PROPERTIES OF MINIATURE X- AND Z'-ELONGATED RECTANGULAR AT-CUT QUARTZ RESONATORS OF DIFFERENT SIZES

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In this study, we present the different properties of beveling process, equivalent series resistance (ESR), temperature curves, temperature hysteresis, and shock resistance of different sizes of X- and Z'-elongated rectangular AT-cut quartz plates. The results show the Z'-elongated quartz strip mounted on the two width sides has better performance in temperature hysteresis and shock resistance. And for mode coupling, beveling process, and temperature curve, X- and Z'-elongated rectangular AT-cut quartz plate have their respective properties.

Keywords: AT-Cut Resonator, Quartz Crystal Plate, Aspect Ratio

1. INTRODUCTION

Rectangular AT-cut quartz resonators were first developed in the early 70s for their small size and ease of manufacture. Many studies were performed on the resonant properties of different aspect ratio of the rectangular plate. Based on the studies, one can deduce the following. When the length of the rectangular plate is along the X direction and the width to thickness ratio is small (i.e. DT-cut), the coupling between the thickness-shear (TS) mode and the face-shear mode is strong [1][2]. On the other hand, as the length of the rectangular plate is along the Z' direction and the plate is mounted on the two width sides, the TS mode is coupled more strongly with the flexure mode [3][4]. The studies, though provided valuable information for designers, are considered dated as today's quartz crystal resonators are of much smaller sizes. For example, nowadays a typical 3225 (3.2mm by 2.5mm) 9.8 MHz packaged quartz crystal still has the blank thickness of about 0.17mm but the blank size is only 2.1mm by 1.5mm. The length-to-thickness and the width-to-thickness ratio are both small. The earlier design rules for larger blanks may no longer applicable nowadays.

2. ORIENTATION OF RECTANGULAR AT-CUT QUARTZ CRYSTAL PLATE

Due to the cubic frequency-to-temperature curve of TS mode, AT-cut quartz crystals are highly temperature stable and widely employed in crystal resonator applications.

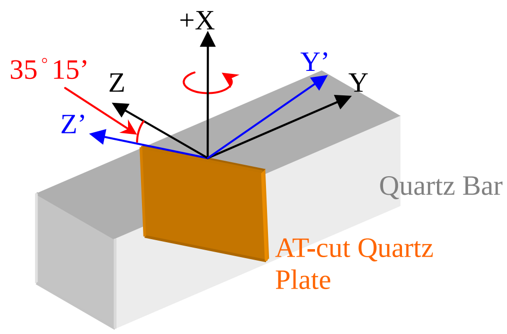

Figure 1. Global coordinate of a quartz bar and the local AT-cut plate coordinate

As shown in figure 1, a virtual slice (the plate) is aligned with respect to the global crystal axes, +X, Y, and Z initially, and the plate is defined as having the normal in Y direction. Then, for AT-cut, the plate is rotated around 35°15' counterclockwise about the +X axis, and the Y and Z axes move with the plate as Y' and Z' axes, which the Y' is the new normal direction.

For miniaturization, the packaging type of quartz resonators were changed from DIP (dual-in-plane) to SMD (surface mount device), and the quartz crystal chips were changed from round to strip. Different length to width ratios, i.e. X- and Z'-elongated shown in figure 2, cause different mode couple, energy trapping, and stress-frequency characteristics.

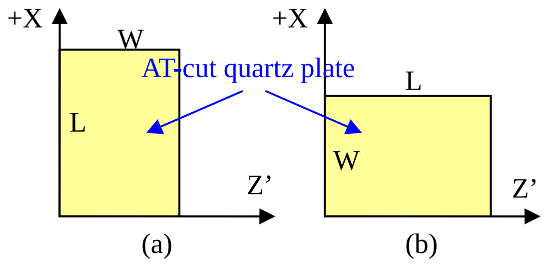

Figure 2. (a) X-elongated and (b) Z'-elongated rectangular AT-cut quartz plates

3. PROPERTIES OF X- AND Z'-ELONGATED RECTANGULAR AT-CUT QUARTZ CHIP

In this section, the beveling frequency shift, ESR, frequency-to-temperature curve, temperature hysteresis, and shock resistance of X- and Z'-elongated rectangular AT-cut quartz plates are presented.

