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Wideband ZnO Multimode Transducer Consisting of c-axis Normal and Tilted Orientation Layers

c 軸垂直配向と傾斜配向 ZnO 膜から成る
広帯域縦波横波トランスデューサ

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1. Introduction

Wideband ultrasonic transducers in the ultra-high-frequency (UHF) range are required for a nondestructive evaluation. The frequency bandwidth is narrow in the case of a convensional thickness-mode transducer, because even-order overtones cannot be excited. Nakamura et al. reported wideband VHF transducer consisting of domain priodically inverted $LiNbO_3$ plate, which excites both fundamental and second-overtone modes.[1)] Combination of these mode excitation makes an wideband excitation possible.

On the other hand, we previouslly developed a transducer consisting of single c-axis tilted ZnO layer, as shown in **Fig. 1(a)**.[2)] This transducer excites longitudinal wave and shear wave.

In this study, we propose a wideband multi layer transducer consisting of c-axis normal and tilt ZnO layers, as shown in **Fig. 1(b)**. c-axis normal ZnO local epitaxial layer can be grown on a Au (111) layer, because ZnO (0001) and Au (111) have a local epitaxial relationship even though these films are polycrystal.[3)] We predicted that c-axis normal ZnO layer formes on Au electrode due to the local epitaxial effect during the initial stage of ZnO deposition, and c-axis tilted orientation gradually forms as growth progressed (Fig. 1(b)). This means that c-axis normal and tilted ZnO layers can be continuously grown.

To demonstrate this prediction experimentally, we investigated the crystal growth of the film. Furthermore, we showed that this film is suitable for a wideband transducer.

2. ZnO Transducer Fabrication

Multilayer transducer as shown in Fig. 1(b) was fabricated on a silica glass substrate (0.625 mm thickness, ED-B, Tosoh) with Au (111) (0.15 μm) / Ti (0.01 μm) films. FWHM of the XRD rocking curve in Au (111) was 5.6°. ZnO film (4.21 μm) was deposited using an RF magnetron sputtering system (RFS-200, Ulvac) under the condition that c-axis tilted ZnO forms.[2)] Next, Cu top electrode film (0.18 μm) was evaporated on the ZnO film surface.

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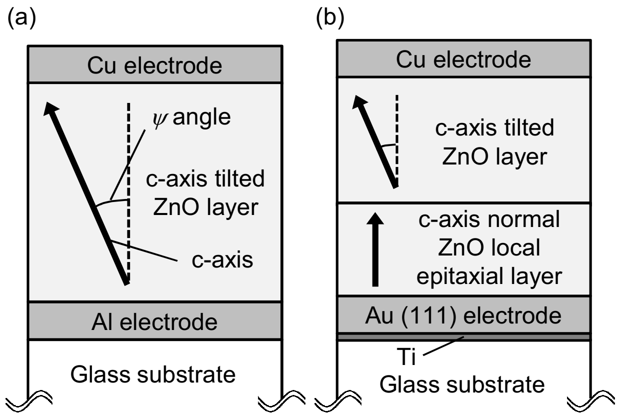

Fig. 1 Structures of the ZnO transducers with (a) single c-axis tilted orientation layer and (b) c-axis normal and tilt multilayer.

3. Crystalline Orientation of the Transducer

The crystalline orientation of the transducer was determined by an XRD pole figure. **Fig. 2(a)** and **2(b)** show ψ-scan profile curves of ZnO (0002) in the single layer transducer (Fig. 1(a)) and the multilayer transducer (Fig. 1(b)), respectively. The ψ angle, where the peak appears, corresponds to the c-axis tilt angle from the normal to the transducer surface. Single layer transducer had only one peak at ψ = 21.6° in Fig. 2(a). In contrast, multilayer transducer had two strong peaks at ψ = -0.7° and 22.0° in Fig. 2(b). ψ-scan FWHM of the peak at ψ = -0.7° was 6.6°. This result showed that c-axis normal ZnO local epitaxial layer was grown on the Au (111) layer. The peak at ψ = 22.0° indicates that c-axis 22.0° tilted ZnO layer was also formed.

Cross-sectional SEM image of the multilayer transducer is shown in **Fig. 3**. Normal crystal grains growth during the initial stage of film deposition was observed. Crystal growth direction tilted as growth progressed. The ZnO transducer with c-axis normal and tilt layers thus can be fabricated without changing the conditions during the deposition.

