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Analysis Method for Ti:$LiNbO_3$ Acoustic Channel Waveguide on $LiNbO_3$ Substrate

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Summary
A novel analysis approach based on transverse resonance method (TRM) is presented for Ti:$LINbO_3$ acoustical channel waveguide on $LiNbO_3$ substrate. In this paper, we give how to construct the equivalent circuit of Ti:$LiNbO_3$ acoustical channel waveguide and the equivalent circuit of acoustical directional coupler with constant gap formed by Ti:$LiNbO_3$ acoustical channel waveguide. And respective dispersion equations are deduced from the given equivalent circuits. The results show that this analysis approach is effective, simple and convenient.

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1. Introduction

Acoustical waveguide formed by Ti:$LiNbO_3$ technique on $LiNbO_3$ substrate is useful for the integrated acousto-optic devices [1, 2, 3]. Although one's have obtained some valuable results [4, 5], it is necessary to study new and effective analysis method for it. In this paper, we present a equivalent circuit method for Ti:$LiNbO_3$ acoustical waveguide, with help of the so called transverse resonance method(TRM) based on transmission line theory [6], and using this method, we deduce dispersion equation of acoustical directional coupler with constant gap formed by Ti:$LiNbO_3$ waveguides. As compared with the field analysis method [7], this method is effective, simple and convenient.

2. Theory

2.1. Analysis of basic Ti:$LiNbO_3$ acoustic channel waveguide

The basic structure of acoustic channel waveguides is shown in Figure 1a, where the substrate material is X-cut, Y-propagating $LiNbO_3$ crystal, on which doped region (Ti:$LiNbO_3$) and undoped regions ($LiNbO_3$) are formed via Ti-indiffusion technique, and the SAW is excited via the piezo- electric effect by a RF-signal ($f \simeq 170\,\mathrm{MHz}$, $P_{\mathrm{el}} \simeq 30\,\mathrm{mW}$) to interdigital transducer electrodes of suitable periodicity. It was found experimentally that the phase velocity of Rayleigh-type SAW is increased about 0.3% for the Ti-doped area [8], and the Ti concentration at the surface and the penetration depth of Ti is 160-nm. Taking account of, for X-cut, Y-propagating SAW's on $LiNbO_3$, the particle displacement in X-direction (y-axis in Figure 1) is dominant [9], so the SAW can be described reasonably in a scalar approximation by this strain component only, and the reduction to a one-dimensional problem can be made using a one-dimensional velocity profile $V(x)$ in the transverse direction. The $V(x)$ can be determined by laser probing technique [10], the measured velocity profile is approximately step-function with constant velocities V_0 within the undoped regions and V_{Ti} within the doped regions (see Figure 1b). Once getting the velocity profile $V(x)$, we need to handle just the transversal, scalar and one-dimensional wave equation [11]:

$$\left\{ \frac{\partial^2}{\partial x^2} - \left(2\pi f_{ac}\right)^2 \left[\frac{1}{V_{\mathrm{eff,p}}^2} - \frac{1}{V^2(x)} \right] \right\} u_p(x) = 0, \qquad (1)$$

where $u_p(x)$ and $V_{\mathrm{eff,p}}$ denote the transversal strain in x-direction and the phase velocity of the guided SAW made, respectively. The solution of equation (1) is of the type $u_p = \exp(-\mathrm{j}k_x x)$, thus, $\partial^2/\partial x^2 = -k_x^2$ is valid. And we can rewrite equation (1) as

$$\left(-k_x^2\right) u_p(x) + \left[\frac{(2\pi f_{ac})^2}{V^2(x)} - \frac{(2\pi f_{ac})^2}{V_{\mathrm{eff,p}}^2} \right] u_p(x) = 0 \qquad (2)$$

by defining the "acoustic refraction index" in terms of

$$n_{\mathrm{saw}} = V_0/V(x), \qquad (3)$$

where $V(x)$ is shown schematically in Figure 1b within undoped region, $V(x) = V_0$, thus $n_{\mathrm{saw}} = n_{saw1} = 1$, and

