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AN ANALYSIS TECHNIQUE FOR THE WAVEGUIDE ON THE SAW CONVOLVERS[1)]

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By using the scalar potential theory, dispersion relations for all the modes in the waveguide on the YZ-$LiNbO_3$ are obtained. In this analysis, wave-numbers of the fast and slow regions are obtained by using a proper curve fitting technique for the data of the Rayleigh wave velocities of electroded and unelectroded YZ-$LiNbO_3$. Dispersion relations obtained by the presented technique are compared with the experimental results.

I. INTRODUCTION

The applications of the surface acoustic waves are used in the signal processing systems and radar applications. The convolvers and correlators are among these applications. Especially correlators and convolvers give a new interpretation to acoustic signal processing. In acoustic convolvers or correlators the interactions of the acoustic surface waves are used to perform a convolution or a correlation of two different input signals. The interaction of two waves is performed in the waveguide part of the device.

The problem of the waveguide on the convolver designed with the focused interdigital transducer has been discussed. To obtain the guided propagation of the SAW in a specified direction, various techniques have been used. It has been mentioned that there are four different waveguide structures for SAW devices. First the overlay (plane) waveguides in which a thin film strip is placed on a substrate, secondly the topographic waveguides, which consist of a local deformation of the substrate surface itself, thirdly those in which a local change has been produced by the properties of the substrate material, and fourthly circular waveguides [1]. These waveguide structures are shown in the Fig. 1.1. In the SAW convolvers, the plane waveguide structure is usually used. The wave propagation at the waveguide is investigated by the scalar potential theory developed for this structure. The scalar potential theory has been introduced for the isotropic structure [2]. To take the anisotropy effect of the crystal into account, this theory has been modified by

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considering that the wave velocity depends on the propagation direction as a parabolic function of the propagation angle [3]. In this work, using wave velocities of the substrate material rather than the parabolic curve fitting, dispersion relations for all wave modes are obtained and computer simulations are performed.

2. PLANE WAVEGUIDES

There are two basic plane waveguides. These structures are slot and strip waveguides as shown in Fig. (1.1.a) and Fig. (1.1.b). The device in this work has the strip waveguide. In the strip waveguide the SAW velocity at the central region is reduced by covering a thin film layer on a substrate. The thickness of the thin film in this region is smaller than the wave length of the SAW. In the analysis of the SAW guide the scalar potential theory described by Knowless [2] is the starting point. Knowless has shown that the propagation of SAW has been investigated by a unique scalar potential function on a semi-infinite isotropic medium. Knowless' scalar wave equation is of the form:

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial z^2} + \frac{\omega^2}{v^2}\Psi = 0, \tag{2.1}$$

where v is the surface wave velocity, ω is the radian frequency, x and z are coordinates of the surface plane. Waveguides have been modelled, as shown in Fig. (2.1), for both the slot and the strip waveguide structures. It has been believed that the waveguides consist of three different regions. In these regions V_s and V_f are the wave velocities of the central region and the side regions, respectively. In the central region, the wave velocity is slower than that of the neighbour regions.

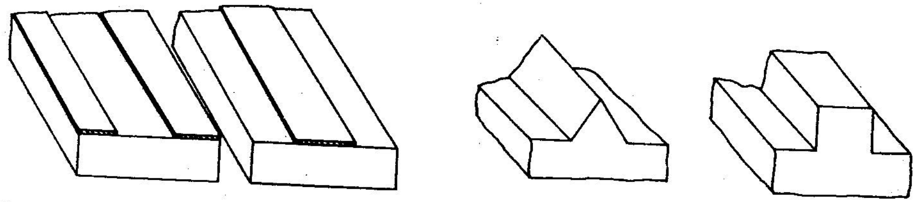
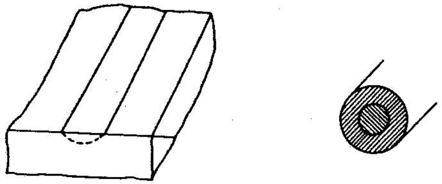


Fig. 1.1(a), (b) Plane Waveguides; (c), (d) Topographic Waveguides;



(e) Third type Waveguide; (f) Fourth type Waveguide.

