PZT Thin Films for SAW and BAW Devices

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Abstract – This paper summarises recent work of piezoelectric PZT thin film preparation and its applications to SAW and BAW devices in telecommunication systems. A number of PZT preparation methods have been reported. Amongst them, sputtering and sol-gel methods, which are discussed in this paper, seem to be two of the major candidates for practical applications. Although PZT thin films have not yet been applied to practical devices, their large electromechanical coupling factor would be promising for developing devices with wider bandwidth in UHF and SHF ranges.

I. INTRODUCTION

Since lead zirconate titanate (PZT) ceramics was revealed to possess a large electromechanical coupling in mid 1950s[1], it has widely been applied to many sorts of electronics devices. Although most of piezoelectric single crystals have been applied to developing devices like filters and resonators in RF bands, PZT ceramics has mainly been applied to low frequency (up to a few MHz) and/or high power devices like hydrophones, actuators, etc. In spite of an extremely large electromechanical coupling factor, relatively large loss of PZT ceramics has made it difficult to realise PZT-based signal processing devices at high frequencies.

In mid 1980s, high quality PZT thin films were successfully prepared and applied to ferroelectric random access memory (FRAM) devices[2], where such various preparation methods as MOCVD[3], sputtering and laser ablation[4] were attempted. Amongst them, sputtering and sol-gel methods seem to be two of the major candidates for practical piezoelectric applications. This is because they are able to prepare PZT thin films of relatively high quality with conventional equipment.

Although most of papers have mainly discussed ferroelectric properties and/or crystallographic characteristics of PZT thin films, some authors have pointed out that PZT thin films prepared by sputtering and/or sol-gel methods could be used as piezoelectric materials even in SHF range. If PZT thin films having an extremely large coupling factor in UHF and SHF ranges are developed, they should become an alternative material for realising signal processing devices in future communication systems where wider bandwidth and better temperature stability are required. From this point of view, we survey piezoelectric PZT thin films prepared by sputtering and sol-gel methods for high frequency device applications.

II. SPUTTERING METHOD

Sputtering method is most conventionally employed for preparing piezoelectric thin films such as ZnO and AlN. The method may also be effective in preparing high quality PZT thin films.

In mid 1980s, Adachi et al. fabricated an SAW delay line using an epitaxially deposited (Pb,La)(Zr,Ti)O_3 (PLZT) film on a sapphire substrate[5]. They employed rf-planar magnetron sputtering system with $Pb_{0.72}La_{0.28}Ti_{0.93}O_3$ powder as a target. The film was polarised as shown in Fig. 1(a), in which an ambient temperature was gradually cooled from $200°\mathrm{C}$ to room temperature. After the polarisation, two IDTs (periodicity: $12\ \mu\mathrm{m}$) were fabricated to generate and detect SAWs which propagate toward $<\bar{1}\bar{1}2>$ direction (see Fig. 1(b)).

The frequency response of the delay line for the 0th mode SAWs is shown in Fig. 2. The normalised

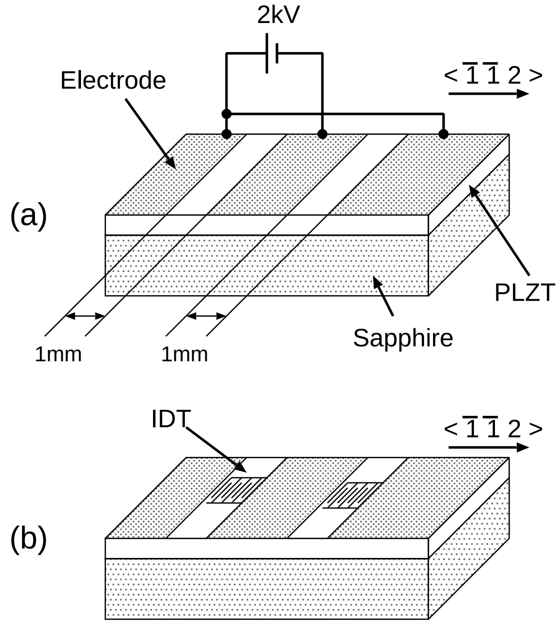

Figure 1: SAW delay line using epitaxially deposited PLZT film on sapphire substrate : (a) polarisation process, (b) SAW device structure [5].

