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# Electromechanical coupling coefficient of SH-SAW in c-axis parallel oriented ZnO film / amorphous substrate structure

c 軸平行配向 ZnO 膜/非晶質基板構造における
SH-SAW の電気機械結合係数

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## 1. Introduction

A shear horizontal type surface acoustic wave (SH-SAW) device can be used as a sensor operating in the liquid, because SH-SAW propagates at liquid/solid interface without energy leakage to the liquid. Therefore, this device can detect changes in the electrical and mechanical properties (conductivity, relative permittivity and viscosity) of liquid [1)].

In previous studies, we have studied a ZnO film whose c-axis is oriented parallel to the substrate plane (c-axis parallel oriented ZnO film) [2)]. This film excites SH-SAW and can be deposited on various substrates, for example, a silicon IC and curved surface, without use of the epitaxial technique [2)]. On the other hand, SH-SAW device with large electromechanical coupling coefficient ($K^2$) value is necessary for the sensor based on an acoustoelectric effect. The sensitivity is proportional to $K^2$ value in electric property measurement. $K^2$ value depends on $\psi$ and H / $\lambda$ where $\psi$ defined as the angle between the in-plane c-axis direction of the c-axis parallel oriented ZnO film and the $x_2$-direction (the third Euler angle), H is film thickness and $\lambda$ is wavelength, as shown in **Fig. 1**. We previously investigated theoretical $K^2$ value in IDT / ZnO (0º, 90º, $\psi$) film / silica glass substrate structure [3)]. As a result, maximum value of $K^2$ = 3.4 % was found at $\psi$ = 55º with H / $\lambda$ = 0.21.

In this study, we fabricated IDT / ZnO (0º, 90º, $\psi$) film / silica glass substrate structure and evaluated $K^2$ values. Finally, excitations of SH-SAW were performed in the liquid, using the substrate structure with large $K^2$ value.

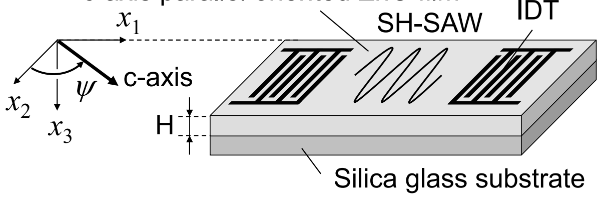


Fig. 1 IDT / ZnO (0º, 90º, $\psi$) / silica glass substrate structure.

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## 2. Sample fabrication

The c-axis parallel oriented ZnO films ({11$\bar{2}$0} ZnO film) were deposited on the silica glass substrates (25×100×0.5 mm$^3$, ED-B, Tosoh) using an RF magnetron sputtering system [4)]. Formation of the (11$\bar{2}$0) ZnO film was confirmed by XRD patterns. Four samples with $\psi$ angle of 0º, 30º, 60º and 90º were prepared. Film thickness in all samples were adjusted to 4.5-5.0 $\mu$m which corresponds to the H / $\lambda$ of 0.18-0.25. $K^2$ values around H / $\lambda$ = 0.18-0.25 are almost constant and are equal to the value at H / $\lambda$ = 0.21 in theoretical prediction.

Transversal filter type IDT aluminum electrodes were fabricated on the c-axis parallel oriented ZnO films. IDT electrodes consisting of 54 finger pairs with the wavelength of $\lambda$ = 20 $\mu$m were prepared. Overlap length and the distance between two IDTs were set to 250$\lambda$ and 300$\lambda$.

## 3. Measurement of electromechanical coupling coefficient

$K^2$ value of SH-SAW is given by the following equation [5)], $K^2 = \pi \times G_a / (4N \times B)$ (**Eq. 1**) where $N$ is the finger pairs, $G_a$ is the radiation conductance and $B$ is the susceptance at center frequency.

Reflection and transmission coefficents of $S_{11}$, $S_{22}$ and $S_{21}$ were measured by a network analyzer (E5071B, Agilent Technologies). $K^2$ values were estimated by using Eq. 1 where $G_a$ and $B$ were calculated from $S_{11}$ and $S_{22}$. **Fig. 2** shows the $K^2$ values of four samples at $\psi$ = 0º, 30º, 60º and 90º. Maximum $K^2$ value was estimated to be 2.2 % at $\psi$ = 60º, minimum $K^2$ values were estimated to be 0.2 % and 0.1 % at $\psi$ = 30º and 90º. $K^2$ value at $\psi$ = 0º was estimated to be 1.6 %.

## 4. Theoretical analysis

The propagation characteristics of SH-SAWs in the structure types A, B, C and D as shown in Fig. 2, were calculated. Fig. 2 shows theoretical $K^2$ values in the A to D structures at H / $\lambda$ = 0.21. Several points were not shown, because we could not obtain a convergent solution in the calculation.

