HYBRID ACOUSTIC WAVES IN PIEZOELECTRIC PLATES

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Abstract – The conditions for zero-order and high-order hybridization of the acoustic waves propagating in a piezoelectric crystal plate have been studied. The dependence of the phase velocity of the hybrid waves on the parameter hf (h = plate thickness, f = wave frequency) is established for the potassium niobate and lithium niobate plates possessing various crystallographic orientations and sheet condutances. It is found that hybridization takes place when the sheet conductance exceeds a certain critical value, which can vary within broad limits depending on the plate material and orientation. The degree of dispersive repulsion of the coupled modes increases with the electromechanical coupling coefficient.

I. INTRODUCTION

Under certain conditions, the waves of different types propagating in a multimode waveguide system exhibit coupling and cannot exist independently of one another. Such coupled waves are referred to as hybrid modes. The phenomenon of hybridization is well known in dielectric electromagnetic waveguides [1], magnetic materials [2], and some other systems. In recent years, it was reported that hybrid modes can also exist in strongly piezoelectric crystals.

In particular, it was theoretically predicted that coupled surface waves of the Rayleigh and Gulyaev-Blustein types can propagate along the Z axis of a metal-coated (Y+ 66^0) - cut semi-infinite crystal of lithium niobate [3]. Our theoretical results [4] showed that an Y-cut plate of potassium niobate with one electrically shorted surface can exhibit a weak coupling between an antisymmetric A_0 wave and an SH_0 wave with shear horizontal polarization propagating in the X+15^0 direction. These waves form a hybrid mode provided that the parameter hf (h = plate thickness and f = the wave frequency) is close to 1000 m/s. No hybridization takes place when both surfaces of the plate are electrically open. However, our knowledge about the conditions of hybridization of acoustic waves in piezoelectric crystals is not enough exhaustive and this phenomenon requires further thorough investigation.

This paper continues theoretical investigations of the coupled zero-order acoustic waves of the A_0 – SH_0 type propagating along the X+15^0 direction in Y-cut potassium niobate crystals. We have attempted at finding new hybrid couples among the acoustic modes of both zero and higher orders in a lithium niobate plate. Thorough analysis revealed the existence of another hybrid couple, formed by a symmetric first-order Lamb