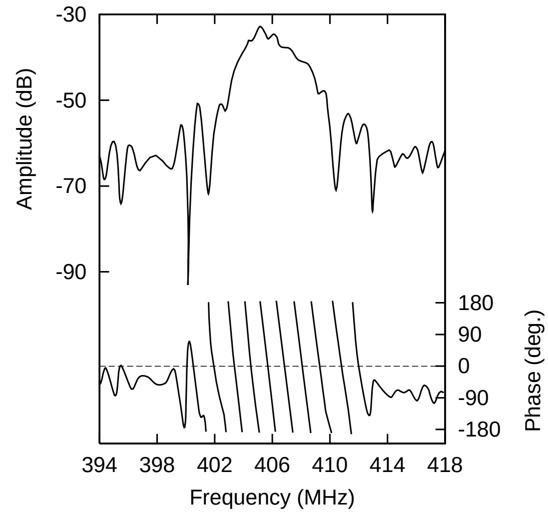

Figure 2: Frequency response between two IDTs for 0th mode SAWs[5].

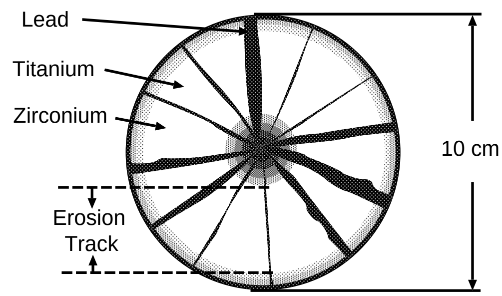

Figure 3: Multi-element metal target for PZT deposition[7].

thickness Kd $(= 2\pi d/\lambda)$ of the film is 0.42, where K and λ are the wavenumber and wavelength of SAWs, respectively, and d is the film thickness. They reported that the PLZT thin films have a coupling factor k^2 of about 0.85% and a temperature coefficient of delay TCD of approximately $85\ \mathrm{ppm}/°\mathrm{C}$.

Piezoelectric PZT or PLZT films can be prepared by the sputtering method using hot or cold pressed PZT or PLZT as a target. However, Sreenivas et al. pointed out that this sort of target have some disadvantages; for an example, oxygen deficiency and stoichiometric variations on the target surface occur after repeated use[7]. To avoid these disadvantages, they employed reactive sputtering using a multi-element metal target as shown in Fig. 3. They suggest that the multi-element metal target could possess the following advantages, (1) possibility of increasing sputtering rates, (2) possibility of increasing target area, (3) cleaned target surface by sputter etching, (4) simple modification of target composition, and (5) easy incorporation with dopant metals. They fabricated an SAW delay line using IDTs (periodicity: $100\ \mu\mathrm{m}$) deposited on the PZT films of the composition of $\mathrm{Zr}/\mathrm{Ti} = 58/42$. In the device, the SAW response was observed at $38.4\ \mathrm{MHz}$ with the PZT film of $3.4\ \mu\mathrm{m}$ thickness. The value of k^2 was estimated to be from 0.57% to 0.79% depending on the film thickness ($Kd = 0.21 \sim 0.37$).

Zhang et al. used a ZrTi alloy target on which PbO pellets are placed[6]; the atomic ratio of Pb/(Zr+Ti) is easily controlled by the number of the pellets.

It may generally be true that the film deposition of the materials belonging to the binary oxide system such as $\mathrm{PbTiO_3}$ (PT) is easier than those belonging to the ternary oxide system like PZT. Misu et al. developed thin film bulk acoustic resonators (FBARs) using a sputter-deposited PT thin film as shown in Fig. 4[9]. They suggested that the dense PT films with few pores could be prepared by doping La, although the La doped PT film has poorer crystallographic characteristics than non-doped PT films[8].