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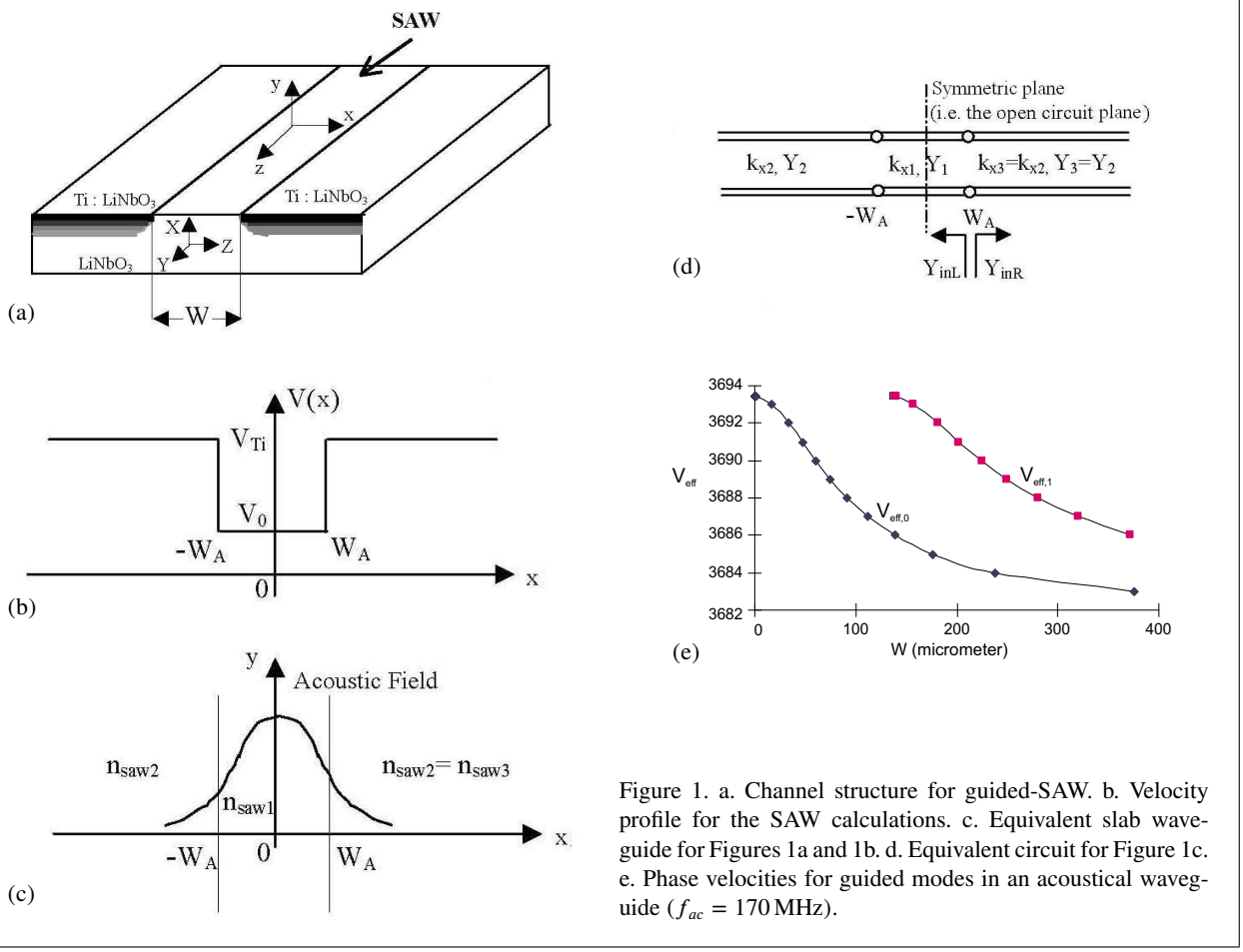


Figure 1. a. Channel structure for guided-SAW. b. Velocity profile for the SAW calculations. c. Equivalent slab waveguide for Figures 1a and 1b. d. Equivalent circuit for Figure 1c. e. Phase velocities for guided modes in an acoustical waveguide (f_{ac} = 170 MHz).

