3J3-3

Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 599-600
18-20 November, 2009

Piezoelectric Boundary Acoustic Wave in Cu electrode/ Rotated YX-LiNbO$_3$ Substrate Structure with Partially Covered SiO$_2$ Layer

Yiliu Wang[†‡], Ken-ya Hashimoto, Tatsuya Omori and Masatsune Yamaguchi (Graduate School of Engineering, Chiba University)

1. Introduction

It is known that for practical devices the temperature coefficient of frequency (TCF) is an important factor. Usually zero TCF is most preferred. Substrate material LiNbO$_3$ or LiTaO$_3$ has the negative TCF, while SiO$_2$ possesses positive TCF, it is possible to realize zero TCF device with SiO$_2$ over the substrate (shown in **Fig. 1**). Nakai and coworkers theoretically and experimentally discussed about the SiO$_2$ overlay shape (convex or concave or flat) influence on the Rayleigh SAW propagation characteristics, such as TCF, reflection coefficient, electromechanical coupling factor [1]. Yet, to the authors knowledge, there is no report on TCF of the SiO$_2$ slotted structure or topped structure. In this paper, we discuss about the SiO$_2$ allocation influence on the propagation characteristics of piezoelectric boundary acoustic wave (PBAW).

2. Simulation and Analysis

1. Simulation Steps:

The simulation is carried out for two kinds of SiO$_2$ allocation structures, slotted and topped as shown in **Fig. 2 (a)** and **(b)**, where the YX-LN substrate is of semi-infinite. For metal grating materials, Cu grating is assumed. Cu thickness h_m is fixed at 0.2p [2]. In ref [2], where the structure is with semi-infinite SiO$_2$ overlay as shown in **Fig. 1**, numerical results showed that the temperature coefficient of velocity (TCV) of the PBAW resonance frequency could be −2.88 ppm/$^\mathrm{o}$C. In the following, the finite SiO$_2$ with different allocation will be examined, especially its influence on the temperature coefficient. By changing the thickness of SiO$_2$ (represented by h_a and h_b in Fig.1, respectively), how the TCV of the PBAW would change.

Using the software – SYNCO, we calculated $\hat{Y}$ (ω) of an infinitely long metal IDT of the structure as a function of the relative frequency fp/V_B (V_B = 4,752 m/s is the fast-shear BAW velocity in LN). From the susceptance curve, we can get the resonance and anti-resonance frequency of certain modes (f_r and f_a).

Then, we calculated relative admittance for various SiO$_2$ thickness to help distinguish the modes. The electro-mechanical coupling factor of one certain mode can be evaluated by the difference of f_r and f_a. In addition, TCV of PBAW resonance frequency is estimated by

$$\mathrm{TCV} = (f_r|_{30^\mathrm{o}\mathrm{C}} - f_r|_{25^\mathrm{o}\mathrm{C}})/(5 f_r|_{25^\mathrm{o}\mathrm{C}})$$

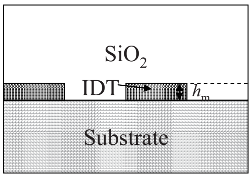
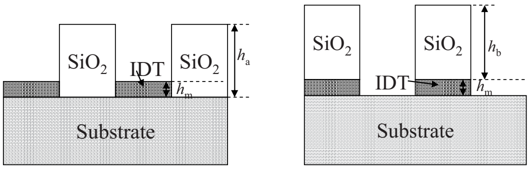


Fig. 1 Cross-section of SiO$_2$ semi-infinite overlay structure.



a) Slotted SiO$_2$ b) Topped SiO$_2$

Fig. 2 Cross-section of two kinds of SiO$_2$ allocation

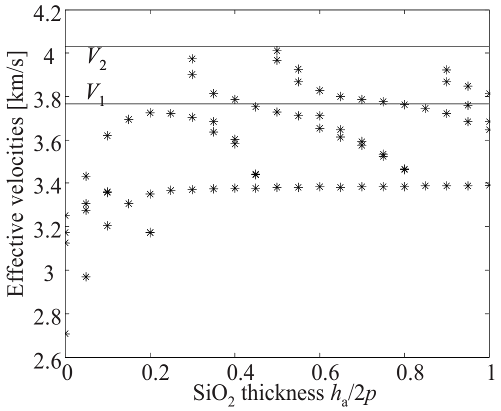
2. Simulation Results and Analysis

Fig. 3(a) shows the change in the effective velocities (V_r=2$f_\mathrm{r}p$, V_a=2$f_\mathrm{a}p$) with the SiO$_2$ thickness for the slotted SiO$_2$ structure with the Cu grating, where V_2 (=4,031m/s) represents the slow shear bulk acoustic wave velocity in LN. V_1 (=3,766 m/s) is for the shear bulk acoustic wave velocity in SiO$_2$, which determines whether the acoustic wave is leaky or not; when $V<V_2$, it is non-leaky. Otherwise, it is leaky. We can see the coupling between different modes, which makes it quite difficult to distinguish the modes. However, it is quite clear that there is one straight branch which keeps constant and approaches to 3.4 km/s. Comparing this value with ref. [3], this should be the SH-type PBAW resonance frequency effective velocity. With the aid of RLC-model, we get the coupling factor K^2 curve shown in **Fig. 3(b)**, together with the TCV. The coupling factor decreases with the increase in SiO$_2$ thickness. In **Fig. 3(b)**, when SiO$_2$ thickness is over 1p, K^2 tends to be maintaining constant though with some small fluctuations (within 2%). These fluctuations might be due to the mode-coupling as shown in Fig. **3(a)**. The PBAW coupling factor of 20% can be realized in this structure. Also, TCV tends to be constant around −33 ppm/$^\mathrm{o}$C.

