CONSIDERATION OF LBO SAW RESONATOR STABILIZED VOLTAGE CONTROLLED OSCILLATOR FOR PLL-FM MODULATOR

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Abstract

The method of making to high performance to optimize the fundamental property of lithium tetraborate ($Li_2B_4O_7$: LBO) used as stabilized material for the SAW is researched.[1] In this paper, LBO SAW-PLL modulator is examined. LBO can miniaturize the SAW resonator because the loss is a little and the reflection coefficient is large, and there are as much as one percent electromechanical coupling factor. Because an inductor necessary to increase a changeable range of the frequency becomes unnecessary, it stabilizes further and the device can be miniaturized. However, LBO SAW had the fault with a bad temperature characteristic. LBO is a special material where linear expansion coefficient α_{11} and α_{33} have anisotropy in the side of the opposite sign. It has been understood to be able to make the temperature characteristic ST-cut quartz level by appropriately choosing compared with the vicinity of the SAW chips. In high frequency, there is a possibility that the SAW-PLL modulator that uses the SAW resonator that uses this new structure LBO can change into VCXO.

Introduction

SAW VCO that consists of the combination of quartz SAW resonator and the inductor is a small SAW oscillator of high purity with an unnecessary multiply. Up to now, the research and development has been advanced in the frequency domain of UHF band from the VHF band as for this quartz SAW VCO. It had been put to practical use by 145MHz SAW-PLL modulator of a small wireless transceiver for an analog car telephone in the past. PLL method is often used to obtain a steady oscillation source, and has an excellent characteristic in the phase noise characteristic etc. However, the VCXO is widely used from the delay of the frequency adjustment cost and development for a digital cellular phone as for quartz SAW-PLL modulator.[2,3]

LBO Wafer Lithography Process

LBO is a paraelectrics crystal with 4mm symmetry. Alkali etching is adapted in photolithographic process for LBO wafer. The productive process of the developed lithography is shown in the mass production of the wafer for LBO in Figure 1. The negative type photoresist that the formation of a fine pattern of 0.3µm resolution is possible is used. Negative type photoresist (TSMR-iN200:Tokyo Ohka Kogyo) can control Line & Space. That is, if the exposure time is lengthened, Line & Space can be large, and becoming thin of the line of the photoresist at the etching time be corrected. Even if the pinhole is generated on the pattern, the negative type photoresist can avoid the IDT short pattern. Post Exposure Barking (P.E.B.) process is indispensable, and the photoresist pattern changes depending on the condition so that the chemical amplification type negative photoresist may cause the negative type reaction after it exposes it. TSMR-iN200 is P.E.B. . The temperature is 110℃～120℃.

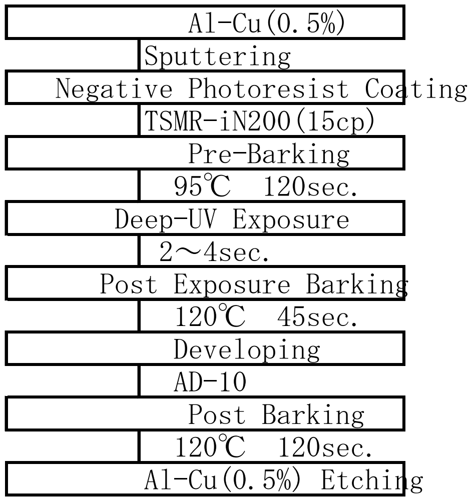


Figure 1: LBO wafer lithography process

It changes into a lift-off process as a pattern formation method, and the alkali etching is used for the SAW device of the LBO substrate. Figure 2 is etching characteristics of the Al-Cu electrode film by the dip method. It is understood to be constant the etching speed, and to be able to control at time in 35℃ temperature. This AL-4 is not seen as for the damage given to the photoresist. In this AL-4, even Al-Cu(0.5%) film thickness 3.5µm on practical use good at etching is verified.

