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Parameter Extraction of COM Equations Including Two SAW Coupling for TC-SAW Structures

TC-SAW 構造における SAW 結合を考慮した COM パラメータの算出

Yulin Huang[1, 2†], Jingfu Bao[1], Xinyi Li[1,2], Benfeng Zhang[3,2], Tatsuya Omori[2], and Ken-ya Hashimoto[2,3] (Univ. of Elec. Sci. and Tech. of China, [2]Chiba Univ., [3]Shanghai Jiao Tong Univ.)
黄裕霖 [1, 2†],鮑景富 [1],李昕熠 [1,2], 張本鋒 [3,2],大森達也 [2],橋本研也 [2,3] ([1] 電子科技大, [2] 千葉大, [3] 上海交通大)

1. Introduction

Suppression of the shear-horizontal (SH) SAW is mandatory to design temperature compensated (TC) surface acoustic wave (SAW) devices on θ degree rotated Y-cut $LiNbO_3$ (θ-LN)[1], where the Rayleigh SAW is the main mode. However, it is not easy because the electromechanical coupling for SH-SAW varies very quickly with θ and electrode and SiO_2 thicknesses.

The authors investigated SAW properties on the Cu-grating/θ-LN substrate structure, and reported that the rapid variation is caused by the coupling between the Rayleigh and SH SAWs, and their behaviors can be explained well with the coupling of modes (COM) theory including the coupling between two different SAWs[2]

This paper investigates SAW properties on the SiO_2-overlay/Cu-grating/θ-LN structure. The COM equations with two SAW coupling is used to show how parameters appearing in the theory change with θ and Cu electrode and SiO_2 thicknesses. It is also shown how optimal θ for SH-SAW suppression changes with the structural design.

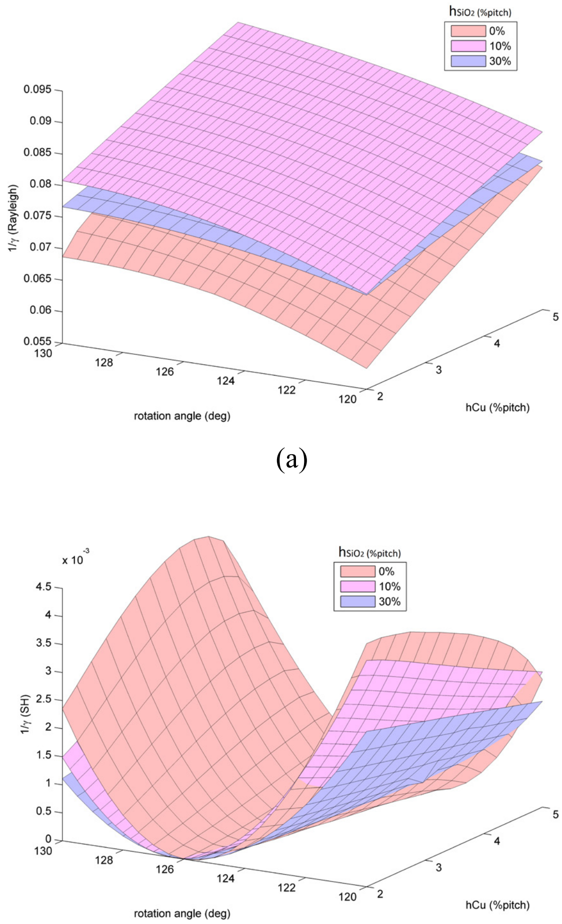
2. Variation of γ with structural parameters

Input admittance of infinitely long interdigital transducers (IDTs) with the period p_I were calculated the SiO_2-overlay/Cu-grating/θ-LN structure using the FEM software COMSOL. The SiO_2 top surface was assumed to be flat, and the metallization ratio was set at 0.5. The periodic boundary condition was applied to the SAW propagation direction.

