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Theoretical Analysis of Leaky SAW Properties on Reverse-Proton-Exchanged Substrate
逆プロトン交換基板上の漏洩弾性表面波の伝搬特性解析

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1. Introduction

Leaky surface acoustic waves (LSAWs) have an inherent attenuation because they lose energy by continuously radiating the bulk wave into the substrate. In a previous paper, we assumed a layered structure of air/bulk $LiNbO_3$ (LN) layer/elastically softened LN substrate and calculated the LSAW attenuation. It has been found that, in a certain range of the rotation angle for the rotated Y-X LN, the attenuation can be reduced by controlling the elastic constant of the softened LN.[1] To realize such a layered structure, we applied a reverse proton exchange (RPE) process[2] to 41° Y-X LN, and the measured propagation loss of the LSAW was decreased by carrying out RPE.

The buried PE layer by RPE process is known to have not only the softened elastic constants but also the reduced piezoelectric constants as compared with the bulk LN.[3] In this study, for 10° Y-X LN with a larger coupling factor, the LSAW attenuation on a structure of air/bulk LN/modified LN was calculated when all material constants of the PE layer were taken into consideration. Furthermore, the attenuation of the longitudinal-type LSAW (LLSAW) on the (90°,90°,36°)-cut LN[4] was also calculated.

2. Theoretical Calculation

The substrate structure after RPE process has a four-layered structure as shown in **Fig. 1(a)**. For convenient calculation, the combination of the buried PE layer and the LN substrate was regarded as a modified LN and a three-layered structure air/bulk LN/modified LN was assumed as shown in **Fig. 1(b)**. The elastic constants c'_{ij} and the piezoelectric constants e'_{ij} of the modified LN were expressed by Ac_{ij} and Be_{ij}, respectively, where c_{ij} and e_{ij} are bulk values and A and B are parameters. It is known that the elastic constants and the piezoelectric constants after PE are approximately 60%[5] and 20%[6] of those of the bulk LN, respectively. The material constants of the PE layer approach the bulk value with post annealing time.[9] Therefore, the parameter A was set to be ranged from 0.6 to 1.0.

The density ρ and the dielectric constants ε_{ij} are

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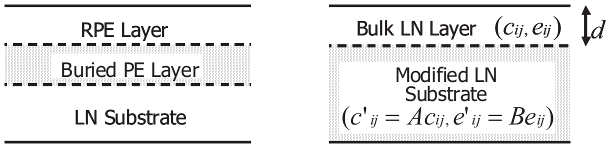


(a) RPE　　(b) Analytical model

Fig. 1 Structures of RPE and analytical model.

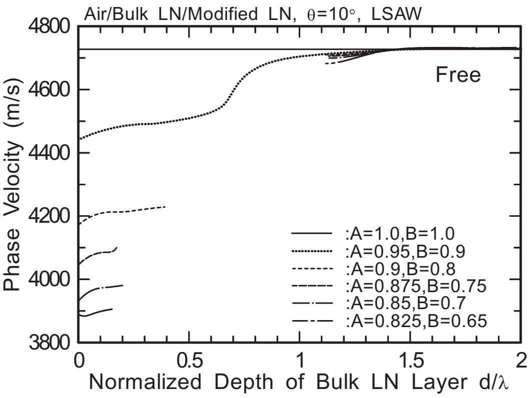
Table. I Material constants of modified LN substrate.

A ($c'_{ij}=Ac_{ij}$)	B ($e'_{ij}=Be_{ij}$)	ρ' [kg/m³]	$\varepsilon'_{11}/\varepsilon_0$	$\varepsilon'_{33}/\varepsilon_0$
1.000	1.00	4700	44.0	29.0
0.950	0.90	4675	45.4	32.3
0.900	0.80	4650	46.8	35.5
0.875	0.75	4638	47.4	37.1
0.850	0.70	4625	48.1	38.8
0.825	0.65	4613	48.8	40.4
0.800	0.60	4600	49.5	42.0
0.700	0.40	4550	52.3	48.5
0.600[5]	0.20[6]	4500[7]	55.0[8]	55.0[8]

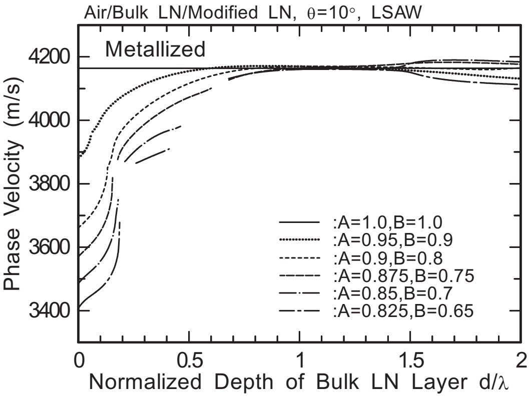
also changed after PE.[7,8] As shown in **Table. I**, the rates of change of e'_{ij}, ρ', and ε'_{ij} were assumed to be equivalent to that of c'_{ij}. **Figure 2** shows the calculated phase velocity as a function of the normalized depth d/λ of the bulk LN layer for (a) the free and (b) metallized surface cases. The corresponding attenuations are shown in **Fig. 3**.