within Ti-indiffusion region, $V(x) = V_{Ti} = V_0 + 0.31\%V_0$, thus $n_{\text{saw}} = n_{\text{saw2}} = 0.9969$, therefore, equation (2) can be rewritten as

$$u(x)\left(-k_{xi}^2 - k_z^2 + k_0^2 n_{\text{saw}i}^2\right) = 0, \tag{4}$$

where $k_z = 2\pi f_{ac}/V_{\text{eff,p}}$ and $k_0 = 2\pi f_{ac}/V_0$, and k_{xi} denotes the wave number, i.e., the propagation constant in x-direction. From equation (4), due to $u(x) \neq 0$, we have

$$k_{xi}^2 + k_z^2 - k_0^2 n_{\text{saw}i}^2 = 0, \tag{7}$$

where

$$k_{xi} = \pm\sqrt{k_0^2 n_{\text{saw}i}^2 - k_z^2} \qquad i = 1, 2, \tag{8}$$

or

$$k_{x1} = \pm\sqrt{k_0^2 n_{\text{saw1}}^2 - k_z^2} \qquad \text{for region 1,} \tag{9}$$

$$k_{x2} = \pm\sqrt{k_0^2 n_{\text{saw2}}^2 - k_z^2} \qquad \text{for region 2.} \tag{10}$$

The "±" denote propagating direction of the transverse wave, i.e., "+" sign denotes positive x-direction, and "−" sign denotes negative x-direction. The k_z denotes the propagation constant of guided SAW in z-direction in Ti:LiNbO$_3$ channel, and the k_0 denotes the wavenuber of SAW propagating on LiNbO$_3$. Therefore, the Ti:LiNbO$_3$ channel waveguide can be equivalent to three regions: region1 ($n_{\text{saw1}} = 1$), region2 ($n_{\text{saw2}} = 0.9969$), and region3 ($n_{\text{saw3}} = n_{\text{saw2}} = 0.9969$), shown schematically in Figure 1c. Due to SAW is confined in region 1, the k_{x1} has to be real, and k_{x2} has to be imaginary, we have

$$k_{x1} = \sqrt{k_0^2 - k_z^2} > 0, \tag{11}$$

$$k_{x2} = \pm\mathrm{j}\alpha_{x2}, \tag{12}$$

$$\alpha_{x2} = \sqrt{k_z^2 - (0.9969)^2 k_0^2} > 0. \tag{13}$$

To obtain the dispersion equation of Ti:LiNbO$_3$ acoustical waveguide, we applied the transverse resonant method (TRM) to this problem, similar to the case of microwave and guided optic wave. According to transmission line theory, wave propagating in x-direction can be equivalent to circuit shown in Figure 1d. The TRM need that on the arbitrary reference plane in x-direction, such as $x = W_A$, or $x = -W_A$, the sum of input admittance Y_{inL} and Y_{inR} satisfies

$$Y_{inL} + Y_{inR} = 0, \tag{14}$$

where the Y_{inL} denotes the input admittance at $x = W_A$ when looking toward the negative x-direction, and the Y_{inR} denotes the input admittance at $x = W_A$ when looking toward the positive x-direction. Moreover, it is worth pointing that in Figure 1d the fact that the standing wave is formed in x-direction, means that resonance take place in

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x-direction, and because the guided-SAW propagates in z-direction, the resonance in x-direction is called transverse resonance (TR).

Now, let $x = W_A$ plane as reference plane, we have

$$Y_{inL} = \mathrm{j}Y_1 \tan\left(-k_{x1}W_A\right), \tag{15}$$

$$Y_{inR} = Y_2 = k_{x2}/\omega\mu_e, \tag{16}$$

where

$$Y_1 = k_{x1}/\omega\mu_e, \tag{17}$$

$$Y_2 = k_{x2}/\omega\mu_e, \tag{18}$$

denote the wave admittances of equivalent medium 1 (region 1) and medium2 (region2), respectively. In equation (17), ω denotes angle frequency of SAW, and μ_e denotes the equivalent permeability of equivalent medium. By substituting equation (17) into equation (15), and equation (18) into equation (16), with help of equations (11), (12), and (13), we have

$$k_{x2}/\omega\mu_e + \mathrm{j}\left(k_{x1}/\omega\mu_e\right)\tan\left(-k_{x1}W_A\right) = 0, \tag{19}$$

or

$$\tan\left(k_{x1}W_A\right) = \alpha_{x2}/k_{x1}, \tag{20}$$

and if selecting $x = -W_A$ as reference plane, we can obtain the same equation like equation (20). From equation (20), we can obtain the dispersion equation of Ti:LiNbO$_3$ acoustical waveguide as follows

$$k_{x1}W = q\pi + 2\arctan\left(\alpha_{x2}/k_{x1}\right), \quad q = 0, 1, \ldots \tag{21}$$