Fig. 1(a) shows change of the ratio capacitance γ of the Rayleigh SAW with θ and the Cu thickness h_{Cu} when the SiO_2 thickness h_{SiO2} is chosen as a parameter. Here γ was estimated by $(f_a^2/f_r^2-1)^{-1}$, where f_r and f_a are the resonance and anti-resonance frequencies. It is seen that γ^{-1} changes very slowly with θ and h_{Cu}. It is interesting to note that γ^{-1} increases with h_{Cu} while it takes a maximum with respect to h_{SiO2} at $h_{SiO2} \sim 0.1p_I$. This γ^{-1} increase can be explained by SAW energy concentration due to the mass loading while the γ^{-1} decrease at large h_{Cu} is due to SAW energy penetration into non-piezoelectric SiO_2 layer.

Fig. 1(b) shows γ^{-1} of the SH SAW. It changes abruptly at θ~125° and θ giving minimum γ^{-1} changes gradually with h_{Cu} and h_{SiO2}.

huangyulin@chiba-u.jp



(a)

(b)

Fig. 1 Variation of γ^{-1} of (a) Rayleigh and (b) SH SAWs on SiO_2-overlay/Cu-grating/θ-LN structure with θ and Cu and SiO_2 thicknesses

3. Parameter extraction for COM equations

Coupling of modes (COM) equations including the coupling between two SAWs are given in the following form [2]:

$$\frac{\partial U_{1\pm}}{\partial x} = \mp j\theta_{1u}U_{1\pm} \mp j\kappa_1 U_{1\mp} \mp j\kappa_{cc}U_{2\pm} \mp j\kappa_{cr}U_{2\mp} \pm j\zeta_1 v \quad (1)$$

$$\frac{\partial U_{2\pm}}{\partial x} = \mp j\theta_{2u}U_{2\pm} \mp j\kappa_2 U_{2\mp} \mp j\kappa_{cc}U_{1\mp} \mp j\kappa_{1r}U_{R\pm} \pm j\zeta_2 v \quad (2)$$

$$\frac{\partial i}{\partial x} = -4j\zeta_1\{U_{1+}+U_{1-}\} - 4j\zeta_2\{U_{2+}+U_{2-}\} + 2\pi jfCv \quad (3)$$

where θ_{un} κ_n, and ζ_n are the detuning factor, reflection coefficient, and excitation efficiency of the n-th mode. And C is the static capacitance per unit length, v is the applied voltage, f is the frequency, and i is the current on the busbar. Newly introduced two coefficients κ_{cc} and κ_{cr} are responsible to collinear and reverse couplings between two SAW modes, respectively. In the equations, the IDT is assumed to be symmetrical and bidirectional.

In the following analysis, we assume that θ_{un} changes linearly with f, and is expressed as $\theta_u=2\pi/p_I\times c_n(f/f_{rn}-1)-\kappa_n$ where f_{rn} is the resonance frequency of the n-th mode when the mode coupling is ignored, and c_n is the ratio between phase and group velocities of the n-th mode.

These parameters were determined by fitting dispersion relations of two SAW modes obtained by these COM equations with those obtained by the FEM calculation. The result shows that most of all parameters change moderately with θ and h_{Cu} but two parameters ξ_2 and κ_{cr} change rapidly, and are mainly responsible for the variation of optimal angle for the SH-SAW suppression.

Figs. 2(a) and (b) show variation of ξ_2 and κ_{cr} with θ and h_{Cu} when h_{SiO2} is chosen as a parameter. They change linearly with θ and h_{Cu}. On the other hand, they change in a complex manner with h_{SiO2}. This may be due to non-flatness of the top surface when h_{SiO2} is small or zero,

In [2], it was shown that the single resonance condition is given by

$$\frac{f_{r2}}{f_{r1}} - \left(\frac{\kappa_c\zeta_1 p_I}{c_1\zeta_2\pi}+1\right)\left(\frac{\kappa_c\zeta_2 p_I}{c_2\zeta_1\pi}+1\right)^{-1} = 0 \qquad (4)$$

Fig. 3 shows variation of the left side of Eq. (4) with θ when h_{cu} and h_{SiO2} are chosen as parameters. Zero crossing points gives the single mode resonance. The point translates to lower θ with h_{cu} while to higher θ side with h_{SiO2}. This result agrees well with those given by the FEM analysis shown in Fig. 1.