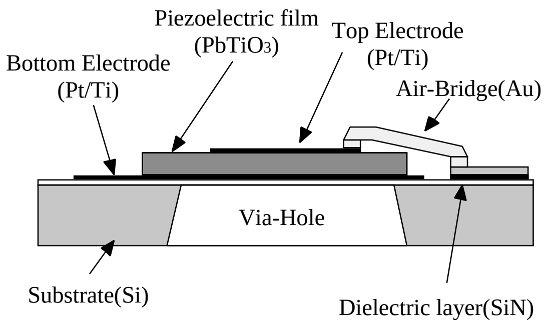

Figure 4: Thin film bulk acoustic resonator (FBAR) using $PbTiO_3$ thin film[9].

Figure 5 shows the frequency response S_{11} of the FBAR using La doped PT. The Q factor and coupling factor k_t^2 for the thickness longitudinal mode of the FBAR were estimated to be 100 and 1.1% at 1.4 GHz, respectively. Here, for the FBAR using the non-doped PT film, Q and k_t^2 were 70 and 4%, respectively.

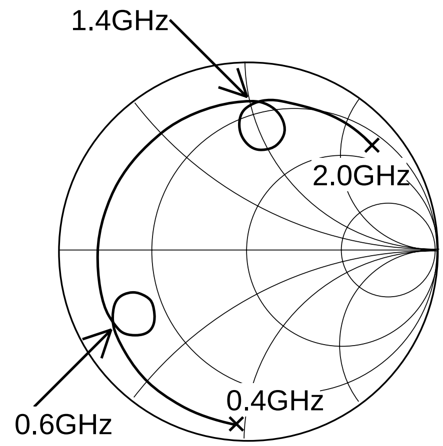

Figure 5: Reflection coefficient S_{11} of FBAR using La doped PT film[8].

III. Sol-gel method

Sol-gel method is very simple but effective method in preparing thin films. When preparing high quality PZT films[10], one could employ this sol-gel method successfully.

The thickness of dense PZT films obtained by a single batch (a sequence of coating precursor solution, prebaking and sintering) is limited to circa $0.1\ \mu\mathrm{m}$ because strong internal stress induced in the film results in small cracks. Thus, both coating and prebaking processes should repeatedly carried out until the thickness of the film gets a specified value (see Fig. 6[11]).

Luginbuhl et al. have developed Lamb wave devices using the PZT films of $0.75\ \mu\mathrm{m}$ thickness prepared by sol-gel method[12]. The operating frequencies were $2 \sim 4$ MHz. Although the PZT films need a dc bias field to make the piezoelectric coupling maximal and fatigue occurs with extended use, the authors concluded that the PZT films by sol-gel method provide a stronger piezoelectric coupling and generally produces higher acoustic powers than ZnO or AlN films.

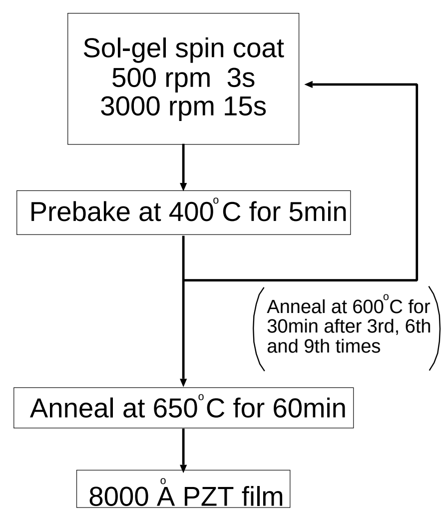

Figure 6: Flow diagram for preparing PZT thin films of $0.8\ \mu\mathrm{m}$ thickness[11].

Device applications of the sol-gel deposited PZT films in UHF and SHF ranges were discussed[11][13]. In particular, ref.[13] showed that the PZT film of $2.65\ \mu\mathrm{m}$ thickness possesses k_t of about 40% at 730 MHz, while the dielectric constant was about 700 and almost constant up to about 3 GHz. The value of k_t is comparable to that of PZT bulk ceramics.

