2P3-6

Proceedings of Symposium on Ultrasonic Electronics, Vol. 33 (2012) pp. 205-206
13-15 November, 2012

Loss Reduction of Longitudinal-Type Leaky SAW by Reverse Proton Exchange – Dependence of Recovery of Piezoelectricity on Fabrication Conditions –

逆プロトン交換による縦型漏洩弾性表面波の低損失化 —圧電性回復の作製条件依存性—

Masaya Abe‡ and Shoji Kakio (Univ. of Yamanashi)
阿部 真也‡，垣尾 省司 (山梨大院・医工)

1. Introduction

The longitudinal-type leaky surface acoustic wave (LLSAW) has advantages for application to high-frequency SAW devices because of its high phase velocity close to that of a longitudinal bulk wave.[1] However, the LLSAW has huge inherent attenuation because it loses energy through the continuous radiation of shear horizontal and shear vertical bulk waves into the substrate.

In our previous works, to reduce the attenuation of an LLSAW, we proposed a layered structure of air, a bulk $LiNbO_3$ (LN) layer, and an elastically softened LN substrate. When the layered structure was applied to X36°Y-LN with a large coupling factor K^2 for the LLSAW,[2] zero attenuation for the metallized surface was obtained theoretically at a bulk layer depth of 0.2-0.4 λ (λ: wavelength).[3] To realize such a layered structure, a reverse proton exchange (RPE) process,[4] in which a proton-exchanged (PE) layer with an elastically soft property is buried in the substrate, was applied to X36°Y-LN. In comparison with the virgin wafer, the measured propagation loss for the free surface on the RPE wafer was decreased threefold and the resonance properties were improved markedly.[3] However, there was a problem that the recovery of piezoelectricity due to the RPE process was insufficient on almost the entire area of the sample.

In this study, the dependence of the recovery of piezoelectricity on the fabrication conditions was investigated by evaluating the LLSAW resonance properties.

g11me003@yamanashi.ac.jp

2. Sample Fabrication

Table I shows the sample fabrication conditions, which are denoted No.0-7. Sample No.0 corresponds to a sample fabricated under the conditions in our previous study,[3] for which the results are used as reference data. These samples were fabricated by first forming an initial PE layer by immersing a 3-inch X-cut LN wafer in a dilute solution of benzoic acid, and then forming an RPE layer by immersing the PE wafer in a melted mixture of $LiNO_3$-$NaNO_3$-KNO_3, which acted as a Li^+ source. The parameters used to investigate the dependence on the fabrication conditions were the dilution rate (Li 1.0 or 2.0 mol%) in the PE process, the RPE temperature (300, 310, or 320 °C), and the Li^+ concentration (33, 66, or 100%) in the Li^+ source in the RPE process with the PE temperature fixed at 250 °C. The PE time was set so that the PE layer depth was 1.7 μm, and the RPE time was set so that the RPE layer depth was 1.1 μm. The RPE layer depth (0.3 λ) was designed in accordance with the results of our theoretical investigation.[3]

The same electrode patterns as those in our previous paper[3] were fabricated on the samples using an Al film with a thickness of 0.02 λ for 36°Y propagation. The resonator electrodes consisted of interdigital transducers (IDTs) with a period λ of 3.6 μm and reflectors. Eighteen different resonators were fabricated with an aperture W of 15, 25, or 50 λ, N=30, 100, or 200 IDT pairs, and N_R=0 or 50 refractors. Input and output IDTs with λ=3.6 μm, N=10 or 30 split-finger pairs, and propagation path lengths L of 5-50 λ were also fabricated.

Table I Fabrication conditions and evaluation results for LLSAW resonator.

No.	PE			RPE			Number of resonators with inductivity (/1800)
	Temp. (°C)	Li^+ (mol%)	Time (h)	Temp. (°C)	Li^+ (%)	Time (h)	
0[3]	250	1.0	5.0	300	33	9.0	6
1					66		0
2					100		0
3				310	33		3
4					66		4
5				320	33		0
6					100		0
7		2.0	23.0	300	33		26

3. Experimental Results and Discussion

The resonance property of each sample was measured by a network analyzer. The number of resonators having inductivity among the 1,800 resonators (18 types × 100 blocks) on each wafer sample was regarded as the ratio of the area in which the recovery of piezoelectricity due to the RPE process is sufficient. This number is shown in Table I. For sample No.0 (the reference sample), the number of resonators having inductivity was 6.

