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High Temperature Sensor Using β–Phase Quartz

β相水晶を用いた高温センサー

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1. Introduction

The Quartz has been widely used for resonators and filters because of its excellent elctromechanical characteristics. Quartz has a transition temperature at 573 ºC. The electromechanical characteristics of quartz have been well investigated for α–phase (below 573 ºC), however the characteristics in β–phase have not been clarified.

We investigated the piezoelectric properties of β–phase quartz plates from about 600 ºC up to 900 ºC. Clear piezoelectric resonances wth high quality factors were observed[1,2]. By using the large frequency temperature coefficient, β–phase quartz may be applicable to temperature sensors in high temperature region above 600 ºC. We proposed also an semi-wireless configuration using the β–phase quartz temperature sensor.

2. Properties of β–phase quartz

The α–phase quartz belongs to point group class 32, however β–phase quartz is higher symmetric of class 622.
The piezoelectric e constant tensor of point group class 622 is represented by

$$\begin{pmatrix} 0 & 0 & 0 & e_{14} & 0 & 0 \\ 0 & 0 & 0 & 0 & -e_{14} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \quad (1).$$

In this case, it's impossible to obtain thickness vibration by perpendicular field excitation with applied electric field parallel to the crystal axis, X, Y or Z. Therefore, rotated Y–cut plates were used for the experimental samples. The piezoelectric e constant tensor for the θ–rotated Y–cut coordinate is given by

$$\begin{pmatrix} 0 & e'_{12} & e'_{13} & e'_{14} & 0 & 0 \\ 0 & 0 & 0 & 0 & e'_{25} & e'_{26} \\ 0 & 0 & 0 & 0 & e'_{35} & e'_{36} \end{pmatrix} \quad (1').$$

In a rotated Y–cut plates, piezoelectric vibration is excited through e'_{26}, which can be written by using the component e_{14}

$$e'_{26} = -e_{14} \sin\theta\cos\theta \quad (2).$$

Elastic stiffness and permittivity also concern the piezoelectric excitation of vibration. Elastic stiffness tensor is represented by

$$c'_{66} = c_{66}\cos^2\theta + c_{55}\sin^2\theta \quad (3),$$

and permittivity is given by

$$\varepsilon'_{22} = \varepsilon_{11}\cos^2\theta + \varepsilon_{33}\sin^2\theta \quad (4).$$

From equations (2)-(4), electromechanical coupling constant k_t is represented by

$$k_t = \sqrt{\frac{e'^2_{26}}{\varepsilon'_{22}c'_{66}}} \quad (5).$$

Resonance frequency is given by

$$f_r = \frac{1}{H}\sqrt{\frac{c'_{66}}{\rho}} \quad (6),$$

where H is the plate thickness and ρ is the density.

Figure 1 shows frequency temperature characteristics for AT-cut and BT-cut plates above 600 ˚C. Large positive temperature coefficients were observed. This suggests that the β-phase quartz is suitable for precise high temperature sensor.

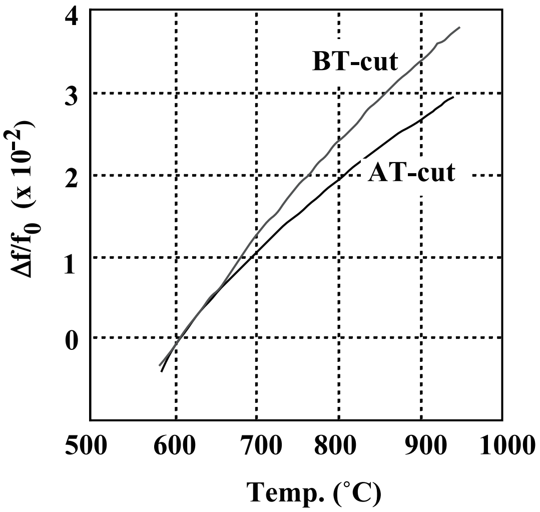

Fig. 1 Frequency temperature characteristics.

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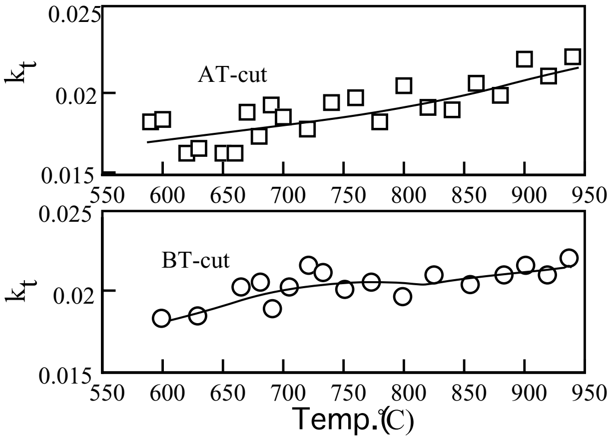

Fig. 2 Temperature dependence of k_t.

