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Effect of sputtering geometry on ($11\bar{2}0$) textured ZnO piezofilm

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1. Introduction

To prepare a shear mode transducer and resonator in the VHF-UHF range [1–3], it is necessary for a ZnO piezofilm to have a unidirectionally aligned crystallite *c*-axis in the plane. The thickness distribution of the film is expected to be constant. It is also more convenient if we can fabricate this film on various material surfaces without epitaxy. In previous studies, we have attempted to fabricate unidirectional ZnO films using an RF magnetron sputtering apparatus [4–7]. However, the crystallite *c*-axis was randomly oriented in such films fabricated at the center of the anode, whereas it was unidirectionally aligned in such films fabricated at the edge of the anode. In addition, the film thickness decreased as the distance between the point of fabrication and the anode center increased. This indicates that the unidirectional crystallite alignment and uniform film thickness are not simultaneously achieved at the same position. The uniform film thickness is generally achieved by the planetary rotation of the substrate during deposition [8]. In our ZnO film, however, the planetary rotation seems to result in the random orientation of the crystallite *c*-axis. In this study, therefore, we have attempted to investigate the effects of sample geometry during sputtering on the film structure (*c*-axis alignment) and thickness.

2. Sample fabrication

Pyrex glass of 1 mm thickness was used as the substrate. The aluminum electrode film of 0.3 μm thickness was evaporated on the substrate. The ZnO film was fabricated using a conventional RF magnetron sputtering apparatus (Ulvac RFS-200 using a neodymium magnetron). The deposition conditions used are shown in Table 1. The substrates were set at three substrate positions labeled A, B and C, as shown in Fig. 1. Sample (A) was set parallel to the anode (substrate position (A)). In contrast, samples (B) and (C) were inclined 30° to the anode plane. Sample (B) is near the target at the edge of the anode (substrate position (B)). Sample (C) is near the target at the anode center (substrate position (C)).

3. Evaluation of crystallite orientation

The *c*-axis orientation at each point of the films was characterized using an X-ray diffractometer (RINT 2000 Rigaku). Figures 2–4 show the XRD patterns measured every 5 mm from the anode center. The ($11\bar{2}0$) peaks appear near $2\theta = 56°$ in Figs. 2 and 3. The ($11\bar{2}0$) and ($10\bar{1}0$) XRD peaks appear near $2\theta = 56°$ and 32°, respectively, in Fig. 4. These results indicate that the crystallite c-axis of all samples lies in the substrate plane. The peak near $2\theta = 38°$ represents the (111) peak of the aluminum electrode.

4. Evaluation of crystallite alignment and film thickness

The XRD patterns revealed only the crystallite orientation in the equatorial plane, whereas the ω-scan rocking curve and φ-scan pole figure analysis gave quantitative information on the extent of crystallite alignment. The crystallite alignment in the substrate normal direction was estimated using the full width at half maximum (FWHM) of the ω-scan rocking curve. The crystallite alignment in the substrate plane was estimated using the FWHM of the φ-scan curve. The FWHMs were multiplied by 2/3 in order to cancel the effect of the CuKα_2 ray. The film thickness was measured by a stylus method (SJ-400 Mitutoyo).

The FWHM of the ($11\bar{2}0$) ω-scan rocking curve of sample (A), (B) and (C) is shown in Fig. 5. The FWHM of the ($11\bar{2}2$) φ-scan curve of sample (A), (B) and (C) is shown in Fig. 6. The film thickness distribution of the sample (A), (B) and (C) is shown in Fig. 7.

5. Discussion

5.1. Sample (A)

The minimum FWHM of the ($11\bar{2}0$) ω-scan rocking curve was observed at the measurement point of 25 mm, as shown in Fig. 5. This indicates a good crystallite alignment at this point. In addition, the minimum FWHM of the ($11\bar{2}2$) φ-scan curve of sample (A) could also be observed at the 25 mm from the anode center. The FWHM of the ($11\bar{2}2$) φ-scan curve increased at the anode center. These results reveal that the crystallites are almost unidirectionally aligned in the plane at the measurement point of 25 mm, whereas they tend to have a poor alignment in the plane at the anode center. As shown in Fig. 7, the film thickness gradually decreased as the distance between the measurement point and the anode center increased.

5.2. Sample (B)

In sample (A), the crystallites were unidirectionally aligned at the measurement point of 25 mm from the anode center, however, the film thickness was not perfectly uniform at this point. To obtain film with uniform thickness, sample (B) was fabricated at substrate position (B). In sample (A), the thickness gradually decreased as the distance between the measurement point and the anode center increased. At

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Table 1 Deposition conditions.