The attenuation for the free surface decreases with increasing depth in the bulk LN layer and vanishes immediately before the phase velocity exceeds that of the fast shear bulk wave in the modified LN. Although the solution is not obtained when the phase velocity exceeds that of the bulk wave, it appears again at approximately a normalized depth of 1.1 because the LSAW senses a fast shear bulk wave in the bulk LN layer. Then, the attenuation increases from zero and converges to the bulk value. When the parameter A is 0.95, the solution exists at all depths.

On the other hand, for the metallized surface, the LSAW is converted to a Love-type SAW without attenuation for d/λ below 0.2, because the phase velocity is slower than a slow shear bulk wave. When the phase velocity exceeds a slow shear bulk wave, the LSAW solution appears until it exceeds a fast bulk wave. The attenuation decreases toward zero as the increase in d/λ. Then, the LSAW solution appears again because the LAW senses a

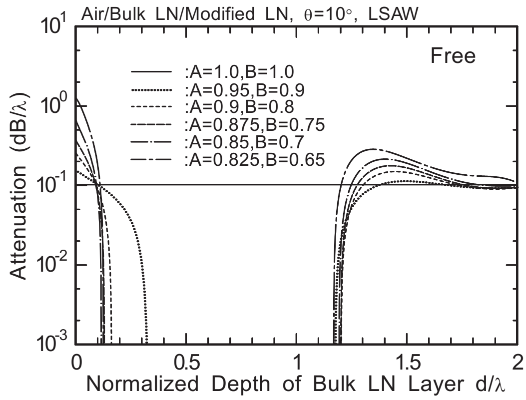


(a) Free

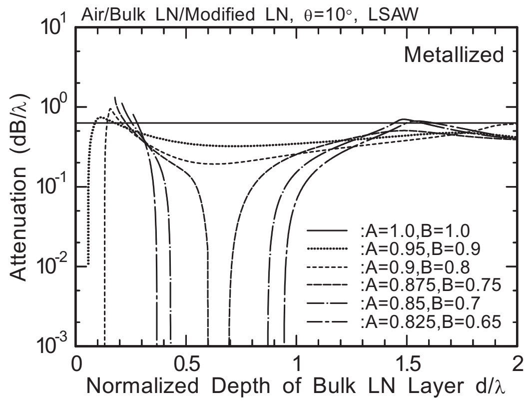


(b) Metallized.

Fig. 2 Calculated phase velocity of LSAW for θ=10°.



(a) Free



(b) Metallized.

Fig. 3 Calculated attenuation of LSAW for θ=10°.

bulk wave in the bulk LN layer and the attenuation increases from zero. For a parameter A below 0.825, a difference between the phase velocity of a slow shear wave and that of a fast shear wave becomes too small to exist the LSAW solution.

Figure 4 shows the calculated LLSAW attenuation on the (90°,90°,36°)-cut LN for the metallized surface. When the normalized depth d/λ was smaller than 0.6, the attenuation decreased as compared with the bulk value.

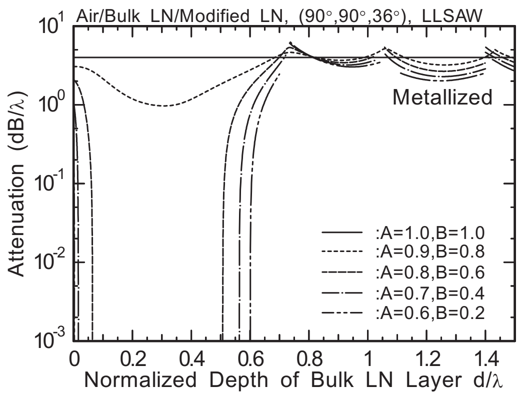


Fig. 4 Calculated attenuation of LLSAW on (90°,90°,36°)-cut LN.

3. Conclusion

The LSAW and LLSAW properties on the RPE substrate were calculated. It was found that the condition in which the attenuation decreases as compared with the bulk value exists for the free and metallized surfaces. We will experimentally investigate these effects using RPE process.

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