PROC. JSSF-2, KYOTO, 1980
J. PHYS. SOC. JPN. **49** (1980) SUPPL. B, pp. 197–199.

Some Aspects on $LiTaO_3$ Substrates for Surface Acoustic Wave Devices

Kimio SHIBAYAMA and Kazuhiko YAMANOUCHI

Research Institute of Electrical Communication, Tohoku University Katahira 2-1-1, Sendai, 980

The wave propagation characteristics—especially in the standpoint of the effective electromechanical coupling coefficient, K and the temperature coefficient of delay—are surveyed for $LiTaO_3$ single crystal plates and $SiO_2/LiTaO_3$ type substrates. The useful orientations in rotated Y-cut, X-propagation are found in 36°-cut ($K^2=0.045$) and 126°-cut ($K^2=0.021$). In the case of SiO_2 film fabricated by plasma-CVD techniques, we have obtained such a substrate as has not only good temperature characteristics (≈ -2 ppm/°C) but also well suppressed side lobe characteristics in filter construction.

§1. Introduction

Recently, the applications of surface acoustic waves (SAW) for electronic devices are done actively. In these circumstances, the material characteristics become important when the devices are put into practice. Especially, we take interest in the properties of electromechanical coupling coefficient (K) and the temperature coefficient of delay (TCD). For $LiNbO_3$ single crystals, we have found several useful cutting orientation along x-axis of rotating Y-cut plane.[1)] $LiTaO_3$ crystal also belongs to class 3m as is the case with $LiNbO_3$ crystal. Some interesting results, therefore, may be expected in suitable orientations for rotated Y-cut. In this paper, we describe several results obtained through our studies for $LiTaO_3$ single crystal plates and $LiTaO_3$ substrates having SiO_2 thin film on them.

§2. Rotated Y-cut, X-propagation $LiTaO_3$

Let us consider the coordinate system as shown in Fig. 1. In this figure, x is taken in the direction of propagation, z in the direction transverse to the propagation, θ is the rotation angle from Y-cut plane. For the elastic and piezoelectric constants, and temperature coefficients, we used the values shown in ref. 6 and 7. Figure 2 shows the phase velocities and electromechanical coupling coefficients (K) versus angle of rotation. In the figure, the solid curve represents the open-circuit surface and the broken curve the short-circuit one. For the branch of Rayleigh wave, the effective electromechanical coupling coefficient is almost zero (maximum value, $K^2=0.0038$). The investigation, therefore, should be done for the branch of leaky surface waves. The leaky wave, in general, gets attenuated during propagation,

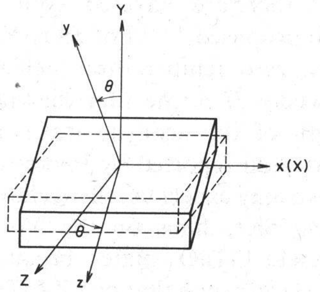

Fig. 1. Rotated Y-cut plate and coordinate system.

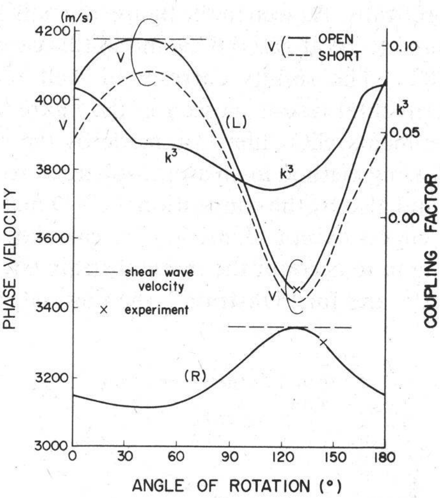

Fig. 2. Velocities and coupling coefficient, K^2 versus angle of ratation. R: Rayleigh wave branch, L: leaky surface wave branch.

because the wave goes into the inner part of the substrate. Fortunately the attenuation term goes to zero for the opencircuit surface on $\theta = 37^\circ$ and 126°, and for short-circuit surface on $\theta = 35.5^\circ$ and 128°. According to further investigation, the distribution of the displacement on 126° cut is very similar to those of Rayleigh waves. Therefore we can say that this wave is a Rayleigh-type wave. On the other hand, U_z the displacement component towards z-axis, is predominant on 36° cut.

