Transactions of the Materials Research Society of Japan 28 [1] 169-171 (2003)

HIGH-FREQUENCY OSCILLATOR USING HIGH-PERFORMANCE SINGLE-CRYSTAL PZNT91/9

Kouichi Harada, Yasuharu Hosono, Tsuyoshi Kobayashi and Yohachi Yamashita

Power Supply Materials and Devices Laboratory, Corporate R&D Center, Toshiba Corp.

1, Komukai Toshiba-cho, Saiwai-ku, Kawasaki 212-8582, Japan

Fax : +81-44-520-1286, koichi1.harada@toshiba.co.jp

High-frequency plate oscillators were formed from (001) wafers. These were 7.6 mm wide×25 mm long and oscillator thickness was about 0.120 mm and 0.128 mm. The electrodes of these oscillators were formed by sputtered 0.03 and 0.12-μm-thick Au/Cr and poled at 0.3 kV/mm at room temperature, about 25 ℃. Dielectric constant ε before poling gradually decreases from 1 mm to 0.128 mm thickness and drastically decreases at 0.120 mm. However, dielectric constant ε_{33}^{T} recovers due to poling. Resonance frequency of 0.120-mm-thick oscillator is about 15 MHz and that of 0.128-mm-thick oscillator is about 14 MHz. Electromechanical coupling coefficients k_t of 0.128 mm and 0.120-mm-thick oscillators are almost the same as that of more than 0.260-mm-thick oscillators. High-frequency plate oscillator for 15 MHz can be produced using PZNT91/9 single crystal.

Key words: High-frequency, oscillator, PZNT91/9, Piezoelectric material

1. INTRODUCTION

$Pb[(Zn_{1/3}Nb_{2/3})_{0.91}Ti_{0.09}]O_3$ single crystal (PSC) has a large electromechanical coupling coefficient, k_{33}>90%[1]. We investigated various approaches to growing large PSC that are suitable for the manufacture of ultrasonic cardiac array probes. The growth of large PSC by the modified flux method has already been reported[2]. High-quality images were produced by ultrasonic echocardiography using PSC cardiac probes[3]. The results indicate that the probes made of the PSC components have greater penetration depths and higher resolution than the PZT ceramic transducers[3]. Many ultrasonic probes for peripheral vascular conditions are used as well as cardiac probe. Since peripheral vascular disease is not far from the surface, resolution has priority over penetration for peripheral vascular probes. The middle frequency of the oscillator for peripheral vascular probes is about 6 MHz, and oscillator thickness is about 0.120 mm. Handling of this oscillator is very difficult and electrical properties may be affected. In this report, trial production and electrical properties of the PSC oscillator for peripheral vascular probes are reported.

2. EXPERIMENTAL PROCEDURE

The PSC was grown by the solution Bridgman method using a PbO flux. The process of PSC growth has been reported in detail [4]. Obtained PSC ingot was sliced into 0.44-mm-thick (001) wafers by multi-wire saw. These wafers were lapped with white Al_2O_3 powders, #2,000. The lapped PSC wafers are 120-128 μm in thickness. Cr/Au electrodes with a thickness of 0.03 and 0.12 μm- were deposited on both sides of PSC by sputtering.

The 10 pieces 7.6 mm wide× 25 mm long with plate oscillators of 0.120-0.128 mm in thickness were formed from (001) wafer. For electromechanical coupling factor of rectangular bar mode k_{33} , an attempt was made to form 0.200-0.070 mm wide ×0.128 mm thick ×7.6 mm long, bar oscillators from (001) wafer. The oscillator's width, 0.070 mm, is similar to that of the medical array ultrasonic transducers with 6.0 MHz center frequencies. In order to measure the piezoelectric properties, the specimens were poled at 0.3 kV/mm at room temperature, about 25 ℃. The electromechanical coupling factor k_t was measured by the resonance and anti-resonance method using Network analyzer 4195A (Yokogawa-Hewlett Packard). Piezoelectric constant d_{33} was measured by d_{33} meter Model ZJ-3D (Institute of Acoustics Academia Sinica). Capacitance and dissipation factors tan δ were measured by LF-Impedance Analyzer 4192A (Yokogawa-Hewlett Packard).