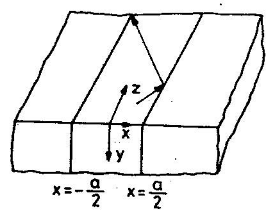


Fig. 2.1. The chosen coordinates system.

The wave propagation at the slow and the fast regions are investigated by Ψ_s and Ψ_f, the scalar potentials, which are described for each region respectively. In these regions the wave equations are as follows:

$$\begin{aligned} &\frac{\partial^2 \Psi_s}{\partial x^2} + \frac{\partial^2 \Psi_s}{\partial z^2} + \frac{\omega^2}{v_s^2}\Psi_s = 0, \quad -\frac{a}{2} < x < \frac{a}{2} \\ &\frac{\partial^2 \Psi_f}{\partial x^2} + \frac{\partial^2 \Psi_f}{\partial z^2} + \frac{\omega^2}{v_f^2}\Psi_f = 0, \quad x > \frac{a}{2} \end{aligned} \tag{2.2}$$

To obtain the dispersion relation, the wave equations are solved by using the boundary conditions given for the scalar potential. Under the boundary conditions at $x = \pm\frac{a}{2}$ the displacements and normal components of stress are continuous at discontinuity. Similar boundary conditions may be constructed from the scalar potential. In the isotropic homogeneous case the Knowless scalar potential is proportional to the surface normal component of displacement. Therefore the boundary conditions can be taken as follows:

$$\Psi_s = \Psi_f \qquad x = \pm\frac{a}{2} \tag{2.3}$$

and

$$C_s\frac{\partial \Psi_s}{\partial x} = C_f\frac{\partial \Psi_f}{\partial x} \tag{2.4}$$

at $x = \pm\frac{a}{2}$, where C_s and C_f are effective stiffeness constants for the slow and the fast regions respectively. In guides having a low dispersion, two regions have almost the same velocities and effective stiffeness constants of both. Thus the boundary condition (2.4) becomes

$$\frac{\partial \Psi_s}{\partial x} = \frac{\partial \Psi_f}{\partial x} \tag{2.5}$$

at $x = \pm\frac{a}{2}$. The scalar potential solution of the wave equation may be obtained as follows:

$$A\exp\left\{-k_{x_f}\frac{a}{2}\right\} = B\cos(k_{x_s}\frac{a}{2}) \tag{2.6}$$

$$k_{x_f}A\exp\left\{-k_{x_f}\frac{a}{2}\right\} = Bk_{x_s}\sin(k_{x_s}\frac{a}{2}). \tag{2.7}$$

By applying the boundary conditions the following dispersion relations for symmetric modes are obtained

$$\mathrm{tg}\,(k_{x_s}\frac{a}{2}) = \frac{k_{x_f}}{k_{x_s}}, \tag{2.8}$$

where k_{x_f} and k_{x_s} are the transverse decay constants in the form:

$$k_{x_s} = \frac{\omega}{V_s}$$
$$k_{x_f} = \frac{\omega}{V_f}. \tag{2.9}$$

For inverse symetric modes we have

$$\mathrm{cotg}\,(k_{x_s}\frac{a}{2}) = -\frac{k_{x_f}}{k_{x_s}}. \tag{2.10}$$

The dispersion relations may be modified to include crystal anisotropy. In the anisotropic waveguide, the wave velocity depends on the angle Θ which is measured with respect to the waveguide axis. For this Θ dependence, there are different approaches in literature [2], [3]. The transverse decay constants have been given as follows;

$$ak_{x_f} = (\beta a)^2 - \left[\frac{V_p\beta a}{V_{of}(\Theta_f)}\right] \tag{2.11}$$

and

$$ak_{x_s} = \left[\frac{V_p\beta a}{V_{os}(\Theta_s) - \Delta_s\beta a(t/a)}\right] - (\beta a)^2, \tag{2.12}$$

where β is equal to ω/V_p, the waveguide phase velocity V_p, the system parameter t/a and Δ_s is the mass loading effect.

3. THE DISPERSION CURVES

The dispersion curves have been obtained from the equations (2.8)-(2.12) by using a computer program. The dispersion curve is the function of the variable βa. In the calculations the parameter t/a has been taken as 0.002 for the $LiNbO_3$ substrate with the thin film 180 nm. The mass loading effect value $\Delta_s = 116.4$ has been used. First, the main mode dispersion curve which includes the mass loading effect for the isotropic case has been shown in Fig. (3.1).