An FBAR was fabricated using the PZT thin film deposited on a Si substrate which is coated with a $Pt/Ti/SiO_2$ layer (see Fig. 7). The Pt/Ti layer is used as a bottom electrode and as a buffer layer preventing

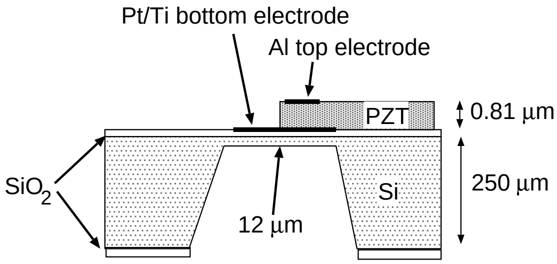

Figure 7: Basic structure of PZT film / Silicon diaphragm resonator[13].

Table 1: Device parameters of SAW delay line.

IDT finger width	3 μm
Periodic length of IDT fingers	12 μm
IDT aperture length	400 μm
Number of IDT finger pairs	20
IDT separation distance (center-to-center)	480 μm
PZT film thickness	0.8 μm

Pb from diffusing into the Si substrate. In the preparation of PZT thin films, the Pb diffusion is one of the problems to be carefully considered; Pb-rich precursor solution (ex. $\mathrm{Pb} : \mathrm{Zr} : \mathrm{Ti}{=}105 : 52 : 48$) is often used[14].

Figure 8 is the impedance response of the fabricated FBAR. Although there appear some spurious responses, it is seen from the figure that antiresonance Q factor of about 84 was obtained at 1.7 GHz. Note that the resonance Q is reduced to 50, which is caused by parasitic resistance of $1.5\ \Omega$. This relatively large resistance may originate in large resistivity of the Pt layer. Because of its large mass density, the Pt layer also reduces centre frequency considerably[14]. The result suggests that some alternative materials having low resistivity and small mass density should be developed for the effective buffer layer.

In ref. [13], SAW propagation on the PZT thin film was also experimentally discussed. An SAW delay line was fabricated by depositing Al IDTs on the PZT thin film of $0.8\ \mu\mathrm{m}$ thickness on a sapphire substrate. The device parameters are shown in Table 1.

The film was polarised by superposing dc bias field as shown in Fig. 9. The directions of the adjacent polarisation are reversed (see Fig. 9), which makes the equivalent IDT periodicity half of the geometrical periodicity of $12\ \mu\mathrm{m}$. Insertion loss of the delay line is shown in Fig. 10. Three major responses are observed at about 0.43 GHz, 0.76 GHz and 1.00 GHz with the insertion loss of 40 dB, 21 dB and 33 dB, respectively. The theoretical cal-

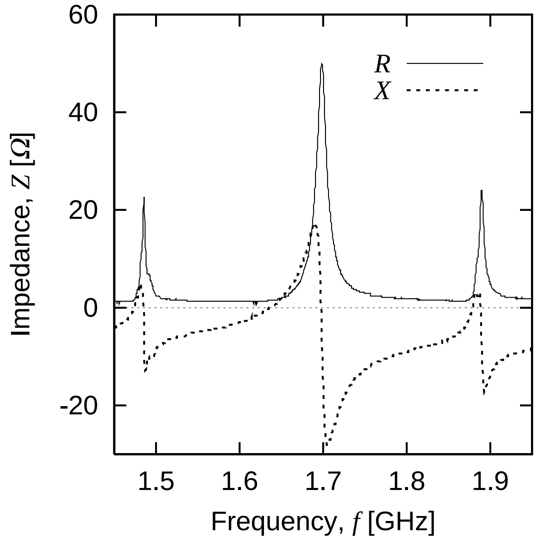

Figure 8: Impedance response of PZT film / Silicon diaphragm resonator[13].

