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Effect of particle irradiation direction in magnetron sputtering on piezoelectricity of c-axis parallel oriented ZnO films

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1. Introduction

ZnO is a piezoelectric material with a hexagonal wurtzite structure. ZnO films with the crystal c-axis parallel to the substrate and aligned in one direction are suitable for excitation of shear acoustic waves. They are expected to be applied to thickness shear-mode film resonators and surface-horizontal surface acoustic wave devices[1)]. In our previous study, the c-axis parallel oriented film was obtained by an RF magnetron sputtering deposition[2)]. However, there is a problem that highly oriented films can be obtained only in small areas. It is important to obtain them over a large area for practical use.

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[3)]. 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)].

The in-plane direction of the c-axis is also important for excitation of shear acoustic waves. The in-plane direction of the c-axis is aligned unidirectionally in the direction of ion beam irradiation[3)]. In the case of RF magnetron sputtering using a coaxial cylindrical magnet, the in-plane direction of c-axis is aligned in the radial direction of the magnet[4)]. Near the center, it is, however, difficult align in one direction because negative ions are expected to be irradiated from all directions due to the symmetry of the magnet. In this study, shields were installed to limit the irradiation direction of negative ions and deposition particles. We investigated the effect of particle irradiation direction on the piezoelectricity of the c-axis parallel oriented ZnO films by varying the distance between the shields and the substrate.

2. ZnO film preparation

ZnO films were grown on an Al/silica glass substrate by RF magnetron sputtering apparatus, as shown in **Fig. 1 (a)**. **Fig. 1 (b)** shows the details of the shield installation. The stainless-steel plate was used as the shields to limit the irradiation direction of the particles to the radial direction. As the distance between the shields and the substrate (S-S distance) increases, the particle irradiation from the circumferential direction is expected to be suppressed. Therefore, Four ZnO samples were prepared with varying S-S distances of 0, 4, 10, and 15 mm. No shield was installed for the S-S distance of 0 mm in this experiment. 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% for all samples. The deposition time was adjusted to achieve film thicknesses of 2.1-2.3 μm at 30 mm from the anode center.

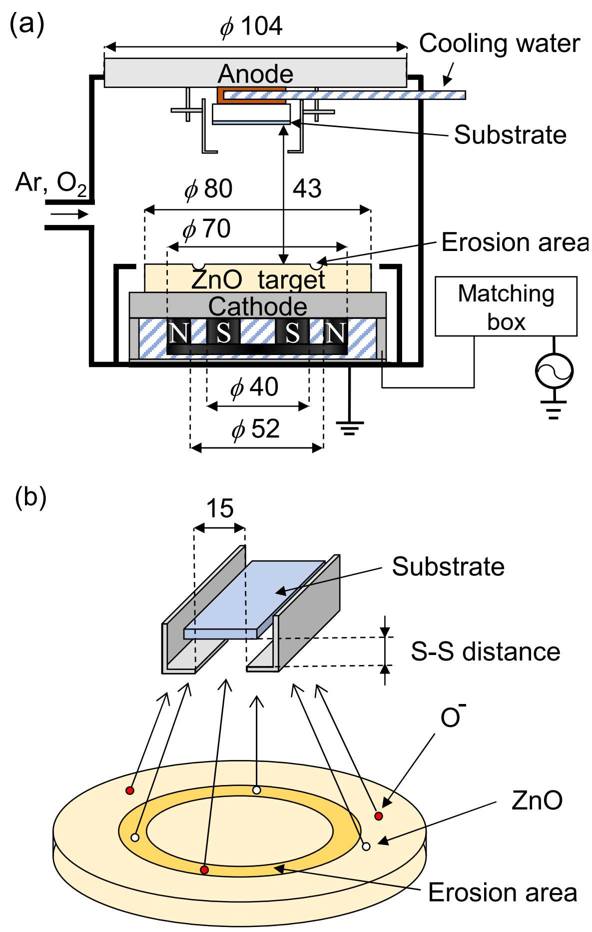

Fig. 1 (a) RF magnetron sputtering apparatus and (b) schematic image of shield installation.

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3. Crystalline orientations and piezoelectric properties

The crystal orientations of the ZnO films were evaluated by X-ray diffraction (XRD) analyses. A $(11\bar{2}0)$ peak was observed in all samples by 2θ-ω scan XRD patterns. In order to evaluate the in-plane crystalline orientation, the full width at half maximum (FWHM) of the $(11\bar{2}2)$ plane ϕ-scan curve was measured. FWHM values of ϕ-scan curve in ZnO films grown by varying the S-S distance are shown in **Fig. 2** as a function of distance from anode center. The minimum ϕ-scan FWHM of 25.3° was obtained at the distance from the anode center of 30 mm in the sample grown with the S-S distance of 0 mm. The distance of 30 mm from the anode center is above the target erosion area where a large amount of negative ions are generated. In the cases of the S-S distance of 10 and 15 mm, the FWHM values above the erosion area were relatively small.

