JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 8, No. 4, August 2006, p. 1589 - 1592

Better calculation of SAW in $LiNbO_3$ and new designed configuration of acousto-optic tunable filters

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In this paper, a new non-collinear configuration of acousto-optic tunable filters (AOTF) which uses X cut Y propagation lithium niobate (X-Y $LiNbO_3$) as surface acoustic wave (SAW) waveguide is designed in which the interdigital transducer should be inclined 4.18°. Cubic spline interpolation method (a drafting acid used to draw smooth curves through a set of points) is used to obtain the walk-off angular (the angular from the propagation direction to the power-flux vector) curve with the gained velocity curve of SAW directly and calculation of SAW propagation in X-Y $LiNbO_3$ gives that the walk-off angular is 4.18°.

(Received June 8, 2006; accepted July 20, 2006)

Keywords: SAW, non-collinear AOTF, Interdigital transducer, Cubic spline

1. Introduction

AOTF are usually designed collinear or quasi-collinear using X-Y $LiNbO_3$ which is anisotropic and piezoelectric as SAW waveguide before [1][2] and they are fabricated ignoring the walk-off angular which usually exists when acoustic wave propagates in anisotropic crystals. But actually a walk-off angular about 4°exists in the propagation of SAW in X-Y $LiNbO_3$ that causes the confusion of acoustic field. In this paper, a new non-collinear AOTF which does not cause confusion of acoustic field is designed having an angular compensation set and the angular is about 4° and the configuration scheme is given. The design is based on the analysis of the propagation characters of SAW in $LiNbO_3$. Development is given to the calculation proceeding of walk-off angular curve that cubic spline interpolation method [3] is employed to get walk-off angular curve from the velocity-angular curve directly. It is simpler than methods used before, but it can get the same result [4] using values of the elastic and piezoelectric constants of $LiNbO_3$ taken from the work of G. Kovacs, M. Anhorn [5]. New method is described to get the walk-off angular curve in part two. The third part gives the analysis of the acoustic filed of collinear or quasi-collinear AOTF and shows the designed scheme of AOTF with the design reason given.

2. New method to get walk-off curve

2.1 Walk-off angular curve gained by cubic spline interpolation method of the third kind boundary condition

In X-cut $LiNbO_3$, the propagation direction of SAW investigated is in Y-Z plane, which has an angular θ from Y axis (X, Y, Z are crystal axis) as shown in Fig. 1. K is the wave vector of SAW.

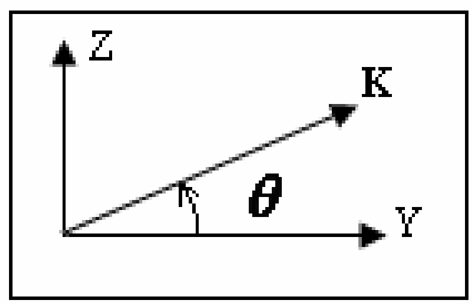

Fig. 1. The coordinate systems used in the calculation.

For study the propagation characters of SAW in $LiNbO_3$, a computer program is written to get the velocities using global optimal method [6] based on the theory of J. J. Campbell and W. R. Jones's method [7] with the result shown in Fig. 2 and the values of the elastic and piezoelectric constants of $LiNbO_3$ are taken from the work of G.. Kovacs, M. Anhorn [5]. But that is not enough, because when acoustic wave propagates in anisotropic crystals, the direction of power flowing usually deviates from the propagation direction and the angular between them is walk-off angular ϕ. Fig. 3 shows it. The same condition also occurs when SAW propagates in X-Y $LiNbO_3$.

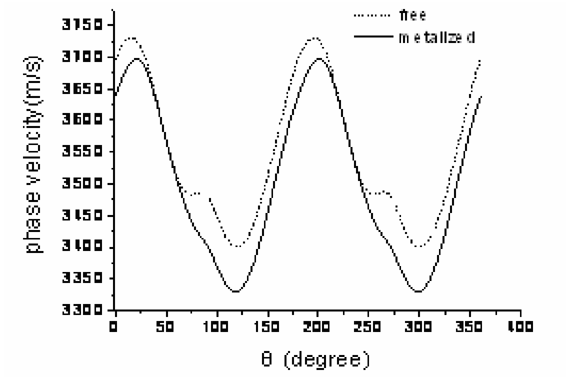

Fig. 2. Phase velocity curve of SAW in X-Y $LiNbO_3$ (θ is the angle from Y axis).

