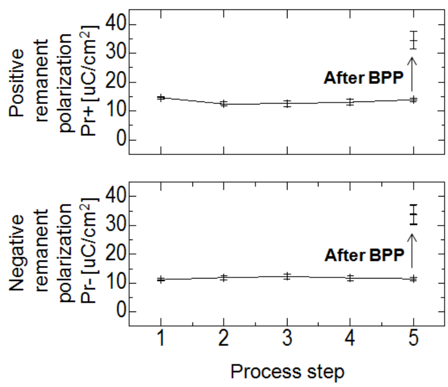

Figure 6. The variation in remnant polarization on thirty four points within a range of the 150 mm diameter after each fabrication step. Error bars signify the unbiased estimate of the variance.

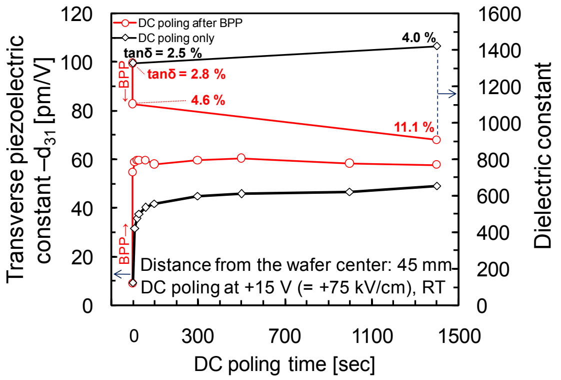

Figure 7. The transverse piezoelectric constant $-d_{31}$ and dielectric constant as a function of DC poling time.

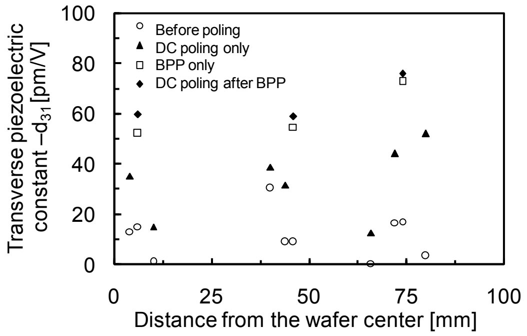

Figure 8. The result of characterization of (a) transverse piezoelectric constant $-d_{31}$ as in-plane distribution.

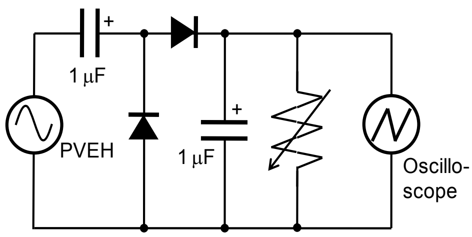

Figure 9. The schematic diagram of direct current output power measurement circuit.

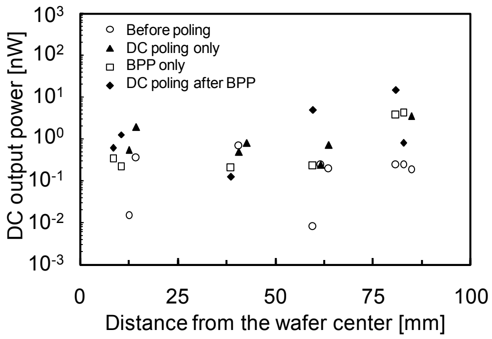

Figure 10. DC output power of a harvester in the mechanical resonance.

characterized. Combination poling treatment of DC and bipolar pulse poling increased the $-d_{31}$ from 33 ± 13 to 65 ± 8 pmV^{-1}. Maximum DC power from a harvester treated by DC poling after bipolar pulse poling is about five times larger than a one treated by DC poling only. The results indicate that the combination poling is a suitable poling method for mass-production of PZT thin film devices compared with direct current poling.

Acknowledgements

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