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Sputtering deposition of c-axis parallel oriented ZnO film with limited particle irradiation and resonance property as shear-mode resonator

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1. Introduction

ZnO is a piezoelectric material with a hexagonal wurtzite structure. ZnO films with the crystalline c-axis parallel to the substrate and aligned in one direction can excite shear waves and are suitable for thickness shear-mode resonators[1)].

The c-axis parallel $(11\bar{2}0)$ orientation is induced by irradiation the substrate with highly energetic particles during ZnO deposition, instead of the (0001) orientation[1)]. In the case of the RF magnetron sputtering, negative ions such as O^- generated near the ZnO target are accelerated toward the substrate by the negative bias applied to the ZnO target, resulting in the c-axis parallel oriented film[2)]. To obtain high piezoelectricity, the in-plane direction of c-axis requires alignment in one direction. However, it was difficult to align in one direction near the center because negative ions were expected to be irradiated from various directions due to the symmetry of the magnet in the magnetron sputtering with cylindrical magnet[3)]. In our previous study, the in-plane direction of c-axis were aligned near the anode center by limiting the direction of particle irradiation using shields and improved the piezoelectricity[4)]. In this study, c-axis parallel oriented ZnO films were grown on 4-inch silicon on insulator (SOI) substrates. The shields for 4-inch were fabricated and installed on RF magnetron sputtering apparatus to limit particle irradiation. Then, shear-mode resonators were fabricated using the films and resonance property of shear-mode resonators were measured.

2. ZnO film preparation

ZnO films were prepared on Au electrodes / 4-inch SOI substrates by an RF magnetron sputtering. **Fig.1(a), (b)** shows the sputtering apparatus and shields installation. The four stainless-steel shields were installed radially to separate deposition areas at 90°. The shields limited particle irradiation to the substrate from the circumference direction of the target during the sputtering. A ZnO ceramic target with 80 mm diameter was used. A sample prepared without the shields was also prepared for comparison.

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The deposition conditions were fixed at an RF power of 100 W, a total gas pressure of 0.1 Pa, and a gas ratio of oxygen to argon of 75 %. The sputtering time was adjusted to achieve film thickness of 2.2 μm at 30 mm from the anode center.

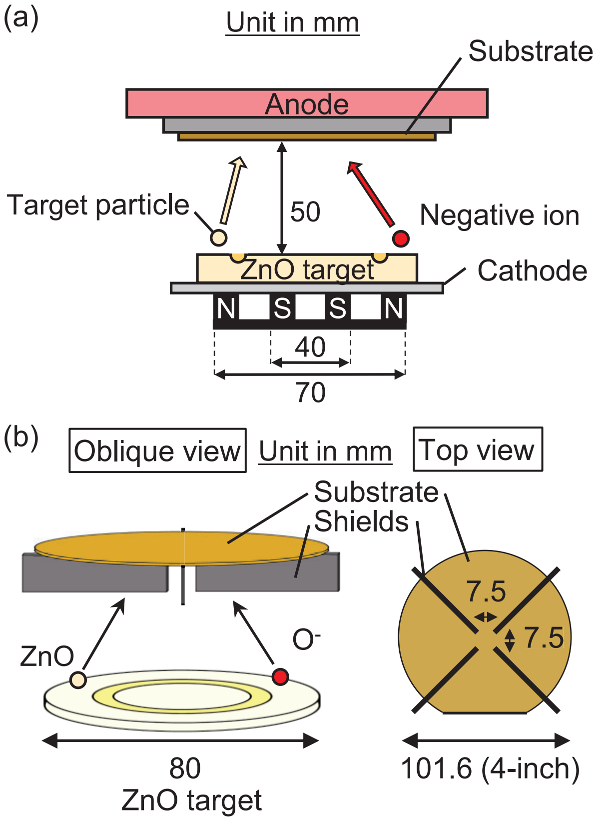

Fig. 1(a) RF magnetron sputtering apparatus and (b) schematic image of shields installation.

3. Crystalline orientation and resonance property

The crystalline orientations of the ZnO films were evaluated by X-ray diffraction (XRD) analysis. A $(11\bar{2}0)$ peak was observed in all measurement points in 2θ-ω scan XRD patterns, indicating that the c-axis was parallel to the substrate. To evaluate the in-plane crystalline orientations, the full width at half maximum (FWHM) of the $(11\bar{2}2)$ plane ϕ-scan curve was measured. **Fig.2** shows FWHM values of the $(11\bar{2}2)$ plane ϕ-scan curves as a function of distance from anode center. The FWHM values of the samples prepared with shields were smaller in all evaluation points. The minimum ϕ-scan FWHM of 33.5° was obtained at the distance from anode center of 35 mm in the samples prepared with shields. The distance of 30 mm from the anode center is above the target erosion area where a large number of negative ions are generated[2]. The in-plane direction of the c-axis is relatively aligned by sputtering with a shield for the 4-inch substrate. The FWHM values of ω-scan curve were similar between the sample fabricated with and without shields.

