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Rayleigh mode SAW with high electromechanical coupling in the c-axis tilted ZnO

c 軸傾斜配向 ZnO 膜/石英基板構造のレイリーSAW における高い電気機械結合係数

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1. Introduction

Much interest has been focused on the passive SAW microsensors such as gas sensor and ultraviolet sensor.[1-4] SAW velocity in a piezoelectric medium changes due to the adsorbed mass effect and acoustoelectric effect. Degree of electromechanical coupling (K^2 value) in the piezoelectric medium directly determines the limitation of sensitivity in the acoustoelectric type SAW sensors. High K^2 SAW substrate is therefore required.

A ZnO film on glass substrate, which has relatively high K^2, is good candidate for the sensor application because of its low cost and easy preparation. Electromechanical coupling in ZnO crystal has anisotropy, and it depends on the direction of electric field. Fig. 1 shows the relationship between the direction of electric field and the bulk quasi-shear mode k'_{15} value. The value reaches maximum at the c-axis direction tilted to the electric field because the contribution of e_{33} to the quasi-shear mode coupling increases with increasing the c-axis tilt. Based on this anisotropy, we considered that our recently developed c-axis tilted ZnO film[5] could enhance the K^2 value in the case of Rayleigh SAW.

Hexagonal ZnO film usually tends to grow in a direction perpendicular to the substrate plane. K^2 value in the c-axis tilted ZnO films therefore has not been well-investigated for the SAW devices.

In this study, we theoretically analyzed the K^2 value in the c-axis tilted ZnO film on silica glass substrate structure, and demonstrated that K^2 value in the c-axis tilted film is higher than that in the usual c-axis oriented (0001) ZnO film[1] in the Rayleigh SAW. In addition, we demonstrate the growth of c-axis tilted ZnO film on silica glass substrate by RF magnetron sputtering method.

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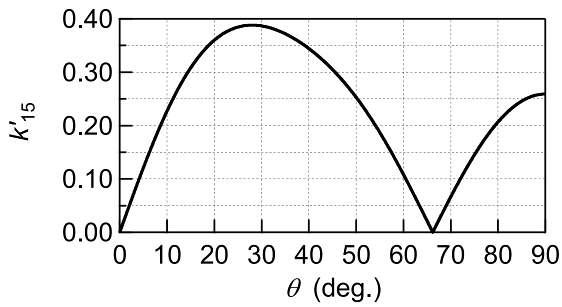

Fig. 1 Relationship between c-axis tilt angle and electromehanical coupling coefficient k'_{15} in ZnO single crystal.

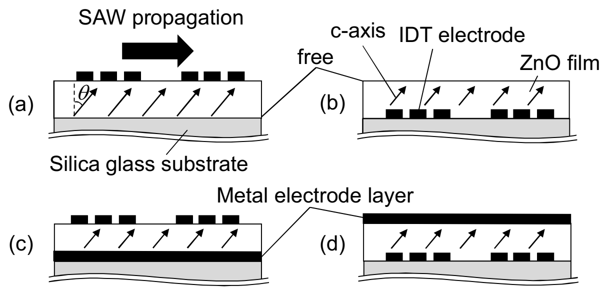

Fig. 2 Cross-sectional diagrams of the four types of film/substrate (a) structure A, (b) structure B, (c) structure C and (d) structure D.

2. Theoretical analysis for the Rayleigh SAW

K^2 value of the SAW changes due to the configuration of the IDT electrode as shown in Fig. 2. We analyzed the K^2 value as functions of film thickness and c-axis tilt angle θ in these four configurations, by using the Farnell and Adler's method.[6] Physical constants of ZnO single crystal reported by Smith were used in the analysis.[7] c-axis tilt direction corresponds to the SAW propagation direction in the analysis.

The results of K^2 values are contour plotted in Fig. 3. Maximum K^2 value in usual c-axis oriented film was found to be $K^2 = 2.6$ % at $kH = 3.4$. K^2 values larger than 2.6 % were found in c-axis tilted film in all configurations. Fig. 4 shows the profile curve of the Fig. 3 at $\theta = 0, 20, 40, 60$º in the structure D in which highest K^2 value was observed. Maximum K^2 value of

3.7 % was found at kH = 2.9 which is much larger than K^2 = 2.6 % in usual c-axis oriented film.

K^2 values in the structure B and D tend to be large compared with the structure A and C. Fig. 5 shows the profile curves at θ = 40º at each structure. Enhancement of electric field perpendicular to the substrate plane induced by the metal over layer, probably results in the maximum K^2 value in the structure D.

3. c-axis tilted ZnO film deposition

c-axis tilted ZnO film was fabricated on a silica glass substrate using an RF magnetron sputtering system (Ulvac, RFS-200). The substrate was set 80° to the ZnO target at the anode center.[5] Sputtering conditions were fixed at the total gas pressure of 1 Pa, the Ar/O_2 gas ratio of 1/3, RF power of 200 W, and substrate temperature of 400 ºC.

