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Polarization-inverted multilayer shear mode resonator with c-axis parallel AlN films fabricated by IBAD

IBAD 法による c 軸平行配向 AlN 薄膜を用いた極性反転多層膜すべり共振子

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1. Introduction

c-axis parallel AlN films excite pure shear wave. These films are suitable for SH-SAW device[1,2] and thickness shear mode film resonator [3,4].

As shown in Fig. 1, the resonator with single piezoelectric layer excites fundamental mode resonance, on the other hand, polarization-inverted multilayer resonator excites high-order mode resonance. Resonant frequency of high order mode resonator is higher than that of fundamental mode resonator in the case that entire film thickness is same. Namely, the film thickness of high order mode resonator is thicker in same operating frequency. Therefore, high order mode resonator is expected to have high power handling capability.

In general, c-axis parallel AlN film is fabricated by using an epitaxial growth technique. But the polarization direction of the film is determined by polarization direction of the substrate and the direction can not be inverted in this technique, as show in Fig. 1 (a). In contrast, c-axis in-plane direction might be determined by the direction of ion beam irradiation in ion beam assisted deposition (IBAD) technique.

In this study, we examined c-axis parallel polarization-inverted multilayer AlN film deposition by using ion beam assisted RF magnetron sputtering. In-plane crystalline orientation and piezoelectric properties of the multilayer AlN film were investigated.

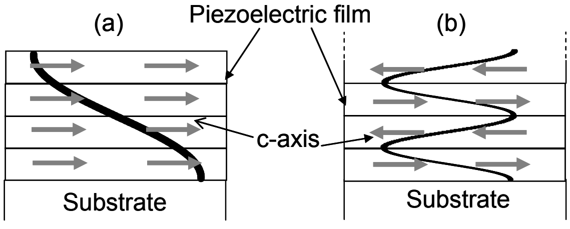

Fig.1 (a) Single polarization film by an epitaxial growth technique.
(b) Polarization inverted multilayer film by IBAD technique.

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2. Polarization-inverted AlN film deposition

We considered that in-plane crystal growth direction should be controlled by ion beam irradiation direction. To examine this, c-axis parallel multilayer AlN film was fabricated by using 3 kV accelerated Ar / N_2 ion beam irradiation. The incident angle of ion beam irradiation was fixed to 20º in all deposition. As shown in Fig. 2, *a*-angle, which is the in-plane angle of the beam, was adjusted by rotating substrate in each layer deposition. Thus, the crystal growth direction in the layers should be changed, and in-plane direction of c-axis is expected to be controlled.

Three samples labeled sample A, B and C were prepared. Sample A, B and C was two-layered, four-layered, and seven-layered AlN multilayer film, respectively. Substrate was rotated 180º in samples A and B in each layer deposition (Fig. 2 (a)). Substrate was rotated 30º interval in sample C in each layer deposition (Fig. 2 (b)). All layers were deposited in same deposition conditions.

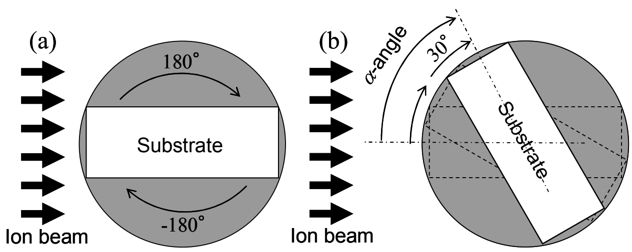

Fig. 2 The direction of ion beam irradiation in (a) sample A, B and (b) sample C.

3. Crystalline orientation

X-ray pole figure analysis of samples was performed to evaluate in-plane crystalline orientation. Fig. 3 (a) and (b) show (0002) pole figure of sample B and ϕ–scan curve at ψ = 83º. ϕ-angle and ψ-angle indicated in-plane direction of c-axis and tilted angle of c-axis, respectively.

The pole diffracted from first layer was observed at ψ = 82º and ϕ = 270º, and the pole from second layer was observed at ψ = 82º and ϕ = 90º. These results show that c-axis was almost parallel to substrate plane in both layers, and the in-plane growth direction of c-axis in second-layer was inverted. Fig. 4 (a) and (b) show (0002) pole figure of sample C and ϕ–scan curve at ψ = 83º. Interestingly, the poles diffracted from each layer were observed at ϕ=30º interval between 0º to 180º. These ϕ angles corresponded with α-angle (in-plane angle of the beam). These results demonstrate that the crystal growth direction can be controlled by adjusting in-plane ion beam direction without depending on crystalline orientation of under layers.