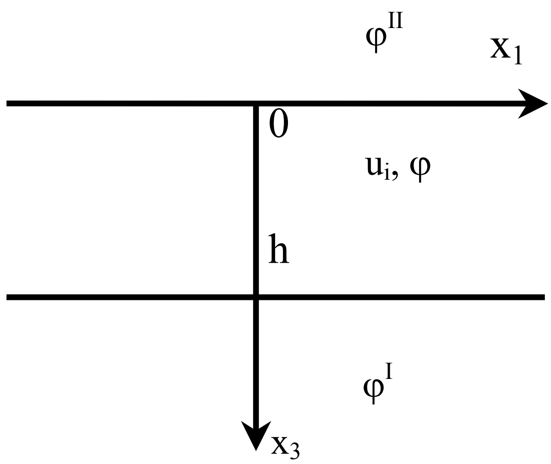

Figure 1: Geometry of the problem

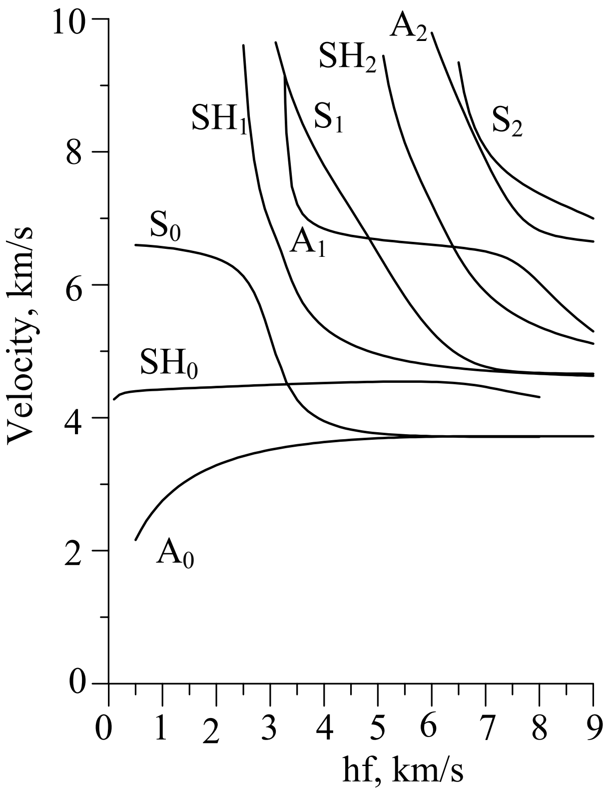

Figure 2: Phase velocity in km/s versus the parameter hf in km/s for the nine lowest plate wave modes in Y-cut, X-propagation lithium niobate plate

wave S_1 and a second-order wave with shear horizontal polarization SH_2 propagating in an Y-X plate of lithium niobate. In addition, we have theoretically studied the influence of a thin (as compared to the wavelength) conducting layer on the characteristics of the aforementioned hybrid modes in piezoelectric plates of potassium niobate and lithium niobate.

II. THEORETICAL ANALYSIS AND RESULTS

In order to find new hybrid couples, we have solved the problem of acoustic wave propagation in a piezoelectric plate of thickness h occurring in vacuum, with (i) both surfaces electrically open or (ii) one surface electrically shorted. The numerical solution of a system of the equations of motion, Laplace equation, and material equations for a piezoelectric medium in combination with standard boundary conditions was described in detail elsewhere [5]. The analysis yielded the dependences of the wave phase velocity on the parameter hf for the aforementioned materials in various crystallographic situations. From these data, we determined the regions of parameters and the modes for which the hybridization is possible. The geometry of the problem under consideration is shown in Fig.1. Waves propagate along the x_1 direction of a piezoelectric plate bounded by planes x_3=0 and x_3=h. We consider a two dimensional problem in which all field components are assumed to be constant in the x_2 direction. A typical plot of dispersion characteristics for the first few modes is shown in Fig. 2. This figure refers to waves propagating along the X- axis of a Y-cut lithium niobate plate. For calculations we used lithium niobate material constants reported by Kovacs, et al. [6].

Then we have studied the influence of a thin conducting film on the characteristics of hybrid couples. It was assumed that the conducting layer thickness is small as compared to the wavelength λ, so that the mechanical load upon the plate could be ignored. The method of solving such problems, whereby the presence of a conducting layer is taken into account only in the electrical boundary conditions, was described previously [7].

Figure 3 shows plots of the phase velocities of the A_0 and SH_0 waves propagating in the X+15^0 direction versus parameter hf for the Y-cut potassium niobate plates with various values of the sheet conductance. Figure 4 presents analogous curves for the S_1 – SH_2 hybrid couple propagating along the X axis in the Y-cut plates of lithium niobate. These results allow us to conclude that hybridization arises when the surface conductivity exceeds a certain critical value σ_{cr}, which can vary

