Acousto-optical Characteristics of TeO_3/3C-SiC/$LiNbO_3$ layered structure

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Abstract

In the present work, use of thermally stable multi-layeredTeO_3/3C-SiC/128º*Y-X* $LiNbO_3$surface acoustic wave (SAW) structure, as a potential acousto–optic (AO) device has been proposed. The acoustic properties like figure of merit and diffraction efficiency of the layered structureTeO_3/3C-SiC/128º*Y-X* $LiNbO_3$ is examined using theoretical calculations.It is found that the thermally stable layered structure TeO_3(0.007l)/3C-SiC (0.09 l)/128º*Y-X* $LiNbO_3$ exhibits a high value of acousto optical figure of merit $(8.56 \times 10^{-12} s^3 g^{-1})$ coupled with good overlap between acoustic and optic field. The proposed acousto optic device is based on crystalline silicon carbide (SiC) which is known to withstand harsh environment. Thus the thermally stable TeO_3/3C-SiC/128º*Y-X* $LiNbO_3$ multi-layered SAW structure would be a potential and cost effective device suitable for acousto optic applications in severe environment conditions.

PACS classification numbers: Acoustic properties of thin films (43.35.+d) Thermal stability (68.60 Dv) Silicon carbide (61.80.Jh)

1. Introduction

The field of integrated optics uses a number of acousto optic (AO) devices like modulators, deflectors, tunable optical filters, optical switches, etc (Guofang et al. 2007; Jain et al. 1992; Kakio 2015; Mohammadalizadeh et al. 2010; Tsai et al. 1992). Efficiency of surface acoustic wave (SAW) devices used for AO applications banks upon the acousto-optical properties of the medium in which sound wave and light wave interact. Till now SAW devices based on $LiNbO_3$, $LiTaO_3$ single crystal and various layered structure like TeO_2/ $LiNbO_3$, $LiNbO_3$/Sapphire, ZnO/ Diamond, etc have been investigated (Belovickis et al. 2012; Guofang et al. 2007; Shandilya et al. 2008). Lack of flexibility in tailoring the SAW propagation characteristics like SAW phase velocity and temperature coefficient of delay (TCD) as per the need of the application, is the major limitation for the use of the single crystal based acoustic devices. On the other hand, it has been established that the use layered SAW structure provides more flexibility in tuning the various properties like TCD, phase velocity, coupling coefficient, etc of acoustic devices as per the requirement (Dewan et al.2008; Tsubochi et al. 1982; Tomar et al. 2001).

Recently, a temperature stable TeO_3/3C-SiC/ 128º*Y-X* $LiNbO_3$ multi-layered SAW structure has been found (Soni 2018), that possess high value of SAW phase velocity (~4390 ms^{-1}) and electromechanical coupling coefficient (~9.8%) at normalized over layer thickness of TeO_3 =0.007λ and 3C-SiC = 0.09λ (Soni 2018). This multi-layered SAW device is based on crystalline 3C-Silicon Carbide (SiC), which is a promising material for high frequency application and could sustain harsh environment (Mehregany et al. 2000). Since 3C SiC is being widely used in photonics and opto-electronics (Yamada et al. 2011; Liu et al. 1993), so in the present work an attempt has been made to investigate the acousto optic properties of the thermally stable TeO_3( )/3C-SiC()/128º*Y-X* $LiNbO_3$ layered SAW device. The SAW propagation characteristics for the layered structure and the field profiles are calculated theoretically using the software developed by (Fahmy et al. 1975). The temperature stable TeO_3( )/3C-SiC() /128º*Y-X* LiNbO3 SAW structure is found to exhibit

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a high value of acousto optical (AO) figure of merit and high diffraction efficiency.

Theoretical Calculations

The possible use of TeO_3( )/3C-SiC() /128°*Y-X* LiNbO3 SAW layered structure in acousto optic devices is examined theoretically by calculating the figure of merit and diffraction efficiency. The IDTs are placed on the top of 128°*Y-X* LiNbO3 piezoelectric crystal. The configuration of TeO_3()/3C-SiC() /128°*Y-X* LiNbO3 SAW layered structure studied for acousto-optic application is shown in figure 1.

