Model Parameter Extraction of Lateral Propagating SAWs with Mode Coupling on TC-SAW Resonators

TC-SAW 共振子における SAW 間結合を含む横モード伝搬のモデル化

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1. Introduction

It is known that in temperature compensated (TC) surface acoustic waves (SAW) resonators on the θ degree rotated Y-cut LiNbO3 substrate, both Rayleigh and shear horizontal (SH) SAWs exist, and their coupling gives significant impacts on their lateral propagation[1].

Recently, the authors proposed the extended thin plate model for the analysis of lateral SAW propagation including two-sAW coupling[1, 2], and pointed out that the piston mode operation (PMO)[3] is possible without phase shifters when two SAW modes are coupled[4].

This paper investigates how parameters defined in the extended thin plate model change with SiO2 thickness, electrode thickness and rotation angle on SiO2/overlay/Cu-grating/θ deg. rotated YX-LiNbO3 (θ-LN) substrate structure.

2. Parameter determination

Fig. 1 shows the frequency dependence of the lateral wavenumber βy on an infinitely long grating on SiO2/Cu/128-LN structure with grating period p of 2 µm when the longitudinal wavenumber βz is fixed at π/p. The calculation is performed by the finite element method (FEM). The width lCu and thickness ℎCu of grating electrodes are 0.5p and 0.06p, respectively, and the SiO2 thickness ℎSiO2 is 0.6p.

There are four branches; two of them are due to the coupled Rayleigh SAW while the others are due to the coupled SH SAW. They exhibit the cutoff nature at the frequencies ℎb and ℎs giving the stopband edges, and each mode propagates laterally only above the corresponding cutoff frequency and is evanescent below the frequency. Only one branch is excitable electrically for each SAW mode. In this case, both the lower branches are excitable.

The extended thin plate model[1,3] gives the dispersion relations of these coupled SAW modes as solutions of

\[
\begin{bmatrix}
  a_1 \beta_z^2 + b_1 \beta_y^2 - \rho \omega^2 / c_{66} & b_1 \beta_z \beta_y \\
  b_1 \beta_z \beta_y & b_2 \beta_z^2 + a_2 \beta_y^2 - \rho \omega^2 / c_{66}
\end{bmatrix} = 0
\]

where \(a_i = c_{ij} / c_{66}, b = 1 + c_{ij} / c_{66}, c_{ij}\) are effective elastic constants, \(\omega\) is the radial frequency, and \(\rho\) is the mass density.

Theses parameters are determined from cutoff frequencies \(f_b\) and \(f_s\) and second-order gradient of the calculated dispersion curves at these frequencies. Only those of excitable branches are considered in the fitting. Fig. 1 also shows the fitted dispersion curves calculated by Eq. (1) with these parameters. It is seen that agreement is excellent with the FEM result. In this cases, \(a_1 = 0.92, a_2 = 0.48, b = 0.17\).

Fig. 1 Frequency dispersion of \(\beta_y\) when \(\beta_z = \pi / p\). Solid lines: calculated by FEM, and marks (▲ and •): calculated by the model given by Eq. (1)

3. Variation of model parameters with structural parameters

The procedure described above was applied to the SiO2/Cu/θ-LN structure, and we investigate how the model parameters \(a_1, a_2, \) and \(b\) change with SiO2 and Cu thicknesses \(h_{SiO2}\) and \(h_{Cu}\) and the rotation angle \(\theta\).

Fig. 2 shows variation of \(a_1, a_2, \) and \(b\) with \(h_{SiO2}\) and \(h_{Cu}\). For three \(h_{Cu}\) settings. It is seen that influence of \(h_{Cu}\) and \(\theta\) is relatively small, and they only affect the amplitude of the parameters. On the other hand, \(a_1\) and \(b\) change parabolically with \(h_{SiO2}\) while \(a_2\) decreases monotonically with \(h_{SiO2}\).

Parameters in gap region are also extracted. The procedure is the same as that of IDT region but there exists only one electrode per IDT period and the width of electrode is set at \(l_{Cu} = 0.75p\). To reduce the SAW velocities, \(h_{Cu}\) is set quite large in the case.

The results are shown in Fig. 3. In this case, all the parameters change smoothly with \(h_{Cu}\), \(\theta\) and \(h_{SiO2}\). It should be noted that \(b\) is more sensitive than other.

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two parameters to $h_{\text{SiO}_2}$, $\theta$ and $h_{\text{Cu}}$.

4. Conclusion

This paper discussed how the parameters defined in extended thin plate model change with SiO$_2$ thickness, electrode thickness and rotation angle on the SiO$_2$/Cu/\(\theta\)-LN structure.

We will apply the parameters determined in the paper to find structures to support the PMO by using the technique given in [4]. Details will be discussed at the conference.

Acknowledgement

The work was partially supported by the Natural Science Foundation of China (No. 11174205 and No. 11474203). XYL acknowledges the support of the Japanese Government (MEXT) for the scholarship through the Super Global University Project.

Reference