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Polarity inverted Al-polar ScAlN/O-polar ZnO multilayers for high conversion efficiency transducer in the GHz range
Al 極性 ScAlN/O 極性 ZnO 極性反転多層構造を用いた GHz 帯高効率トランスデューサ

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1. Introduction

Polarity inverted multilayer piezoelectric transducers are attractive for high order mode excitation and high power operation. In the ultrasonic microscope applications, n-fold low capacitance of nth polarity inverted multilayer enables n-fold increase of emission area in the transducer without sacrificing impedance matching between the transducer and 50Ω measurement system. Large emission area leads to concentration of ultrasonic. We previously reported the control of the polarity in ScAlN and ZnO films by ion beam irradiation during film growth. We found that the usual ScAlN and ZnO films grown by a standard planar sputtering possess (0001) Al-polarity and (000-1) O-polarity, respectively [1-2].

In this study, we considered that the polarity inverted (0001)/(000-1) multilayer can be easily obtained by depositing usual (0001) Al-polar ScAlN film on usual (000-1) O-polar ZnO film. To check this assumption, we fabricated polarity inverted (0001) ScAlN/(000-1) ZnO two layer film transducer (**Fig. 1**) by using a conventional magnetron sputtering. The polarity inversion phenomenon was observed by using a press test and the transducer conversion loss characteristics.

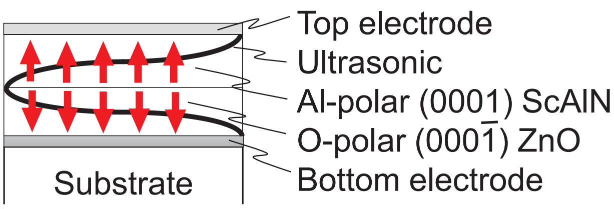

Fig. 1 Polarity inverted Al-polar (0001) ScAlN/O-polar (000-1) ZnO film transdurcer

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2. The growth of polarity inverted multilayer structure

c-axis oriented ZnO films (approximately 4.2μm) were grown on highly oriented (0001) Ti film/silica glass substrate by off-axis deposition geometry. c-axis oriented ScAlN films (approximately 3.9μm) was grown on the ZnO films by on-axis deposition geometry. In addition, single-layered ZnO and ScAlN film were prepared on the same substrate to check their polarity direction.

3. Crystalline orientation

Figs. 2 (a) and (b) show XRD patterns for ScAlN/ZnO multilayer film and ω-scan rocking curve of second layer ScAlN film and first layer ZnO film, respectively. As shown in Fig. 2 (a), (0002) ZnO peak at around 34º and (0002) ScAlN peak at around 36º were observed. As shown in Fig. 2 (b), ω-scan rocking curves FWHM in ZnO and ScAlN film were 1.6º and 2.8º, respectively, showing that c-axis of each layer is normal to the substrate plane.

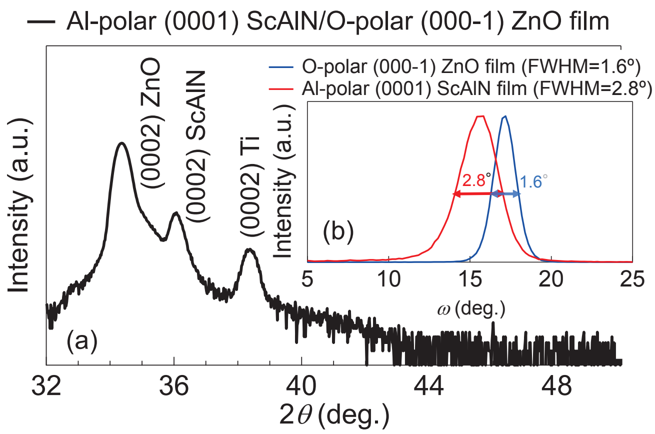

Fig. 2 (a) XRD patterns for ScAlN/ZnO multilayer film and (b) ω-scan rocking curve of second ScAlN layer and first ZnO layer

4. Polarity direction of the each layers

The polarity direction of the layers were determined by a press test using an oscilloscope. As shown in **Fig. 3**, positive response, indicating O-polarity, was observed in the first layer ZnO film when the compressive stress was applied, whereas the negative response, indicating Al-polarity, was observed in the second layer ScAlN film.

