Acoustic Wave Devices using Periodical Poled Z-cut $LiTaO_3$ Plate

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***Abstract*— Though acoustic wave devices using a periodical poled Pb(Zi$_x$, Ti$_{1-x}$)O$_3$ (PZT) ceramic plate on Si substrate, a periodical poled Pb(Zr$_{0.2}$Ti$_{0.8}$)O$_3$ thin film on (001)SrTiO$_3$ substrate, and a periodical poled Z-LiNbO$_3$ substrate have been reported, their frequency responses were very weak as 0.1 to 3dB. It is considered that because their periodical poled devices have neither electrode fingers of intergiditial transducers (IDTs) nor grating electrode reflectors, they do not have any effective reflection to realize a good frequency response, while conventional SAW devices have them. This time, authors have proposed an effective reflector for the periodical poled substrate device and applied it to a resonator and a resonator filter using a periodical poled Z-plane LiTaO$_3$ plate, which is different from previously reported substrates. As the result, authors realized the resonator and the resonator filter having good frequency characteristics such as an impedance ratio of 33dB, and an insertion loss of 2.6 dB and a relative bandwidth of 2.2 %, respectively, for the first time.**

***Index Terms*— Periodical Poled Z-LiTaO$_3$, Resonator, Resonator filter, Reflector**

I. Introduction

Surface acoustic wave (SAW) devices have been key device in consumer electric equipments such as mobile phones and TVs[1]. Currently, high frequency SAW devices are required. When the high frequency devices are realized by shortening lines (fingers' width) and spaces (gaps' width) (L&S) of an interdigital transducer (IDT), its device is weak to an input electrical power. Authors consider that an acoustic device composed of a top-electrode/periodical poled (PP) substrate/bottom-electrode would be strong to the input electrical power compared with the conventional SAW devices using the IDT, if this PP device could be realized. So, the authors attempted to fabricate the PP device.

An in-line-filed model and a cross-field model by Smith are simple equivalent circuits explaining the IDT of the SAW. An electrical field distribution of the structure consisting of the top-electrode/PP substrate/bottom-electrode looks like one of the cross-field model. So, it is considered that a device composed of the top-electrode/PP substrate/bottom-electrode structure could generate an acoustic wave. As this electrical field distributes from the surface to the bottom of the substrate, the generated acoustic wave is similar to a kind of plate waves. On the other hand, the electrical field of the SAW distributes only on the surface of the substrate. So, the SAW is similar to the top-electrode/very thin PP plate/bottom-electrode on the substrate having the electrical field only on surface of the substrate. It is considered that the devices composed of the

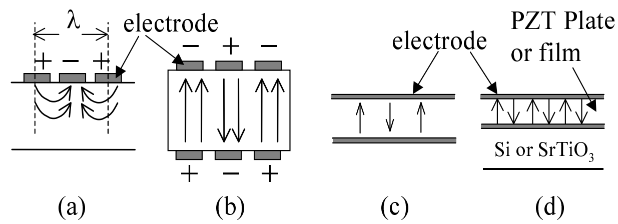

Fig1. Electric field distribution model of IDT: (a) actual, (b) cross-field-model, (c) PP plate, and (d) Thin PP plate or film on substrate.

PP structure are strong to the input electrical power compared with conventional SAW devices using the IDT.

It was reported that acoustic devices composed of a PP Pb(Zr$_x$,Ti$_{1-x}$)O$_3$ (PZT) plate on Si substrate, a PP Pb(Zr$_{0.2}$,Ti$_{0.8}$)O$_3$ thin film on (001)SrTiO$_3$ substrate, and a PP Z-LiNbO$_3$ had only weak responses of 0.1 to 3 dB such as impedance, conductance, or susceptance [2]-[4]. Conventional surface acoustic wave (SAW) resonator type devices such as a resonator, a multi-mode resonator filter, and a ladder type filter realize a good frequency characteristics by applying a reflection of electrode fingers of the IDT and grating reflectors at the both sides of the IDT. So, this reason is considered that their PP devices have neither the IDTs nor the grating reflector electrodes for the reflection of the acoustic wave.