3. RESULTS AND DISCUSSIONS

Electrodes of plate oscillators were so tough that they did not exfoliate from PSC surface by rubbing with the tips of tweezers. However, some plate oscillators were warped by sputtering heat as shown in Fig.1. Although bar oscillators with 0.200-0.100 mm width can be cut from (001) wafer with 0.128 mm thickness by dicing saw, bar oscillators with width smaller than 0.100 mm were very difficult to form. When cutting width was smaller than 0.100 mm, almost all PSC oscillators were broken.

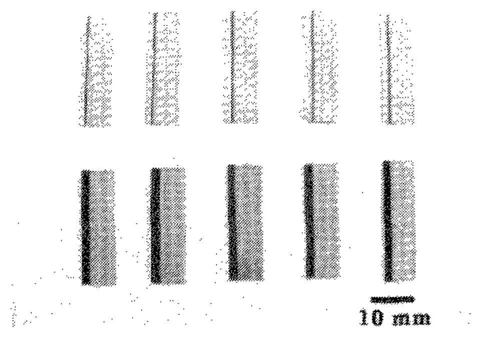


Fig.1 High-frequency oscillators of PSC

Figure 2 shows thickness dependence of dielectric constant ε and dissipation factors tan δ of plate PSC oscillators before poling. ε gradually decreases when thickness decreases from 1.00 mm to 0.128 mm and drastically decreases from 8000 to 4000 at 0.120 mm thickness. tan δ behaves very similarly to ε. However, tan δ drastically increases at 0.128 mm and 0.120 mm. These results probably show that penetration of mechanical damage by polishing is about 0.06 mm (=1/2×0.12 mm).

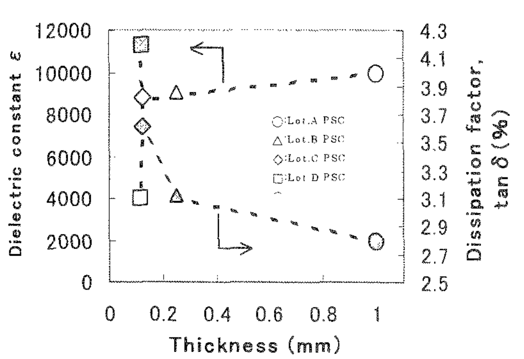


Fig.2 Dielectric constant ε and dissipation factors tan δ of plate PSC oscillators before poling

Figure 3 shows thickness dependence of dielectric constant $\varepsilon_{33}{}^{T}$ and dissipation factors of plate PSC oscillators after poling.

After poling, $\varepsilon_{33}{}^{T}$ is stable for thickness change. Also, tan δ changes little. Increase at 0.128 mm thickness is probably attributable to the property of lot C. These results show that $\varepsilon_{33}{}^{T}$ and tan δ, which deteriorated by lapping, can recover by poling.

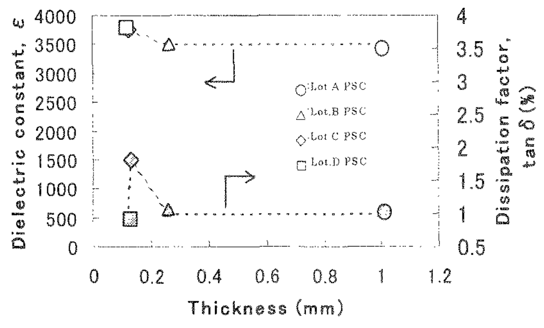


Fig.3 Dielectric constant $\varepsilon_{33}{}^{T}$ and dissipation factors tan δ of plate PSC oscillators after poling

Figure 4 shows thickness dependence of piezoelectric factor d_{33} and electromechanical coupling coefficient k_t of plate PSC oscillators. k_t is stable against change of thickness. This also shows that poling recovers damage to PSC.

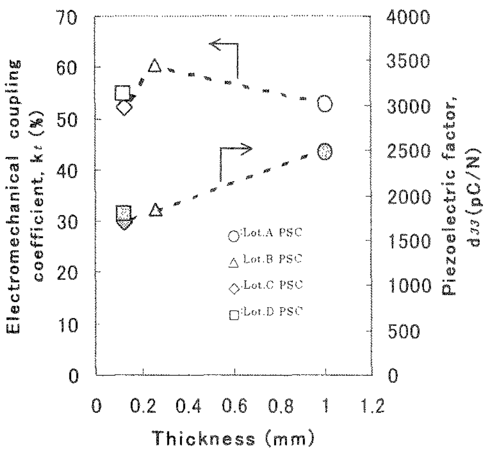
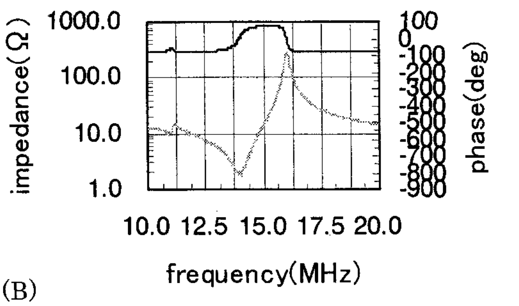