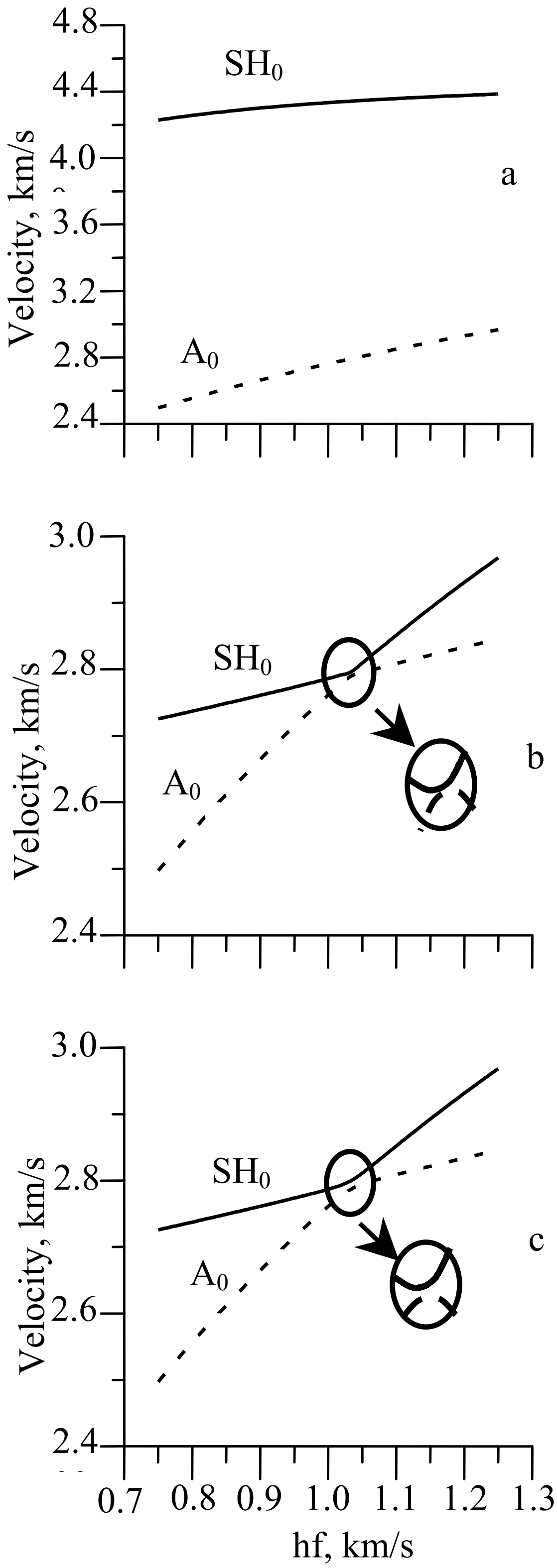

Figure 3: Plots of the phase velocity of the A_0 and SH_0 waves propagating in the Y-(X+15^0) potassium niobate plate with various values of sheet conductance: $\sigma = 10^{-8}$ S (a); $\sigma = \sigma_{cr} = 4\times10^{-4}$ S (b); and $\sigma = 10^{-2}$ S (c).

