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Applications of Langasite Family Crystals to Piezoelectric Devices
ランガサイト系結晶の圧電デバイスへの応用

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1. Introduction

AT-cut α-quartz resonators employing the thickness-shear mode are widely used as a reference clock of electronic devices all over the world. In recent years, a demand of miniaturizing crystal oscillator is growing with development of high-performance electronic devices needed for such as a smart phone. The present oscillator size in mass-produciton is 1.6×1.2 mm^2, and further miniaturization has been progressed by many researchers. However, the miniaturization of the crystal oscillator arises a serious problem that crystal impedance (CI) increases due to decreasing of crystal element area. Low-CI crystal oscillators are necessary beacause power consumption during oscillation increases in propotion to CI. Although one of the solutions for reducing CI is to utilize a piezoelectric crystal with a high electromechanical coupling factor, there is a problem that most of piezoelectric crystals have deterioration of a temperature coefficient of frequency (*TCF*).

The authors focus on langasite family crystals as a piezoelectric crystal instead of α-quartz. The langasite family crystals, belonging to the crystal system of point group 32 as same as α-quartz, have mainly been studied as substrates for surface acoustic wave (SAW) devices with superior *TCF* close to that of α-quartz and a larger electromechanical coupling factor exceeding that of α-quartz.[1-5)]

In this report, taking $La_3Ga_5SiO_{14}$(LGS) and $Ca_3NbGa_3Si_2O_{14}$(CNGS) among langasite family crystals, we discussed results of numerical calculations and experimental characteristics of the piezoelectric bulk resonators of thickness-shear mode.

2. Numerical Calculation

Numerical calculations of electromechanical coupling factor (k^2) and *TCF* were performed for rotated *Y*-cut thickness-shear modes (*X*-axis polarized particle displacement) of LGS and CNGS in a temperature range from -10 to 70°C. Definitions of *TCF* and k^2 are represented in the following equations,

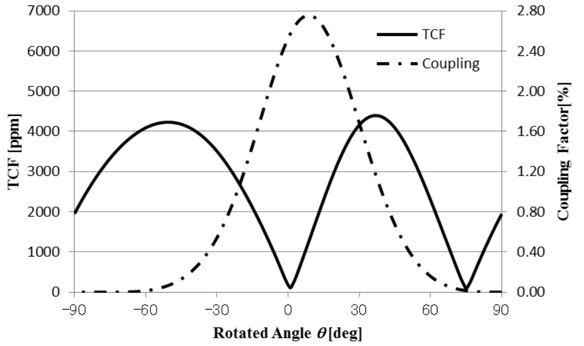

Fig. 1 TCF and coupling factor of LGS.

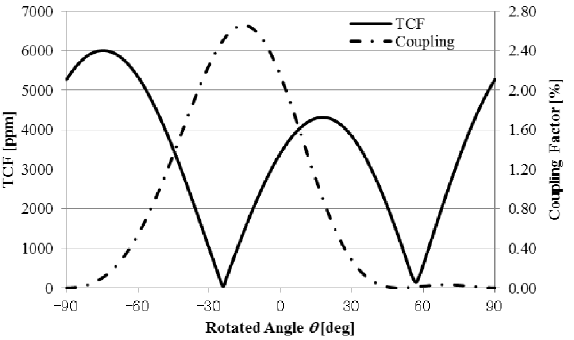

Fig. 2 TCF and coupling factor of CNGS.

$$TCF = \frac{f - f_o}{f_o} - \alpha \quad , \qquad (1)$$

$$k^2 = \frac{{v_O}^2 - {v_S}^2}{{v_O}^2} \quad , \qquad (2)$$

where f is the resonant frequency at each temperature, f_0 is the resonant frequency at the reference temperature, α is the thermal expansion coefficient of the propagation direction, v_O is acoustic wave velocity with the piezoelectric effect, v_S is acoustic wave velocity without the piezoelectric effect. Acoustical physical constants and temperature coefficients of Ohashi et al.[6)] were used in the numerical calculations. The calculation results of the *TCF* and k^2 were shown in Fig. 1 for LGS and in Fig. 2 for CNGS. Rotated angles where *TCF* is smaller and k^2 is larger were located at θ = 0° for LGS and at θ = -24.5° for CNGS. Both of the coupling factors for 0° rotated