Most of the previously reported plates or films for the PP devices were Pb(Zr, Ti)O$_3$ or LiNbO$_3$, but LiTaO$_3$ was not so reported. This time, authors have proposed effective reflectors for the PP device and fabricated a resonator and a resonator filter using PP Z-LiTaO$_3$ (PPLT) plate, which is different from above-mentioned substrates. As the result, authors realized the resonator and the resonator filter having good frequency characteristics such as an impedance ratio of 34dB, and an insertion loss of 2.6 dB and a relative bandwidth of 2.2%, respectively, for the first time.

II. Principle and Calculation

An in-line-filed model and a cross-field model by Smith are simple equivalent circuits explaining the IDT of the SAW. Figs. 1(a) and (b) show an actual IDT model and the cross-field model by Smith, respectively. Fig. 1(c) shows a structure consisting of a top electrode/PP substrate/bottom-electrode. The cross-field model in Fig. 1(b) looks like the structure in Fig. 1(c). It is considered that a device composed of the

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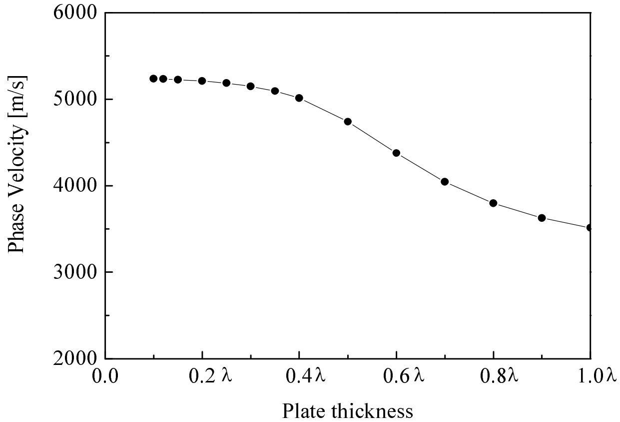

Fig2. Velocity of structure of Fig.1(c) as function of thickness.

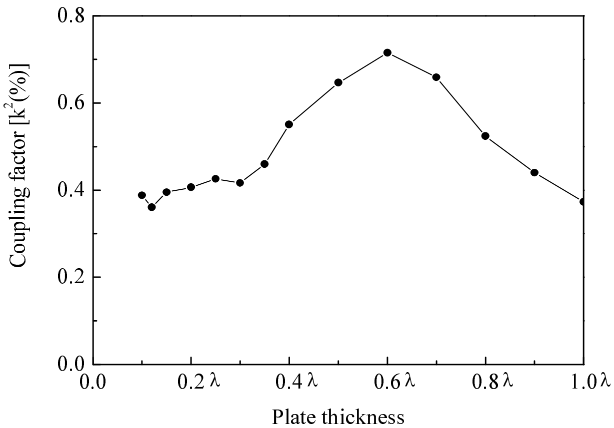

Fig3. Electromechanical coupling factor of structure of Fig.1(c) as function of thickness.

structure in Fig. 1(c) could generate an acoustic wave. An actual SAW device has an electrical field only on the surface of the substrate as shown in Fig. 1 (a). The SAW has the similar electrical distribution to that of a structure composed of a top-electrode/very thin PP plate/bottom-electrode on substrate as shown in Fig. 1(d). Acoustic waves generated in the structures of Figs.1 (c) and (d) correspond to a plate wave on a thin plate and a SAW, respectively.

Conventional SAW devices with short L&S of the IDTs, which realize a high frequency device, are weak to an input electrical power. But it is considered that there is a possibility that the device composed of the top-electrode/PP substrate/bottom-electrode is strong to that compared with them.

Authors attempt to fabricate low frequency devices consisting of the PP structure shown in Fig. 1 (c) using $LiTaO_3$ crystal plate, because it is difficult to polarize periodically only the surface of substrate and its process is complex. Though the structure shown in Fig. 1(c) requires very thin $LiTaO_3$ plate, a normalized plate thickness is become thin by using a long polarized periodic length. But the generated frequency is very low.

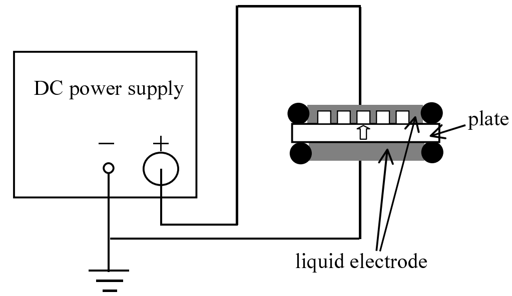

Fig4. Polarization system.