In the anisotropic case there have been described new functions for the wave velocities from data in the Ref. [4]. For the slow and the fast regions these functions are different from the parabolic wave velocity function which has been used in literature. These functions which have been obtained by using a proper curve fitting technique for the data of the Rayleigh wave velocities of YZ-$LiNbO_3$, are:

$$V_{os} = A0 + A1\cos 2\Theta_s + A2\cos 4\Theta_s + A3\cos 6\Theta_s \tag{3.1}$$

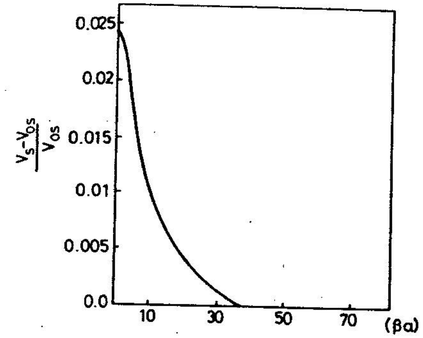


Fig. 3.1. In the isotropic case the main mode dispersion curve.

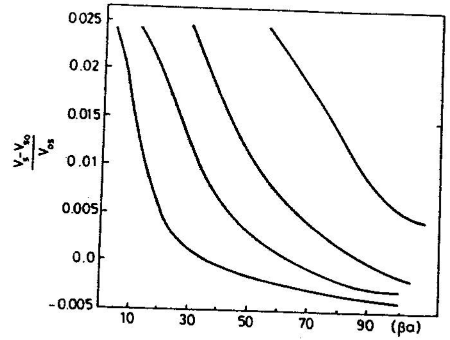


Fig. 3.2. The dispersion curves for the eq. (3.1) – (3.4).

and

$$V_{of} = A10 + A11\cosh 2\Theta_f + A12\cosh 4\Theta_f + A13\cosh 6\Theta_f \tag{3.2}$$

where the function coefficients are:

$$A0 = 0.9737648 \qquad A1 = 0.04095614$$
$$A2 = -0.0010427 \qquad A3 = -0.01490759 \tag{3.3}$$

and

$$A10 = 0.983396 \qquad A11 = 0.0352977$$
$$A12 = -0.0017487 \qquad A13 = -0.0167613 \tag{3.4}$$

The dispersion curves which are obtained by using the velocity relations in equations (3.1) and (3.2), are shown in Fig. (3.2). Next the dispersion curves related to the above velocity relation and the velocity relation in Ref. [3] have been drawn. These curves and the experimental results are shown in Fig. (3.3).

4. DISCUSSION

As it is shown in Fig. (3.3) the theory of the scalar potential gives good results in the investigation of the waveguide problem compared with the fittings of the velocity approaches to the experimental results. It can be seen that the approach given in this work is better than other approaches.

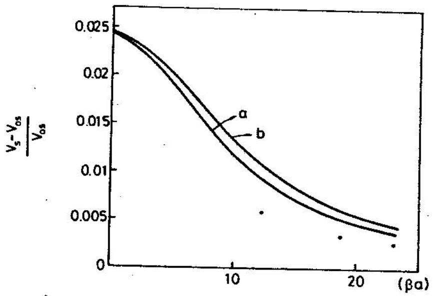


Fig. 3.3.(a) The relative velocity curve for the approach given in this work; (b) The relative velocity curve for the velocity function in the ref. [3]; (c) Dots are the experimental results.

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ТЕХНИКА АНАЛИЗА ВОЛНОВОДОВ С ПРИМЕНЕНИЕМ КОНВОЛЬВЕРОВ ПАВ.

С применением скаларной потенциальной теории полученны для YZ-$LiNbO_3$ дисперсионные управнения для всех мод в волноводах. Из анализа данных волновых скоростей Рейли в электродном и безэлектродном YZ-$LiNbO_3$, с применением математической подгонки, получены волновые числа быстрой и медленной областей. Таким образом полученные дисперсионные управления сравниваются с экспериментальными данными.