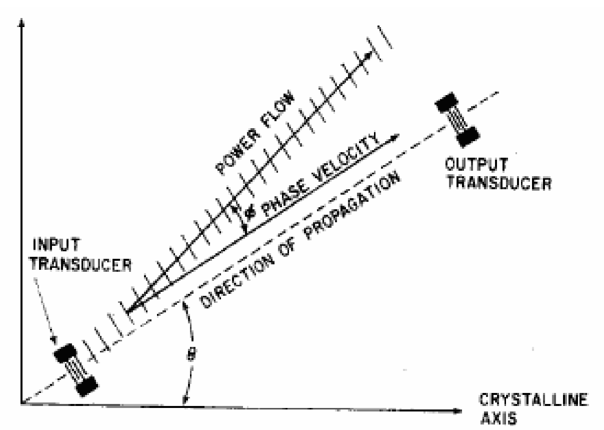

Fig. 3. Phenomenon of power flowing away of acoustic wave in anisotropic crystals.

So further investigation is done to get the velocity walk-off angular after the curve of velocities gained, it can be obtained from the formula following [6]

$$\phi = arctg(\frac{1}{V}\frac{\partial V}{\partial \theta}) \quad (1)$$

ϕ is the Walk-off angular wanted which is gotten by the third kind boundary condition cubic spline interpolation method [3] in this paper. V is the scalar value of phase velocity of SAW. Splines are drafting acids used to draw smooth curves through a set of points. Weights are attached at the points to be connected and a flexible strip is shaped around the weights and mathematical models of spline curves can be created using this idea. It is smooth and continuous at the interval and splines can be used to fit even the most random of data making numerical analysis possible even when the actual function is not known. It can be used to interpolate and get differential quotient and integral values.

Because V is a continuous and periodic function of θ with the period is 180 degree and the numerical values of V, the first and second derivatives of V to θ are equal at the endpoints, it is agree with the requirement of the third kind boundary condition cubic spline interpolation method. So the method can be used to achieve the interval values of V and $\frac{\partial V}{\partial \theta}$ curve conveniently then the walk-off angular curve can be obtained giving the same result with others [4] for example of SAW in X-Y $LiNbO_3$. Of course, enough points of velocities are needed.

Another usual method is to get the direction of energy flow with the velocity curve first. For obtaining the direction of energy flow one can calculate the velocity at neighboring angles to the desired one thus obtaining a small segment of the two-dimensional "slowness" (1/V) surface. The normal to this surface is then obtained numerically to give the group velocity and hence the direction of energy flowing corresponding to the one of phase velocity [8]. It is needed too many velocity points if the walk-off angular curve for one orientation is wanted.

The cubic interpolation method is simpler compared with the other method.

The property of SAW propagating in X-Y $LiNbO_3$ has been studied and the velocity curve is obtained first shown in Fig. 2 (free means the free surface, metallized means the metallized surface), then the cubic spline interpolation method is used to gain the walk-off angular curve with the result shown in Fig. 4.

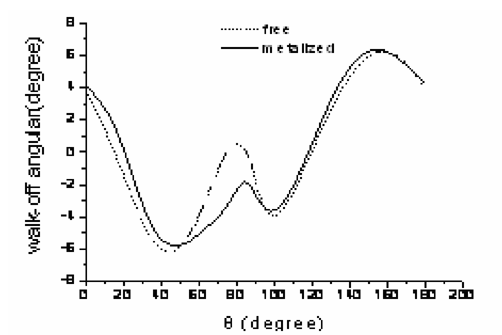

Fig. 4. Walk-off angular curve of SAW in X-Y $LiNbO_3$ (θ is the angle from Y axis).

3. Analysis and design

3.1 Analysis of the SAW filed of collinear or quasi-collinear AOTF

From the calculation result above, there is an angular of 4.18°exists when SAW propagates in X-Y $LiNbO_3$, which declares that when the propagation direction of SAW is horizontal, the power flowing direction deviates from it of the angular 4.18°. The phenomenon is shown in Fig. 5. That will cause confusion of acoustic field in collinear or quasi-collinear AOTF.

