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Theoretical and Experimental Consideration of Optimum Gold Film Thickness for SH-SAW Biosensor on Quartz

水晶 SH-SAW バイオセンサにおける金膜厚最適化の理論と実験における考察

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1. Introduction

Today the detection of biological reactions is indispensable in many fields of science and medicine. There are various important requirements for a sensor platform, for example portability, low cost per test, maximum achievable sensitivity and specificity, and ease of use. Shear horizontal surface acoustic wave (SH-SAW) based biosensors must be one of the strong candidates. A palm-sized electronic reader connected to a sensor device for detecting antigen-antibody reactions has been already realized [1]. However, there are only few papers on the numerical analysis of SAW biosensors [2]-[4]. Numerical analysis of SH-SAW biosensors must be one of the important factors for the commercialization of SH-SAW biosensors in the future.

The numerical analysis of SAW biosensors on 36° Y-cut X-propagation lithium tantalite (36YX-LT) has already been reported [2]. A leaky SAW can propagate on 36YX-LT. In the liquid, the leaky SAW has a propagating loss due to energy leakage of a longitudinal wave. On the other hand, a pure SH-SAW can propagate on 36° Y-cut 90° X-propagating (36Y-90X) quartz. The pure SH-SAW has virtually zero propagation loss in a liquid. Also the quartz based SH-SAW has attractive temperature-stable characteristics. So we have been approaching biosensors using quartz based SH-SAWs.

It has been already reported that the calculated mass loading sensitivities of SH-SAW on quartz were too small to confirm the experimental results of the SH-SAW biosensor [4]. It might be concluded that the viscosity sensitivity can be dominant rather than the mass loading sensitivity for the SH-SAW biosensors on 36Y-90X quartz [3]. The aim of this study is to optimize the gold-film-thickness of the SH-SAW biosensors on 36Y-90X quartz. Finally, we compared the experimental results of the SH-SAW biosensor with calculated results.

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2. Numerical calculation

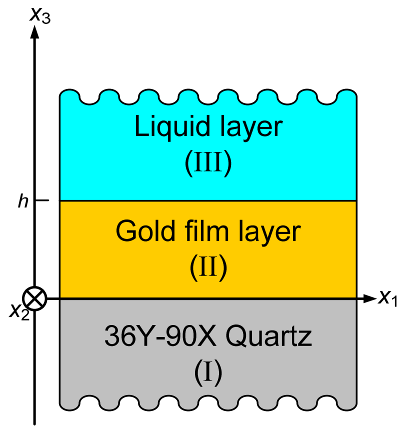


Fig. 1 Calculation model.

A numerical calculation method has been proposed by Campbell and Jones [5]. In this study, a numerical calculation method for SH-SAW propagation characteristics, which is a modified Campbell and Jones method involving the effect of liquid viscosity [6] is applied to quartz.

The structure model of the calculation used in the present study is shown in **Fig. 1**. There are three layers: substrate (I), metal (II), and liquid (III). The substrate layer (I) is 36Y-90X quartz, the metal layer (II) is gold film, and the liquid layer is the Newtonian fluid. The SH-SAW propagates along the x_1 direction. The liquid layer and substrate are considered as semi-infinite layers while the gold film is considered as a finite layer.

In the cases on layers (I) and (II), we can use a numerical calculation method proposed by Campbell and Jones [5]. In the case of layer (III), we can use the numerical calculation method reported by Moriizumi et al., [6]. The boundary conditions between (I) and (II), (II) and (III) are the continuities of the displacement and stress x_3 direction.

3. Experimental

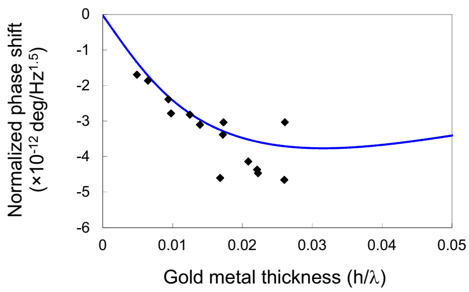
Several SH-SAW biosensors are designed and fabricated on 36Y-90X quartz substrates. The

SH-SAW biosensors consist of input and output interdigital transducers (IDTs), and a sensing area between them. The sensing area is covered with a gold film. The center-to-center distance between the input and output IDTs is 2mm. The split finger IDTs having a periodicity of 10, 15, and 20μm and the gold film thicknesses are 100, 210, 320, 430, and 640nm. Although a titanium film of 12nm thickness is used as an adhesive layer between quartz and gold film, we ignored it in calculation. The IDTs have an aperture of 0.4mm and 80 finger pairs.

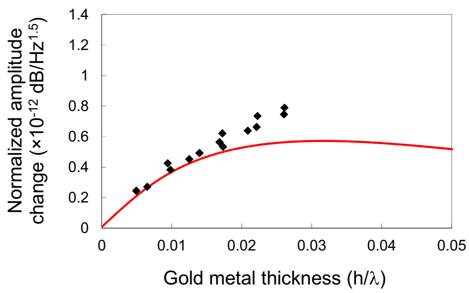
In order to investigate viscosity sensitivity of the SH-SAW biosensor, water and glycerol mixture of 10 wt% are used as sample liquid. They are added to the sensing area of SH-SAW biosensors, and measure phase and amplitude change from water to glycerol mixture using network analyzer. Since three wavelengths of IDTs and five gold film thicknesses exist, the fifteen center frequency exists from 177MHz to 480MHz. The temperature of the glycerol mixture is kept at a 23 degree Celsius.

4. Results and discussions

The velocity and attenuation changes of the SH-SAW 10 wt% were calculated. The material constants of the glycerol mixture, such as viscosity and density, were obtained from a technical data handbook [7]. The temperature of the glycerol mixture was kept at a 23 degree Celsius during experiments. We calculated the values of material constants at 23 degree Celsius using a spline interpolation from the article data.



(a) Phase shifts.



(b) Amplitude changes.

Fig. 2 Normalized phase shifts and amplitude changes of water to glycerol mixtures of 10 wt% as function of gold film thickness.

Normalized phase shifts and amplitude changes from water to glycerol mixture of 10 wt% as a function of normalized gold film thickness are shown in **Fig. 2**. In **Fig. 2**, the phase shifts and amplitude changes are shown using the normalized values of 1.5 power of frequency.

The wavelengths of gold film thickness are obtained using the SH-SAW velocities in the case of that film thickness on 36Y-90X quartz substrate. The solid lines show the calculated results, the diamond symbols show the average of the experimental results. Very good agreements between calculated and experimental results are obtained as shown in **Fig. 2**. Maximum phase shift and amplitude change are obtained at the gold film thickness of larger than or equal to 0.02 h/λ. Also at those thicknesses, the error of the phase shift and amplitude change due to thickness variation is minimized.

5. Conclusions

This paper describes a numerical analysis of liquid-phase SH-SAWs on 36Y-90X quartz which is covered with different thickness of gold films. The velocities and attenuations of the SH-SAW which propagate on liquid / gold-film / 36Y-90X quartz structure are calculated. The calculated and experimental results for the SH-SAWs are compared using normalized values by the 1.5 power of frequencies. Good agreements between calculated and experimental results are obtained. The maximum phase shifts and amplitude changes are obtained at the gold film thickness of larger than or equal to 0.02 h/λ. Also at those thicknesses, the variations of the phase shifts and amplitude changes due to gold film thickness variation can be minimized. We will show an optimized design of SH-SAW biosensors in consideration of insertion loss in the near future.

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