Putting the measured value $V_{Ti} = 3693.41$ m/s and the known value $f_{ac} = 170 \cdot 10^6$ Hz into equation (21), with help of equations (5), (6), (9), and (13), we obtain a set of discrete values of the p-th mode propagation velocities, i.e., the eigenvalue $V_{\mathrm{eff},p}$ ($p = 0, 1, \ldots$) as a function values of waveguide width W. Here, in order to illustrate main properties of the modes, we have calculated that of $p = 0$ and $p = 1$ and make them fitted curves shown in Figure 1e, which shown that the cutoff width of mono-mode ($p = 0$) is $W = 137.85\,\mu$m at the condition of $f_{ac} = 170$ MHz, i.e., we can get mono-mode only if the channel width W is less than $137.85\,\mu$m. Here, we select $W = 110\,\mu$m so as to ensure mono-mode transmission which is crucial for the effective transmitting of guided- SAW.

2.2. Analysis of acoustical directional coupler with constant gap

The basic structure of the acoustical directional coupler of constant gap is shown in Figure 2a, where the substrate material is x-cut, y-propagating LiNbO$_3$ crystal, on which doped regions (Ti:LiNbO$_3$) and undoped regions (LiNbO$_3$) are formed via Ti-indiffusion technique, and SAW is excited via the piezo-electric effect by a RF-signal to interdigital transducer electrodes of suitable periodicity. In this case, the velocity profile for the SAW calculations is shown in Figure 2b.

Based on discussing above, the acoustical directional coupler with constant gap made by Ti:LiNbO$_3$ channel waveguide can be equivalent to two types of slab waveguide, one is related to even symmetric plane of acoustic field profile, $x = 0$, and the other is related to odd symmetric plane of acoustic field, $x = 0$, and they are all divided in three regions: region 1 ($n_{\mathrm{saw1}} = 1$), region 2 ($n_{\mathrm{saw2}} = 0.9969$) and region 3 ($n_{\mathrm{saw3}} = 0.9969$), which is shown in Figure 2c. And equivalent circuits corresponding to Figure 2c are shown in Figure 2d and Figure 2e, respectively. Further, on the one hand, the even symmetric plane $x = 0$ of acoustical field profile can be equivalent to open-circuited plane, on which the equivalent voltage is maximum. And according to the transmission line theory, the three regions can be equivalent to cascade of three sections of transmission lines, and respective admittances and wavenumbers are Y_2 and k_{x2}, Y_1 and k_{x1}, as well as Y_3 and k_{x3}, shown schematically in Figure 2d. On the other hand, odd symmetric plane of acoustical field profile can be equivalent to short-circuited plane, on which the equivalent voltage is minimum. Also, the three regions can be equivalent to cascade of three sections of transmission lines, respective admittances and wave numbers are Y_2 and k_{x2}, Y_1 and k_{x1}, as well as Y_3 and k_{x3}, where Y_3 and k_{x3} are equal to Y_2 and k_{x2}, respectively, shown schematically in Figure 2e.

The analysis for the acoustical directional coupler of constant gap is also based on equation (1). In Figure 2d and 2e, because SAW is confined in region 2, the k_{x1} has to be real, and the k_{x2} and k_{x3} have to be imaginary, i.e., the k_{x1}, k_{x2} and α_{x2} satisfie equations (11), (12) and (13).

To obtain the dispersion characteristics of the acoustical directional coupler, we have to obtain the equations for Figure 2d and Figure 2e, respectively, by using the transverse resonance method (TRM) here which need that on the arbitrary reference plane in x-direction, such as $x = g/2 + W$, the sum of input admittance Y_{inL} and Y_{inR} should equal to zero, i.e.,

$$Y_{inL} + Y_{inR} = 0, \tag{22}$$

where Y_{inL} denotes the input admittance at $x = g/2 + W$ plane when looking toward the left of $x = g/2 + W$ plane, and Y_{inR} denotes the input admittance at $x = g/2 + W$ plane when looking toward the right of $x = g/2 + W$ plane. Firstly, we deduce the dispersion equation for Figure 2d from equation (22) using TRM. According to the transmission line theory, the input admittance at $x = g/2$ plane when looking toward the left of $x = g/2$ plane is

$$Y_{g/2} = Y_2\frac{Y_L + Y_2\tanh(\gamma g/2)}{Y_2 + Y_L\tanh(\gamma g/2)}, \tag{23}$$

where Y_2 is given by equation (18), Y_L is the load admittance, here $Y_L = 0$, and the propagation constant is given by

$$\gamma = 0 + \mathrm{j}k_{x2}, \tag{24}$$

thus

$$Y_{g/2} = \frac{-\mathrm{j}\alpha_{x2}}{\omega\mu_e}\tanh\left(\alpha_{x2}g/2\right). \tag{25}$$