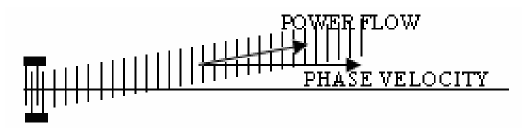

Fig. 5. Phenomenon of power flowing away of saw.

Analysis of that is given below. In collinear AOTF using X-Y $LiNbO_3$, the acoustic waveguide and the optic waveguide are collinear with the common scheme is shown in Fig. 6 [1]. From Fig. 5, it can be known that the direction of power flowing is not as same as the optic waveguide, it deviates so that the energy of SAW will reflect when it arrives at the upper bonder of the acoustic waveguide then it will overlap with the incident SAW beam and it will reflect again when it arrives the next bonder. Reflected and incident SAW have different directions. It is shown in Fig. 7. Reflection of power of SAW at bonders causes many overlapped regions and so the confusion of acoustic field.

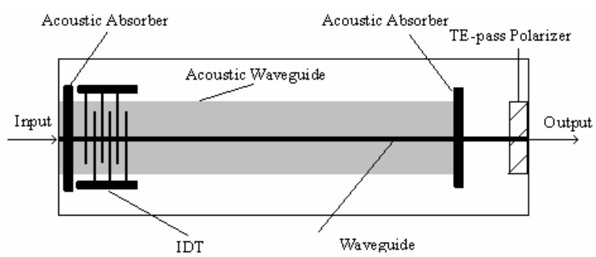

Fig. 6. The scheme of collinear AOTF.

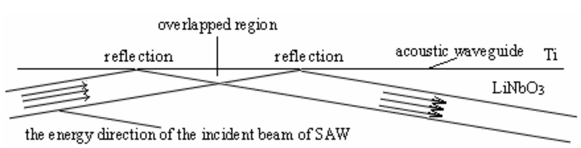

Fig. 7. The propagation of SAW in collinear AOTF.

The quasi-collinear AOTF have the similar features because in them the angles between acoustic waveguide and optic waveguide are very small [2]. So the designs which ignore the walk-off angular are not perfect.

3.2 Design of new AOTF

For design, the image of Fig. 5 is traversed the angular of -4.18° and Fig. 8 can be gained, in which the direction of power flowing is horizontal that can have the same direction with optic waveguide in AOTF. The transducer is also traversed the angular -4.18° and the new AOTF is designed according to Fig. 8.

The scheme of the designed non-collinear AOTF is shown in Fig. 9, the acoustic waveguide is X-Y $LiNbO_3$ and the interdigital transducer get the direction which revolutes -4.18° from the vertical direction. The direction of the power flowing is horizontal that is as same as the one of optic waveguide. In this scheme, there is no confusion of acoustic filed and make better use the energy of SAW.

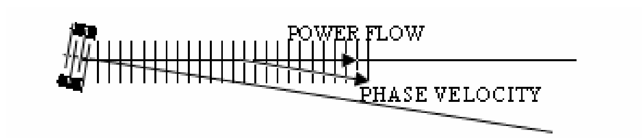

Fig. 8. SAW excited by inclined interdigital transducer.

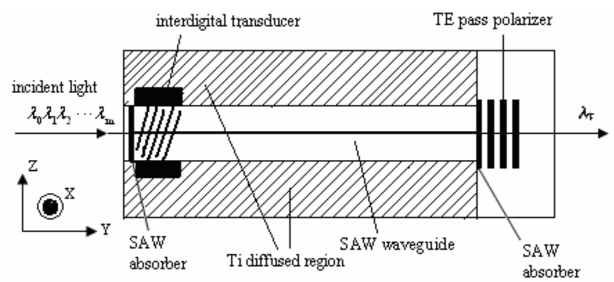

Fig. 9. Configuration scheme of designed acoustic-optic tunable filters (AOTF).

4. Conclusion

A new proceeding has been proposed to study SAW propagating in anisotropic and piezoelectric crystals which use cubic spline interpolation method to gain walk-off angular curve. SAW in X-Y $LiNbO_3$ substrate is investigated. A new configuration of acousto-optic tunable filters has been designed in which the interdigital transducer should be inclined 4.18°.

Acknowledgments

This work was supported by the National Nature Science Fund of China (No. 1008400).

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