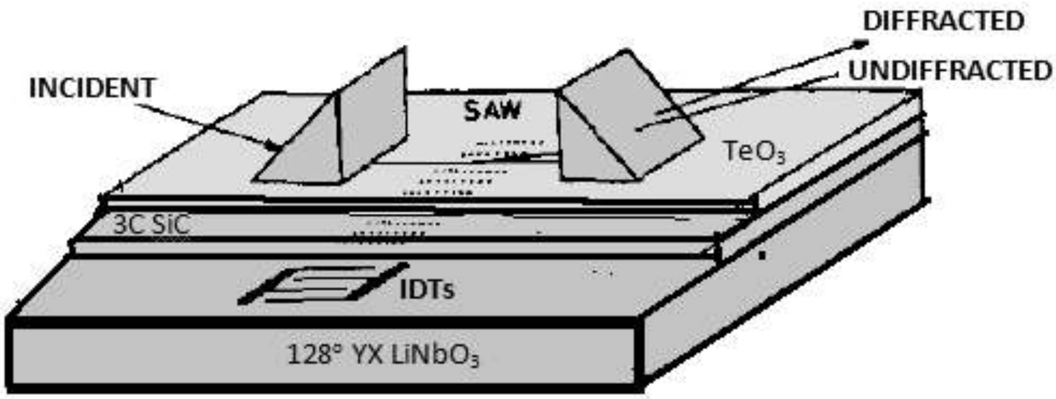

Figure 1: TeO_3( )/3C-SiC() /128°*Y-X* LiNbO3 multilayered acousto optic device configuration with IDTs placed on the top of $LiNbO_3$ crystal.

The required field profile and acoustic wave propagation characteristics of TeO_3( )/3C-SiC()/128°*Y-X* $LiNbO_3$ layered structure has been calculated theoretically using the SAW program developed by Fahmy et al. 1975.The coordinate system used in the current work is given in figure 2. Here x_1 is the direction of propagation of surface wave whose amplitude vanishes as x_3 tends to negative of infinity.

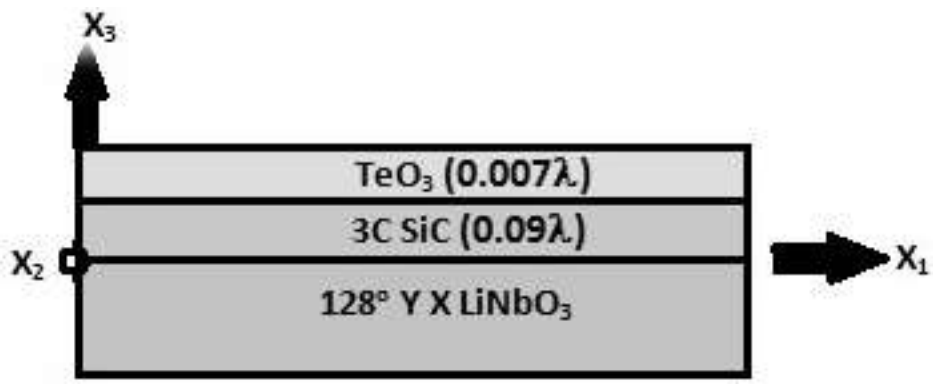

Figure 2: The coordinate system used in the present work.

The material parameters like elastic constants, density, refractive index, dielectric constant, photo elastic constants, etc used in the present study have been taken from the earlier reported work (Soni 2018).

AO Figure of Merit

The vital probe that determines the efficiency of an acousto optic device is its figure of merit. The figure of merit for the layered structure is defined as (Shandilya et al.2008)

$$M = \frac{n^6 p^2}{\rho v_p^3} \qquad (1)$$

Where and are the respective appropriate photo elastic tensor and refractive index of wave guiding layer.

