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SAW Properties of PLZT Epitaxial Thin Films

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Thin films of PLZT with (111) orientation were epitaxially grown on c-plane of sapphire by rf-magnetron sputtering. The poling treatment was carried out under an applied field along ⟨$\bar{1}\bar{1}2$⟩ direction of PLZT and SAW was excited along the same direction by an interdigital transducer. The coupling constant k^2 was about 0.85% for the fundamental mode of SAW at normalized thickness $Kd=0.42$. The result indicates that the piezoelectric effect of the present PLZT thin film is as strong as $BaTiO_3$.

§1. Introduction

The quaternary solid solution of PLZT [(Pb, La) (Zr, Ti)O_3] is well-known as a transparent ceramic material with strong electrooptic (E-O) effect.[1] From the viewpoint of application to integrated optics, we have studied the epitaxial growth of PLZT thin films on sapphire and fabricated optical switches using the E-O effect.[2] It is known that PLZT also exhibits strong piezoelectric effect.[3] In the field of integrated optics, optical devices which possess both E-O and acousto-optic (A-O) operation are of much interest.

We recently tried to excite a surface acoustic wave (SAW) on the PLZT/sapphire structure and confirmed the strong piezoelectricity of the PLZT thin film. This paper describes the method of preparing PLZT epitaxial thin film, the fabrication procedure of SAW devices using PLZT film and their SAW properties.

§2. Film Preparation

Thin film of PLZT was prepared by rf-planar magnetron sputtering system. The sputtering target was PLZT (28/0/100) [$Pb_{0.72}La_{0.28}Ti_{0.93}O_3$] powder which was obtained by sintering the stoichiometric mixture of PbO, La_2O_3 and TiO_2 powder. The reason we adopted PLZT (28/0/100) composition is that we have fabricated opto-electronic devices using thin films of this composition which have high tansparency and strong electro-optic effect.[4] We found c-plane of sapphire was suitable as a substrate for growing epitaxial PLZT thin film of optical grade. A polished wafer of sapphire was set up parallel to the target. Epitaxial thin films with perovskite structure were reproducibly obtained under the conditions summarized in Table I.

A reflection high-energy electron diffraction pattern of epitaxial PLZT is shown in Fig. 1. The epitaxial relations were confirmed to be (111)PLZT//(0001) sapphire and

Table I. Sputtering conditions.

Target diameter	100 mm
Target-substrate spacing	35 mm
Rf voltage	1.7 ~ 2.0 kV
Input power	150 ~ 250 W
Sputtering gas	Ar(60%)+O_2(40%)
Gas pressure	0.5 Pa
Substrate temperature	580°C
Deposition rate	80 ~ 100 A/min

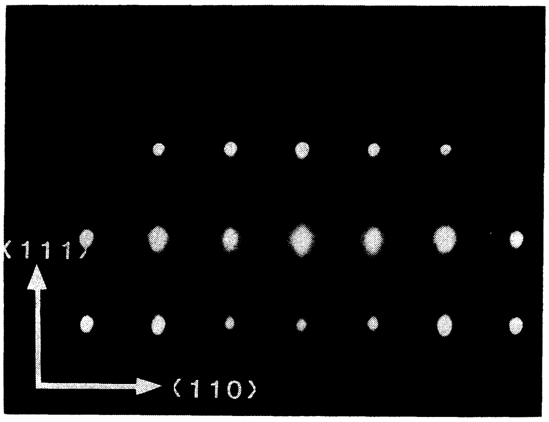

Fig. 1. Reflection high-energy electron diffraction pattern of epitaxial PLZT thin film grown on c-plane of sapphire.

⟨$\bar{1}\bar{1}2$⟩PLZT//⟨$\bar{1}\bar{1}20$⟩ sapphire. The inductively coupled plasma emission spectrometry analysis indicated that the film contained more Pb atoms than the target and the film composition was estimated to be PLZT (20/0/100). Although the ceramics of this composition has a tetragonal system, we could not separate the lattice constants a and c for the film and we regarded the structure as a pseudo-cubic system. The lattice constants were $a \sim c \sim 3.95$ A. The surface of the film was very smooth and no crystallites were observed. Optical transmittance measurement showed that the thin film was transparent at visible and near infrared regions.

