3P1-2

# Film growth of c-axis parallel oriented ZnO films by RF magnetron sputtering for improvement of electromechanical properties

電気機械特性の向上に向けた RF スパッタ法による c 軸平行配向 ZnO 膜の作製

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## 1. Introduction

Shear mode acoustic wave devices are suitable for measurement of liquid properties. c-Axis parallel $(10\bar{1}0)$ and $(11\bar{2}0)$ oriented ZnO films can excite shear mode acoustic wave. It is expected that these films are applyed to shear mode FBAR or SH-SAW devices[1)].

ZnO crystal grain has hexagonal wrutzite structure. In general, ZnO films tend to be oriented the most close-packed (0001) plane in sputtering depositions. However, we found that c-axis parallel $(10\bar{1}0)$ and $(11\bar{2}0)$ plane are grown by negative oxygen ions bombardment to the substrate from the surface of ZnO target during the deposition[2)]. The most close-packed (0001) plane are suppressed to grow because of the ion collision. On the other hand, because $(10\bar{1}0)$ and $(11\bar{2}0)$ planes are low surface atomic density than (0001) plane, these planes are hardly affected by the ion collision. In the result, c-axis parallel oriented films can be grown.

There are two problems in c-axis parallel ZnO films. The one is low shear mode electromechanical coupling coefficient $k_{15}$. The value of c-axis parallel oriented film are 53 % of the value of ZnO single crystal. The other is thickness of piezoelectrically-inactive layer $d_n$ which is a non-oriented layer grown in the initial stage of the film growth. It is necessary to decrease this layer for using devices.

In previous study, we found that the amount of ion bombardment to the substrate affected thickness of piezoelectrically-inactive layer[3)]. Therefore, in this study, we tried to decrease the piezoelectrically-inactive layer with changing the amount of ion bombardment to the substrate. In addition, we also tried to improve the electromechanical coupling coefficient $k_{15}$. In general, annealing treatment is famous method to improve crystalline orientation of ZnO films. This method can relieve internal stresses and improve the lattice defect of oxygen. Therefore, we studied to improve the crystlline orientation with the annealing treatment.

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## 2. Decreasing piezoelectrically-inactive layer

In this experiments, target-substrate distance (T-S) was changed. It is expected that the amount of ion bombardment increase with decreasing T-S.

**Figure 1** shows RF magnetron sputtering systems. Four samples were prepared on Al/Silica glass substrates by an RF magnetron sputtering. The deposition conditions were total gas pressure of 0.1 Pa, the argon-to-oxygen ratio of one to three and RF power of 50W. T-S of each sample was set at 44 mm, 35 mm, 25 mm, 23 mm. Then, the deposition times were adjusted to arrange the same film thickness.

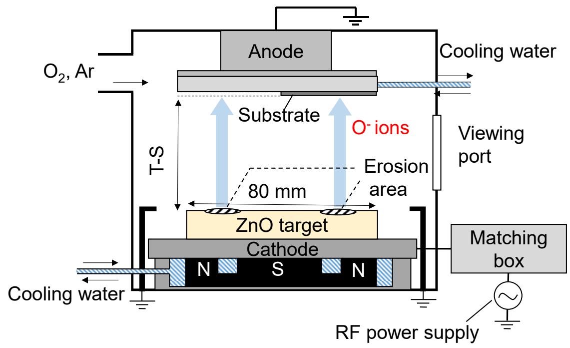


Fig.1 RFmagmetron sputtering system.

**Figure 2** shows the XRD patterns of the samples. It is observed that the peak of intensities are changed from the $(11\bar{2}0)$ peak to the $(10\bar{1}0)$ peak. $(10\bar{1}0)$ plane is low surface atomic density than $(11\bar{2}0)$ plane. It is suggested that ion bombardment to the substrate increased with decreasing the T-S.

Next, High-overtone bulk acoustic resonator (HBAR) structures were fabricated by evaporated Cu top electrodes in order to investigate electromechanical properties. The conversion losses were measured by a network analyzer (E5071C, Agilent Technologies). Then, $k_{15}$ value and $d_n$ were estimated by the one-dimensional transmission line model[3)]. **Figure 3** shows the result of 44 mm T-S. In the comparison with the values of the simulation and experiment, the $k_{15}$ value and the $d_n$ value were estimated at 0.15 and 0.7 $\mu$m, respectively. The $k_{15}$ and $d_n$ values of all samples were arranged in the

**Table I**. The piezoelectrically-inactive layer $d_n$ were decreased as the decrease of T-S because of increasing the amount of ion bombardment to the substrate.