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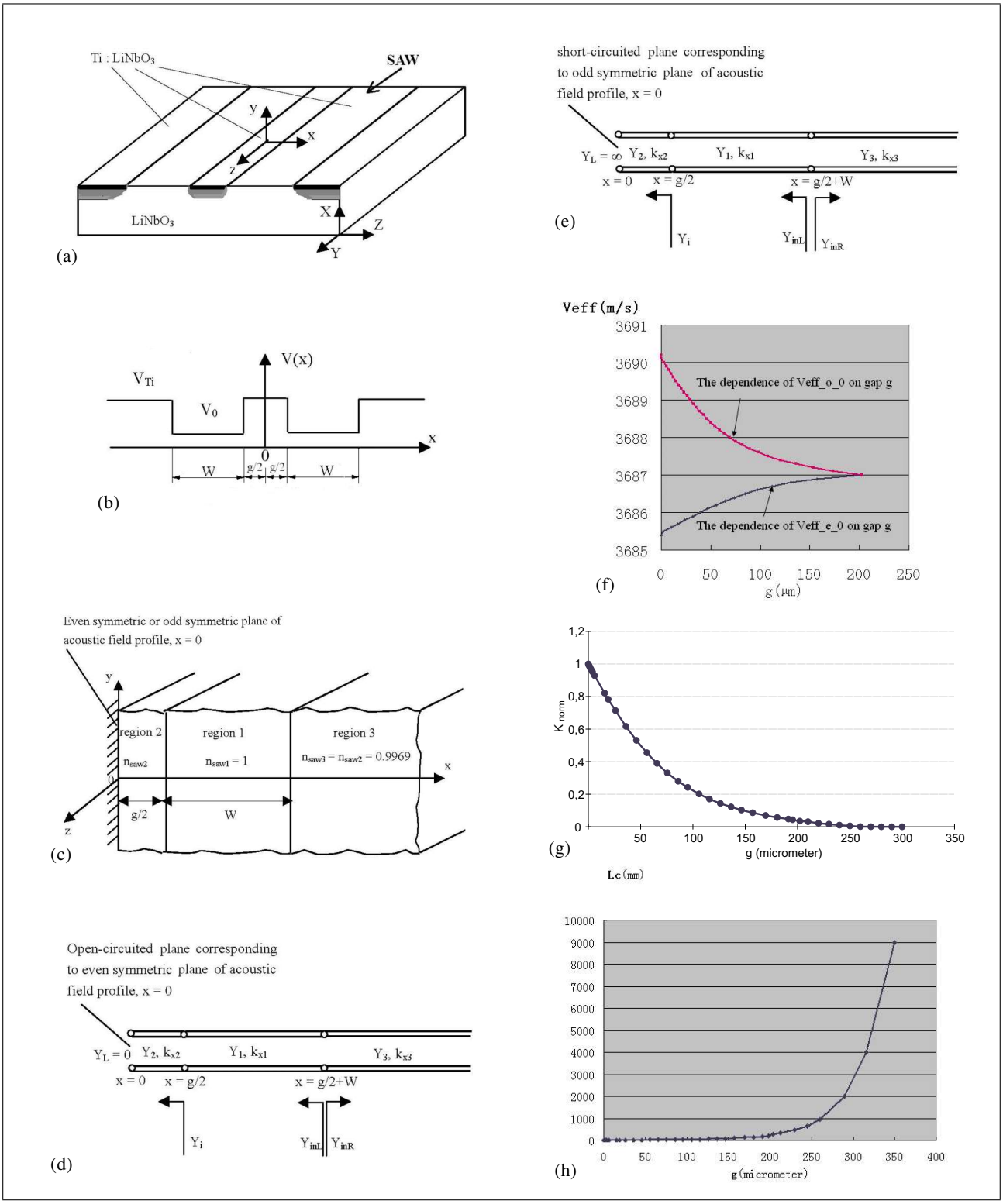