Fig.4 Piezoelectric factor d_{33} and electromechanical coupling coefficient k_t

Figure 5 shows a typical frequency response and an impedance of a 0.128-mm-thick PSC plate oscillator (A) and a 0.120-mm-thick one (B). There are no spurious mode and clear peak in impedances. Therefore, these oscillators are very suitable for application as high-frequency oscillators. However, it is very difficult to produce 0.07-mm-wide rectangular bar oscillator. We intend to resolve the problem of fabrication for array probe and produce high-frequency ultrasonic transducer for peripheral vascular disease in the near future. Results of this study are summarized in Table 1.

(A)



(B)

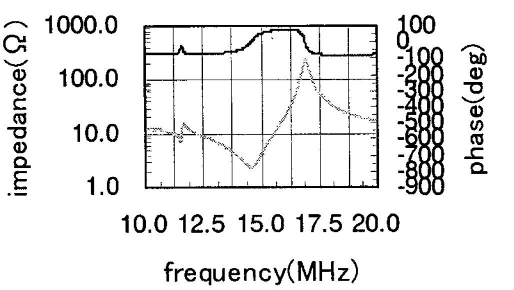


Fig.5 A typical frequency response and an impedance of a 0.128-mm-thick PSC oscillator (A) and a 0.120-mm-thick one (B)

Table I Results of this study

Thickness(mm)	1	0.26	0.128	0.120
Lot.	A	B	C	D
Dielectric constant (before poling)	10000	8900	8630	4030
Dissipation factor, tan δ (before poling)	0.03	0.03	0.04	0.04
Dielectric constant (after poling)	3500	3500	3750	3800
Dissipation factor, tan δ (after poling)	0.01	0.01	0.02	0.01
Electromechanical coupling coefficient, k_t(%)	53	60	52	55
Piezoelectric constant, d_{33}(pC/N)	2500	1800	1700	1800
Array fabrication	OK	OK	NG	NG

4. CONCLUSION

The 0.120-mm-thick and 0.128-mm-thick plate oscillators were produced with PZNT91/9 piezoelectric single crystal (PSC). We investigated relations between thickness of oscillator and its electrical properties. The results are as follows:

1) High-frequency plate oscillator for 15 MHz can be produced using PZNT91/9 single crystal.

2) Dielectric constant ε gradually decreases when thickness decreases from 1 mm to 0.128 mm and drastically decreases from 8000 to 4000 at 0.120mm thickness. tan δ behaves very similarly to ε. However, tan δ drastically increases at 0.128 mm and 0.120 mm.

3) After poling, $\varepsilon_{33}{}^{T}$ is stable against thickness change. Also, tan δ changes little.

4) Electromechanical coupling coefficient k_t is stable against change of thickness. This also shows that poling recovers damage to PSC.

5) There are no spurious mode and clear peaks in impedances. Therefore, these oscillators vibrate with single and normal mode. If a 0.07mm-wide plate oscillator can be cut, high-frequency ultrasonic transducer for peripheral vascular disease can be realized.

REFERENCES

[1] J. Kuwata, K. Uchino and S. Nomura, Jpn. J. Appl. Phys. 21,1298-302(1982).
[2] T. Kobayashi, S. Shimanuki, S. Saitoh and Y. Yamashita, Jpn. J. Appl. Phys. 36, 6035-38 (1997)
[3] S. Saitoh, T. Takeuchi, T. Kobayashi, K. Harada, S. Shimanuki and Y. Yamashita, Jpn. J. Appl. Phys., Vol. 38, No. 5B, 3380-84 (1999)
[4] K. Harada, S. Shimanuki, S. Saitoh, and Y. Yamashita, J. Am. Ceram. Soc., Vol.81 [11] 2785-88(1998)

(Received December 21, 2002; Accepted January 31, 2003)