RF power	60 W
Total gas pressure	0.09 Pa
Sputtering gas composition ratio	$Ar/O_2 = 1/3$
Sputtering time	20 h

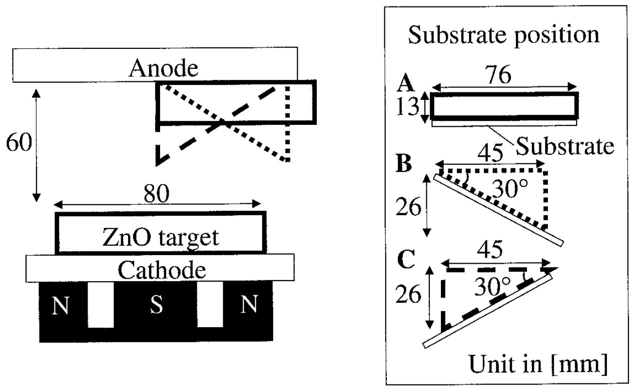

Fig. 1 Substrate position (A), (B) and (C) in conventional RF magnetron sputtering apparatus.

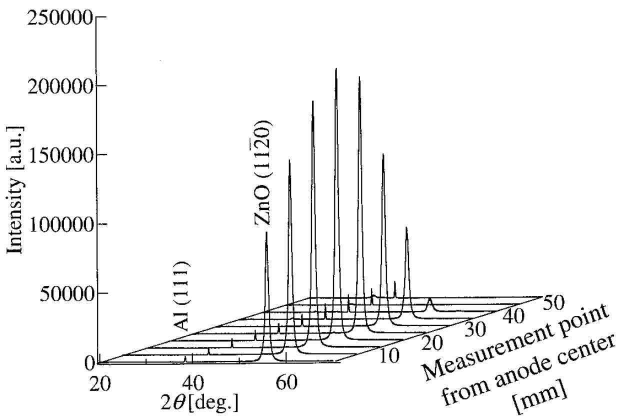

Fig. 2 XRD pattern of sample (A) as a function of measurement point from anode center.

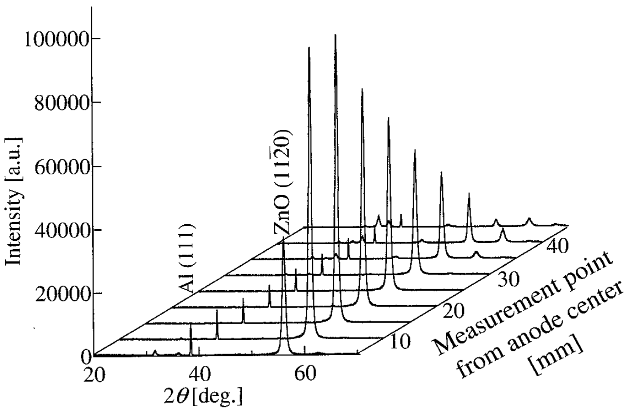

Fig. 3 XRD pattern of sample (B) as a function of measurement point from anode center.

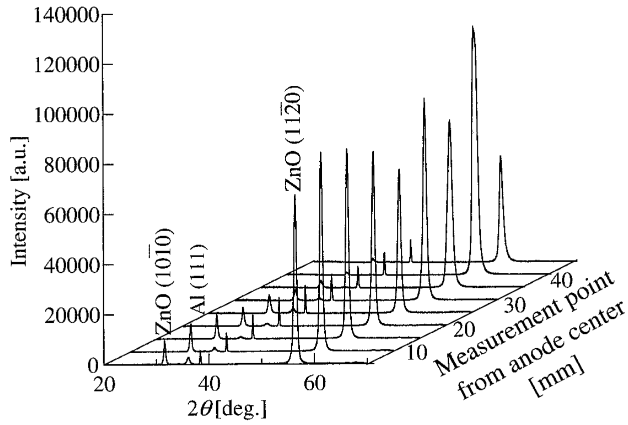

Fig. 4 XRD pattern of sample (C) as a function of measurement point from anode center.

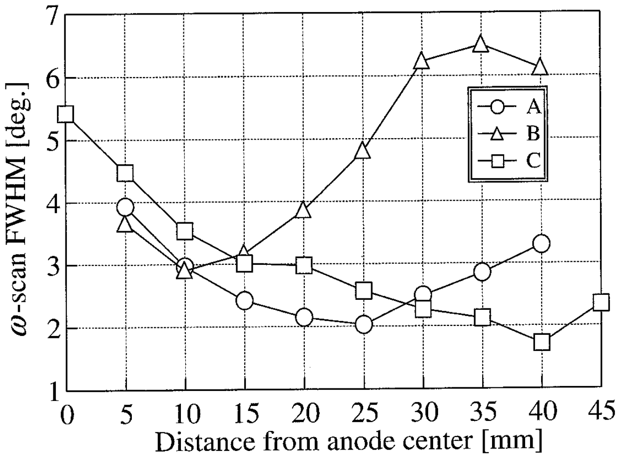

Fig. 5 FWHM of ω-scan rocking curve of sample (A), (B) and (C) as a function of measurement point from anode center.