Y-cut LGS and -24.5° rotated *Y*-cut CNGS are greater than 0.81% for AT-cut α-quartz.[7)]

3. Experiments and Discussion

According to the numerical calculation results in Figs. 1 and 2, we fabricated piezoelectric resonators using 0°*Y*-cut LGS and -24.5°*Y*-cut CNGS and evaluated these resonance characteristics. External size of the piezoelectric resonator fabricated is 3.2×2.5 mm^2. Typical resonance characteristics of the resonators at room temperature are shown in Fig. 3 for LGS and in Fig. 4 for CNGS. The values of CI were 5.8 Ω at the resonance frequency 21.8 MHz for LGS and 1.3 Ω at 19.3 MHz for CNGS. These CI values are significantly smaller than 20 Ω for the equivalent size of an AT-cut α-quartz resonator. From these results, it was demonstrated that drastic reduction in CI of piezoelectric resonators can be achieved by using langasite family crystals.

Next, the frequency temperature characteristics of the resonators fabricated with the 0°*Y*-cut LGS and -24.5°*Y*-cut CNGS are shown in Fig. 5. *TCF* in a temperature range from -10 to 70°C are 150 ppm for LGS, 60 ppm for CNGS, while that for AT-cut α-quartz is 10 ppm.[8)] We found that the resonator particularly using CNGS can attained extremely small CI as well as the superior *TCF* comparable to that of AT-cut α-quartz. In the temperature characteristics of *TCF*, we could confirm that the experimental results were in excellent agreement with the calculated results using the constants of Ohashi et al.[6)]

4. Conclusion

We demonstrated that langasite family crystals, particularly CNGS, can realize high-performance piezoelectric resonators with very small CI and comparable *TCF* for AT-cut α-quartz resonator in this study.

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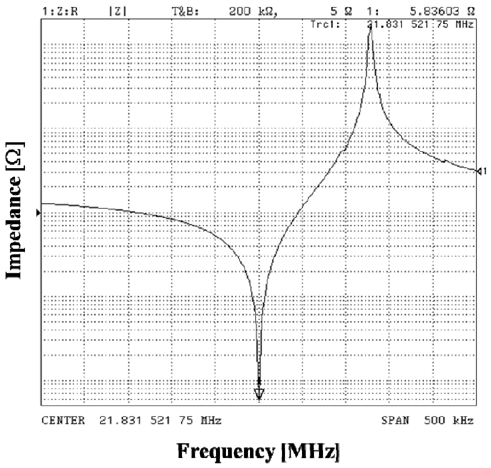

Fig. 3 Resonance characteristics of LGS.

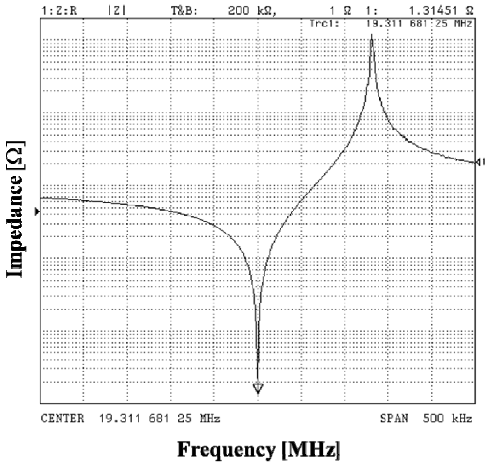

Fig. 4 Resonance characteristics of CNGS.

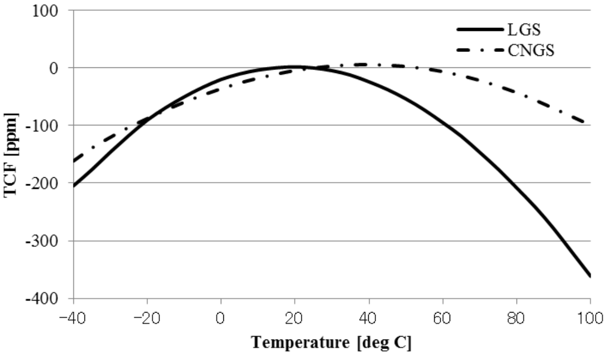

Fig. 5 Temperature characteristics of resonators for LGS and CNGS.