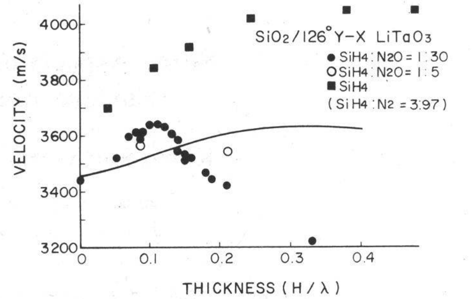

Fig. 4. Theoretical and measured velocities versus H/λ.

§3. Rotated Y-cut, X-propagation $LiTaO_3$ Structure with a Thin SiO_2 Film

In the present time, it seems hard to find null-temperature orientations for $LiTaO_3$ single crystals,[8] therefore, layered type structures have been proposed.[9,10] For SiO_2/YZ $LiTaO_3$ structures, zero temperature coefficient ($H/\lambda = 0.57$, where H is the film thickness and λ wavelength of the acoustic wave, and $K^2 = 0.014$) has been reported by Parker *et al.*[9]

Now, we may expect excellent characteristics by coating SiO_2 films on the 36° and 126° rotated Y-cut $LiTaO_3$ plates, because their K-values are larger than that of YZ $LiTaO_3$ plates as stated above. Figure 3 shows the temperature coefficient of delay for 126° cut, obtained theoretically. As seen in the figure, the null TCD is found to be at $H/\lambda = 0.29$ and in this case, $K^2 = 0.027$. The results correspond well to the experimental results as seen in the figure.[11] In experiments, SiO_2 films are made by the usual sputtering method in an atomosphere of Ar and O_2, and also by the conventional CVD method. The curves except "Unstrain" is calculated by taking in to account the thermal strain effect of films,[11] and for "Unstrain", the thermal strain effect is neglected. In the figure, T_d is the temperature of the substrate during the sputtering operation. On the other hand, "$SiO_2/36^\circ$ rotated Y-cut $LiTaO_3$ structure gives the null TCD when $H/\lambda = 0.32$, and $K^2 = 0.052$.

We have recently observed much interesting results[12] for $SiO_2/LiTaO_3$ substrates such as the characteristics greatly deviate from the theoretical expectation. The temperature coefficient of delay were evaluated by measuring the variation of the oscillation frequency of an oscillator with surface wave delay line. In this case, SiO_2 films have been made by "plasma-CVD method". As a result of careful experimentation it has found that the wave propagation characteristics are controlled by the amount of gas flow ratio : "$SiH_4 : N_2O$". Figures 4 and 5 show the phase velocity and temperature characteristics for various film thicknesses H and the gas flow ratios respectively. The temperature coefficients of delay were measured by the same method as above. The crystal substrates are of 126° rotated Y-cut $LiTaO_3$. The solid curves shown in Figs. 4 and 5 correspond to the theoretical ones. Each theoretical result corresponds well with the experiments done by

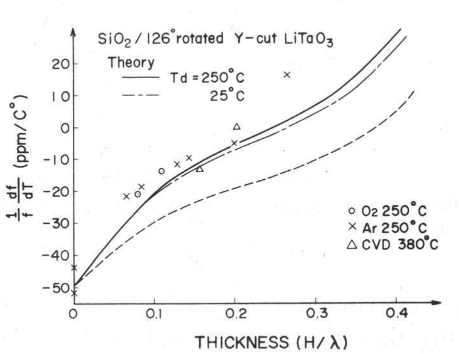

Fig. 3. Theoretical and measured temperature dependence versus H/λ.