Figure 2. a. Geometry of an integrated acoustic directional coupler with Ti:LiNbO$_3$ waveguide. b. Velocity profile for the SAW calculations. c. Equivalent waveguide corresponding to 2.a and 2.b. d. Equivalent circuit corresponding to 2.c under the condition of even symmetric plan of acoustic field profile, $x = 0$. e. Equivalent circuit corresponding to 2.c under the condition of odd symmetric plan of acoustic field profile, $x = 0$. f. The dependence of even mode and odd mode phase velocities, i.e., $V_{\mathrm{eff},0,e}$ and $V_{\mathrm{eff},0,o}$ on gap g, respectively, at the condition of $p = 0$, $W = 110$ micrometer, and $f_{ac} = 170\,\mathrm{MHz}$. g. The dependence of K_{norm} on gap g, at the condition of $f_{ac} = 170\,\mathrm{MHz}$, $p = 0$, and $W = 110$ micrometer. h. The dependence of coupling length L_c (micrometer) on gap g, at the condition of $f_{ac} = 170\,\mathrm{MHz}$.

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Therefore

$$Y_{inL} = Y_1 \frac{Y_{g/2} + jY_1 \tan(k_{x1}W)}{Y_1 + jY_{g/2} \tan(k_{x1}W)} = \frac{k_{x1}}{\omega\mu_e} \frac{-j\alpha_{x2} \tanh(\alpha_{x2}g/2) + jk_{x1} \tan(k_{x1}W)}{k_{x1} + \alpha_{x2} \tanh(\alpha_{x2}g/2) \tan(k_{x1}W)} \quad (26)$$

and

$$Y_{inR} = Y_2 = k_{x2}/\omega\mu_e = -j\alpha_{x2}/\omega\mu_e. \quad (27)$$

Substituting equation (26) and equation (27) into equation (22), we obtain the dispersion equation for even mode as follows

$$\frac{k_{x1}}{\omega\mu_e} \frac{-\alpha_{x2} \tanh(\alpha_{x2}g/2) + k_{x1} \tan(k_{x1}W)}{k_{x1} + \alpha_{x2} \tanh(\alpha_{x2}g/2) \tan(k_{x1}W)} - \frac{\alpha_{x2}}{\omega\mu_e} = 0, \quad (28)$$

or

$$k_{x1}W = q\pi + \arctan\left\{ \frac{\alpha_{x2}}{k_{x1}} \frac{1 + \tanh(\alpha_{x2}g/2)}{1 - (\alpha_{x2}/k_{x1})^2 \tanh(\alpha_{x2}g/2)} \right\} = q\pi + 2\arctan(k_{x1}/k_{x2}) - \arctan\left\{ \frac{2(k_{x1}/k_{x2}) \exp(-k_{x1}g)}{1 + (k_{x1}/k_{x2})^2 + [(k_{x1}/k_{x2})^2 - 1] \exp(-k_{x1}g)} \right\}, \quad (29)$$
$$q = 0, 1, 2, \ldots$$

Next, we deduce dispersion equation for Figure 2e from equation (22) using TRM. Let also $x = g/2 + W$ plane as reference plane, according to the transmission line theory, we obtain the dispersion equation for odd mode as follows

$$k_{x1}W = p\pi + \arctan\left\{ 2\frac{\alpha_{x2}}{k_{x1}} \frac{1 + \coth(\alpha_{x2}g/2)}{1 - (\alpha_{x2}/k_{x1})^2 \coth(\alpha_{x2}g/2)} \right\} = q\pi + 2\arctan(k_{x1}/k_{x2}) + \arctan\left\{ \frac{2(k_{x1}/k_{x2}) \exp(-k_{x1}g)}{1 + (k_{x1}/k_{x2})^2 + [(k_{x1}/k_{x2})^2 - 1] \exp(-k_{x1}g)} \right\}, \quad (30)$$
$$q = 0, 1, 2, \ldots$$

