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Cut Angle Dependencies of Resonant Characteristic of β-Phase Quartz

β相水晶における共振特性の切断方位依存性

Seiji Mutoh and Takehiko Uno (Faculty Eng., Kanagawa Inst. of Tech.)
武藤 星児　宇野 武彦 (神奈川工科大 工）

1. Introduction

The Quartz has been widely used for resonators and filters because of its excellent elctromechanical characteristics. Quartz has the transition temperature at 573ºC. 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.

Some authors reported piezoelectric resonance of β-phase quartz below 1,000˚C(1,2). We investigated the piezoelectric resonance characteristics above 1,000˚C. Clear piezoelectric resonances were observed from the phase transition temperaature(573˚C) to 1,300˚C. From the symmetricity of β-phase quartz, the maximum electro-mechanical coupling constnt is obtainable for rotated Y-cut plates around 45˚. In high temperature region above 1,000˚C, the dielectric loss affects to the resonance characteristics especially to the *Q* factor. Because the dielectric loss of ε_{33} is much larger than tha of the ε_{11}, *Q* factor depends on the cut angle of the plate above 1,000˚C. In this paper, we investigate the cut angle dependence of the resonance characteristics of the β-phase quartz from the viewpoints of frequency temperature characteristics, electromechanical coupling constants and Q factors.

2. Properties of *β*–phase quartz

The β-phase quartz belongs to point-group 622 and only one piezoelectric constant element, e_{14}(=-e_{25}), exists. Thickness shear vibration can be excited for rotated Y-cut plates by the constant e'_{26} given by

$$e'_{26} = -e_{14}\sin\theta\cos\theta \quad (1)$$

Resonance frequency is given by

$$f_r = \frac{1}{H}\sqrt{\frac{c'_{66}}{\rho}} \quad (2).$$

Here, *H* is the plate thickness, *ρ* is the density and c'_{66} is gigen by

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

The electromechanical coupling constant k_t is given by

$$k_t = \sqrt{\frac{e'^{2}_{26}}{\varepsilon'_{22}c'_{66}}}, \quad (4)$$

and dielectric permittivity is given by

$$\varepsilon'_{22} = \varepsilon_{11}\cos^2\theta + \varepsilon_{33}\sin^2\theta \quad (5).$$

From Eq.(1), the maximum piezoelectricity may be obtained for 45˚RY-cut. However, from Eq.(4), maximum electromechanical coupling is obtained slightly different angle from 45˚. As the coupling constant does not depends on the cut angle so sharp, fairly large coupling can be obtained from 30 to 50˚ RY-cut plates.

In Refs.(1) and (3), it is noted that transition to tridymite occurs at around 850˚C and piezoelectricity disappears. However, we observed piezoelectric resonance above 850˚C up to 1,300˚C as shown in **Fig. 1**.

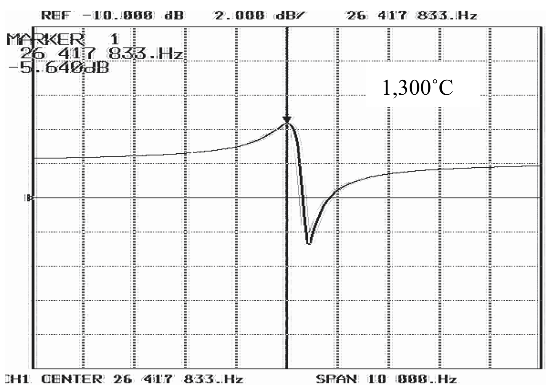

Fig. 1 Piezoelectric resonance of an AT-cut plate at 1,300˚C.

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tk_u-no@ele.kanagawa-it.ac.jp

Figure 2 shows elastic stiffness c_{44} and c_{66} obtained from the frequency temperature characteristics for two cut angles of 35˚44' and 42˚ rotated Y-cut plates.