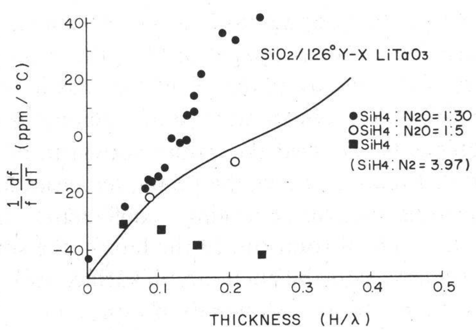

Fig. 5. Theoretical and measured temperature dependence versus H/λ.

sputtering method as stated above. We have obtained an excellent result not only for temperature characteristics (≈ -2 ppm/°C) but also especially for the frequency response.[12] In this case, the gas flow ratio is $SiH_4:N_2O=1:30$, and the film thickness H is $H/\lambda \approx 0.14$. This thickness correspond to approximately half of the theoretically expectated value ($H/\lambda \approx 0.25$).

§4. Boundary Waves

Under a certain condition, it is confirmed theoretically that the higher modes of surface waves turn to boundary waves which propagate along the interface separating the layer and the crystal plate.[13,14] In filter experiments, therefore, we often observe both the responses caused by the surface wave and the boundary wave. However, when a suitable condition is satisfied, for example: the substrate with SiO_2 film made by plasma-CVD ($SiH_4:N_2O=1:30$) for $LiTaO_3$ (126°Y-X) and $H/\lambda=0.416$, we can observe very excellent filter characteristics followed by the boundary wave only.

§5. Conclusion

We were able to obtain surface acoustic wave materials with large coupling coefficients and small temperature coeffcients from $LiTaO_3$. Especially, for layered structure type such as SiO_2/36° and 126° rotated Y-cut, X-propagation $LiTaO_3$, we have found much interesting results on the plasma-CVD making film—the thickness of the film corresponds to approximately half of the theoretically expected value.

References

1) K. Shibayama: Izv. Akad. Nauk SSSR Ser. Fiz. **4** (1977) 672 [in Russian].
2) K. Iwahashi, K. Yamanouchi and K. Shibayama: *Proc. Ultrasonic Committee*; in Inst. Electron. Comm. Eng. Jap. **US77–43** (1977) 37 [in Japanese].
3) K. Yamanouchi, K. Iwahashi and K. Shibayama: Wave Electronics **3** (1979) 319.
4) K. Nakamura, M. Kazumi and H. Shimizu: *Proc. 1977 Ultrasonic Symposium*, IEEE (1977) 819.
5) T. I. Browning and M. F. Lewis: Proc. 1978 Ultrasonic Symposium, IEEE (1978) 586.
6) A. W. Warner, M. Onoe and G. A. Coquin: J. Acoust. Soc. Am. **42** (1967) 1223.
7) R. T. Smith and H. S. Welsh: J. Appl. Phys. **42** (1971) 2219.
8) Y. Shimizu: J. Acoust. Soc. Jpn. **36** (1980) 140 [in Japanese].
9) T. E. Parker and H. Wichansky: *Proc. 1975 Ultrasonic Symposium*, IEEE (1975) 503.
10) S. Furukawa, T. Moriizumi, Y. Kino and Y. Nakayama: J. Acoust. Soc. Jpn. **36** (1980) 350 [in Japanese].
11) K. Yamanouchi, M. Ishii and K. Shibayama: Electron. Lett. **14** (1978) 784.
12) W. Chujo, K. Yamanouchi and K. Shibayama: *Proc. Ultrasonic Committee*, in Inst. Electron. Comm. Eng. Jap. **US80–3** (1980) 15 [in Japanese].
13) K. Yamanouchi, M. Iwahashi and K. Shibayama: IEEE Trans. SU, **SU-25** (1978) 384.
14) W. Chujo, K. Yamanouchi and K. Shibayama: *Proc. Ultrasonic Committee*, in Inst. Electron. Comm. Eng. Jpn. **US80–4** (1980) 21 [in Japanese].