By solving equations (29) and (30), with help of the equation (9), (10), we can obtain the $V_{\text{eff},p,o}$ and $V_{\text{eff},p,e}$ whose subscript e and o mean the even mode and odd mode, respectively, for different waveguide width W and gap g. And taking account of requirement of mono-mode waveguide [9], we calculate $V_{\text{eff},0,o}$ and $V_{\text{eff},0,e}$ as a function of gap g at $W = 110\,\mu$m and $p = 0$, i.e., the condition of mono-mode for $f_{ac} = 170$ MHz, and then fit the curves of g dependence of $V_{\text{eff},0,o}$ and $V_{\text{eff},0,e}$, respectively, which are shown in Figure 2f, where upper solid line expresses g dependence of $V_{\text{eff},0,o}$ based on equation (30), and lower solid line indicates g dependence of $V_{\text{eff},0,e}$ based on equation (29). This figure indicates: $V_{\text{eff},0,o}$ is maximum at $g = 0$ and exponentially decreases with g increasing and as a result $V_{\text{eff},0,o} \to 3687.0$ m/s with $g \to \infty$; while $V_{\text{eff},0,e}$ is minimum at $g = 0$ and exponentially increases with g increasing and as a result $V_{\text{eff},0,e} \to 3687.0$ m/s with $g \to \infty$. It is the predictive results in theory that both $V_{\text{eff},0,o}$ and $V_{\text{eff},0,e}$ all approach 3687.0 m/s, i.e., the mono-mode phase velocity at the condition $W = 110\,\mu$m and $f_{ac} = 170$ MHz, as $g \to \infty$, and in this cases, the degeneration arises between even modes and odd modes.

The propagation constants along z for each mode of the acoustical directional coupler of constant gap are, according to equations (5), (6)

$$k_{z,o} = 2\pi f_{ac}/V_{\text{eff},p,o}, \quad (31)$$
$$k_{z,e} = 2\pi f_{ac}/V_{\text{eff},p,e}. \quad (32)$$

The coupling coefficient K between the two guides and the length L called coupling length necessary for complete transfer of power from one to the other are related to the propagation constants $k_{z,e}$ and $k_{z,o}$ by

$$K = \frac{\pi}{2L} = \frac{k_{z,e} - k_{z,o}}{2} = \frac{1}{2}\left[\frac{2\pi f_{ac}}{V_{\text{eff},p,e}} - \frac{2\pi f_{ac}}{V_{\text{eff},p,o}}\right]. \quad (33)$$

We calculate the coupling coefficient, K, from equation (34) under the conditions of $p = 0$ and $W = 110\,\mu$m and $f_{ac} = 170$ MHz, with help of equation (9) and (10), and fit the curve of calculated results of g dependent of coupling coefficient K_{norm} which is the normalized value, i.e., $K_{\text{norm}} = K/K_{\max}$, shown in Figure 2g. And it indicates: K_{norm} has maximum unity at $g = 0$, and then exponentially decreases with g increasing and at last $K_{\text{norm}} \to 0$ as $g \to \infty$, in fact, K_{norm} has nearly approached to 0 at about $g = 350\,\mu$m. Also it shows that the K_{norm} is not only for strong coupling but for the weak one as well.

The dependence of coupling length L_c on gap g, of acoustical directional coupler with constant gap, is shown schematically in Figure 2h. Figure 6 indicates the $L_c = L_0 \exp(\gamma g)$, where L_0 and γ are the constants only related to the parameters of waveguide, and here they are determined as $L_0 = 6.7$, $\gamma = 0.01734/\mu$m, using fitting method. In [12] the exponential variation of the coupling length as function of the gap has been analyzed experimentally even for large gaps. From their experimental data we can easily obtain $L_0 = 6.8$ mm and $\gamma = 0.021/\mu$m by fitting. So, good agreement between simulation and experiment is achieved.

3. Conclusions

We, for the first time, apply the transverse resonance method (TRM) to the analysis of Ti:$LiNnO_3$ acoustic channel waveguide on X-cut, Y-propagating $LiNbO_3$ crystal, on which doped region (Ti:$LiNbO_3$) and undoped regions ($LiNbO_3$) are formed via Ti-indiffusion technique, and to the acoustical directional coupler with constant gap been made up of the Ti:$LiNbO_3$ acoustical channel waveguide. The conclusions are

1. With help of concept of acoustical index expressed by n_{saw}, the Ti:$LiNbO_3$ acoustical channel waveguide can be equivalent to slab waveguide formed by three regions: region 1 ($n_{\text{saw1}} = 1$), region 2 ($n_{\text{saw2}} = 0.9969$),

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and region 3 ($n_{saw3} = n_{saw2}$), and then, the three regions are equivalent, along the transverse direction, to the series connection of three transmission lines having different wave number, k_i ($i = 1, 2, 3$), and wave admittance Y_i ($i = 1, 2, 3$), and finally, by using TRM, we can obtain dispersion equation for the waveguide.