Figure 2 shows the temperature dependence of coupling factor k_t. The factor also increased with temperature.

3. The *β*–phase quartz temperature sensor

Because of the high TCF, the *β*–phase quartz resonator is suitable for precise temperature sensor above 600 ˚C. In some applications, it is desired to use with wireless. We investigated the possibility of wireless sensor by *β*–phase quartz. **Figure 3** shows the experimental system. In the experiment, the resonator was placed in a vacuum chamber of an oven as shown in **Figure 4**. **Figure 5** shows the experimental result. The frequency response decreases with the spacing of the metal plates.

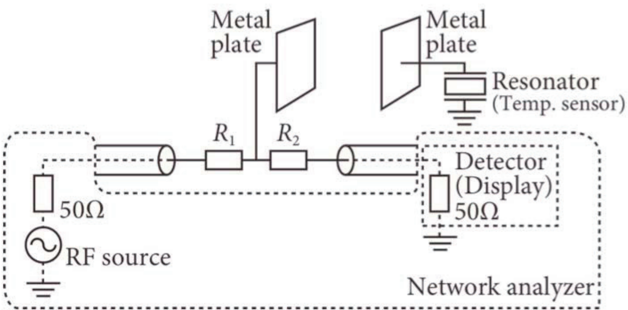

Fig. 3 Experimental system for wireless sensor.

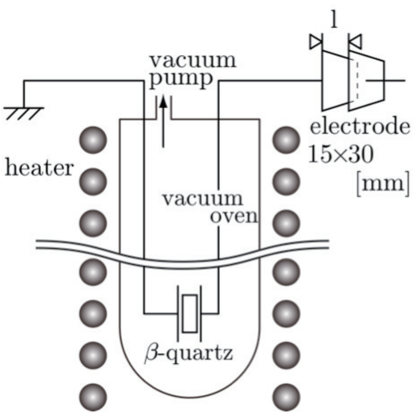

Fig. 4 Experimental system (2).

However, resonance was detected spacing less than about 20 mm.

Figure 6 shows an configuration of the *β*-phase quartz temperature sensor for crystalline process in contact epitaxial method[3].

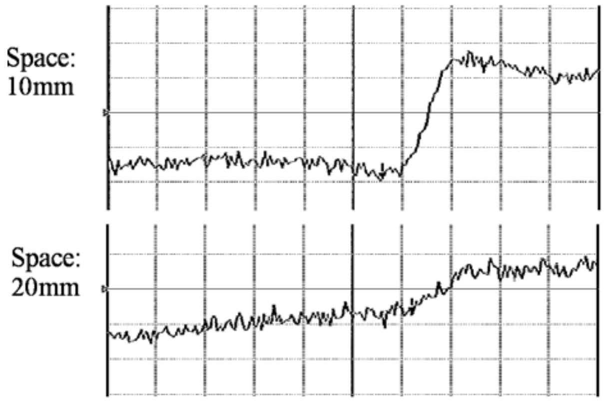

Fig. 5 Detected resonance signal.

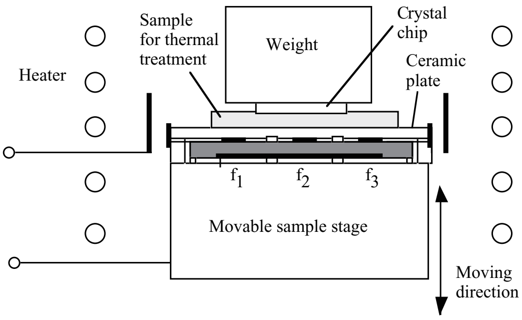

Fig. 6 Application to the temperature distribution measurement of contact epitaxial process.

4. Conclusion

We investigated the piezoelectric resonance of *β*-phase quartz from 580 ˚C up to 900 ˚C. The resonance frequencies increased with temperature for rotated *Y*-cut quartz plates such as AT-cut and BT-cut plates. Because of the large TCF, *β*-phase quartz is applicable to precision temperature sensor. We proposed a semi-wireless configuration of the sensor for application to thermal treatment process.

Acknowledgment

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