For the evaluation of piezoelectricity, HBAR structures of Cu/ZnO film/Al/silica glass substrate were fabricated. The conversion losses of the HBARs were measured using a network analyzer. The electromechanical coupling coefficient k_t^2 was estimated by comparing the experimental conversion loss with the theoretical conversion loss calculated from the linear propagation model using Mason's equivalent circuit[3]. k_t^2 values of the ZnO films grown by varying S-S distance as a function of distance from anode center were shown in **Fig. 3**. The maximum k_t^2 value of 2.9% was obtained above the erosion area with S-S distance of 0 mm. Relatively high k_t^2 values were obtained above the erosion area when the S-S distances are 10 and 15 mm.

The S-S distances of 15 and 10 mm are thought to suppress the incidence of particles with large angles of incidence from the circumferential direction onto the substrate. The c-axis is not aligned in the in-plane direction due to irradiation of particles with large incident angles from the circumferential direction. This results in a decrease in piezoelectricity. The S-S distance of 4 mm did not sufficiently suppress the irradiation of particles with large incident angles from the circumferential direction, and thus could not prevent the degradation of piezoelectricity. FWHM vlues of ω-scan rocking curve were 4.2, 5.9, 5.6, and 6.2° at the locations where the largest k_t^2 values were obtained at S-S distances of 0, 4, 10, and 15 mm, respectively. In this range, out-of-plane c-axis variation has no significant effect on piezoelectricity, and the alignment of the in-plane c-axis is important.

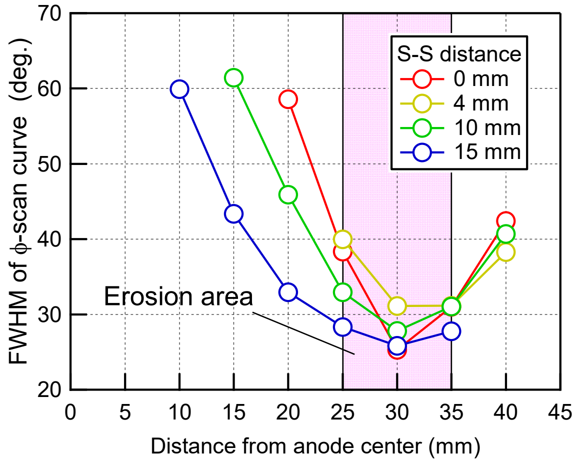

Fig. 2 FWHM of ϕ-scan curve in ZnO films grown by varying the S-S distance as a function of distance from anode center.

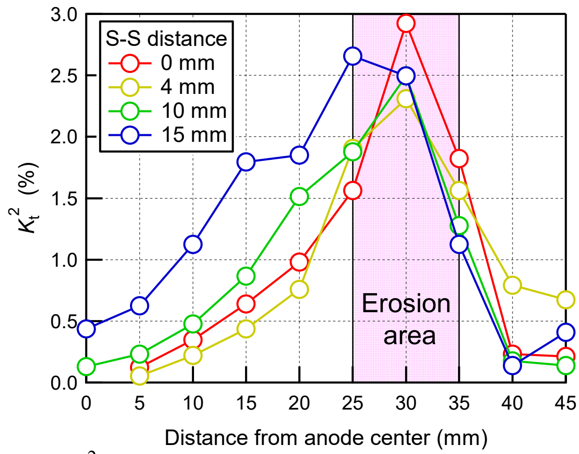

Fig. 3 k_t^2 of the ZnO films grown by varying S-S distance as a function of distance from anode center.

4. Conclusion

We investigated how the piezoelectricity is affected by the incidence of particles with a large angle of incidence from the circumferential direction Particles with large incident angles from the circumferential direction caused the c-axis in the in-plane direction to be unaligned, resulting in a decrease in piezoelectricity. In addition, when the FWHM of ω-scan is smaller than 6.2°, the alignment of the c-axis in the in-plane direction has a relatively large effect on the piezoelectricity.

References

1. A. Tanaka, et al.: IEEE Trans. Ultrason. Ferroelectr. Freq. Control **55** (2008) 2709.
2. S. Takayanagi, et al.: Appl. Phys. Lett. **101** (2012) 232902.
3. T. Yanagitani, et al.: J. Appl. Phys. **102** (2007) 044115.
4. T. Kawamoto, et al.: Jpn. J. Appl. Phys. **49** (2010) 07HD16.