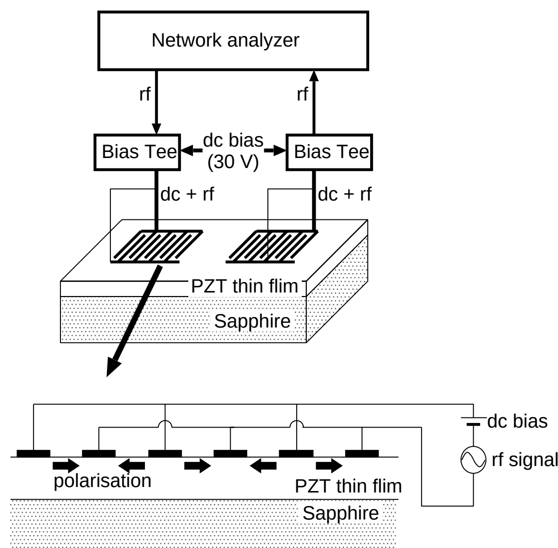

Figure 9: Basic structure of PZT film/sapphire substrate SAW delay line[13].

culation suggests that two responses at 0.76 GHz and 1.00 GHz may be attributed to the fundamental and second order IDT resonance for the lowest order SAW mode propagating on the PZT film/sapphire substrate structure. The response at 0.42 GHz seems as if it was attributed to SAWs having its wavelength of about $12\ \mu\mathrm{m}$. This is totally inconsistent with the assumption that because of the reversed polarisation, the equivalent periodic length should $6\ \mu\mathrm{m}$, and the reason for this has not yet been understood completely.

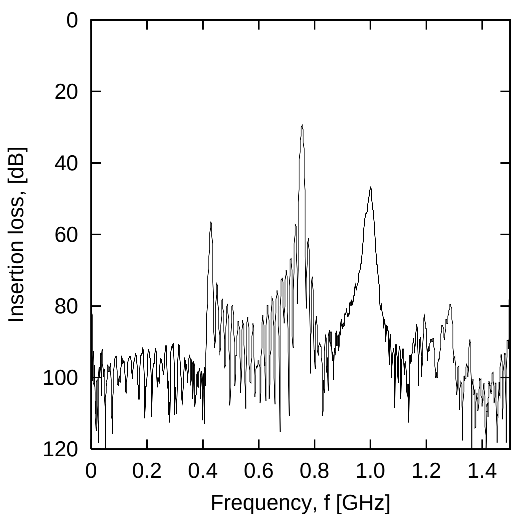

Figure 10: Frequency response of SAW delay line on PZT film / sapphire substrate structure[13].

As described above, one of the drawbacks of the sol-gel method is that one should repeat the processes for the spin-coating of PZT precursor solution and prebaking several times. The present authors have proposed modified sol-gel method as one of the attempts to prepare PZT films of nearly $1\ \mu\mathrm{m}$ thickness by a single batch[15].

Figure 11 shows the process, where the PZT precursor is poured into small pits made of by ZnO film. The thickness and diameter of the pit are $1.2\ \mu\mathrm{m}$ and $200\ \mu\mathrm{m}$, respectively. After drying, the precursor gel is etched along the rims of the ZnO mould by the solvent of the precursor in order to prevent ZnO from chemical reacting with PZT. After sintering, the ZnO mould is removed by acetic acid solution.

It is reported that k_t^2 of the PZT small disc fabricated by this method is about 4% at 2.1 to 2.6 GHz.

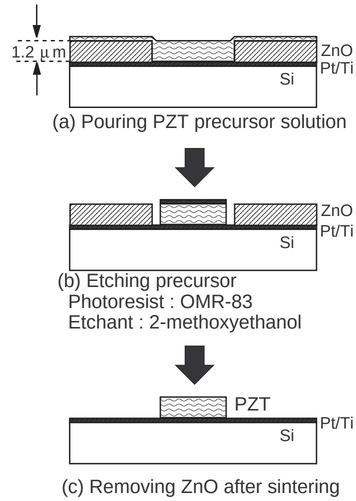

Figure 11: Modified preparation process of PZT films.

IV. Conclusion

This paper has surveyed preparation of PZT thin films and their application to BAW and SAW devices. In particular, a large electromechanical coupling factor of PZT would be most promising for developing devices with wider bandwidth in UHF and SHF ranges. As was discussed, however, a lot of problems are still left for practical applications, and should be resolved in future work.

Acknowledgments

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