Thick PZT epitaxial film for ultrasonic transducer in the 80 MHz range

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1. Introduction

The frequency range of 20–100 MHz ultrasonics are promising for photoacoustic imaging [1], which is useful to observe blood in vivo at high resolution. PVDF (Polyvinylidene Difluoride) is a common material[2] for ultrasonic transducers for photoacoustic imaging as shown in Fig. 1. However, electromechanical coupling of PVDF ($k_t^2=4\%$[2]) is too low for practical application. On the other hand, PZT is an attractive material for applications such as medical imaging, resonator and so on due to its high $k_t^2$. We previously reported high $k_t^2$ of 28.1%[3] of PTO (the PZT family) epitaxial thin films.

In order to achieve lower frequency operation, thicker film is one of the approaches. However, internal stress control becomes more difficult as the film gets thicker. Many studies of PZT thick film transducers, therefore, were centered on the use of polycrystalline films.

In this study, we reports sputter PZT epitaxial thick film (16.0 μm) high efficient transducer operating in the 20–100 MHz.

2. Growth of PZT thick film

PZT thick films were grown on conductive single crystalline La–SrTiO$_3$ (La–STO) substrate by RF magnetron sputtering [9,10], as illustrated in Fig. 2. Growth conditions are summarized in Table I. The substrate is at the floating potential to reduce the effects of ion–irradiation–induced stress during the deposition.

Next, we measured crystalline quality of the PZT thick film. As shown in Fig. 3, strong PZT (002) peak was observed at around $2\theta=43^\circ$. (002) peak rocking curve FWHM of the PZT were measured to be $0.4^\circ$ which shows high crystalline quality.

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**Table I** Growth conditions

<table>
<thead>
<tr>
<th>Ar/O$_2$</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition time</td>
<td>100 hours</td>
</tr>
<tr>
<td>RF power</td>
<td>100 W</td>
</tr>
<tr>
<td>Deposition pressure</td>
<td>0.5 Pa</td>
</tr>
<tr>
<td>Deposition temperature</td>
<td>500 ℃</td>
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</tbody>
</table>

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Fig. 1 Relationship between the operating frequency and ultrasonic measurement system.

Fig. 2 The RF magnetron sputtering system.

Fig. 3 XRD pattern and rocking curve of the PZT thick film.
3. Evaluation of the electromechanical coupling $k^2$

We fabricated the high-overtone bulk acoustic resonator (HBAR) structure (Au/PZT/La-STO substrate).

Next, we obtained the impulse response by an inverse Fourier transform of the reflection coefficient $S_{11}$ measured using a network analyzer (E5071C, Agilent Technology), as illustrated in Fig. 4. As shown in Fig. 5, ultrasonic echoes reflected from the bottom of the substrate were observed at 89 nsec. intervals. From longitudinal velocity and thickness of PZT and La-STO substrate, these echoes were determined to be longitudinal wave. Longitudinal wave conversion loss (CL) was calculated by a Fourier transform of the first echo.

Fig. 6 shows experimental CL and theoretical one simulated by Mason’s equivalent circuit model. The minimum CL of 2.8 dB was found at 89 MHz. $k^2$ estimated by comparison of experimental and theoretical CLs was 26.0%, which is much higher than that of PVDF (4%).

4. Conclusion

In recent years, ultrasonic applications are receiving attention in medical imaging for its safety and versatility to investigate various properties. Particularly, most photoacoustic microscopy uses transducers operating in the 20–100 MHz. However, PVDF commonly used for transducers in the 20–100 MHz exhibits low piezoelectricity.

In this study, we achieved PZT thick epitaxial growth (16 μm) by using RF magnetron sputtering. $k^2$ of the PZT is estimated to be 26.0%. This $k^2$ are much higher than that of PVDF (4%). Therefore, PZT thick film transducer is well suited for photoacoustic imaging and medical ultrasonic applications.

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References


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