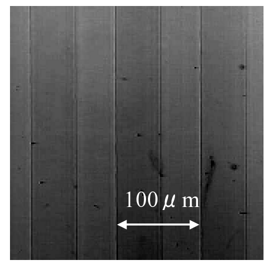

Fig5. Surface of substrate after periodic polarization (example of λ=100μm).

Figs. 2 and 3 show calculated velocity and electromechanical coupling factor of a fundamental symmetrical mode on the PPLT plate. When the normalized thickness is 0.5λ to 0.7λ, a largest coupling factor is obtained. However, its value is not so large compared with other Lamb waves and conventional SAWs [5-7]. Authors attempted the PP devices using the $LiTaO_3$ single crystal plate of thickness of 0.5λ to 0.7λ.

III. FABRICATION

Fig. 4 shows a polarizing system. After polishig and forming periodical chemical resist lines on the top surface of the $LiTaO_3$ plate, the substrate was polarized by applying a DC voltage to liquid electrodes on both sides of the plate as shown in Fig.4. The lines without the resist were polarized in the opposite direction. After polarizing, the substrate was washed and the resist lines were removed. Fig. 5 shows the photograph after chemically etching the surface of the plate. When the surface of the substrate with the alternately polarized -c and +c plane lines was etched, the -c-plane lines were etched faster than the +c-plane ones. Fig. 5 shows an example of the etched -c-plane lines of the width of 50 μm, for instance. A relatively large coupling coefficient is comparatively obtained at the normalized thickness 0.5λ to 0.7λ as shown in Fig. 3. When both of the width of -c and +c-plane lines are 250μm, a polarization period length is 500μm, which is correspond a wavelength λ. Therefore, when the substrate thickness is 350μm, the normalized thickness is 0.7λ. After that, by depositing electrodes on both side of the substrate and dicing it, the PP device are fabricated.

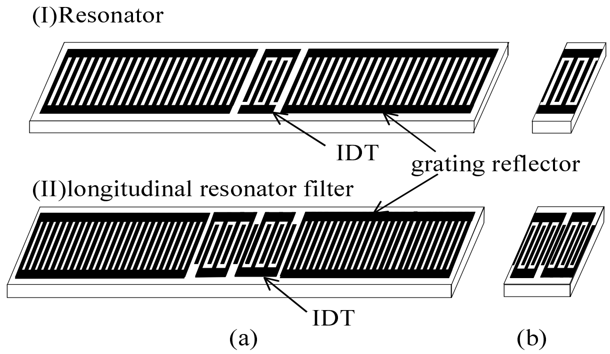

Fig6. Schematic views of I (a) conventional SAW resonator, II (a) conventional longitudinal resonator filter, I (b) edge reflection type resonator, and II(b) edge reflection type longitudinal resonator filter.

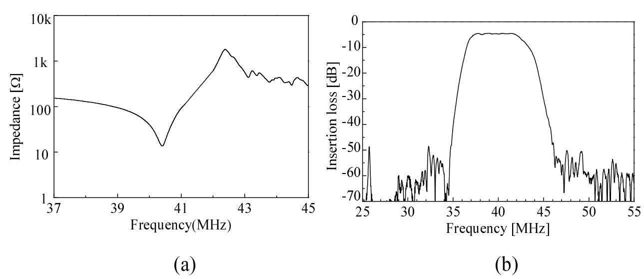

Fig7. Frequency characteristics of (a) resonator and (b) longitudinal resonator filter using reflection of SH wave at free edges.

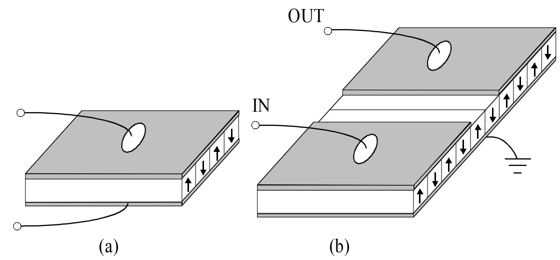

Fig8. Schematic views of (a) PPLT resonator and (b) resonator filter using edge reflection.