3.1. Beveling Frequency Shift

Beveling is a process to shape the central zone of the quartz strip thicker to trap the vibration energy and minimize the mounting loss. As the beveling process progresses, the margin of the crystal plate becomes thinner, and the TS mode frequency becomes higher and higher. However, the TS mode frequency increasing rates due to beveling are different for X- and Z'- elongated plate as single crystal quartz is anisotropic material and the stiffness constants are different in the X and Z' directions.

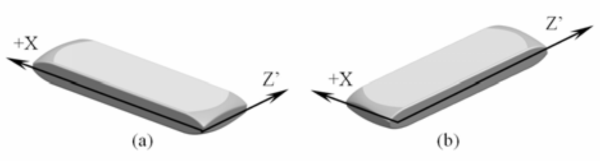

Figure 3. (a) X-elongated and (b) Z'-elongated contour rectangular AT-cut quartz crystal plates

Figure 4 shows a 12MHz resonator example. The thickness of these two quartz crystal plate before beveling are both 0.173mm, but the dimensions are 1.803mm(X)×1.230mm(Z')(X-elongated) and 1.230mm(X)×1.803mm(Z')(Z'-elongated). In this case, the Z'-elongated one has faster TS mode frequency increasing rate during beveling process.

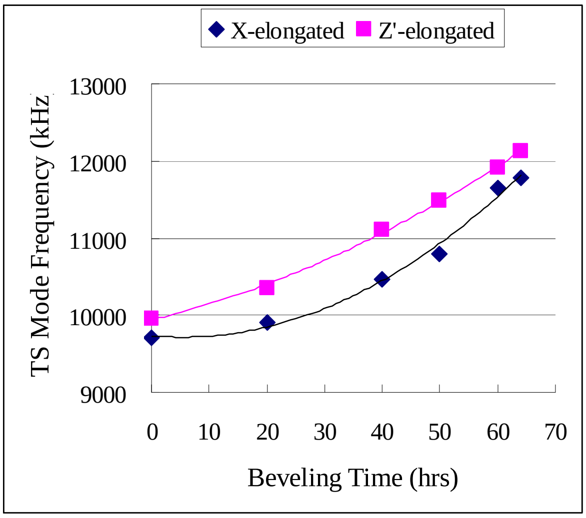

Figure 4. TS mode frequency increasing rate of X- and Z'-elongated crystal plates during beveling

3.2. Frequency-to-Temperature Curve

Both AT- and DT-cut are shear mode in the same crystallographic plane, as shown in figure 5, but the major difference is in the frequency-to-temperature behavior. The normal of AT-cut plate is Y' axis, and the motion is thickness shear; however, the normal of DT-cut plate is Z' axis, and the motion is face shear. Due to the change of Z' dimension of the crystal plate, AT-cut TS mode will couple with DT-cut face shear mode periodically and the frequency-to-temperature will be influenced.

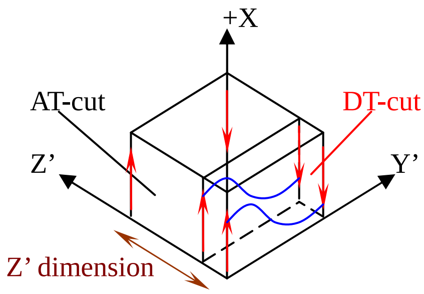

Figure 5. Illustration of AT-cut TS mode and DT-cut face shear mode

Figure 6 shows the frequency-to-temperature curves of two resonator groups with the same thickness and cutting-angle but different length-to-width aspect ratios. The thickness and cutting-angle of both groups are 0.045mm and 35.23°, respectively. But the crystal plate dimensions are 3.5mm(X)×1.785mm(Z')(X-elongated) and 1.785mm(X)×3.5mm(Z')(Z'-elongated). These two groups have different slops of temperature curves, even the cutting-angles are the same.