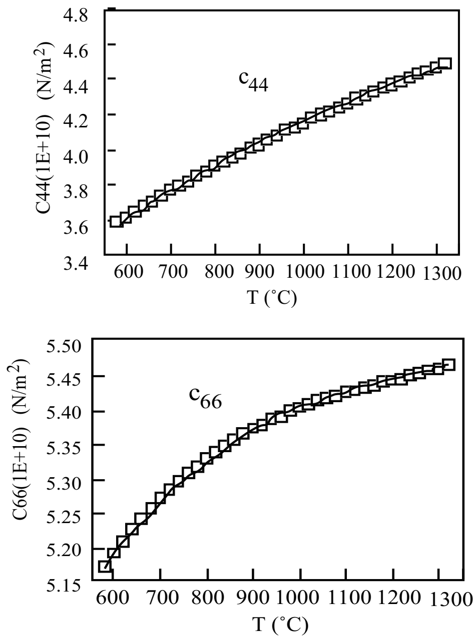

Fig. 2 Elastic stiffness c_{44} and c_{66}.

The values of c_{44} and c_{66} are written as

$$c_{44} = 3.618 \times 10^{10}\left\{1 + \alpha_1 \Delta T + \alpha_2 (\Delta T)^2 + \alpha_3 (\Delta T)^3\right\} \text{[N/m}^2\text{]} \tag{6}$$

$\alpha_1 = 428.1$ [ppm/K], $\alpha_2 = -0.1647$ [ppm/K^2], $\alpha_3 \approx 0$

$$c_{66} = 5.192 \times 10^{10}\left\{1 + \alpha_1 \Delta T + \alpha_2 (\Delta T)^2 + \alpha_3 (\Delta T)^3\right\} \text{[N/m}^2\text{]} \tag{7}$$

$\alpha_1 = 175.3$ [ppm/K], $\alpha_2 = -0.2328$ [ppm/K^2]

, $\alpha_3 = 0.00127$ [ppm/K^3]

From Eqs.(6) and (7), temperature dependence of the resonance for arbitrary cut angle can be estimated. Because of the large positive temperature coefficients of c_{44} and c_{66}, resonators with low temperature coefficient cannot be realized. However, the β−phase quartz is suitable for precise temperature sensors for 600–1,300˚C.

In high temperature region especially above 1,000˚C, temperature characteristics of the dielectric properties affect to the resonance characteristics.

Figures 3 and 4 shows the dielectric permittivity and conductivity, where the parameters are the cut angle. The dielectric permittivity does not so much affects to resonance characteristics, conductivity affects to the Q factor given by

$$Q \approx 1/k_t^2 \tan\delta. \tag{8}$$

Here, k_t is the electromechanical coupling constant given by Eq.(4).

For example, the Q values for 10 MHz at 1,200˚C are, 5,500 for 30˚RY and 2,300 for 45˚RY, respectively.

From above considerations, 30–35˚RY-cut plates may be more suitable for high temperature operation above 1,000˚C. On the other hand, the dielectric loss is negligible below 1,000˚C and cut angle between 30 to 50˚ rotated Y is suitable for the resonators.

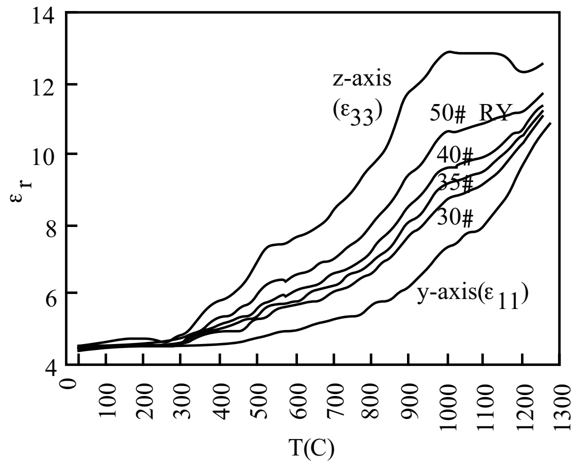

Fig. 3 Relative dielectric permittivity.

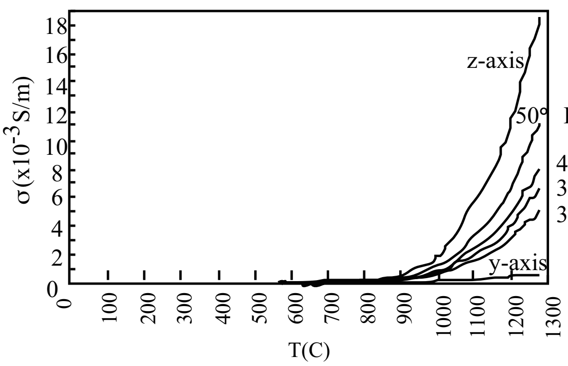

Fig. 4 Conductivity.

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