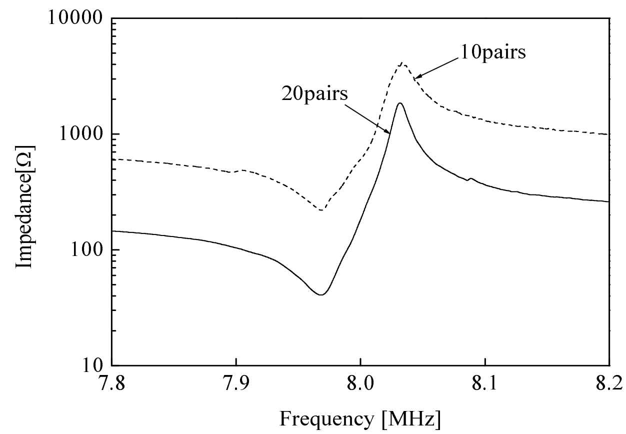

Fig9. Frequency characteristics of PPLT resonator using edge reflection (broken line: IDT with 10 pairs and aperture of 18λ, solid line: 20 pairs and 18λ).

IV. Frequency Characteristics

A. Principle of Resonator and Resonator Filter using Edge Reflection

Conventional SAW resonators and multi-mode longitudinal type resonator filters require grating reflectors at both sides of the IDTs as shown in Figs.6 I(a) and II(a). On the other hand, a resonator and a resonator filter using reflections of a shear horizontal (SH) wave at free edges of a substrate do not require the grating reflectors as shown in Fig. 6 I(b) and II(b), because the SH wave reflects completely at the free edges of the substrate[8][9]. Therefore, the ultra small resonator or resonator filter are realized by using the edge reflection [8][9][11]. When a width of two edge electrode fingers of the IDT is $\lambda/8$, that of other fingers is $\lambda/4$, and the total length L between two edges is $\lambda\times$ N (N is a number of a normal IDT finger pair), the edge reflection type resonator and resonator filter do not have spurious responses due to the edge reflections as shown in Fig. 7 (a) and (b). The spurious response at righ side of an anti-resonance in Fig. 7(a) is not one due to the edge reflection, but is one due to a bulk wave reflected from the bottom of the substrate. When the width of edge electrodes are not $\lambda/8$ or the distance L between the two free edges is different from N $\times\lambda$, spurious responses due to the even modes response of the edge reflection are generated[8][10][11]. Especially, the both positions of the edge are far from above mentioned position, the resonator has large spurious responses [10]. In addition of above condition, various other conditions are required to realize the longitudinal resonator filter without the spurious[9][11]. Authors propose to apply the edge reflection to the PPLT devices.

B. Resonator composed of PPLT

The previously reported PP devices had only very weak responses [2]-[4]. It is considered that the reason is because they did not have the effective reflectors to generate the acoustic wave. The above-mentioned resonator utilizing the edge reflection of the substrate uses the SH wave. Though the PPLT device does not have the SH wave but the longitudinal wave, authors attempted to use the reflection of a longitudinal wave of the PPLT at the substrate edges. Figs. 8(a) and (b) show schematic views of fabricated resonator and resonator filter using the PPLT. A length of the resonator in the propagating direction of the acoustic wave of the PPLT and a vertical width to its direction, which correspond to the finger pair and the aperture of the IDT respectively, was decided by dicing the PPLT. Two PPLT resonators were fabricated. One has the aperture of 10λ and IDT fingers of 10 pairs, and the other 18λ and 20 pairs. An input and an output terminals are connected with the electro-conductive resin. Fig. 9 shows the frequency characteristics of the resonators consisting of 10pair

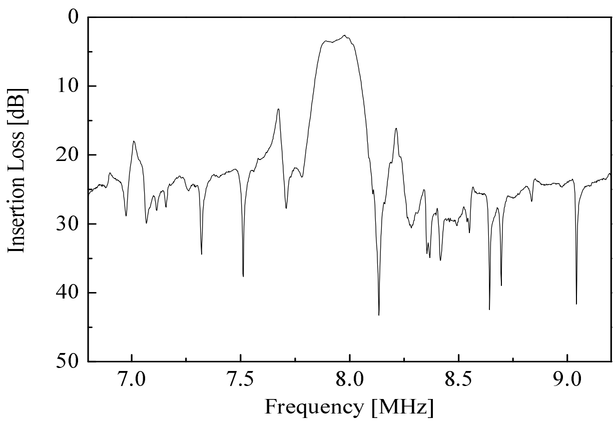

Fig10. Frequency characteristic of PPLT longitudinal resonator filter using edge reflection.

