High efficiency ScAlN thick film hydrophone operating in the ranges of 40-80 MHz
ScAlN 帯高効率ハイドロフォン

Ko-hei Sano$^{1†}$, Rei Karasawa$^1$, and Takahiko Yanagitani$^{1,2,3}$
($^1$Waseda Univ.; $^2$JST PRESTO; $^3$ZAIKEN)

1. Introduction

Ultrasonic hydrophone is used for a imaging technology in medical fields. The resolution of images are determined by frequency of hydrophones. A medical ultrasound diagnostic system and an ultrasonic microscope are generally used in the frequency range of 1 MHz-20 MHz and 100 MHz-2 GHz, respectively. Therefore, the frequency ranges of 20-100 MHz is not well-developed because of less applications or less suitable piezoelectric materials. Recently, the demand for a photoacoustic imaging which is used the range of 20-100 MHz is increasing. PVDF polymer membranes are usually used for ultrasonic hydrophones in the 10-50 MHz. However, their electromechanical coupling coefficient ($k_t^2$) of 4% is not enough for the practical uses.

In recent years, a high piezoelectricity of ScAlN thin films ($k_t^2=15\%$) has been reported[1-2]. The piezoelectric property is improved by increasing the Sc concentration. Its piezoelectricity reaches maximum, when the Sc is approximately 40%. The ScAlN possesses low dielectric loss and high temperature tolerance. Temperature tolerance is important when a high electric field is applied, which is attractive for high power application.

To excite the ultrasonic in the 20-100 MHz, 25 µm-125 µm thick piezoelectric film is required. However, it is difficult to fabricate such a thick piezoelectric film without a crack caused by the internal stress during the deposition.

In this study, we achieved stress free film growth by employing the unique hot cathode RF magnetron sputtering technique, as shown Fig.2. Sc concentration of the film was determined to be 39% by a fluorescent X-ray analyzer (ZSX-PrimusII, Rigaku). The $k_t^2$ value of the thick film were determined by comparing the experimental and the theoretical longitudinal wave conversion losses without the water medium. The experimental conversion losses were measured using a network analyzer (E5071C, Agilent Technologies).

3. Results and discussion

Experimental and theoretical conversion loss curves of the hydrophone without the water medium are shown in Fig.3. The theoretical conversion loss curves were simulated using multilayered Mason’s equivalent circuit model. The $k_t^2$ value of the ScAlN thick film is determined to be 11.9% at the resonance frequency of 43 MHz. Table I shows the typical properties of the piezoelectric film materials. Compared to $k_t^2=4\%$ of PVDF and 8.4% of ZnO thin film, the $k_t^2$ of ScAlN thick film(90 µm) is much larger.

![Fig. 1](image1.png)

**Fig. 1** Structure of thick ScAlN film hydrophone

![Fig. 2](image2.png)

**Fig. 2** The hot cathode RF magnetron sputtering system.

---

1. k-sano@fuji.waseda.jp
2. yanagitani@waseda.jp
Fig. 3 Experimental and theoretical conversion loss curves of the ScAlN thick film. The theoretical curves were simulated by Mason’s equivalent circuit model.

We injected the water medium under the silica glass buffer rod. The time domain impulse response which was obtained by an inverse Fourier transform of $S_{11}$ are shown in Fig.4. The longitudinal and shear reflection waves were periodically observed with 4.1 $\mu$s and 6.4 $\mu$s, respectively. In addition, the wave from the water medium was clearly observed at 5.1 $\mu$s. Fig.5 shows the conversion loss which was measured by using the wave from the water medium. Compared the ScAlN thick film hydrophone with the simulation curve of PVDF one, the conversion loss of the ScAlN is much better than that of the PVDF.

Fig. 4  The time domain impulse response of the hydrophone after injecting the water medium.

4. Conclusion

We achieved stress free extremely thick ScAlN film growth by the unique hot cathode RF magnetron sputtering method. The conversion loss of the ScAlN hydrophone in the water medium is much better than the PVDF one. In the future, ScAlN thick film hydrophones at the frequency range of 20-100 MHz might be useful as a high resolution invivo imaging.

Acknowledgment
This work was supported by JST PRESTO (No. JPMJPR16R8).

References

Table I  $k_t$ and heat resistant temperature of piezoelectric film materials

<table>
<thead>
<tr>
<th>Film Material</th>
<th>$k_t$</th>
<th>$k_t^2$</th>
<th>Heat resistant temperature</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMN-PT (PT 33%)</td>
<td>0.55</td>
<td>30%</td>
<td>$&lt; 130 , ^\circ C$</td>
<td>[3]</td>
</tr>
<tr>
<td>PZT (sol-gel)</td>
<td>0.40</td>
<td>16%</td>
<td>$&lt; 410 , ^\circ C$</td>
<td>[4]</td>
</tr>
<tr>
<td>PVDF</td>
<td>0.20</td>
<td>4%</td>
<td>$&lt; 170 , ^\circ C$</td>
<td>[5]</td>
</tr>
<tr>
<td>ZnO thin film</td>
<td>0.29</td>
<td>8.4%</td>
<td>$&lt; 350 , ^\circ C$</td>
<td>[6]</td>
</tr>
<tr>
<td>ScAlN thin film</td>
<td>0.39</td>
<td>15%</td>
<td>$&gt; 600 , ^\circ C$</td>
<td>[1-2]</td>
</tr>
<tr>
<td>ScAlN thick film (90 $\mu$m-43 MHz)</td>
<td>0.345</td>
<td>11.9%</td>
<td>-</td>
<td>This study</td>
</tr>
</tbody>
</table>