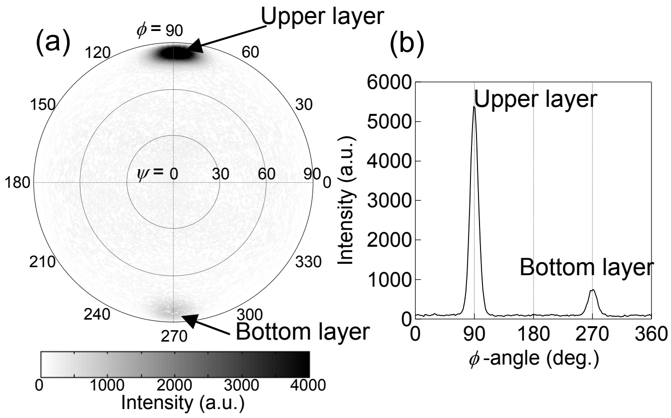

Fig. 3 (a) (0002) pole figure of sample A (two-layered AlN film)
(b) ϕ–scan curve at ψ = 83º of sample A

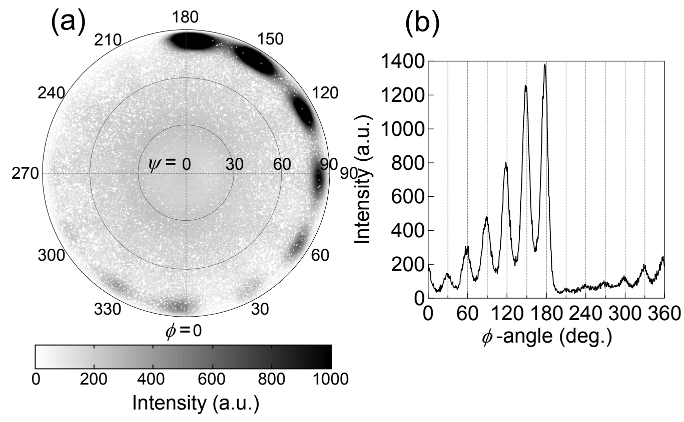

Fig. 4 (a) (0002) pole figure of sample C (seven-layered AlN film)
(b) ϕ–scan curve at ψ = 83º of sample C

4. Piezoelectric properties

Polarization inversion in the layers was evaluated from the conversion loss (CL) characteristics of the film. Resonators consisting of four layers of top electrode / multilayer AlN film / bottom electrode / substrate were prepared to measure conversion loss.

Fig. 5 (a) and (b) show shear wave CL of sample A and B. Fundamental mode resonance was suppressed, and second order mode resonance was excited in sample A (two layer). The resonant frequency of sample A was found to be 1.75 GHz. Similarly, fourth order mode resonance excitation at 1.9 GHz, and suppression of fundamental, second order and third order mode resonance were observed in sample B (four layer). These results showed c-axis parallel polarization were inverted in the samples.

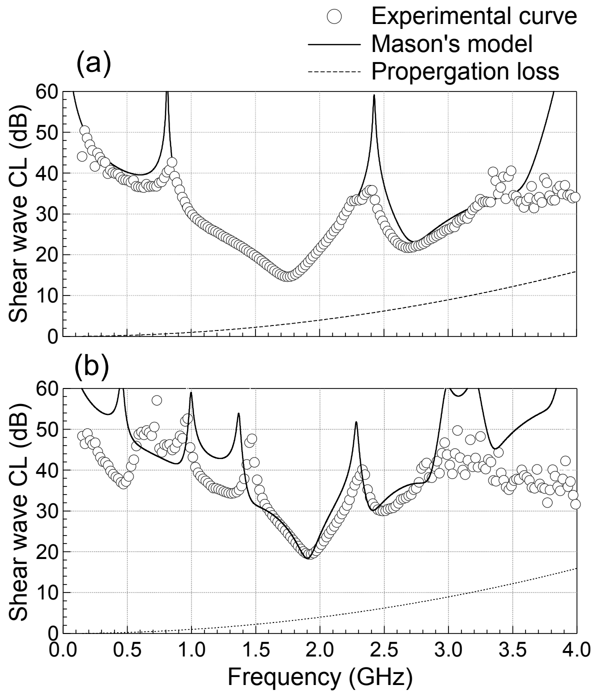

Fig. 5 Shear wave conversion losses of (a) sample A (two-layered AlN film) and (b) sample B (four-layered AlN film)

5. Conclusion

Polarization of c-axis parallel AlN film was controlled by adjusting the direction of ion beam irradiation during deposition. We achieved the fabrication of polarization-inverted multilayer AlN films. High order mode resonance excitation was observed in the polarization-inverted resonator.

References

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