and 20 pairs by broken and solid lines, respectively. Their PPLT resonators use the reflection of the longitudinal bulk wave at the substrate edges, therefore it is little different from the above-mentioned resonator using the edge reflection of the SH wave. However, as the resonators with the impedance ratio of 26 to 34 dB have been realized, it is considered that the longitudinal bulk wave also reflects enough at the free edges. Previous papers reported that resonators or devices using the PP structure had the weak impedance ratio or response of only several dB or less. So, this characteristic is epoch-making as the PP device. It is considered that a larger impedance ratio could be obtained by improving a supporting method of the resonator and optimizing the aperture and finger pair of the IDT, because the impedance ratio of the resonator with the IDT of 20 pairs and the aperture of 18λ is larger than that of 10 pairs and 10λ.

C. Resonator Filter composed of PPLT

Authors have also attempted to fabricate a multi-mode longitudinal resonator filter composed of the PPLT as shown in Fig. 8(b). The filter is composed of the IDT's aperture of 18λ, the input and output IDTs of each 10 pairs, and a gap length of 2λ between nearest fingers of the input and output IDTs. The input and output terminals are connected with the electro-conductive resin as well as the above-mentioned resonators. Fig. 10 shows the frequency characteristic of the filter, which has an insertion loss of 2.6 dB, a relative bandwidth of 2.2 %, and a good attenuation. It is expected that the more excellent frequency characteristic could be obtained by improving the input and output terminals and optimizing the gap length between two IDTs, the IDT's aperture and the finger pair. In order to realize a high frequency device, a very thin PPLT is required. For instance, a 3 GHz PPLT device requires a very thin plate of 360μm and narrow λ of the IDT of 1.8μm.

V. CONCLUSION

The previously reported PP structure devices did not have excellent characteristics so far. Authors have considered that the reason was because the previous PP structure devices did not have any effective reflectors to obtain excellent characteristics. As the SH wave reflects completely at the substrate edge, ultra small resonators and resonator filters utilizing the edge reflection of the SH wave have been reported instead of the grating reflectors. Authors considered that the reflection of the longitudinal bulk wave of the PPLT at the substrate edges might be applied to realize PP devices with a good characteristic. Authors have fabricated the PPLT devices utilizing the edge reflections of the longitudinal bulk wave. As the result, a resonator having the impedance ratio of 34 dB and the resonator filters having an insertion loss of 2.6 dB and a relative 3 dB bandwidth of 2.2% for the first time.

REFERENCES

[1] M. Kadota : Jpn. J. Appl. Phys., vol.44, p.4285(2005).
[2] S. Ballandras: Proc. IEEE Freq. Cont. Symp., p.893(2003).
[3] A. K. Sarin Kumar et al.: Appl. Phys. Lett. vol.85, p.1757(2004).
[4] E. Courjon et al.: Joul. Appl. Phys., vol.102, 114107(2007).
[5] M. Kadota, T. Ogami, K. Yamamoto, Y. Negoro and H. Tochishita: Proc. 37-th Elect. Mech. Symp.,p.69(2008) (Tokyo)[in Japanese].
[6] K. Yamanouchi and K. Shibayama: Jpn. J. Appl. Phys., vol.43, p.856(1972).
[7] K. Nakamura, M. Kazumi, and H. Shimizu : Tech. Rep. of IEICE Japan, US77-42, p.31(1977) [in Japanese].
[8] Y. Suzuki, H. Shimizu, M. Takeuchi, K. Nakamura, and A. Yamada:Proc. IEEE Ultrason. Symp.p.297(1976).
[9] M. Kadota, J.Ago, H.Horiuchi, and M.Ikeura : Jpn. J. Appl. Phys., vol.40, p.3722(2001).
[10] M. Kadota, J.Ago and H.Horiuchi:Proc. IEEE trans. Microwave Theory and Tech., vol. MTT-44, p.2758(1996).
[11] M. Kadota, J. Ago, H. Horiuchi and M. Ikeura : IEEE trans. Ultrason. Ferroelec. Freq. Cont., vol.49, p.1269(2002).