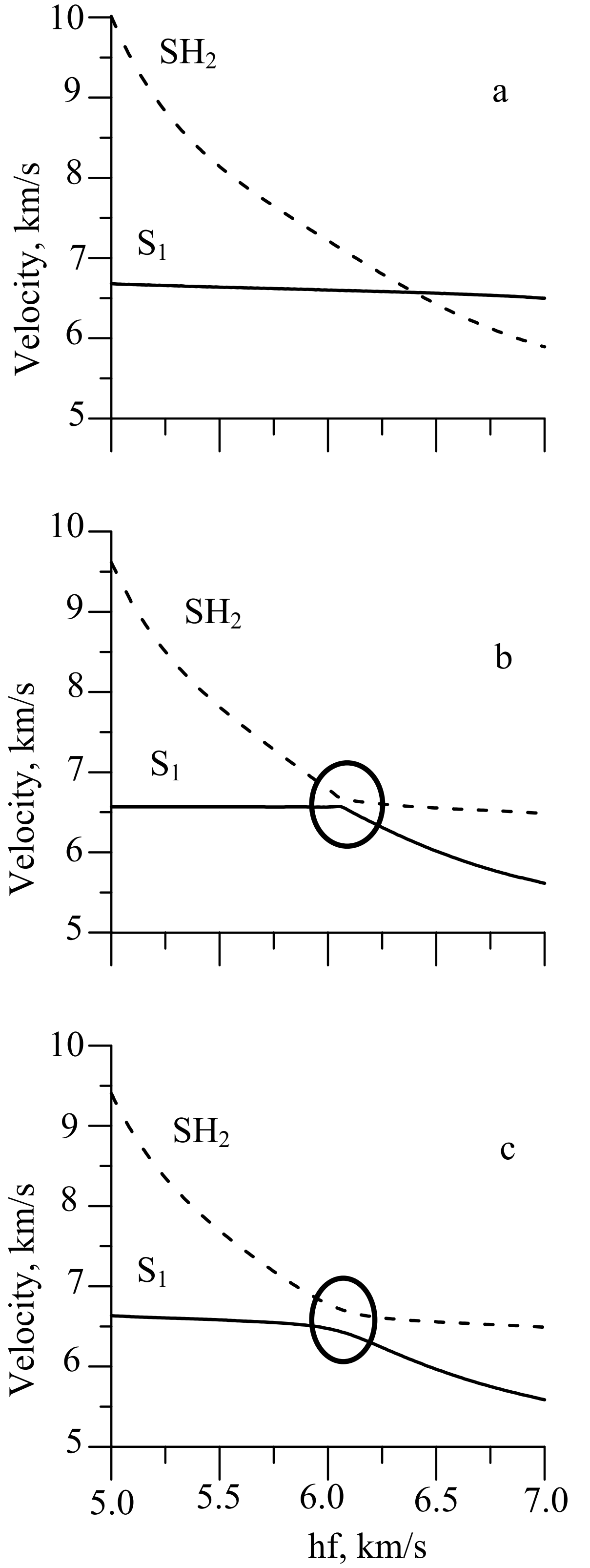

Figure 4: Plots of the phase velocity of the S_1 and SH_2 waves propagating in the Y-X lithium niobate plate with various values of sheet conductance: $\sigma = 10^{-8}$ S (a); $\sigma = \sigma_{cr} = 6\times10^{-6}$ S (b); and $\sigma = 10^{-2}$ S (c).

within broad limits depending on the plate material and orientation. For example, $\sigma_{cr} = 4 \times 10^{-4}$ S for the potassium aforementioned zero-order $A_0 - SH_0$ hybrid couple in a niobate plate with hf ≈ 1040 m/s (Fig. 3b) and $\sigma_{cr} = 6 \times 10^{-6}$ S for the $S_1 - SH_2$ hybrid couple in a lithium niobate plate with hf ≈ 6050 m/s (Fig. 4b). The modes under consideration are not coupled in the same plates with electrically free surfaces, whereby the dispersion curves exhibit no characteristic splitting (Figs. 3a and 4a), For $\sigma = \sigma_{cr}$ the dispersion curves exhibit "repulsion", the extent of which increases with σ and tends to maximum as $\sigma \rightarrow \infty$ (Fig. 3c).

As can be seen from Figs. 2c and 3c, the dispersion curves of the piezoelectrically more active $S_1 - SH_2$ couple propagating in the Y-X lithium niobate exhibit more pronounced repulsion as compared to that for the piezoelectrically less active $A_0 - SH_0$ couple propagating in the Y- (X+15^0) potassium niobate plate. Based on this fact, we conclude that the degree of repulsion between the dispersion curves of coupled modes increases with the electromechanical coupling coefficient of the waves under consideration.

III. SUMMARY

Thus, the results of our investigation showed that piezoelectric plates of a certain crystallographic orientation covered with a thin conducting surface film can feature hybrid modes of the zero and higher orders, provided that the film conductivity exceeds a definite critical value. These results are not only of interest from the fundamental standpoint, but can find practical application in the research and development of various devices such as amplitude and phase modulators and controlled directional couplers. These devices employ piezoelectric plates coated with thin conducting films, the conductivity of which can be controlled by various external factors such as the electric or magnetic field, light, etc.

IV. ACKNOWLEDGEMENT

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