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High efficiency ScAlN thick film hydrophone operating in the ranges of 40-80 MHz

ScAlN 厚膜を用いた 40-80MHz 帯高効率ハイドロフォン

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1. Introduction

Ultrasonic hydrophone is used for a imaging technology in medical fields. The resolution of images are determed 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 maximam, when the Sc is approximately 40%. The ScAlN possesses low dielectric loss and high temperature tolerance. Temperature tolerance is impotant 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 without heating substrate. We fabricate high efficient 43 MHz ultrasonic hydrophone by using the 90 μm ScAlN(Sc:39%) thick film.

2. Experimental

The ultrasonic hydrophone consists of ScAlN thick film(90 μm) and silica glass buffer rod, as shown **Fig.1**. This hydrophone emits acoustic waves from the reverse of the glass rod. The ScAlN thick films were fabricated by using 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.

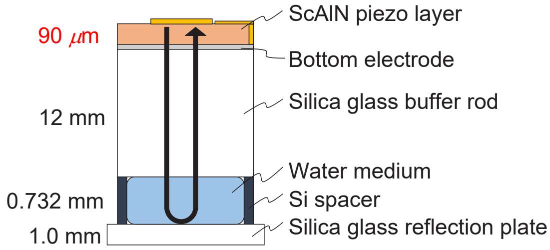

Fig. 1 Structure of thick ScAlN film hydrophone

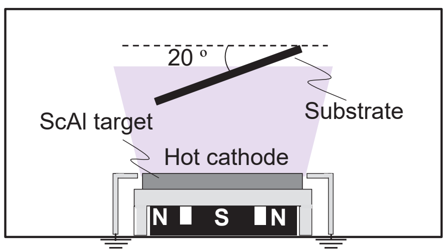

Fig.2 The hot cathode RF magnetron sputtering system.

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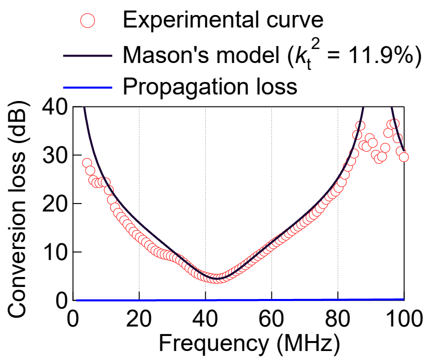

Fig. 3 Experimental and theoretical conversion loss curves of the ScAlN thick film. The theoretical curves were simulated by Mason's equivalent circuit model.

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 μs and 6.4 μs, respectively. In addition, the wave from the water medium was clearly observed at 5.1 μs. **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.

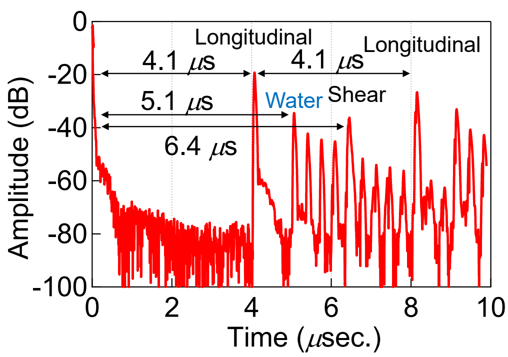

Fig. 4 The time domain impulse response of the hydrophone after injecting the water medium.

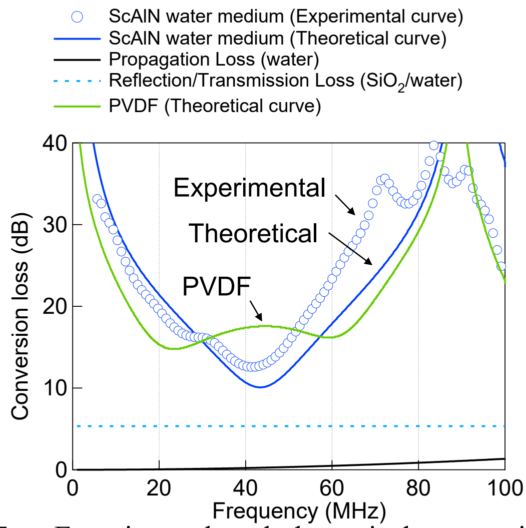

Fig. 5 Experimental and theoretical conversion loss of the ScAlN hydrophone and theoretical conversion loss curves of the PVDF hydrophone.

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

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Table I k_t and heat resistant temperature of piezoelectric film materials

	k_t	k_t^2	Heat resistant temperature	Reference
PMN-PT (PT 33%)	0.55	30%	< 130 ºC	[3]
PZT (sol-gel)	0.40	16%	< 410 ºC	[4]
PVDF	0.20	4%	< 170 ºC	[5]
ZnO thin film	0.29	8.4%	< 350 ºC	[6]
ScAlN thin film	0.39	15%	> 600 ºC	[1-2]
ScAlN thick film (90 μm-43 MHz)	0.345	11.9%	-	This study