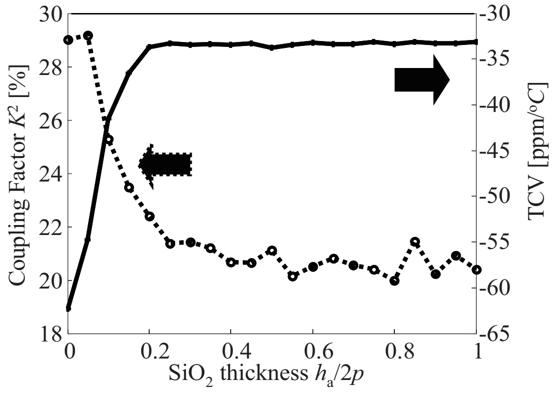
For comparison, the same analyzing method is applied to the topped structure. Results are shown in **Fig. 4**, where (a) is the effective velocities; (b) is the K^2 and TCV curves. In (a), square and triangle modes are the higher modes, while circle mode is the mode of interest with non-leaky nature and relatively strong coupling. K^2 increases first and then decreases monotonically with the SiO_2 thickness, with its maximum value around 29.6%, at SiO_2 thickness 0.1p. When SiO_2 is over 1p, K^2 is less than 12%. This reflects that the mode is the resonance mode in the SiO_2 pillar, which can be further confirmed by the TCV result.

In **Fig. 4(b)**, TCV is improved gradually with the SiO_2, from −80 to +2 ppm/°C, and zero TCV can be realized with SiO_2 thickness 0.94p. However, there is no sign of convergence to some constant value; in other words, if we keep increasing the SiO_2 thickness, TCV will keep increasing. This indicates that this resonance mode is having the main energy concentrated within the SiO_2 pillar rather than the substrate surface. On the other hand, as shown in **Fig. 3** for the slotted SiO_2 structure, the PBAW would have its K^2 and TCV converging to some values and remain constant.

Table 1 compares the K^2 and TCV of two PBAW supported structure, with SiO_2 thickness fixed at 1p. This reveals that with overlay structure, better TCV can be achieved but K^2 will be sacrificed.

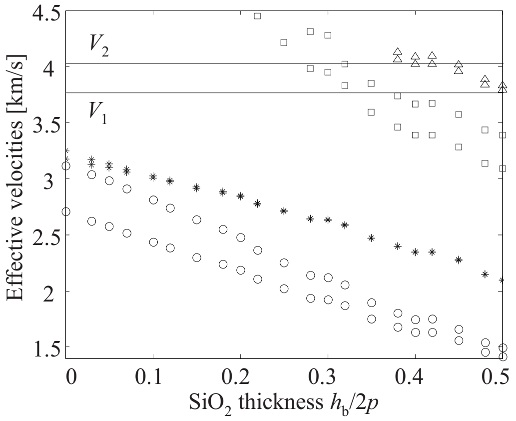


a) Dispersion curve

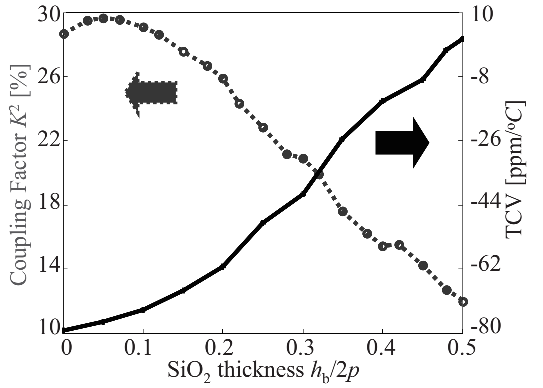


b) Coupling factor & TCV

Fig. 3 Slotted SiO_2 structure



a) Dispersion curve



b) Coupling factor & TCV

Fig. 4 Topped SiO_2 structure

Table 1 PBAW supported structure comparison

	K^2 [%]	TCV [ppm/°C]
Finite flat SiO_2 overlay [3]	17.5	-1.85
Finite slotted SiO_2	21	-33.1

3. Conclusion

In this paper, we discussed about the influence of the SiO_2 allocation on the acoustic wave propagation characteristics. In the simulation, Cu is used as metal grating, YX-LN as the substrate. Results show that in the slotted structure, there propagates the SH-type PBAW, which is similar to that of the SiO_2 overlay structure. If strong coupling is preferred, slotted SiO_2 structure is recommended; while good TCV is implemented using the finite flat SiO_2 overlay structure.

As for the topped structure, no PBAW wave is supported. Acoustic wave tends to have the energy concentrated in the SiO_2, rather than the surface of the YX-LN.

References

1. Y. Nakai, *et al* : Proc. Ultrasonic Electronics Symp., (2008) 169~170.
2. Y. Wang, *et al* : Proc. Frequency Control Symp., (2008) 773~777.
3. Y. Wang, *et al* : Proc. Ultrasonic Electronics Symp., (2008) 133~134.