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 LiNbO3 (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 SiO2 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 SiO2-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 SiO2 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 p1 were calculated the SiO2-overlay/Cu-grating/θ-LN structure using the FEM software COMSOL. The SiO2 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 hCu when the SiO2 thickness hSiO2 is chosen as a parameter. Here γ was estimated by \( (f_r^2/f_a^2 - 1)^{-1} \), where \( f_r \) and \( f_a \) are the resonance and anti-resonance frequencies. It is seen that γ changes very slowly with θ and hCu. It is interesting to note that γ increases with hCu while it takes a maximum with respect to hSiO2 at hSiO2 ~ 0.1p1. This γ increase can be explained by SAW energy concentration due to the mass loading while the γ decrease at large hCu is due to SAW energy penetration into non-piezoelectric SiO2 layer.

Fig. 1(b) shows γ of the SH SAW. It changes abruptly at θ ~ 125° and θ giving minimum γ changes gradually with hCu and hSiO2.

3. Parameter extraction for COM equations

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

\[
\frac{\partial U_{1x}}{\partial x} = \mp j \theta_{\mu} U_{1x} \mp j k_{\mu} U_{1x} \mp j k_{\alpha} U_{2x} \pm j k_{\alpha} U_{2x} \pm j \zeta_v \quad (1)
\]

\[
\frac{\partial U_{2x}}{\partial x} = \mp j \theta_{\alpha} U_{2x} \mp j k_{\alpha} U_{1x} \mp j k_{\alpha} U_{2x} \pm j k_{\alpha} U_{2x} \pm j \zeta_v \quad (2)
\]

\[
\frac{\partial i}{\partial x} = -4 j \zeta_v \left( U_{1x} + U_{2x} \right) - 4 j \zeta_v \left( U_{2x} + U_{2x} \right) + 2 g_{Cv} \quad (3)
\]

where \( \theta_{\mu} \), \( k_{\mu} \), and \( \zeta_v \) 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 \( \kappa_{cc} \) and \( \kappa_{cr} \) 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 \( \theta_{in} \) changes linearly with \( f \), and is expressed as \( \theta_{in} = 2\pi/p_1 \times C_0(f/f_{rn}-1) - \kappa_n \), where \( f_{rn} \) is the resonance frequency of the \( n \)-th mode when the mode coupling is ignored, and \( C_0 \) 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 \( \theta \) and \( h_{Cu} \) but two parameters \( \xi_2 \) and \( \kappa_{cr} \) 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 \( \xi_2 \) and \( \kappa_{cr} \) with \( \theta \) and \( h_{Cu} \) when \( h_{SiO2} \) is chosen as a parameter. They change linearly with \( \theta \) 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

\[
\frac{f_{21}}{f_{11}} = \left( \frac{\kappa_{21} p_1}{c_2 p} + 1 \right) \left( \frac{\kappa_{21} p_1}{c_2 p} + 1 \right)^{-1} = 0
\]  

(4)

Fig. 3 shows variation of the left side of Eq. (4) with \( \theta \) when \( h_{Cu} \) and \( h_{SiO2} \) are chosen as parameters. Zero crossing points gives the single mode resonance. The point translates to lower \( \theta \) with \( h_{Cu} \) while to higher \( \theta \) 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/\( \theta \)-LN structure. The COM equations with two SAW coupling was used to show how parameters appearing in the theory change with \( \theta \), \( h_{Cu} \) and \( h_{SiO2} \). It was also shown how optimal \( \theta \) 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
