NEW APPROACHES OF BEVEL SHAPE GENERATION FOR QUARTZ CRYSTAL

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INTRODUCTION
A crystal of quartz, which is properly cut and polished, is used for wristwatches, clocks, radios, TVs, computers, cell phones and digital cameras as the oscillators, the electric filters or the optical filters. More than two billion crystals are manufactured annually.
The shape of the crystal of quartz has so called bevel shape. That means edges or corners of the device are a few micrometers thinner than center region of that as Figure 1. The bevel shape is effective to reduce spurious and its temperature dependent. The spurious may appear some tens of kilohertz above the wanted series resonance.
The bevel shape has been attained by the barrel polishing technique which is needed long time (more than 200 hours) and result low yielding rate.
The size of the device is continuing smaller. The latest one is a size of less than a millimeter even along long sides of a rectangle. It becomes very hard to manufacture the bevel shape of a small quartz device by the barrel polishing because the weight of device is too light to rotate effectively in the barrel.
We tried new approaches to realize the bevel shape. One is chemical etching technology and the other is spherical lapping technology.

CHEMICAL ETCHING TECHNOLOGY
In chemical etching technology we have investigated about chemical solution, etching conditions, mask materials and masking process.

Chemical Solution and Etching Conditions
We investigated both hydrofluoric acid and ammonium fluoride as the chemical solution of the process with changing working temperature. We conclude that the hydrofluoric acid is better than the ammonium fluoride as etching rate of the latter was too small to apply it to the process.

Mask Materials and Masking Process
Commercially available photo resist material for the silicon process was used as the mask material in the hydrofluoric acid etching. As bonding strength of the photo resist to the quartz surface is weaker than to the silicon wafer, the mask was easily peeled off or got crinkled even within five minutes.
We have developed several improvements on the masking process, for example, surface treatment on the quartz surface prior to spin coating of photo resists or repetition of the spin coating to get thick resist. Finally we could have 0.1 micrometer height difference derived by etching of 20 minutes.

FIGURE 2. Bevel shape formation by chemical etching

FIGURE 3. Simulation model for revealing the etching amount for the bevel shape
In order to assess the 0.1 micrometer height, we conducted the numerical simulation. The simulator was commercially available one and the size of the model was a practical one (1.4 x 1.0 x 0.03-0.04 mm; Figure 3.) with changing the bevel amount 0, 0.1, 1 micrometer respectively. It is cleared in Figure 4 that the simulation result of the 0.1 micrometer step height is much closer to the result of 1 micrometer height.

![Figure 4. Simulation results (temperature dependent). The result of 0.1- micrometer deviation is very similar to that of 1- micrometer deviation.](image)

**SPHERICAL LAPPING TECHNOLOGY**

We have also tried to apply spherical lapping technology for reducing sides of a specimen. In the spherical lapping technology, both the Oscar type lapping (Figure 5) and the conditioning ring type lapping (Figure 6) have tried.

![Figure 5. Oscar-type process for spherical form generation](image)

![Figure 6. Conditioning ring type process for spherical form generation](image)

In both technologies, combination of concave tool and convex jig (specimens holder) is used. After the specimens are glued on the surface of the jig, supply of the slurry and relative motion between the tool and the jig generate bevel shape on the edges of those within a few hours. If you put a lot of specimens on the jig, you can get bevel shaped specimens as much. The yielding rate is expected too much higher than that in the barrel polishing.

One of the differences between the two processes is the relative motion. In the Oscar type, they are rotation and linear reciprocating. In the conditioning ring type process, there are only rotations. The other difference is the size of the tool. The tool for the Oscar type is almost as large as that of the jig. The tool for the conditioning ring type is much smaller than the jig (Figure 6).

**Lapping Conditions**

We have revealed the influences of the process conditions to manufacturing process. Examined parameters are listed below.

1a. Rotation or reciprocating speed
1b. Range of reciprocation
1c. Slurry concentration
1d. Lapping pressure
1e. Figure accuracy of tool or jig
We have revealed that the yielding rate of the process really depends on the shape accuracy of the tool or the jig.

**Bonding Conditions**
One of the key technologies of these processes is bonding specimens to the tool. The bonding process consists of bonding agent supply, pre-heating, pressurization and keeping (with pressure). Examined parameters during our bonding trials are listed below.
2a. Consumption of bonding agent (for each specimen)
2b. Processing temperature
2c. Bonding pressure
2d. Duration of keeping
In order to arrange all the specimens normal to the surface of the jigs (specimen holders), we developed a smoother to be used during the bonding process (Figure 7).

![FIGURE 7. Arrangement of a smoother used during the bonding process](image)

**Effect of Elastic Deformation**
The specimens for this study are very thin up to around 30 micrometers. The elastic deformations during the whole process are not negligible. The transition is thought to be listed below.
The surface of the specimen before the bevel generation process is flat as in Figure 8. After the bonding process the surface of the specimen has some curvature which is a little bit larger than the curvature of the tool. The 'a' indicates the deviation from the ideal flat surface at the end of the specimen.
After the lapping/polishing process the curvature of the specimen usually changes to the curvature of the tool. The 'b' also indicates the deviation from the ideal flat surface at the end of the specimen.
When the specimen is removed from the jig (specimen holder) by, for example, heating, the deformation changes like the spring back in the
plastic deformation process. The ‘c’ also indicates the deviation from the ideal flat surface at the end of the specimen.

**Experimental results**

Figure 9. shows experimental results of these deformations. The ‘a’ to ‘c’ indicate same symbols as in Figure 8.

**Discussions**

The issue here is how the relation between these three kinds of deformation is.

Figure 10 shows the relation between the ‘a’ and the ‘c’ in the various specimens. Figure 10 indicates that the ‘c’, the final shape of the process, strongly depends on the ‘a’, deformation during bonding process. The relation can express a+c=b+3. The ‘b’ is very constant because it is almost same as the curvature of the tool.

So we can derive the following thing. If you can reduce the deviation of the deformation during bonding process on the specimens upon the jig, you can get very stable bevel shape. That means that you can expect very high yielding rate on bevel generating process.

**CONCLUSIONS**

0.1 micrometer step for the bevel shape of quartz crystal is enough to reduce spurious and its temperature dependent.

The chemical etching process is applicable to generate the bevel shape.

The spherical lapping technology is also applicable to generate the bevel shape.

The elastic deformation of the specimen during bonding has strong relation to the spring back amount in releasing from the jig after the spherical lapping.

![FIGURE 10. Relation between the three kinds of deformation](image)