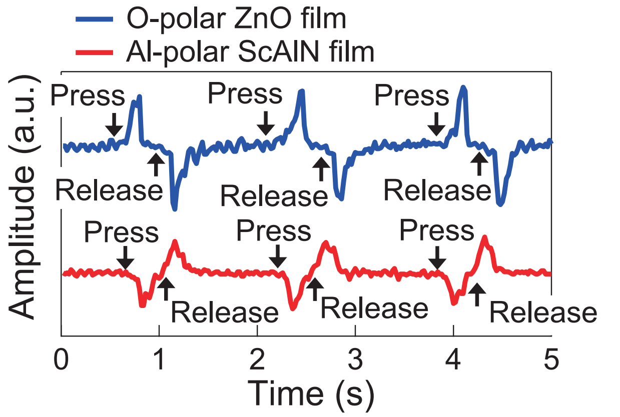

Fig. 3 Piezoelectric responses of second ScAlN layer and first ZnO layer when compressive stress is applied

5. Piezoelectric properties

Transducer structure was fabricated by evaporating Au top electrode film on the surface of the films. The longitudinal wave conversion loss (*CL*) of the transducers were measured by a network analyzer to evaluate polarity inversion in Al-polar (0001) ScAlN and O-polar (000-1) ZnO films [1]. **Figs. 4 (a), (b) and (c)** show the longitudinal wave *CL* for single-layered ScAlN and ZnO films, and two-layered polarity inverted ScAlN/ZnO films. As shown in Fig. 4 (a), single-layered ZnO film transducer excited the 1st mode resonance at 0.68 GHz. As shown in Fig. 4 (b) single-layered ScAlN film transducer excited the 1st mode resonance at 0.74 GHz. 2nd mode excitation were not observed in the single-layered film transducer. As shown in Fig. 4 (c), two-layered (0001) ScAlN/(000-1) ZnO film excited the 2nd mode resonance at 0.72 GHz with suppression of the 1st mode resonance at 0.27 GHz. The experimental *CL* curve agreed well with the theoretical one calculated by Mason's equivalent circuit model including the effects of polarity inversion. This indicates that the polarity direction of the second layer and the first layer are perfectly inverted.

Minimum *CL*s of single-layerd ZnO and ScAlN film transducers are 4.8 dB and 2.8 dB, respectively. Minimum *CL* of 1.8 dB in two-layered (0001) ScAlN/(000-1) ZnO film transducer is smaller than that of typical single-layered ScAlN and ZnO films. Polarity inverted mulatilayer transducer has high conversion efficncy than single-layered film transducers, as expected.

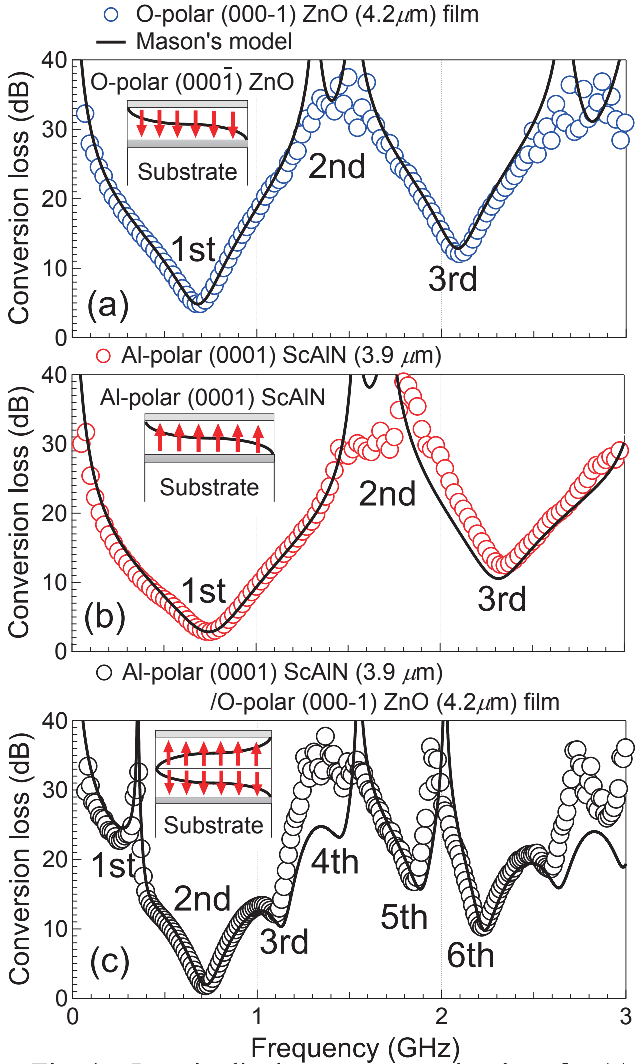

Fig. 4 Longitudinal wave conversion loss for (a) single-layered O-polar (000-1) ZnO film, (b) single-layered Al-polar (0001) ScAlN film and (c) two-layered O-polar (000-1) ZnO/Al-polar (0001) ScAlN film

6. Conclusion

We fabricated polarity inverted Al-polar ScAlN/O-polar ZnO multilayers transducer by a conventional magnetron sputtering. The excitation of 2nd mode resonance and the suppression of 1st mode resonance was clearly observed in the polarity inverted transducer.

References

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