The PLZT thin film had ferroelectric properties with a slimloop D-E hysteresis curve. The temperature dependence of dielectric constant showed anomalous increase at about 150°C and the D-E hysteresis curve disappeared. The anomalous point is considered to be a Curie temperature. Details of these properties were reported in a previous publication.[5]

§3. Experimental Procedure

An as-grown state of epitaxial PLZT thin film had three equivalent anisotropic axes along the edges of a pseudo-cubic lattice, which made an angle of about 35 degrees to the film plane. Poling treatment was done as follows. First, we fabricated Al electrodes with 1 mm gaps on the film surface. Then the temperature was elevated to 200°C which was higher than Curie temperature. Next, we gradually cooled the sample from 200°C by applying voltage of 2 kV as shown in Fig. 2(a). The direction of applied electric field was parallel to

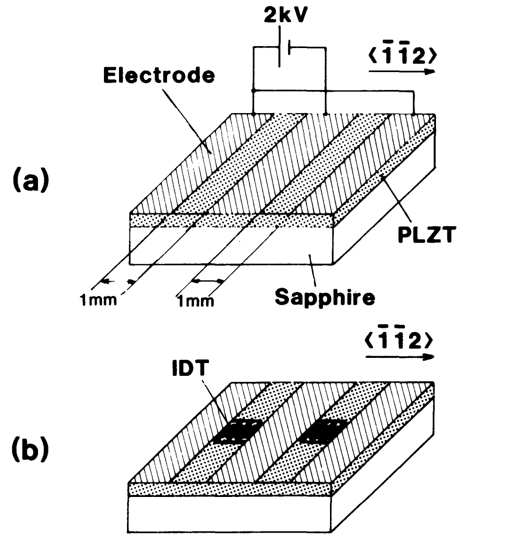

Fig. 2. Fabrication procedure of PLZT SAW devices.

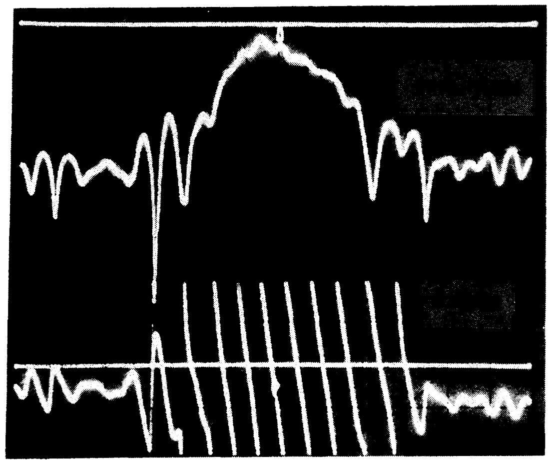

Fig. 4. Transmitting property of IDTs for the 0th mode of SAW. Horizontal scale: 406±12 MHz. Vertical scale: 10 dB/div. with −30 dB offset for amplitude, 90°/div. for phase.

⟨1̄1̄2⟩ of PLZT. The polarization of this region in the thin film would be uniformly arranged to ⟨001⟩. In order to excite and detect SAW, interdigital transducers (IDT) of Al were made by a lift-off method on the polarized regions as shown in Fig. 2(b). The period of the IDT finger was 12 μm and the pair number of the fingers was 80. We propagated SAW along the ⟨1̄1̄2⟩ direction of PLZT.

§4. Experimental Results and Discussion

Figure 3 shows a Smith chart plot of an impedance characteristic of the IDT. The normalized thickness of the film is $Kd=0.42$, where K is the wave number of SAW and d is the film thickness. There existed two modes whose center frequencies were 405 MHz and 455 MHz. Compared to the calculated results shown later, these mode were found to be the fundamental (0th) and the higher-order modes of SAW. An electromechanical coupling constant k^2 was evaluated by the Smith's relation

$$k^2=\frac{\pi^2 f_0 C_T R_a}{2N}, \qquad (1)$$

where N is the pair number of the fingers of IDT, C_T is the capacitance of IDT, f_0 is the center frequency and R_a is the measured radiation resistance.[6] The coupling constant k^2 is calculated to be about 0.85% for 0th mode of SAW, which is a relatively large value. Figure 4 shows the transmitting property of IDTs for the 0th mode of SAW measured by a 50 Ω system with matching circuits for IDTs. The insertion loss at the center frequency was about 30 dB. Figure 5 shows the temperature dependence of delay time which was measured by the frequency of a delay-time oscillator. The temperature coefficient of delay time was approximately 85 ppm/°C.

