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Shear mode electromechanical coupling coefficient of c-axis parallel oriented ZnO films by sputtering with H_2O

H_2O 導入スパッタ法を用いて作製した c 軸平行配向 ZnO 膜のすべりモード電気機械結合係数

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1. Introduction

c-axis parallel (11$\bar{2}$0) and (10$\bar{1}$0) oriented ZnO films can excite shear wave. These films are suitable for shear horizontal surface acoustic wave (SH-SAW) device and thickness-shear mode film bulk acoustic resonator (FBAR) to measure liquid properties (e.g., viscosity and conductivity[1)]).

ZnO crystal has hexagonal wurtzite structure. In general, ZnO film tends to orient the most closed-packed (0001) plane. However, if the substrate is bombarded with energetic ions during RF magnetron sputtering, the (0001) grain growth is suppressed, and (11$\bar{2}$0) or (10$\bar{1}$0) grain can be grown. In previous studies, we found that highly energetic O^- were generated around ZnO target in RF magnetron sputtering[2)]. These O^- ions were accelerated to the substrate by negative bias of the sputtering target, resulting in growth of (11$\bar{2}$0) oriented ZnO films .

In this study, H_2O gas was injected in the sputtering chamber during ZnO film deposition in order to control energetic negative ion generation. O^- and OH^- ion generation are expected by dissociation and electron attatchment of H_2O. Furthermore, H. Yamada et al. reported that crystalline orientation of c-axis perpendicularly oriented ZnO film was improved by injecting H_2O gas because oxigen vacancies in ZnO film were reduced[3)]. We investigated the effect of H_2O gas injection on ion energy distributions during the deposition, crystalline orientations of ZnO films, and shear mode electromechanical coupling coefficients k_{15}.

2. Measurement of ion energy distributions

We measured the flux and energy of ions which enter the substrate during RF magnetron sputtering by an energy analyzer with a mass spectrometer (PSM003-300, Hiden Analytical). **Figure 1** shows an RF magnetron sputtering system with the energy analyzer. The energy analyzer was located above the target erosion area where highly energetic O^- enter the substrarte[2)]. Ar, O_2, and H_2O were injected as the process gas. The ratio of O_2 gas to Ar gas was fixed at 3, and the ratio of H_2O gas to Ar gas ($r_{H_2O/Ar}$) was changed from 0 to 0.30. The discharge conditions were optimize to the RF power of 50 W, the background pressure of 8.0×10^{-4} Pa, and the process pressure of 0.1 Pa.

Figure 2 shows energy distributions of O^- ions which entering the substrrate. O^- energy (160-240 eV) was higher than positive ion energy (15-30 eV), as expected. The O^- flux was increased as the increase of $r_{H_2O/Ar}$. Although the OH^- flux was low, it was also increased as the increase of $r_{H_2O/Ar}$. The increace of highly energetic O^- and OH^- flux was due to the dissociation and electron attatchment of the injected H_2O gas. Therefore, highly energetic negative ion flux can be controled by the H_2O gas injection.

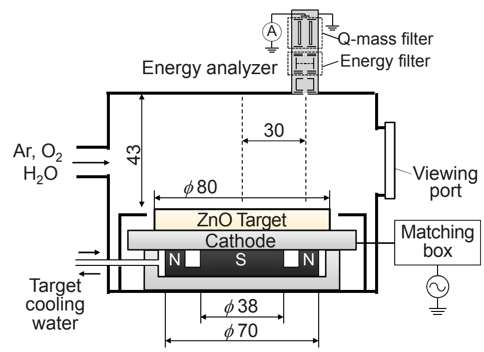

Fig. 1 RF magnetron sputtering system with energy analyzer.

3. Deposition of c-axis parallel oriented ZnO films

ZnO films were fabricated on Al/Silica glass substrates by RF magnetron sputtering. Deposition conditions were set to be same as the measurement conditions of the ion energy distributions. The crystalline orientations of ZnO films were measured by X-ray diffraction (XRD) analysis (X'Pert Pro MRD, Philips).

Figure 3 shows XRD patterns of the samples at $r_{H_2O/Ar}$ of 0, 0.02, 0.04 and 0.08. An intense (11$\bar{2}$0) peak was observed in each sample. the (11$\bar{2}$0) peak of the sample without H_2O injecton

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was broad, compared to that with H_2O injecton. This result indicates the improvement of crystallization due to the reduction of the oxigen vacancies[3].

$(11\bar{2}0)$ ω-rocking curve of the samples were also measured. The full width at half maximum (FWHM) of the samples at $r_{H_2O/Ar}$ of 0, 0.02, 0.04 and 0.08 were 4.1º, 4.1º, 3.9º, and 5.1º, respectively. The FWHM value was decreased with H_2O injecton, but it was increased at $r_{H_2O/Ar}$ of 0.08. In previous study, $(11\bar{2}0)$ orientation was degraded by excess O^- bombardment[4]. Therefore, $(11\bar{2}0)$ grain growth was supressed by large flux of O^- and OH^- bombardment at $r_{H_2O/Ar}$ of 0.08. Consequently, ion bombardment at $r_{H_2O/Ar}$ of 0.04 is suitable for $(11\bar{2}0)$ grain growth in this system.

