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Electromechanical Coupling Coefficient of Lamb Waves in Multilayered Piezoelectric Plates with Distinct Electrode Arrangements

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1. Introduction

When the plate thickness is less than a wavelength, Lamb wave modes exist and propagate in the plate; hence, these devices are so-called Lamb wave devices. Recently, the Lamb wave devices consisted of multilayered piezoelectric plates have been widely used in electro-acoustic and microfluidic devices [1-5]. In order to improve their performances, the phase velocity dispersion and electromechanical coupling coefficient (ECC) of the Lamb wave must be calculated exactly during designing.

Currently, two methods have been widely used to calculate the ECC. One is the acoustic velocity difference method [6], based on the velocity difference under free-surface and metalized-surface electrical boundary conditions. The other is the Green's function method [7-9], which is an exact method. To date, the mthod is still not adopted to caclaulate the ECCs of Lamb waves in a multilayered piezoelectric plate with distinct electrode arrangements.

This paper aims at analyzing exactly Lamb waves in a ZnO/Si multilayered piezoelectric plate with distinct electrode arrangements. First, a transfer matrix [6, 10] is used to calculate the phase velocity dispersion. For exact analyses, the Green's function method is employed to calculate the ECC under distinct electrical boundary conditions. Finally, the influences of the Si thickness on the phase velocity dispersion and ECC are further discussed.

2. The electromechanical coupling coefficient

The electromechanical coupling coefficient K_S^2 of a piezoelectric medium is obtained exactly by the Green's function method and is given by

$$K_S^2 = -2\Gamma_s \varepsilon_s^{(\infty)} \qquad (1)$$

where $\varepsilon_s^{(\infty)}$ is the effective permittivity at infinite slowness and Γ_s is a coupling parameter.

3. Calculation results

ZnO films with *c* axis have been widely used to configure electro-acoustic devices due to their high ECCs. Therefore, a ZnO/Si multilayered plate is taken as the calculation example. The thickness ratio of Si to ZnO is 5:1. In addition, there are four electrode arrangements, shown in **Fig. 1**, in the calculation: the IDTs are deposited on top surface and the interface can be either electrically free or metalized; moreover, the IDTs are deposited on the interface and the top surface can be either electrically free or metalized. The metalization means zero potential and no mechanical loading.

Shown in **Fig. 2** is the phase velocity dispersion of the first two Lamb wave modes for type A, which was calculated by using the transfer matrix. This result shows that the modes both are all-pass modes. We note that the phase velocity of S0 mode is larger than that of A0 mode and surface wave. This is one of the reasons why the Lamb wave devices attract increasing attentions recently.

Fig. 3 and **Fig. 4** show the ECCs for the four electrode arrangements calculated by using the Green's function method. Results show that the ECCs deeply depends on the electrode arrangement. It is worth noting that the ECC of the S0 mode with the electrode arrangements of type D is much larger than that of other modes. However, the price is the increase of fabrication difficulty due to the obvious dispersions of not only phase velocity but ECC.

To further investigate the influence of the Si thickness, the S0 mode of type D is taken as the calculation example. **Fig. 5** and **Fig. 6** are the phase velocity dispersion and ECC for three thickness ratios respectively. The result shows the phase velocity and EEC strongly depends on the Si thickness. Moreover, the EEC increases with decreasing the Si thickness.

4. Conclusions

This paper proposes an exact analysis of Lamb waves in the ZnO/Si multilayered plate with four types of electrode arrangements by the Green's function method. From the calculation results, we can see that the coupling coefficients deeply depends on the electrode arrangement, and the S0 mode with the electrode arrangements of type D is a better choice due to its larger velocity, higher coupling coefficient. Moreover, the EEC can be enlarged by reducing the Si thickness.

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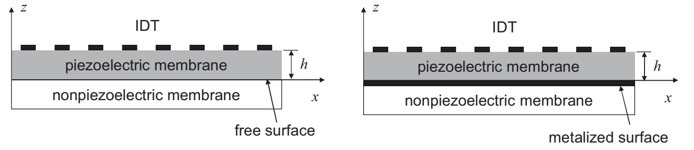
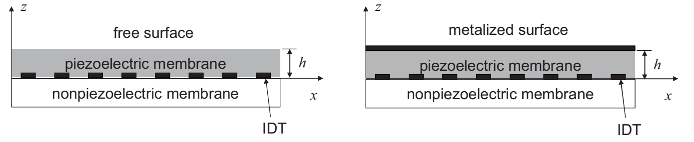


(a) Type A (b) Type B



(c) Type C (d) Type D

Fig. 1 Four types of electrode arrangements.

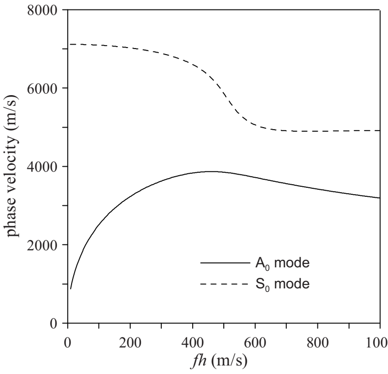


Fig. 2 Phase velocity dispersion of the first two Lamb modes for type A.

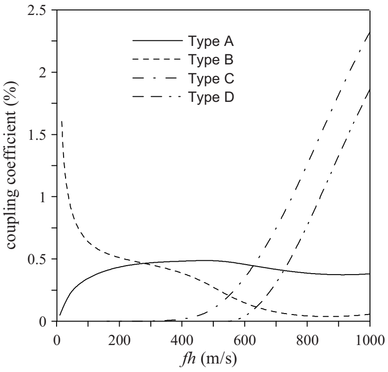


Fig. 3 Coupling coefficient of A0 mode.

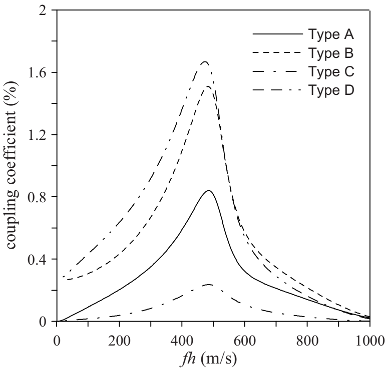


Fig.4 Coupling coefficient of S0 mode.

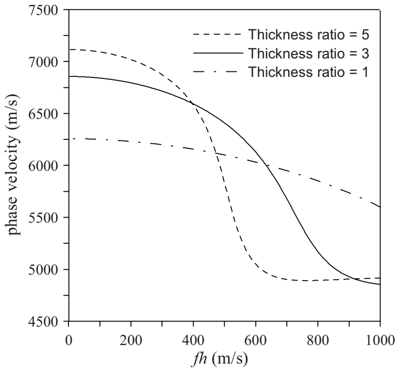


Fig.5 Phase velocity dispersion of S0 mode with the electrode arrangements of type D.

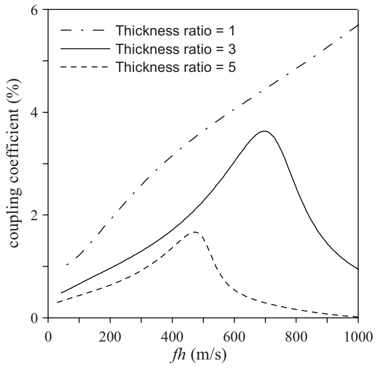


Fig.6 Coupling coefficient of S0 mode with the electrode arrangements of type D.