Shear-mode resonators of top electrode / ZnO films / bottom electrode / support substrate were fabricated by photolithography as shown in **Fig.3**. The admittance curves of the resonators at 18 and 28 mm from the anode center are shown in **Fig.4 (a)** and **(b)**. The maximum peak of resonance was observed around 500-550MHz in all measurements. The ratios of the maximum peak value to the minimum peak value of admittance were large in the sample prepared with the shields. Therefore, the resonance properties were improved in the sample prepared with the shields for limiting the particle irradiation.

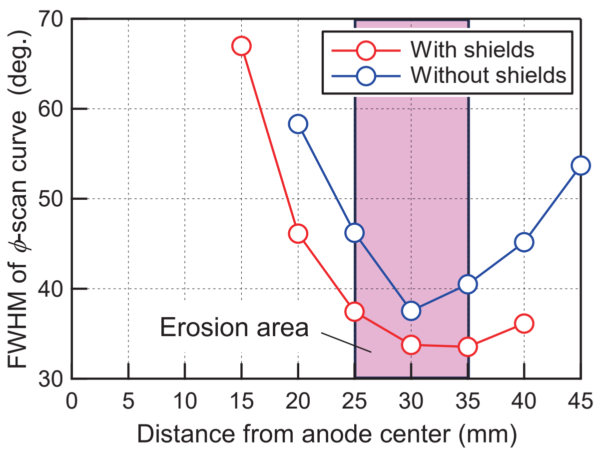

Fig. 2 FWHM of ϕ-scan curve in ZnO films fabricated on Au electrode / SOI substrates as a function of distance from anode center.

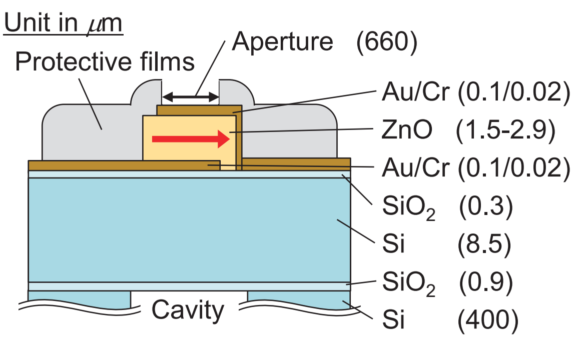

Fig. 3 Schematic image of shear-mode resonator.

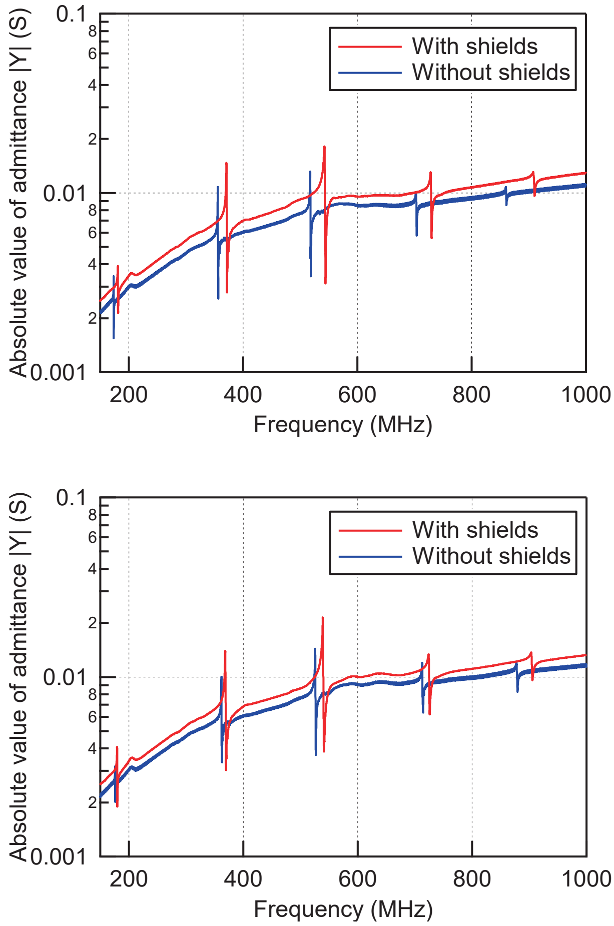

Fig. 4 The admittance curve of the shear-mode resonator at (a) 18 mm and (b) 28 mm from anode center.

4. Conclusion

The c-axis parallel oriented ZnO films were fabricated on 4-inch substrates with shields that limit particle irradiation by an RF magnetron sputtering. Then, the shear-mode resonators were fabricated by using the films. Crystalline orientations of the samples were improved by using shields for 4-inch substrate to limit particle irradiation. As a result, the resonance property was improved. The shear-mode resonators are expected to be fabricated in a large area by using the shields.

References

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