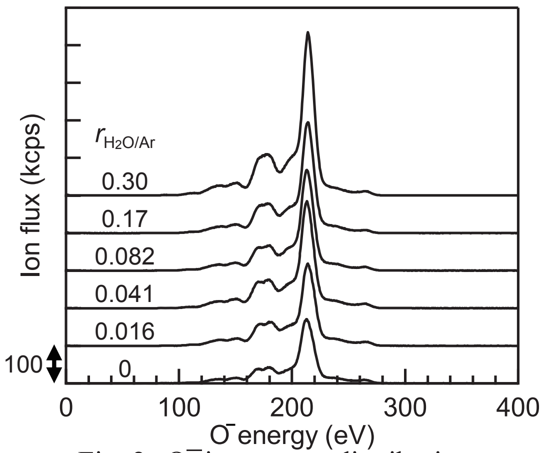

Fig. 2 O^- ion energy distribution.

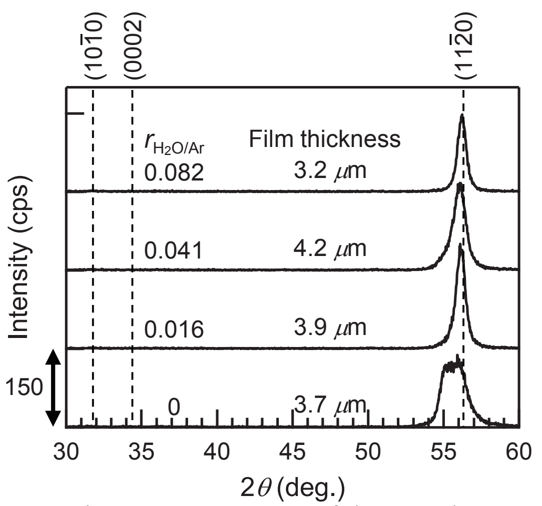

Fig. 3 XRD patterns of the samples.

4. Shear mode electromechanical coupling coefficient k_{15}

High-overtone bulk acoustic resonator (HBAR) structures were fabricated by evaporated Cu top electrodes in order to investigate piezoelectric properties. The conversion losses of the HBAR structures were measured by network analyzer (E5071C, Agilent Technologies). They were also calculated by one-dimensional transmission line model. Then, k_{15} was estimated by comparing between experimental value and calculational value.

Figure 4 shows shear mode conversion losses of the samples. The experimental curves at $r_{H_2O/Ar}$ of 0, 0.02, 0.04 and 0.08 were in good agreement with the experimental curves at k_{15} of 0.16, 0.17, 0.19, and 0,17. These k_{15} changes by H_2O injecton correspond to the FWHM changes. The maximum k_{15} value in the samples was 0.19 at $r_{H_2O/Ar}$ of 0.04, which corresponds to 73% of that in a ZnO single crystal (k_{15}=0.26).

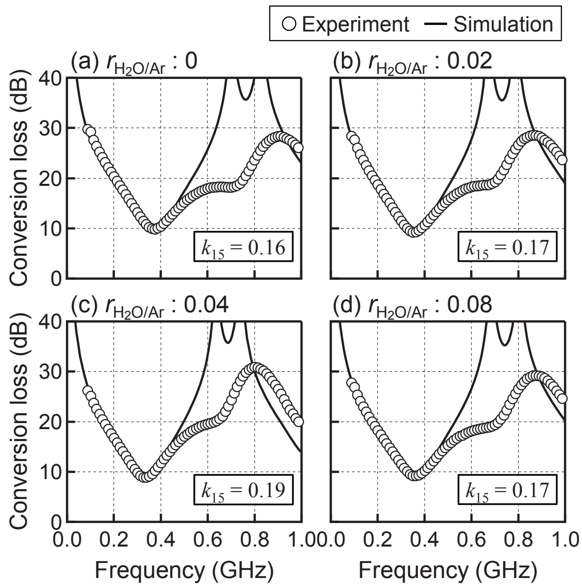

Fig. 4 Conversion losses at $r_{H_2O/Ar}$ value of (a) 0, (b) 0.02, (c) 0.04 and (d) 0.08.

5. Conclusion

We investigated the effect of H_2O gas injection during c-axis parallel oriented ZnO film deposition. Highly energetic O^- and OH^- bombardment was increased with injecting H_2O gas. The crystalline orientation and k_{15} of c-axis parallel oriented ZnO films was improved by moderate H_2O injection. However, they were degraded by excess H_2O injection because of excess O^- and OH^- bombardment. As a result, the c-axis parallel oriented ZnO film of k_{15}=0.19 was obtained.

References

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