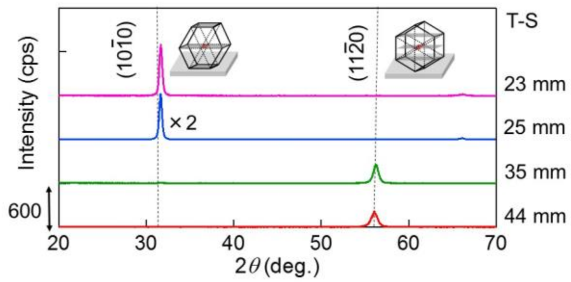


Fig. 2 XRD pattern of the samples.

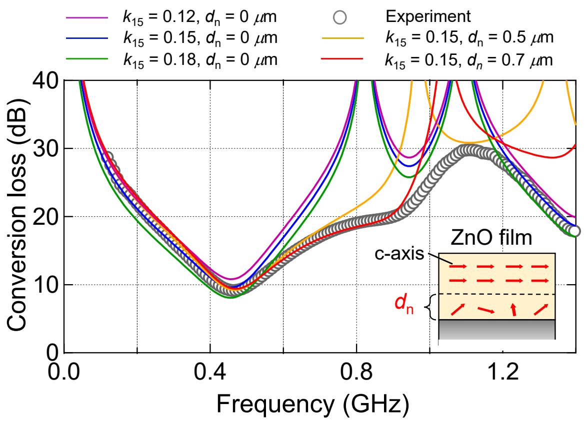


Fig. 3 Conversion loss of the sample at 44 mm T-S.

Table I $k_{15}$ value and $d_n$ of samples

| T-S (mm) | $k_{15}$ | $d_n$ ($\mu$m) |
|---|---|---|
| 44 | 0.15 | 0.7 |
| 35 | 0.14 | 0.5 |
| 25 | 0.15 | 0.4 |
| 23 | 0.13 | 0.3 |

## 3. Improvement in the electromechanical coupling coefficient $k_{15}$

c-Axis parallel oriented ZnO films have strong internal stresses. These films are broken with a conventional annealing process by the relaxation of their own stress. Therefore, the deposition process was stopped at the film thickness of 350 nm, and the sample was annealed at 400°C for two hours. After the deposition restart, the sample was annealed again at the 700nm thickness in the same manner. Finally, the deposition process proceeded until 3.0 $\mu$m thickness. A non-annealed sample was prepared for comparison. These samples were also grown by an RF magnetron sputtering system, as shown in Fig. 1. **Figure 4** and **5** shows XRD patterns of the sample in each annealing process and the final results at the 3.0 $\mu$m, respectively. The $(11\bar{2}0)$ peak was increased because the internal stress was relieved by the annealing treatment. Then, $k_{15}$ values of these samples were estimated. The $k_{15}$ values of non-annealed and annealed sample were 0.15 and 0.18, respectively. It is suggested that the annealing treatment in the initial stage of the film growth is effective for the improvement of the $k_{15}$ value.

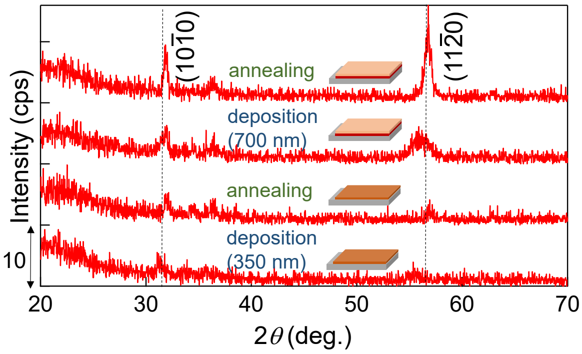


Fig. 4 XRD patterns of the sample in each annealing process.

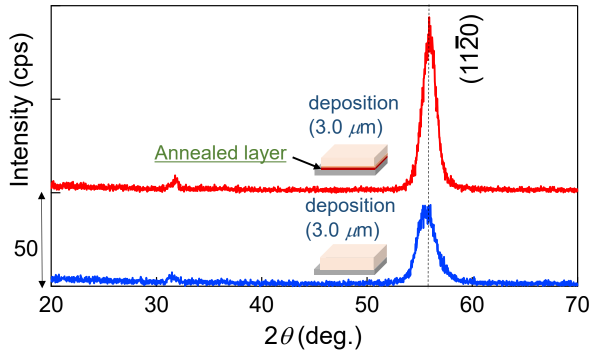


Fig. 5 XRD patterns of non-annealed and annealed sample.

## 5. Conclusion

We investigated the methods of the improvement in the electromechanical properties of c-axis parallel oriented ZnO films. The piezoelectrically-inactive layer $d_n$ was decreased with decreasing T-S. In addition, electromechanical coupling coefficient $k_{15}$ was improved with the annealing treatment in the initial stage of the film growth. Further improvement of the electromechanical properties are expected by the conbimation of these methods.

**References**

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