2. For the acoustical directional coupler with constant gap, due to the structure is symmetric with respect to the $x = 0$ plane, the modes have distributions being either symmetric or anti-symmetric with respect to the $x = 0$ plane. So the region we have to study is only the $x \geq 0$ region, and it can be equivalent to slab waveguides formed by three regions: regions 1 ($n_{saw1} = 1$), region 2 ($n_{saw2} = 0.9969$), and region 3 ($n_{saw3} = n_{saw2}$). Further the three regions are equivalent to three kinds of transmission lines segments: lossless transmission line expressed by wave number k_2, wave admittance Y_2, corresponding to region 2; and loss transmission line expressed by wave number k_1, wave admittance Y_1, corresponding to region 1; as well as loss transmission line expressed by wave number k_3, wave admittance Y_3, corresponding to region 3. And the plane $x = 0$ is equivalent to open-circuited plane where $Y_L = 0$ corresponding to even field distribution or equivalent to short-circuited plane, i.e. $Y_L = \infty$ corresponding to odd field distribution. Thus, the whole regions can be equivalent to series of Y_L and three segment transmission lines. We finally obtain the even mode equivalent circuit when $Y_L = 0$, and the odd mode equivalent circuit when $Y_L = \infty$, and from which we can obtain the even mode dispersion equation and odd mode dispersion equation, with help of TRM.

It is worth pointing out that although this method we use is suitable for the Ti:$LiNbO_3$ acoustical waveguide, it is also possible for us to apply it to study of multi-layers acoustical medium.

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References

[1] J. Frangen, H. Herrmann, R. Ricken, H. Seibert, W. Sohler: Integrated optical, acoustically tunable wavelength filter. Electron. Lett. **25** (1989) 1583–1585.

[2] F. Wehrmann: Integriert akustooptische 2x2 Schaltmatrizen in $LiNbO_3$ für Wellenlängenmultiplexsysteme. Dissertation, Shaker-Verlag, Aachen, 1999.

[3] H. Herrmann, A. Modlich, T. Müller, W. Sohler, F. Wehrmann: Advanced integrated, acousto-optical switches, add-drop multiplexers and WDM cross-connects in $LiNbO_3$,. Proc. of the European Conference on Integrated Optics (ECIO7), Stockholm, April 1997, 578–581.

[4] M. Tanaka: Narrow bandpass filters using double-mode SAW resonators on quartz. Proc. of the 3th Annual Frequency Symposium, 1984, 286.

[5] W. D. Hunt: Mode profiles in waveguide-coupled resonators. IEEE Ultrasonics Symposium Proc., 45.

[6] R. E. Collin: Field theory of guided waves. McGraw Hill Book Co., 1960.

[7] C. Ming, T. T. Tang: Analysis of the acoustical directional couplers with constant gap. Acta Acustica united with Acustica **90** (2004).

[8] H. Herrmann, S. Schmid: Integrated acousto-optical mode converters with weighted coupling using surface acoustic wave directional couplers. Electron. Lett. **28** (1992) 979–980.

[9] A. J. Slobodnik, Jr., E. D. Conway, R. T. Delmonico: Surface wave velocities. – In: Microwave Acoustics Handbook, Vol. 1A. Air Force Cambridge Research Labs., AFRCRL-TR-73-0597, 1973.

[10] E. G. H. Lean, C. Powell: Optical probing of surface acoustic waves. Proc. IEEE **58** (1970) 1939–1947.

[11] H. Herrmann, U. Rust, K. Schafer: Tapered acoustical directional couplers for integrated acousto-optical mode converters with weighted coupling. Journal of Lightwave Technology **13** (March, 1995).

[12] D. A. Smith, J. J. Johnson: Sidelobe susppression in an acousto-optic filter with raised-cosine interaction strength. Appl. Phys. Lett. **61** (1992) 1025–1027.

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