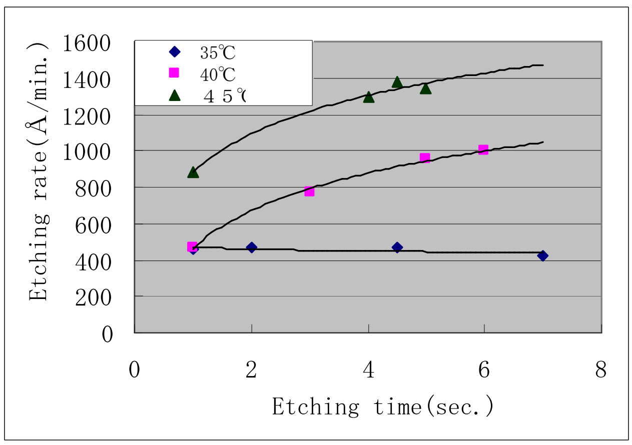


Figure2 : Alkali etching characteristics of AL-4

LBO material characteristics [4-25]

It is examined that the electromechanical coupling factor improves the temperature characteristic of 1% and large LBO to ST-cut quartz. When the velocity of SAW is assumed to be V and the linear expansion coefficient in the direction where the substrate is assumed to be α, TCD of the structural SAW resonator shown in Figure 3 is given by the following expression.

$$TCD = \alpha - \frac{1}{V}\frac{\partial V}{\partial T}$$

Here, it is

$$\alpha = \alpha_{11}(1-\sin^2\theta\sin^2\varphi) + \alpha_{33}\sin^2\theta\sin^2\varphi).$$

In LBO of 45°X-Z (45,90,90), the linear expansion coefficient α becomes α_{33} (-4ppm/℃). Figure 4 shows the linear expansion curve in the direction of each crystal axis. The coefficient of linear expansion in <110> direction is +24ppm/℃.

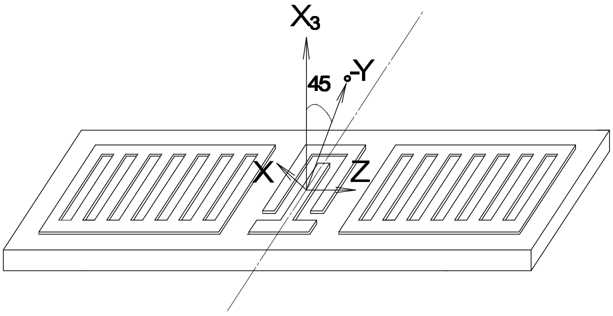


Figure 3 : LBO SAW resonator

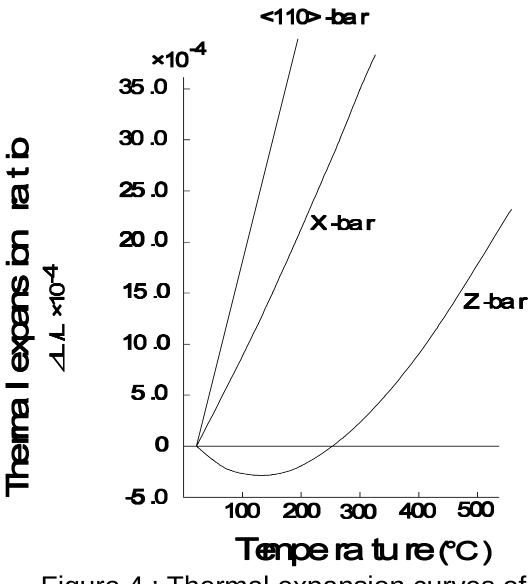


Figure 4 : Thermal expansion curves of LBO (X-bar, Z-bar, and <110>-bar)

Anisotropic three dimensional FEM analysis

The model shown in Figure 5 is analyzed by using the anisotropic three dimensional heat stress FEM. Figure 6 shows the amount of the maximum displacement at each temperature. When it is 4.75 (Z direction length)/2 (Y direction length) = 2.375 compared with the vicinity, the amount of the surface displacement of LBO SAW substrate is the smallest. Figure 7 is a stress chart of the SAW propagation direction of Z of each temperature.