Diffraction Efficiency

Another important parameter for gauging the potential of an acousto optic device is its ability to diffract the optical signal i.e. diffraction efficiency and the latter can be calculated by (Rana et al. 2016):

$$DE = DE(f)_o^{\,2}\left[\frac{\sin\sqrt{DE(f)_o^{\,2}+\left(\frac{K\,\Delta\Theta L}{2}\right)^2}}{\sqrt{DE(f)_o^{\,2}+\left(\frac{K\,\Delta\Theta L}{2}\right)^2}}\right]^2 \qquad (2)$$

Where,is the interaction length or acoustic aperture, is the free space optical wavelength, is the momentum vector of SAW and is variation of incident wave from the Bragg angle.

$$DE(f)_o{}^2 = \left(\frac{\pi}{\lambda_o}\right)^2 n_m n_n{}^2 |\Gamma_{mn}(f)|^2 \left(\frac{L}{\cos\Theta_m \cos\Theta_n}\right) \quad (3)$$

The AO diffraction efficiency varies directly with the overlap between the acoustic and optical fields. depends exclusively on the waveguide parameters and the acoustic frequency and is given by:

$$|\Gamma_{mn}(f)|^2 = \frac{\left[\int U_m(x_3) U_n(x_3) U_{ap} dx_3\right]^2}{\int |U_m|^2(x_3) dx_3 \int |U_n|^2(x_3) dx_3} \quad (4)$$

Where represents field distributions of diffracted and un-diffracted modes respectively, p and r are appropriate photo elastic and electro optic tensor respectively. and represent the normalized strain distributions along the waveguide thickness respectively, which have been calculated using the software developed by Fahmy et al. 1975 and a C program is written to calculate the overlap integral and hence the diffraction efficiency using equations (2), (3) and (4).

Results and Discussions

(I) *Figure of merit*

Figure 3 shows the dispersion of AO figure of merit for TeO_3/3C-SiC() /128°*Y-X* $LiNbO_3$ layered structure as a function of the normalized thickness of TeO_3 layer. The value of AO figure of merit increases with an increase in the normalized thickness of TeO_3 and becomes at zero TCD normalized thickness of 0.007l of TeO_3 over layer.

The increase in the value of acousto optic figure of merit with TeO_3 over layer thickness is attributed to the fact that TeO_3 possess lower surface acoustic wave velocity and with the increase in the TeO_3 over layer thickness, SAW energy will be concentrated more into the TeO_3 layer and therefore the SAW velocity of the layered structure decreases (Soni 2018). Since the AO figure of merit as given by equation (1) varies inversely the cube of SAW velocity, therefore with the increase TeO_3 over layer thickness AO figure of merit increases. As reported earlier, with the integration of 0.007 TeO_{3-} over layer, the SAW layered structure TeO_3/3C-SiC() /128°*Y-X* $LiNbO_3$ becomes thermally stable (Soni 2018) and temperature stability is an important aspect of an efficient SAW device. So the value of AO figure of merit is considered at 0.007 TeO_{3-} over layer thickness.

(II) *Diffraction Efficiency*

Variation of diffraction efficiency with the optical penetration depth (x_3) for TeO_3(0.007)/3C-