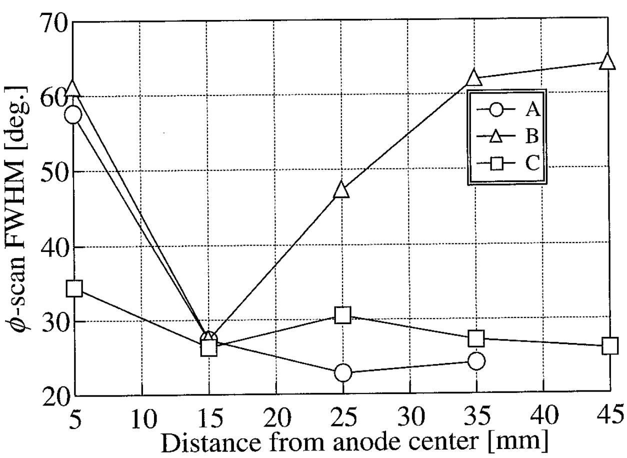

Fig. 6 FWHM of φ-scan curve of sample (A), (B) and (C) as a function of measurement point from anode center.

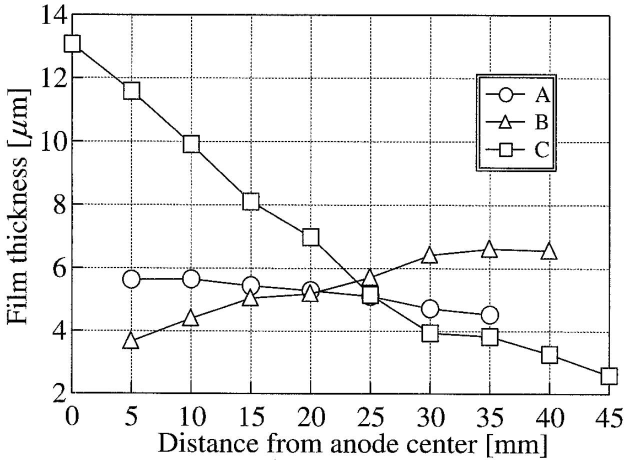

Fig. 7 Film thickness distribution of sample (A), (B) and (C) as a function of measurement point from anode center.

substrate position (B), we expect that the deposition rate will be higher at the edge of the anode because the target is near. As shown in Fig. 7, the thickness gradually increased as the distance between the measurement point and the anode center increased. It was comparatively uniform at the positions of 30–40 mm from the anode center. The uniform thickness in this area was also confirmed in the optical fringe pattern of the film surface. Comparing with the thickness data for sample (A), the uniform thickness area moved to the edge of the anode in sample (B). Sample (B), however, always showed broader FWHM of ω-scan and φ-scan curve than sample (A). This indicates that the crystallite alignment in sample (B) is not as good as that in sample (A). In the uniform thickness area, the FWHM of the $(11\bar{2}2)$ φ-scan curve is more than 60°, indicating a very poor alignment in the plane.

5.3. Sample (C)

Sample (C) was placed near the ZnO target at the anode center. The thickness of sample (C) markedly decreased as a function of the distance from the anode center. The FWHM of the $(11\bar{2}0)$ ω-scan rocking curve was small at the positions from 5 mm to 35 mm. The FWHM of the $(11\bar{2}2)$ φ-scan curve also indicated a unidirectional crystallite alignment in the substrate plane at the positions from 5 mm to 35 mm. These results demonstrate that an excellent crystallite alignment is obtained in a wide area, despite the thickness distribution.

5.4. Conclusion

We have focused on the crystallite alignment and thickness distribution of ZnO piezofilms by changing the sample geometry during sputtering. In substrate position (A), the film thickness decreased as the distance between the measurement point and the anode center increased. In substrate position (B), the uniform thickness area was obtained at the positions of 30–40 mm from the anode center. Sample (B), however, showed a poor crystallite alignment. On the other hand, in substrate position (C), an excellent crystallites alignment was achieved in a wide area. The film thickness, however, showed a strong distribution. These results indicate that the crystallites alignment and film thickness are strongly affected by the substrate position, despite that the other sputtering conditions are identical. To obtain ZnO films of higher quality for the fabrication of a transducer and a resonator, it is necessary to understand the fabrication mechanism in the sputtering plasma region in detail.

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