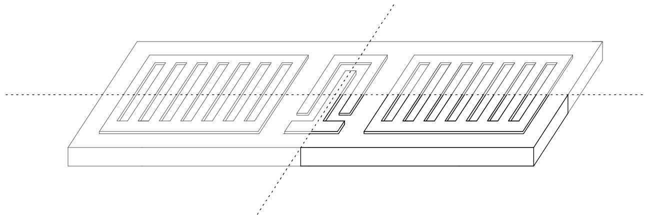
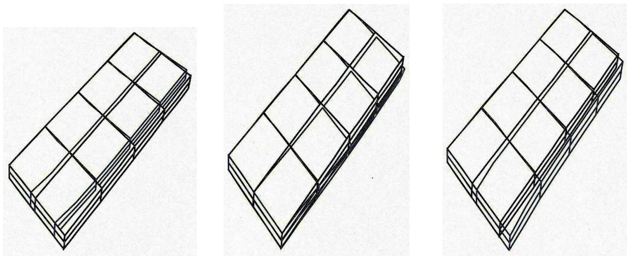
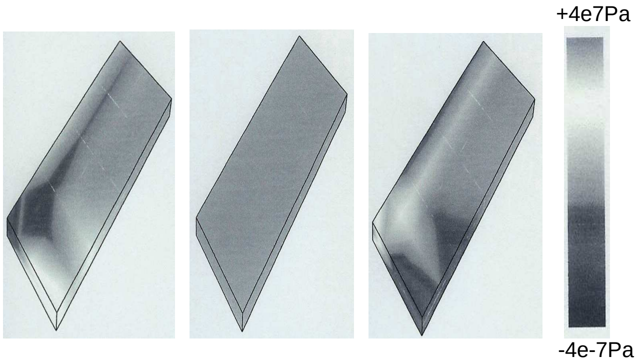


Figure 5 : 1/4 of the model is analyzed.



-30℃ (1.675 μm) 25℃ (0.00002 μm) 85℃ (1.828 μm)

Figure 6 : Amount of the maximum stress displacement within the range of drawing



-30℃ 25℃ 85℃

Figure 7 : Surface stress distribution in direction of Z at each temperature

The LBO SAW device was mounted on a ceramic package as shown in Figure 8. Figure 9 assumes the ratio of length and width to be a parameter, and shows the width of the temperature of 100ppm. In Figure 8, the rubber adhesive of the thickness h=50 μm is used for the adhesive layer where the SAW chip is fixed to a ceramic package. The difference with an analytical result by FEM is considered. The SAW chip is able not to be fixed to a ceramic package uniformly. It is thought that the maximum width of the temperature change shifted because the stress displacement hung to the SAW chip because of this.

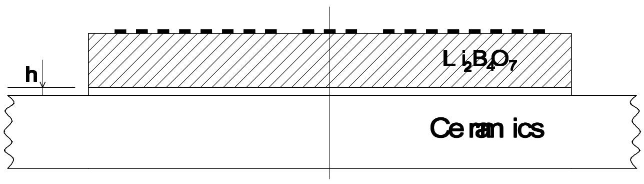


Figure 8 : Mounted structure of LBO SAW resonator

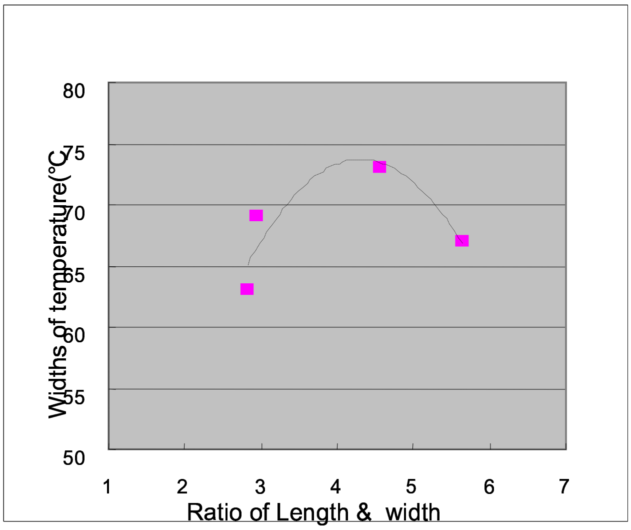


Figure 9 : Width of temperature of 100pppm frequency change or less

SAW VCO for PLL-FM Modulator

Oscillation frequency f of Figure 10 shows the load capacity and an equivalent, parallel of C_L and SAWR capacity is shown that C_0 and the resonance frequency are assumed to be fr by expression (1).