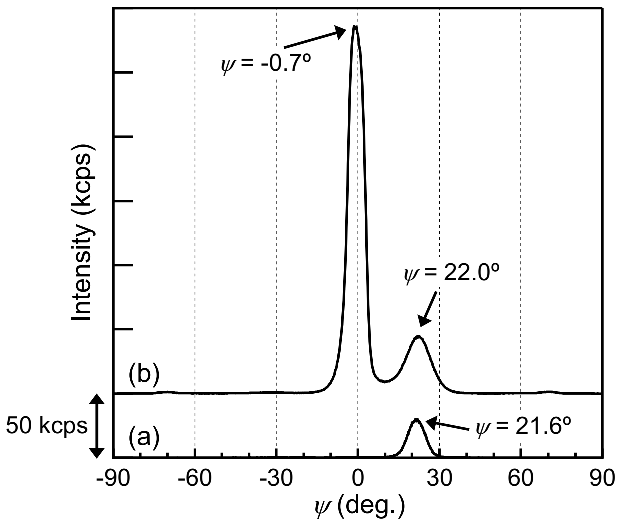

Fig. 2 ψ-scan profile curves of ZnO (0002) of (a) single layer transducer and (b) multilayer transducer.

4. Frequency Characteristics of the Transducer

Fig. 4(a) and **4(b)** show longitudinal wave and shear wave conversion losses of the transducer. Two theoretical curves were calculated by using Mason's equivalent model. One was the characteristic of single layer transducer (the thickness of c-axis normal layer was 4.21 μm) and another one was that of multilayer transducer (the thicknesses of c-axis normal and tilted layers were 1.25 μm and 2.96 μm, respectively). In Fig. 4(a) and 4(b), a second-overtone mode excitation is not found in the theoretical curve of single transducer, because stresses or piezoelectric polarizations induced at the upper and lower parts of the piezoelectric layer cancel each other out. In contrast, fundamental (L_1, S_1) and second-overtone (L_2, S_2) modes were observed in multilayer transducer. Stresses or piezoelectric polarizations induced at the c-axis normal and tilt layers are not equal and are not completely canceled. Therefore, the frequency bandwidth of multilayer transducer was broader than that of single layer transducer.

5. Conclusions

ZnO multimode transducer consisting of c-axis normal and tilt layers has been fabricated using ZnO (0001) / Au (111) epitaxial growth without changing the conditions during the deposition. The frequency characteristics of this transducer are wideband. This UHF transducer has potential for use in a nondestructive evaluation.

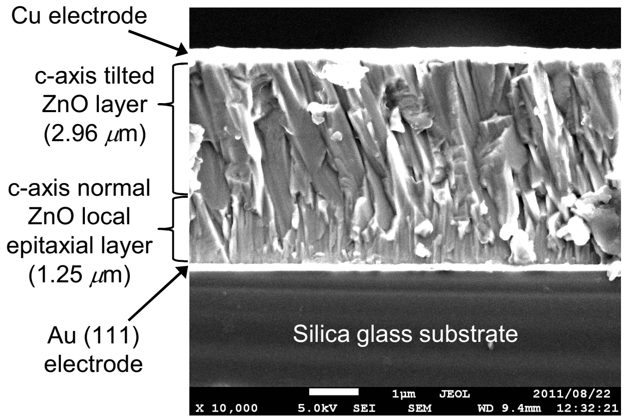

Fig. 3 Cross-sectional SEM image of multilayer transducer.

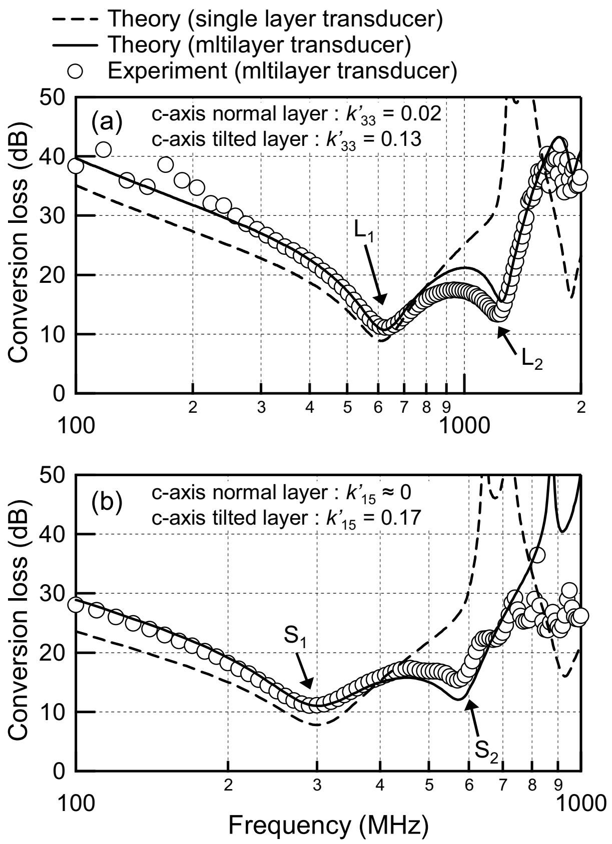

Fig. 4 Experimental and theoretical frequency characteristics of (a) longitudinal wave and (b) shear wave conversion losses of the transducers.

References

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