Electric Field Influence on Lamb and SH Wave Properties in LiNbO₃ Plates

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Abstract: The effect of differently oriented external electric fields on the velocity of Lamb and SH waves propagating in mechanically free thin plates of lithium niobate of various crystallographic cuts is theoretically studied. It is shown that plate thickness may significantly change the dependence of velocity variation on the electric field intensity.

INTRODUCTION

Presently, acoustic devices using an electrically controlled time delay are highly promising. They include acoustic phase shifters, amplitude and phase modulators, high voltage meters, devices with electrically compensated temperature coefficient of delay time, devices for beam steering in phased array antennas, and electronically tunable oscillators. Lithium niobate is one of the most promising materials with strong anisotropy of electroacoustic interaction. The electroacoustic interaction in bulk and surface acoustic waves has been investigated previously [1,2]. The substrate thickness is the smallest dimension of a SAW device and the biasing field is usually applied along this direction. This allows one to obtain the maximum electric field intensity for a given bias voltage. However, in the case of the SAW devices thickness must be much greater than the acoustic wavelength \( \lambda \). For example, for SAW devices thickness is typically greater than 10 \( \lambda \).

In recent years there has been a growing interest in using Lamb and SH waves for a variety of physical, chemical, and biological sensors [3,4]. These waves are also finding applications in measuring the elastic properties of thin films and in microminiature actuators. Important advantages over SAW sensors are obtained by utilizing the lowest order Lamb and SH wave modes, propagating in plates that are very thin compared to the acoustic wavelength. These advantages include higher sensitivity, lower operating frequency, faster response, and ability to operate in contact with liquid media. Moreover, SH wave can propagate without dispersion and provides extremely high value of electromechanical coupling coefficient [5]. However, the influence of external electric field on their properties has not been investigated. Because the Lamb and SH waves devices are usually fabricated on a very thin plate, it is expected to show strong sensitivity to applied bias voltage. This paper is concerned with the propagation of Lamb and SH acoustic waves in lithium niobate plates placed in external electric field.

THEORETICAL MODELS

The geometry of the problem, the basic equations, electrical and mechanical boundary conditions, and method used to analyze the propagation of waves in the presence of a biasing field was similar to that developed previously for the case of SAWs and described in details in Ref.[2]. It has been found that the dependence of velocity variation on the electric field intensity for lithium niobate has a complex nature due to nonlinear piezoeffect and electrostriction. The analysis has shown that the velocity variation may be written as \( \Delta V/V = \alpha E + \beta E^2 \), where \( \alpha \) and \( \beta \) are coefficients depending on crystallographic cut, propagation direction, type of wave, plate thickness and electric field orientation. Below we present the dependencies of these coefficients on propagation direction and plate thickness for Lamb and SH waves of zero order for Y-cut of lithium niobate and electric field orientation being normal to the plate. We consider that both plate surfaces are metallized.

NUMERICAL RESULTS

Fig.1 displays the coefficients \( \alpha \) and \( \beta \) for \( S_{0} \), \( A_{0} \) and \( S_{0} \) waves as functions of the wave propagation direction in Y-cut lithium niobate for different values of ratio \( h/\lambda \), where \( h \) is plate thickness. One can see that maximum dependence on plate thickness for \( S_{0} \) wave occurs for X-axis, where the coefficient of electromechanical coupling is maximum [5]. The propagation directions with weak piezoeffect show smaller dependence of \( \alpha \) and \( \beta \) on plate thickness.

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Moreover both coefficients decrease with increasing of plate thickness. It means that sensitivity for electric field intensity decreases with increasing plate thickness. As for $\alpha_0$ wave one can see that both coefficients increase with increasing of plate thickness in opposite of $SH_0$ wave. Fig. 1c displays that dependencies of $\alpha$ and $\beta$ on propagation direction for $S_0$ wave are more complicated in opposite of previous cases. For some propagation directions these coefficients increase with increasing of thickness, and for another ones decrease or have some optimum value.

\[ \alpha, 10^{-10} \text{ m/V} \]

\[ \beta, 10^{-14} (\text{m/V})^2 \]

FIGURE 1. Variation of coefficients $\alpha$ and $\beta$ as functions of azimuthal angle for $SH_0$, $\alpha_0$ and $S_0$ waves propagating on Y-cut lithium niobate

CONCLUSION

For all types of waves coefficient $\beta$ is always negative and maximum of its value are practically the same. As for coefficient $\alpha$, it may be positive as well as negative. For all types of waves there are certain propagation directions and plate thickness where $\alpha = 0$ and field dependence may be pure quadratic. It can be seen that by changing plate thickness, type of wave and propagation directions one can obtain different dependence of velocity variation on electric field intensity that may be important for practical applications.

REFERENCES