$$f = f_r \cdot \left(1 + \frac{1}{2\gamma} \cdot \frac{1}{1 + \frac{C_L}{C_0}} \right) \qquad (1)$$

It is for the inductivity reactance element as for SAWR . Therefore, maximum frequency changeable width Δf becomes $\Delta f / f_r = (2\gamma)^{-1}$ by assuming CL=0～∞ in expression (1). The temperature compensating of the oscillation frequency is possible for $TF \le (2\gamma)^{-1}$ in doing the amount of the change by the temperature of the resonance frequency of SAWR as TF.

$M_F \cong (\frac{1}{2\gamma}) / TF$ is defined as the second performance index M_F.

Table 1 showed M_F of various SAWR. In the calculation, $\gamma=\pi^2/8k^2$ and the range of the specification temperature were assumed to be 100℃. The amount of the temperature change was large and M_F was low in past LBO clearly from the table.

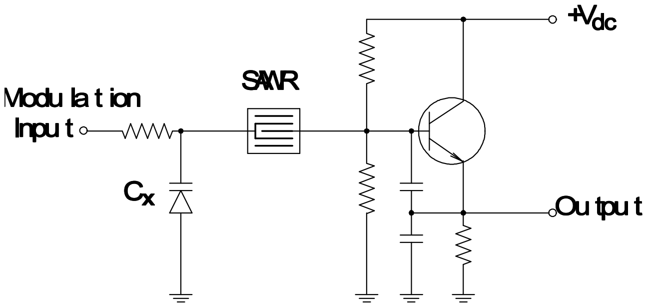


Figure 10 : Basic circuit configuration of SAWR VCO

As for new structural LBO SAWR, the performance index is greatly improved.

Table1 : Performance index M_F of SAWR

Substrate	k^2(%)	γ	M_F
ST-cut Quartz	0.16	770	8.1
128°rot Y-X LiNbO3	5.5	22	3.2
X-112°Y LiTaO3	0.64	193	1.4
$La_3Ga_5SiO_{14}$(0°,140°,25°)	0. 36	342	7. 3
45°X-Z $Li_2B_4O_7$ (New Structure)	1	123	50. 8

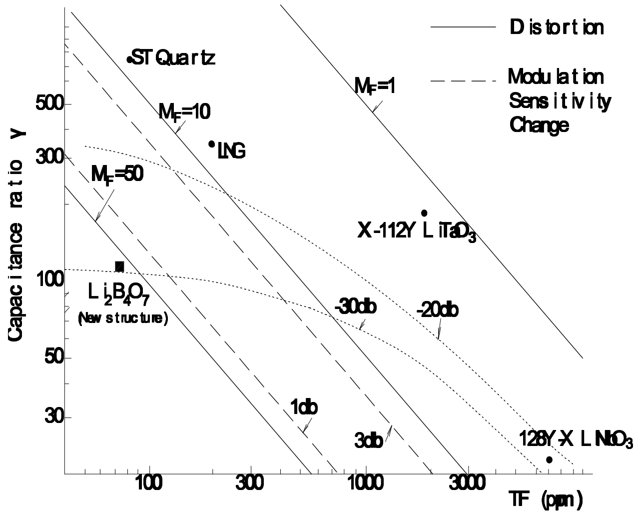


Figure 11 : Characteristics of SAWR (γ and TF) and the modulation characteristics

Figure 11 shows the characteristic of SAWR (γ and TF) and the modulation characteristics. The modulation sensitivity deflection runs side by side as shown in figure, M_F runs side by side with a constant line in a constant line, and it is understood the sensitivity deflection is single meaning decided by M_F. As for the distortion factor, it is understood the limit value is decided compared with capacity. It is new structural LBO SAWR that there is a possibility that the distortion factor -30dB can be achieved within 1dB as for the modulation sensitivity distortion.