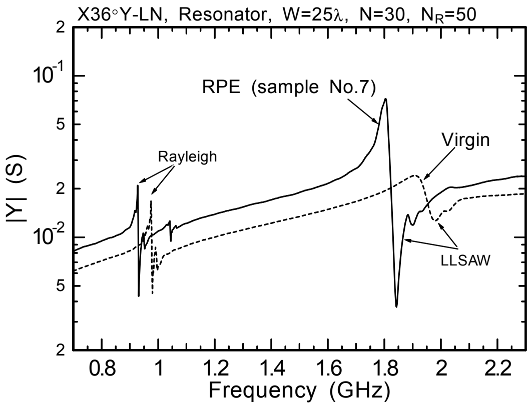
As shown in Table I, for the proton source diluted with Li 1.0 mol%, even if the conditions of the RPE process were changed, the recovery of piezoelectricity was not improved (samples No.1-6). On the other hand, when the Li^+ concentration in the proton source was increased from 1.0 to 2.0 mol% (sample No.7), the number of resonators having inductivity increased from 6 for the reference sample to 26.

It can be considered that when lithium ions are exchanged with protons in the RPE layers, the sign of the polarization is arranged randomly because the polarization axis is parallel to the substrate surface for X-LN. The remaining polarization in the initial PE layer may be increased by increasing the dilution, which may make it easy for the sign of the polarization to be equal to that in the RPE process.

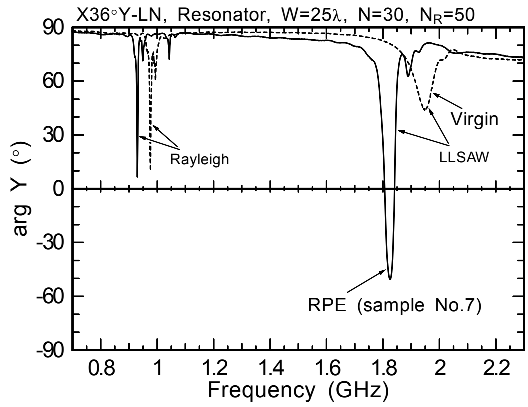
Figures 1(a) and **1(b)** show the measured (a) amplitude and (b) phase of the admittance for the resonator with W=25 λ, N=30, and N_R=50 on the area of sample No.7 with sufficient recovery. A similar improvement in the resonance property of the LLSAW to that in the previous paper[3] was observed in the RPE sample. The admittance ratio was increased from 5.6 to 25.8 dB. The minimum phase reached -50.6° compared with 43.8° for the virgin sample. The antiresonance quality factor Q was increased fivefold from 34 to 150. On the other hand, the bandwidth ratio $(f_a\text{-}f_r)/f_a$ (f_a: antiresonance frequency, f_r: resonance frequency) was decreased from 3.5% to 2.0%.

The propagation loss PL of the LLSAW was estimated from the slope of the minimum insertion loss (N=30) plotted as a function of L for the area of sample No. 7 with sufficient recovery. For instance, PL for the shorted grating was decreased from 0.43 dB/λ for the virgin wafer to 0.17 dB/λ.

From the above results, it can be considered that the area with sufficient recovery due to the RPE process can be further increased by further increasing the Li^+ concentration of the proton source. However, owing to the increase in the Li^+ concentration, the PE time is increased significantly. Therefore, a process that can increase the Li^+ concentration in the initial PE layer to a suitable value, such as postannealing, needs to be adopted.



(a) Amplitude.



(b) Phase.

Fig. 1 Admittance properties of resonator on X36°Y-LN (sample No.7).

4. Conclusions

The dependence of the recovery of piezoelectricity on the fabrication conditions due to the RPE process was investigated by evaluating the LLSAW resonance properties on X36°Y-LN. It was found that increasing the Li^+ concentration of the proton source is effective for increasing the area with sufficient recovery due to the RPE process. To further increase this area, postannealing to increase the Li^+ concentration in the initial PE layer will be investigated.

Acknowledgment

The authors would like to thank Dr. K. Hirota and Mr. A. Mori at Nihon Dempa Kogyo Co., Ltd., for their assistance in fabricating the electrodes.

References

1. T. Sato and H. Abe: Proc. IEEE Ultrason. Symp. (1995) p.305.
2. S. Tonami, A. Nishikata and Y. Shimizu: Jpn. J. Appl. Phys. **34** (1995) 2664.
3. S. Kakio and M. Abe: Jpn. J. Appl. Phys. **51** (2012) 07GC17.
4. J. Olivares and J. M. Cabrera: Appl. Phys. Lett. **62** (1993) 2468.