Crystalline orientation of the sample was determined by an XRD pole figure analysis (Philips, X-Pert Pro MRD). The pole figure showed the c-axis tilt angle of the film was 25º. In addition, grain crystal growth was observed by a cross-sectional SEM image. The direction of the grain growth was unidirectionally-aligned and tilted from the normal to the substrate surface.

4. Conclusion

In this study, we theoretically analyzed the K^2 value in the c-axis tilted ZnO film on silica glass substrate structure. In the result, the theoretical analysis showed that metal electrode layer/c-axis tilted ZnO/IDT/silica glass substrate structure (structure D) had a maximum K^2 value of 3.7 % at kH = 2.9 and θ = 40º. Next, we fabricated a c-axis tilted ZnO film using an RF magnetron sputtering system. The c-axis 25º tilted ZnO film was obtained. Further investigations of the fabrication method for the c-axis 40º tilted ZnO film and measurements of K^2 value in this film are necessary.

References

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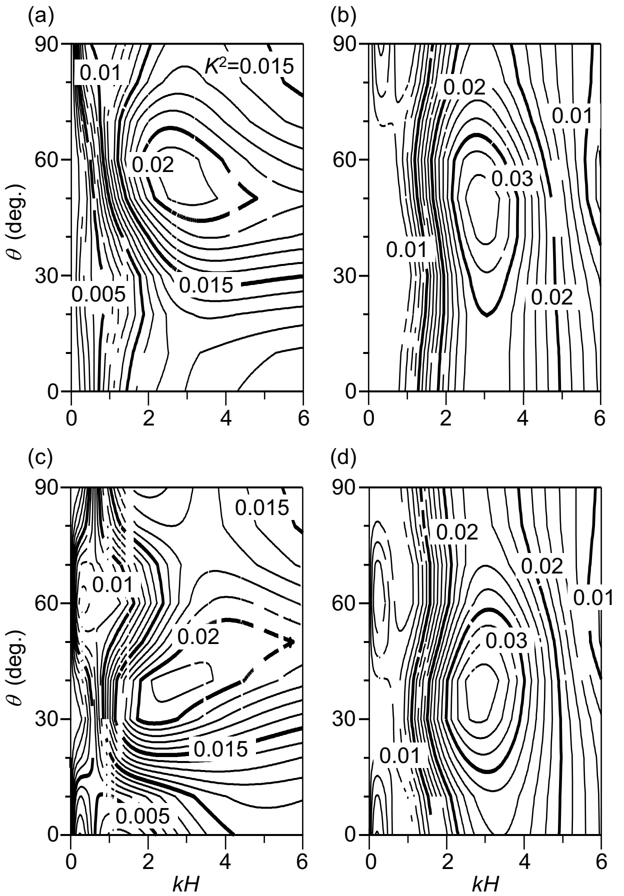

Fig. 3 Caluclated K^2 of the Rayleigh SAW as functions of the c-axis tilt angle θ and normalized film thickness kH in structure (a) A, (b) B, (c) C and (d) D.

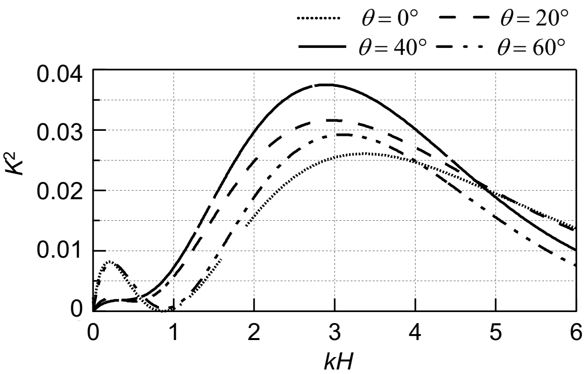

Fig. 4 Profile curves of K^2 as a function of kH in structure D.

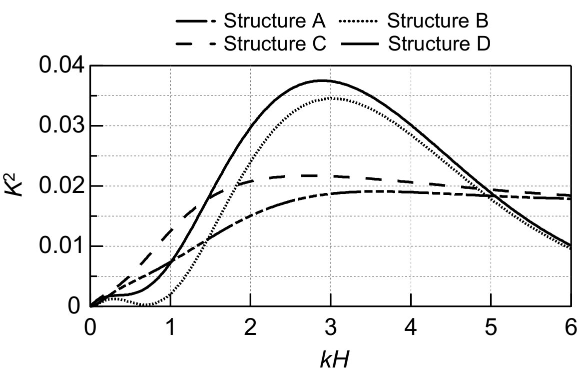

Fig. 5 Profile curves of K^2 as a function of kH at θ = 40º.