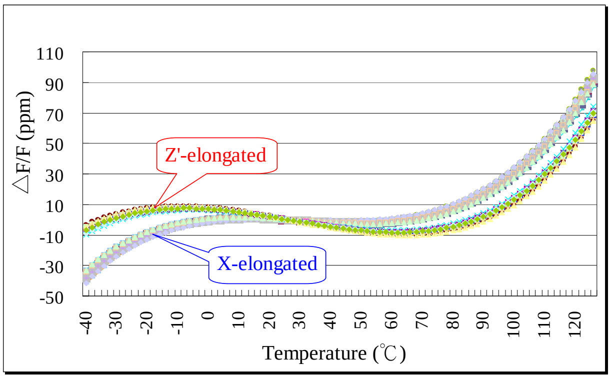

Figure 6. The temperature curves of two resonator groups with same cutting-angle but different length-to-width aspect ratios

3.3. Equivalent Series Resistance

Following the last section, figure 7 shows the ESR (at 25℃) of the two groups in section 3.2. The electrode area is 1.42mm×0.72mm for both Z'- and X-elongated groups; however, the ESR of Z'-elongated resonators is much smaller than that of X-elongated ones. The main causes of the ESR difference are AT- and DT-cut mode coupling and the different distributions of X-direction displacement field along X and Z' axes.

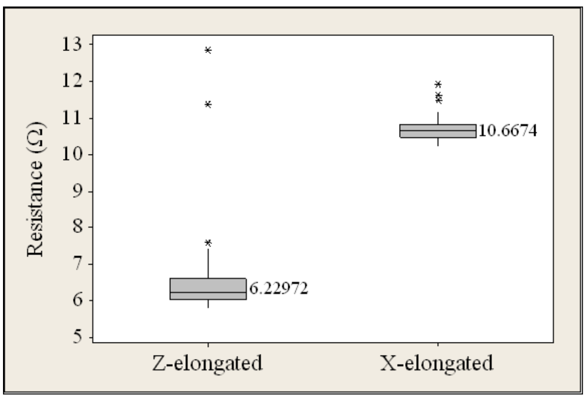

Figure 7. The ESR of Z'- and X-elongated resonator groups with same electrode area

3.4. Temperature Hysteresis

As crystal resonators were went through a thermo cycle, from room temperature (25℃) to high temperature (e.g. 120℃), then to low temperature (e.g. -40℃), and then back to room temperature (25℃), the frequency at 25℃ will likely shift. The frequency shift due to the thermo cycle is temperature hysteresis. It is not apparent in X-elongated crystal plate which is mounted on two width side corners only; however, the temperature hysteresis is much serious as the four corners of the crystal plate are fixed by mounting glue, as shown in figure 8.

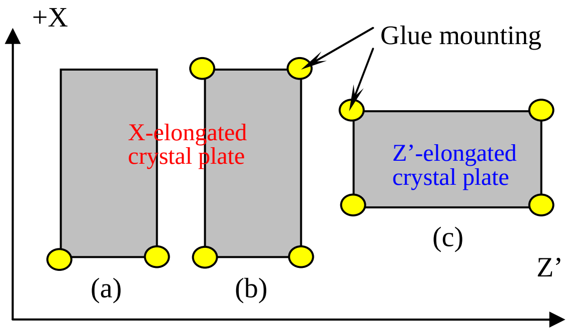

Figure 8. (a) Two corners mounted X-elongated crystal plate

(b) Four corners mounted X-elongated crystal plate

(c) Four corners mounted Z'-elongated crystal plate

Figure 9 shows the temperature hysteresis of two resonator groups which are both 0.051mm thick and four corners mounted. The electrode areas are both 1.8mm×1.2mm, but the crystal plate dimensions are 4.4mm(X)×1.55mm(Z')(X-elongated) and 1.55mm(X)× 4.4mm(Z') (Z'-elongated). It shows the frequency stability of Z'-elongated crystal strip is better than that of X-elongated ones undergoing thermo cycle.