The phase velocity V_p and the coupling constant k^2 of SAW for various PLZT thickness are shown in Fig. 6. The open circle indicates the 0th mode SAW and the solid circle indicates the 1st mode. Since the physical parameters of the present PLZT are unknown, we have calculated the SAW properties using the parameters of $BaTiO_3$ and $PbTiO_3$ for comparison;[7,8] these are equally perovskite-type ferroelectric materials. The epitaxial relations and the propagating direction of SAW were similar to the experiment. The coupling constant k^2 is expressed as follows

$$k^2=2F\frac{\Delta V}{V_p}, \qquad (2)$$

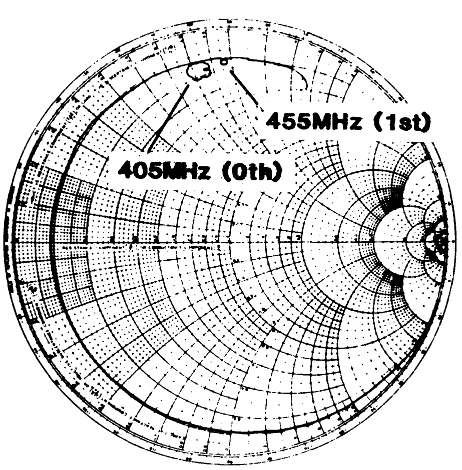

Fig. 3. Smith chart impedance plot for IDT. The normalized thickness of the PLZT film is $Kd=0.42$.

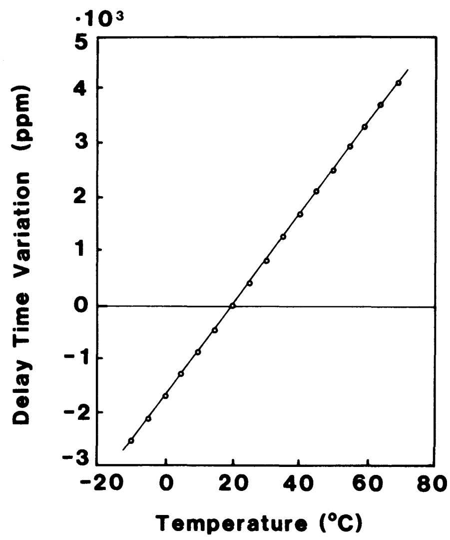

Fig. 5. Temperature dependence of delay time. The slope is about 85 ppm/°C.

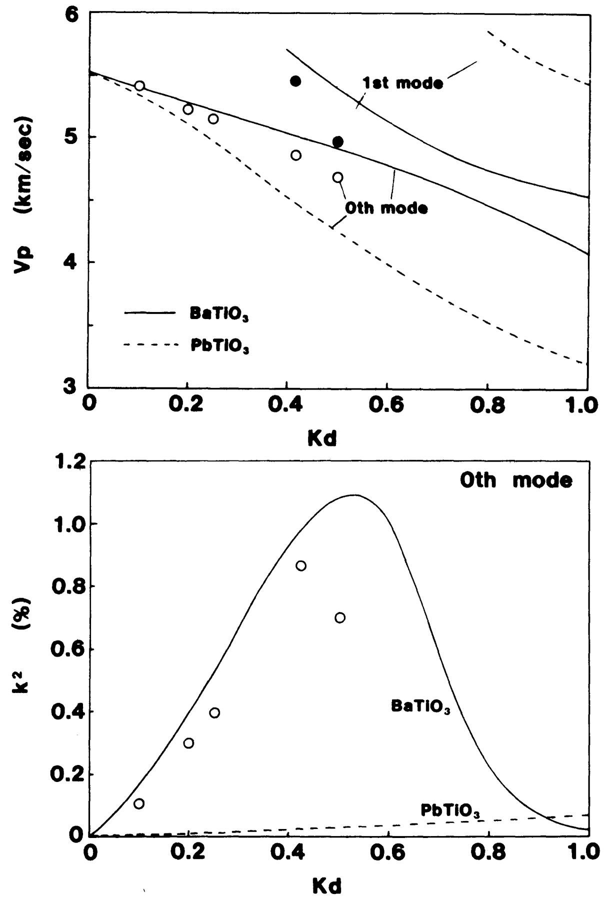

Fig. 6. The phase velocity and coupling constant of SAW for various *Kd*. Dots represent the experimental results for PLZT/sapphire. Lines represent the calculation for $BaTiO_3$/sapphire and $PbTiO_3$/sapphire.

where V_p is the SAW velocity, ΔV is perturbation of velocity and F is the filling factor. The calculation was carried out substituting 1 for F as usual. The results of calculation are shown in the figure by solid lines for $BaTiO_3$ and broken lines for $PbTiO_3$. Although the composition of the present PLZT is similar to $PbTiO_3$, the SAW properties show characteristics close to $BaTiO_3$. The piezoelectric effect of the PLZT thin film seems as strong as that of $BaTiO_3$.

§5. Conclusion

The epitaxial PLZT thin film on sapphire exhibits piezoelectricity and is applicable to SAW devices. The piezoelectric effect of the present PLZT is as strong as $BaTiO_3$. Further optimization of PLZT composition and film thickness will bring even more excellent SAW properties. From this experiment, it is found that PLZT thin film is one of the most attractive materials to realize integrated optic devices using both electrooptic and acousto-optic effects.

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