4. Conclusion

This paper described SAW properties on the SiO_2-overlay/Cu-grating/θ-LN structure. The COM equations with two SAW coupling was used to show how parameters appearing in the theory change with θ, h_{Cu} and h_{SiO2}. It was also shown how optimal θ for SH-SAW suppression changes with the structural design.

We will discuss the behavior more in detail at the conference.

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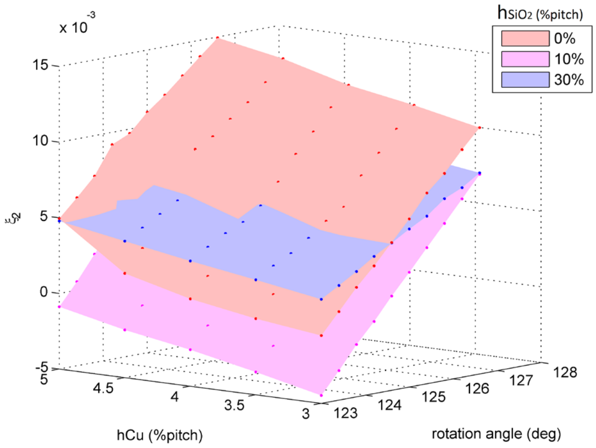
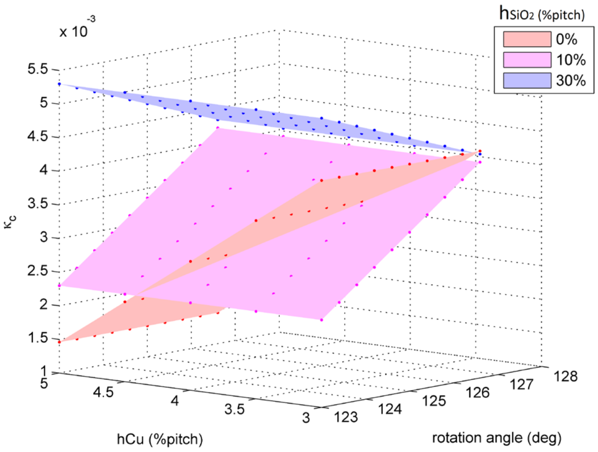
Reference
[1] M.Kadota, et al., Jpn. J. Appl. Phys., **46,** 7S (2007) 4714.
[2] Y.Huang, et al., Proc. IEEE Ultrason. Symp. (2017) [to be published]



(a) exicitation coefficient ξ_2



(b) mode coupling coefficient κ_{cr}

Fig. 2 Variation of ξ_2 and κ_{cr} with θ, h_{Cu} and h_{SiO2}

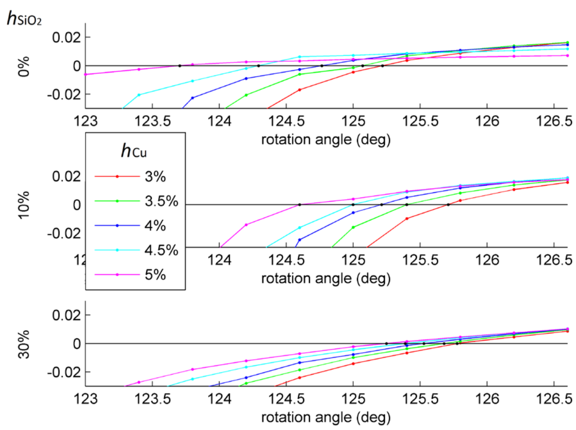


Fig. 3Variation of the zero crossing points with θ