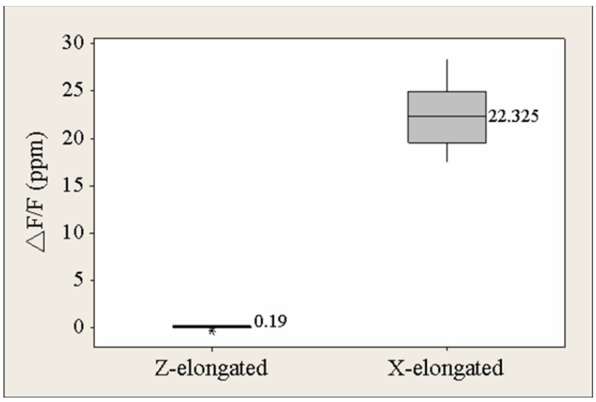

Figure 9. The temperature hysteresis of Z'- and X-elongated resonator groups

3.5. Shock Resistance

Drop test is a method to evaluate the anti-shock ability of resonators. The condition of the drop in this study is free drop, 150cm height, onto concrete ground, and 5 times. The frequency and ESR are measured before and after the test; and the shift of these two properties is an index of shock resistance. Figure 10 and 11 are the frequency and ESR shift of the Z'- and X-elongated resonators due to drop test. Both these two groups are 0.116mm thick, and four corner mounted, but with 3.5mm(X)× 1.82mm(Z')(X-elongated) and 1.82mm(X)×3.5mm(Z') (Z'-elongated) dimension. These two figures shows that the frequency and ESR shift of Z'-elongated crystal resonators are small; that means Z'-elongated plate has better shock resistance, since the coupled flexure vibration is propagated along X-direction and the force-frequency coefficients are not equal in X- and Z'-direction[5].

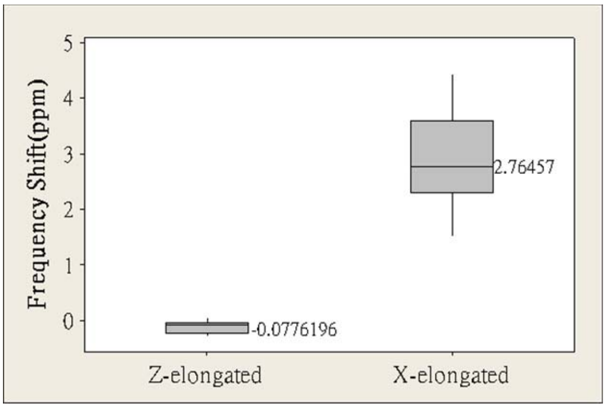

Figure 10. The frequency shift of Z'- and X-elongated resonator groups due to drop test

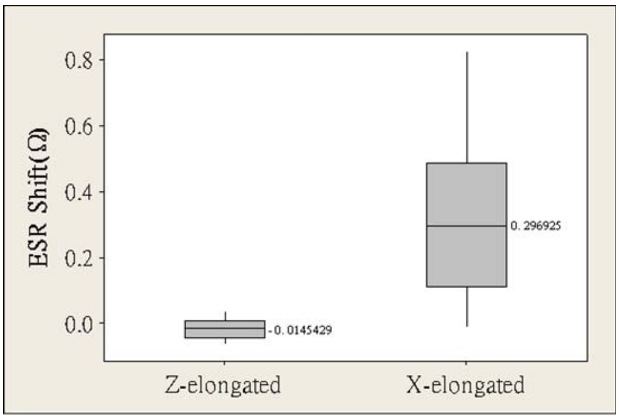

Figure 11. The ESR shift of Z'- and X-elongated resonator groups due to drop test

4. CONCLUSION

In this paper, a series of experiments were performed to study the properties, beveling frequency shift, ESR, frequency- to-temperature curves, temperature hysteresis, and shock resistance of X- and Z'-elongated AT-cut quartz crystal resonators. The results show that the Z'-elongated quartz strip has better performance in temperature hysteresis, ESR, and shock resistance. On the other hand, for beveling frequency shift and frequency-to-temperature curve, X- and Z'-elongated rectangular AT-cut quartz plate have their own properties respectively.

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