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Thin Plate Model for Transverse Mode Analysis of Surface Acoustic Wave Devices

弾性表面波デバイスの横モード解析のための薄板モデル

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1. Introduction

To realize surface acoustic wave (SAW) devices with high performance, such as high quality factor, satisfactory spurious mode rejection level and so on, it's necessary to guide the SAW inside the transducer region. Or else, energy leakage to surroundings and/or in pass-band ripples, will deteriorate quality factor and spurious mode rejection ability[1)].

To analyze the in-plane SAW propagation, the scalar potential theory (SP) [2)] and finite element method (FEM) are often used. The SP theory has extended to include mechanical reflections[3),4)] and asymmetry of the slowness curve[5)], and radiation modes[6),7)]. Although FEM is quite flexible, it is time consuming. This made it not applicable to the optimal design. Besides, since the topologies of IDTs are of vital influence on the device characteristics, it is necessary to make the SP model more flexible.

This paper proposes a thin plate model for the analysis of transverse modes in SAW devices. Since the model starts from wave equations, it is more flexible than the SP theory, various phenomena such as coupling between shear horizontal (SH) and Rayleigh SAWs and scattering and excitation at electrode tips can be taken into account.

2. Thin Plate Model Theory

Let us consider two dimensional (x-y) propagation of shear vertical waves u_z in an infinitesimally thin plate with the thickness h. Electrodes are placed on the top surface of the plate and the back surface is fully metallized, We employ the following wave equation for the discussion:

$$c_{55}\frac{\partial^2 u_z}{\partial x^2}+2c_{45}\frac{\partial^2 u_z}{\partial x\partial y}+c_{44}\frac{\partial^2 u_z}{\partial y^2}+\rho(x,y)\omega^2 u_z = e_{35}\frac{\partial E_z}{\partial x}+e_{34}\frac{\partial E_z}{\partial y} \quad (1)$$

where ω is the radial frequency, e_{ij} is the piezo-electric constant, and ρ is the mass density.

When the stiffness c_{ij} is set unform, continuity of stresses S_{zx} and S_{zy} at boundaries is equivalent to that of $\partial u_z/\partial x$ and $\partial u_z/\partial y$, respectively. Spatial variation of wave velocity and acoustic impendance is considered as that of ρ. Thus the present analysis is equivalent to the SP model[2)]. It should be noted that e_{35} is responsible to SAW excitation at electrode side edges while e_{34} is responsible to that at eletrode tips.

Let us discuss excitation of acoustic waves by the electrodes. When the voltage V is applied between the top and bottom electrodes, the electric field E_z is V/h under the electrodes, and zero elsewhere. Thus $\partial E_z/\partial x$ and $\partial E_z/\partial y$ are non zero only at electrode edges. Then the right terns in Eq.(1) can be set zero, and their influence can be included in the boundary conditions, namely discontinuity in $\partial u/\partial x$ and $\partial u/\partial y$.

Next let us discuss detection of acoustic waves. The charge Q_n induced to the n-electrodes is given by

$$Q_n=\int_{S_n}\left[\varepsilon_{33}E_z+e_{35}\frac{\partial u_z}{\partial x_x}+e_{34}\frac{\partial u_z}{\partial x_y}\right]dS\ , \quad (2)$$

where ε_{ij} is the permittivity and S_n is the area of the top electrode. The first term expresses contribution of the electrostatic coupling given by CV, where C is the static capacitance. The second and third terms express contributions of propagating acoustic waves. Since $\partial u_z/\partial x$ and $\partial u_z/\partial y$ are discountinuous only at the boundaries, their integrations can be estimated from variation of u_z across the boundaries.

Since this model is based on the wave equation, these calculations can be easily implemented into the FEM software having the partial differential equation mode such as COMSOL Multiphysics[4)]. Various supporting functions such as automesh and visualization are implemented in commercial FEM software. They made the simulation flexible and easy to use.

Eqs. (1) and (2) can be solved analytically when infinitely long periodic grating structures with infinite aperture are considered. Thus parameters

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appearing in Eqs. (1) and (2) except e_{34} can be determined by fitting the IDT behavior derived analytically with that obtained by the full wave analysis for the target structure[9].

3. Simulation example

As a demonstration, we analyze two-dimensional SAW propagation in infinitely long IDTs by using the proposed model.

Fig. 1 shows the device structure here we concern. It includes bus bars and gap regions in addition to the interdigital electrodes. In the following calculation, we set at c_{55}=c_{44}, c_{45}=0, e_{34}=0, and the aperture and gap lengths were 10λ and 0.75λ, respectively.

One period is extracted, and the periodic boundary condition was applied to the left and right edges. On the other hand, the perfect matching layers were given to the top and bottom edges of bus bars.

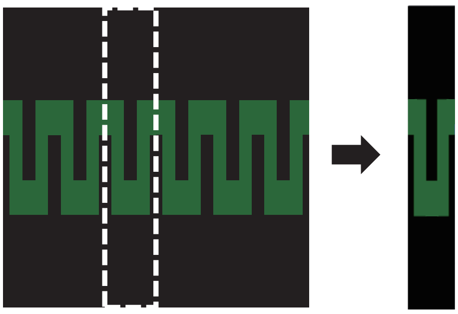

Fig. 1 Model structure implemented in COMSOL

Fig. 2 shows as an example, a calculated admittance characteristics of the infinitely long IDT. Adding to the fundamental mode, a series of satellite resonances, namely transverse modes, can be seen. Although acoustic attenuation is not included in this simulation, the resonance Q is finite. This is due to energy leakage (radiation) toward the bus bar region. It is seen that the Q value becomes worse with an increase in the resonance order.

Fig. 3 shows the calculated displacement distribution at the zeroth and fifth resonances. In addition to the standing pattern at the interdigitated region, energy radiation is clear seen at the bus bar region.

5. Conclusion

This paper described the thin plate model for the analysis of transverse modes in SAW devices.

As a next step, we will apply this model for the case when the coupling between SH and Rayleigh SAWs is significant.

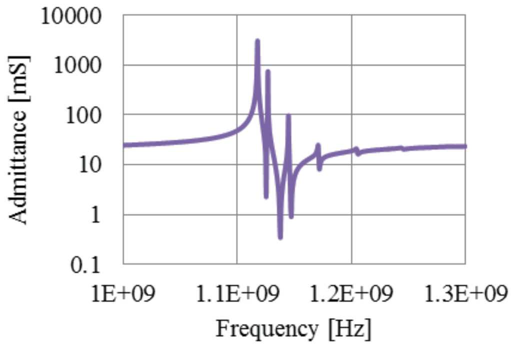

Fig.2 Calculated admittance characteristic

(a) (b)

Fig. 3 Displacement distribution, (a) fundamental resonance, and (b) fifth resonance.

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