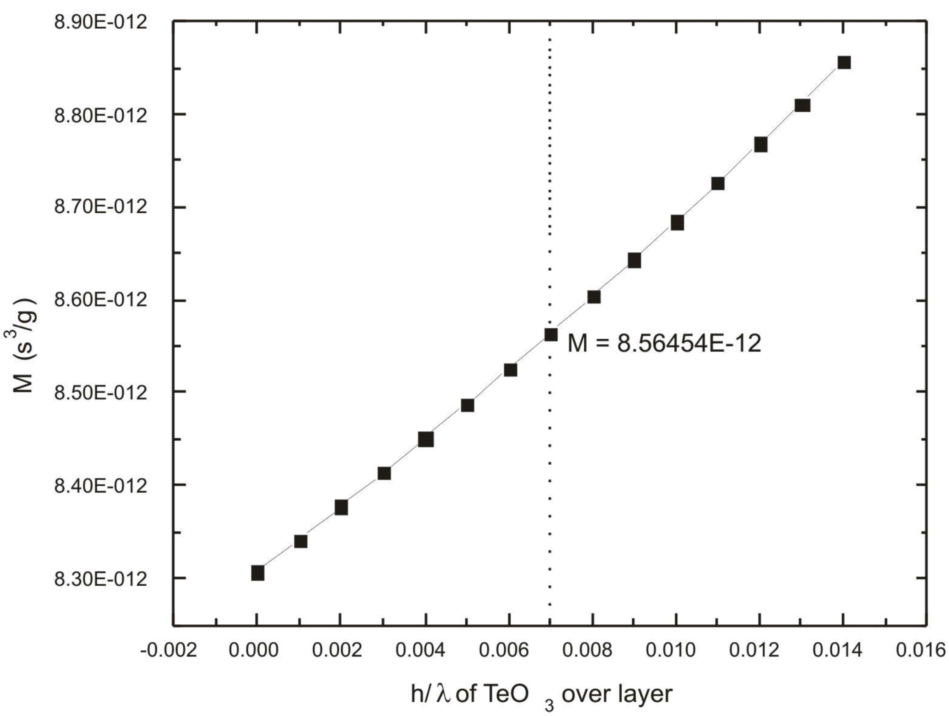

Figure 3: Variation of figure of merit with TeO_{3-} over layer thickness in TeO_3/3C-SiC() /128°*Y-X* $LiNbO_3$ SAW layered structure.

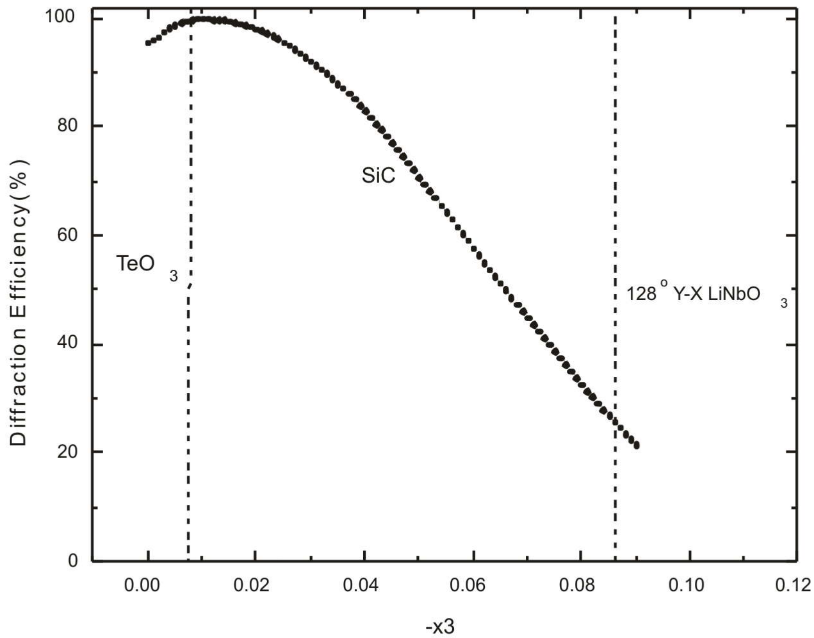

Figure 4: Variation of Diffraction Efficiency with the optical penetration depth for TeO_3(0.007)/3C-SiC() /128° *Y-X* $LiNbO_3$ layered structure

SiC() /128° *Y-X* $LiNbO_3$ layered structure is shown in figure 4. The results show that the maximum overlap (nearly 100%) between acoustic and optical fields exists without TeO_3 over layer. Diffraction efficiency is found to reduce slightly within 4% with the integration of temperature compensated 0.007 TeO_3 over layer. This slight decrease in the value of diffraction efficiency can be compromised for the temperature stability of the considered TeO_3(0.007)/ 3C-SiC()/128° *Y-X* $LiNbO_3$ SAW device. Therefore, it is infer from the figure 4, that the temperature stable TeO_3(0.007)/3C-SiC() /128° *Y-X* $LiNbO_3$ layered structure possess high value of diffraction efficiency (96.1%) indicating it to be boding device to be used in the acousto-optic applications.

Conclusion

In the present work the acousto optic characteristics of thermally stable TeO_3(0.007)/3C-SiC() /128° *Y-X* $LiNbO_3$ layered structure have been examined theoretically. The TeO_3(0.007)/3C-SiC() / 128° *Y-X* $LiNbO_3$ SAW layered structure is found to be optimum for an efficient AO device with high AO figure of merit of coupled with high diffraction efficiency of 96%.

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