Table 2 : SAW PLL Modulator obtained performance

Items	Performances	
Oscillation frequency	145.000000MHz ±2.5ppm	-20℃～+75℃
Output level	-10dB±2dB	-20℃～+75℃
Modulation sensitivity temperature deviation	±1dB or less	-20℃～+75℃
S/N	58dB or more	Modulation frequency 1kHz Frequency deviation 3.5kHz Band width 0～3kHz
Modulation distortion	-30dB or less	Modulation frequency 1kHz Frequency deviation 3.5kHz Band width 0～20kHz
C/N	90dB or more	Offset of carrier 25kHz Band width 15kHz

It was 100kHz as a standard signal, and PLL was composed of the machine of dividing frequency (1450 dividing frequency) and the phase comparator, the Rag lead type loop filter, and LBO SAWR. It is operated with $\Delta f = 500kHz$. The obtained main performance was shown in Table 2. It is the one to satisfy the performance as PLL modulator enough.

Conclusions

The following results were obtained.

1. It has been understood to obtain the temperature characteristic of ST-cut quartz about LBO SAW. It has been understood that the SAW chip shape is devised, and within the wide range of the temperature, there is a possibility that high steady LBO SAW resonator can be realized.
2. The mass production process of LBO SAW was established by combining the etching liquid of negative type photoresist and aluminum film (Al-Cu).
3. There is a difference in the experiment result of the anisotropic three dimensional heat stress FEM analysis. This cause seems for the adhesive line of mounting SAW chips to influence. It is assumed the examination problem in the future.
4. 145MHz SAW-PLL modulator is the one to satisfy the performance as PLL modulator enough.

References

[1]T.Watanabe "Method of extremely effencitly using materials of LBO and quartz in SAW and bulk wave resonator", 2003 IEEE Joint Meeting 17th European Frequency & Time Forum &2003 IEEE International Frequency Control Symposium & PDA Exhibition

[2]S.Urabe"Considaration of SAW Resonator Characteristics for Voltage Controlled Oscillator" IEICE ,Vol.J-66-C No.1,pp.110-111,1983

[3]S.Urabe,T.Habuka, and T.Matsuura"SAW-Resonator Stabilized Voltage-Controlled-Oscillator for PLL-FM Modulator",IEICE,Vol.J65-B No.2,pp177-184,1982

[4]J.Krogh-Moe "The Crystal Structure of Lithium Diborate,$Li_2O/2B_2O_3$"Acta Crysta, 15,pp.190-193(1962)

[5]N.M.Shorrocks, R.W.Whatmore and F.W.Ainger "Lithium Tetraborate – A New Temperature Compensated Piezoelectric Substrate Material for Surface Acoustic Wave Devices" 1981 Ultrasonics Symposium, pp.337-340, (1981)

[6] R.W.Whatmore, N.M.Shorrorocks, C.O'hara, F.W.Ainger and I.M.Young "Litium Tetraborate : A New temperature-Compensated SAW Substrate Materials" Electronics Letters, Vol.17, No.1, pp.11-12 (1981)

[7] B Lewis, N.M.Shorrocks and R W Whatmore "An Assessment of Lithium Tetraborate for SAW Applications" 1982 Ultrasonics Symposium, pp.389-393, (1982)

[8] Y.Ebata, H.Suzuki,S.Matsumura and K.Fukuda "SAW Prpagation Characteristics on $Li_2B_4O_7$" JJAP, Vol.22, Supplement 22-3, pp.160-162, (1983)

[9] K.Fukuta, J.Ushizawa, H.Suzuki, Y.Ebata and S.Matsumura "Growth and Properties of $Li_2B_4O_7$ Single Crystal for SAW Devices Applications" JJAP, Vol.22, Supplement 22-2, pp.140-142, (1983)