It is interesting to note that the $K^2$ values exhibit a maximum at $\psi = 55°$ and a minimum at $\psi = 30°$ and 90º. This behavior is similar to characteristics of the relationship of $k$ value in bulk quasi-shear wave ($k'^2_{15}$) between the c-axis angle $\gamma$ with respect to the electric field, as shown **Fig. 3**. Structure type A and B tend to have larger $K^2$ values than type C and D. This probably results from the difference in the distribution of electric field. The electric field which is parallel to propagation direction seems to be strong in the film region in structure type A and B without metal electrode. In this case, angle between electric field and c-axis is similar to that of Fig. 3. Therefore, $K^2$ value exhibits a maximum at $\psi = 55°$. In contrast, the electric field is vertical to the propagation direction in structure type C and D. This maybe because the $K^2$ value is low.

## 5. SH-SAW excitation in liquid

Experiment of SH-SAW excitation was performed using the device with the maximum $K^2$ value at $\psi = 60°$. Pool made of silicone rubber was fabricated on the space between two IDTs. **Fig. 4(a)** and **(b)** shows insertion losses ($S_{21}$) measured in the case that the before the pool was fabricated and after the pool was filled with water. Rayleigh-SAW and SH-SAW excitation was observed in Fig. 4(a), whereas only SH-SAW excitation was observed in Fig. 4(b), because Rayleigh-SAW could not propagate due to energy leakage to the liquid. We then confirmed that SH-SAW could propagate in liquid / solid interface.

## 6. Conclusion

IDT / ZnO (0º, 90º, $\psi$) film / silica glass substrate structures were fabricated and $K^2$ values were estimated. As a result, maximum $K^2$ value was found to be 2.2 % and this value was 65 % of theoretical $K^2$ value. In this device, SH-SAW excitation and propagation was observed in liquid / solid interface.

## References


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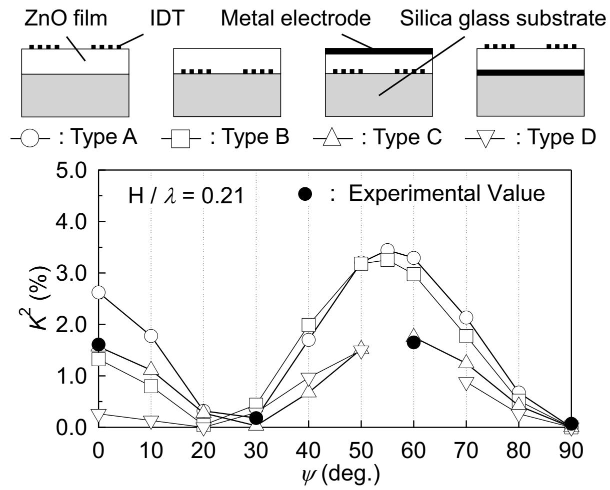


Fig. 2 Experimental and theoretical $K^2$ values of the SH-SAW as a function of angle $\psi$ at H / $\lambda$ = 0.21.

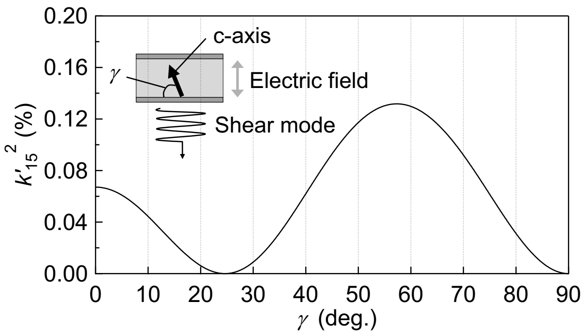


Fig. 3 Theoretical bulk quasi-shear wave $k'_{15}$ as a function of angle $\gamma$.

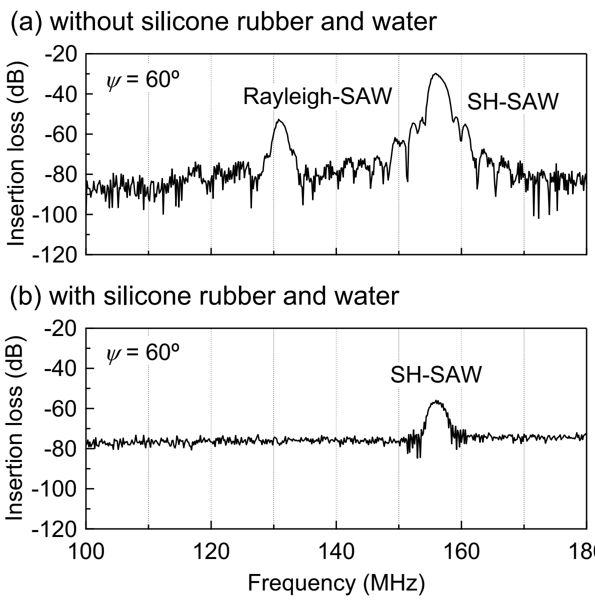


Fig. 4 Insertion loss ($S_{21}$) characteristics obtained from a sample (a) without and (b) with silicone rubber and water.