[10] T.Shiosaki, M.Adachi, H.Kobayashi, K.Araki and A.Kawabata "Elastic, Piezoelectric, Acousto-Optic and Electro-Optic of $Li_2B_4O_7$" JJAP, Vol.24, Supplement 24-1, pp.25-27, (1984)

[11] J.Ushizawa, K.Fukuta, H.Suzuki, Y.Ebata and S.Matsumura "$Li_2B_4O_7$ Single Crystal Substrate for SAW Devices" Technical Report of IEICE, CMP84-23, pp.57-64, (1984)

[12] H.Suzuki, J.Ushizawa, K.Fukuta, S.Matsumuraand Y.Ebata "$Li_2B_4O_7$ Single Crystal for SAW Devices" Technical Report of IEICE , CMP84-24,pp.65-71, (1984)

[13] B Lewis, N.M.Shorrocks and R W Whatmore "An Assessment of Lithium Tetraborate for SAW Applications" 1982 Ultrasonics Symposium, pp.389-393, (1982)

[14] M.Adach, T.Shiosaki and A.Kawabata "Crystal Growth of Lithium Tetraborate ($Li_2B_4O_7$)" JJAP, Vol.24, Supplement 24-3, pp.72-75, (1985)

[15] M.Adachi,T.Shiosaki, H.Kobayashi, O.Ohnishi and A.Kawabata "Temperature Compensated Piezoelectric Crystal for High Frequency Surface Acoustic Wave and Bulk Wave Device Applications" 1985 Ultrasonics Symposium, pp.228-232 (1985)

[16] K.Fujiwara, M.Ono, M.Sakai and N.Wakatsuki "Strip Type Resobnator of Litium tetraborate" 1985 IEEE Frequency Control Symposium, pp.351-355 (1985)

[17] Y.Ebata and M.Koshino"SAW Resonator and Resonator Filter on $Li_2B_4O_7$ Substrate", JJAP, Vol.26, Supplement 26-1, pp.123-125, (1987)

[16] H.Abe,H.Saitou,M.Ohmura, T.Yamada and M.Miwa " Lithium Tetraborate($Li_2B_4O_7$) SAW Resonator" 1987 Ultrasonics Symposium, pp.91-94 (1987)

[18] S.Matsumura,T.Omi,N.Yamaji and Y.Ebata " A 45°X-cut $Li_2B_4O_7$ Single Crystal Substrate for SAW Resonators" 1987 Ultrasonics Symposium, pp.247-252

[19]J.G.Gualtieri,J.A.Kosinski,W.D.Wilber,Y.Lu,S.T.Lin, M.Murray and W.Ruderman " Dilithium Tetraborate($Li_2B_4O_7$) Fabrication Technology" 1992 IEEE Frequency Control Symposium, pp.724-731 (1992)

[20] J.A.Kosinski, Arthur Ballato and Yicheng Lu " Pure-mode Measurement of Dilithium Tetraborate Material Properties " 1993 IEEE International Frequency Control Symposium, pp.359-370 (1993)

[21] Waldemar Soluch " Properties of Pure-mode Measurement ofBustein-Gulyaev Waves in $Li_2B_4O_7$ Crystals" 1993 IEEE International Frequency Control Symposium, pp.237-241(1993)

[22] Shi-Ji Fan "Properties,Production and Application of New Piezoelectric Crystal Litium Tetraborate $Li_2B_4O_7$" 1993 IEEE Ultrasonics Symposium, pp.353-357(1993)

[23] H.Abe, M.Ohmura and H.Saito " SAW Devices on Lithium Tetraborate($Li_2B_4O_7$)" 1994 IEEE International Frequency Control Symposium, pp.289-295(1994)

[24] Natalya F.Naumenko "The Anomalous Elastic Anisotropy of $Li_2B_4O_7$ and its Influence on SAW Properties" 1995 IEEE International Frequency Control Symposium, pp.671-678

[25] Shi-Ji Fan, Jue Wang and Yi-bin Xu "Bridgman Growth of $Li_2B_4O_7$ Crystal of 4-inch Diameter" 1995 IEEE Ultrasonics Symposium, pp.667-670(1995)