An Ultra-Miniature Low-Profile AT Quartz Resonator

Abstract

Presented below are the physical and electrical properties of an ultra-miniature low-profile AT-cut quartz crystal resonator and an overview of its method of production.

I. Introduction

AT-cut quartz crystal resonators have been used in precision frequency control for more than 60 years and are today one of the most widely used types of crystals. While the conventional AT crystal is disc-shaped, the need for smaller components led to the development of the miniature AT-strip. To meet the needs of manufacturers for even smaller components, Statek Corporation has developed an ultra-miniature low-profile quartz crystal as part of its CX-4 family of products. For comparison, the CX-4 requires only about one-third the land area of the CX-1 and about one-half the land area of the CX-3. (See Table 1 and Figure 1.)

A key factor in the production of miniature quartz crystals is the ability to produce resonators with the required dimensional accuracy and precision [1]. As tighter dimensional tolerances are required for smaller resonators (e.g., to maintain proper width-to-length ratios), the production of ultra-miniature resonators such as the CX-4 is all the more difficult. Using the photo-etching process of manufacturing quartz crystals and the wafer backplater, the mass production of the ultra-miniature quartz crystal is made possible. The photo-etching process provides the precision micro-machining and dimensional tolerances required and the wafer backplater provides precise deposition of metal to the resonators' electrodes needed for final frequency adjustment [2].

In Sec. II we outline the photo-etching process used to manufacture a wafer of crystal resonators. In Sec. III we discuss the final frequency adjustment using a wafer backplater. In Sec. IV, we briefly discuss the final assembly of the resonator into its package. Lastly, in Sec. V we give a glimpse of the electrical properties of the finished ultra-miniature quartz crystal resonator.

Table 1: Comparison of Package Sizes

Part Type		Width (mm)	Height (mm)
CX-1	8.00	3.56	1.52
CX-3	6.73	2.62	1.40
CX-4	5.00	1.83	1.10

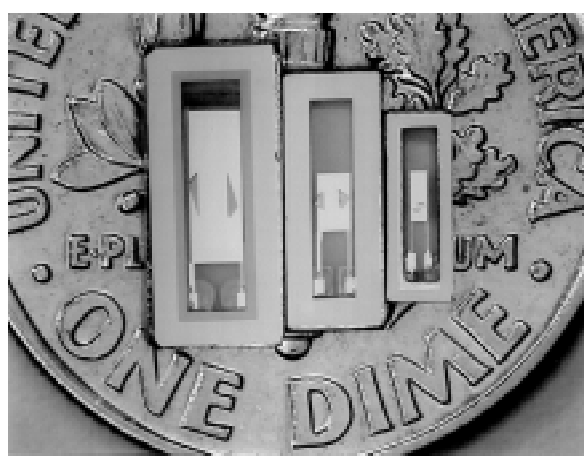

Figure 1: Three AT-strip resonators of three sizes. From left to right: A CX-1 a CX-3, and a CX-4.

STATEK Corporation, 512 N. Main St., Orange, CA 92868 714-639-7810 FAX: 714-997-1256 www.statek.com

II. Fabrication

A typical ultra-miniature AT blank is about 3.50 mm × 0.63 mm. Because of this small size, to obtain an acceptable production yield a tolerance on the order of 2 μm is required. While conventional processing techniques are not capable of meeting this tight tolerance requirement, the photo-etching process is capable of maintaining dimensional tolerances better than 1 μm.

The photo-etching process begins with a polished quartz wafer (1″ × 1″ or larger). These wafers are chemically etched to a predetermined frequency, cleaned, and metalized with a thin film of chrome and gold using an e-beam vacuum deposition system. (Other metals such as aluminum or silver can be used.) The AT-strip pattern is generated photo-lithographically using masks and a double aligner in which the top and bottom surface of the wafer are aligned and exposed simultaneously. The crystal electrodes and probe pad pattern are then defined by a subsequent photo-masking step. The wafers are then chemically metal and quartz etched to form the individual AT-strips. Finally, the top and bottom mounting pads are connected together using aperture masking and thin film metal deposition [2].

Once the photo-etching process is complete, our wafer contains 125 individual ultra-miniature AT-crystal resonators as shown in Fig. 2. Each resonator is physically connected to the wafer by two small quartz tabs that also electrically connect the resonator to probe pads on the wafer. This allows the electrical testing of each resonator while it is still on the wafer.

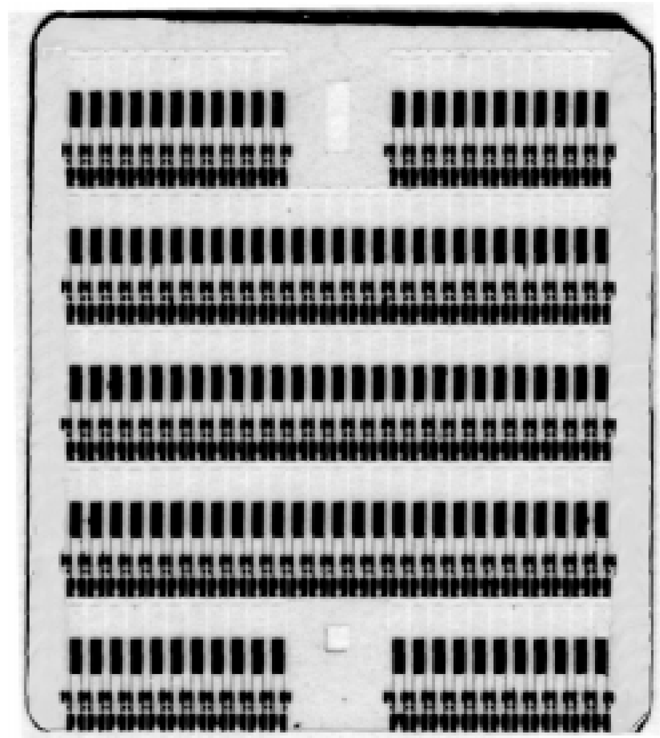

Figure 2: 125 Ultra-miniature AT resonators on a quartz crystal wafer

III. Frequency Adjustment

While the frequencies of the individual resonators on a wafer are fairly close to one another, the variation can be as much as 1%. This variation is attributed to a non-uniformity in the thickness of the wafer (wedging) and, to a lesser extent, a non-uniformity in the thickness of the metalization.

The variation in frequencies of the resonators on the wafer is accounted for in its production so that each resonator now lies above the desired final frequency. Then, using a wafer backplater, a thin film of gold is deposited on the electrode of each resonator to bring their frequency down to this final frequency [1].

The purpose and concept of the wafer backplater is similar to the usual backplating of a quartz-crystal resonator in a package—controlled frequency reduction by deposition of gold. The key difference is that the positioning is much more precise in the wafer backplater system. With the resonator already in the package, the precision to which backplating can be applied to the resonator is limited by the precision to which the resonator can be placed in the package (unless an image recognition system is used). With the resonator still on the wafer, the position of each resonator is fixed and known.

Furthermore, while in both cases gold is deposited on the resonator's electrode through a series of apertures, in the wafer backplater, the aperture that exposes the resonator's electrode to the gold spray is itself a quartz wafer that is fabricated using the same process as the quartz-crystal wafers and using the same mask pattern that is used to generate the crystal wafer. Therefore the dimensions and tolerances of the aperture wafer are that of the crystal wafer and the alignment of the two is better than 25 μm.

As the position of each resonator on the wafer is fixed and known, the wafer backplating system can probe each resonator using the probe pads on the wafer and then automatically backplate each resonator individually.

IV. Assembly

After all the resonators on the wafer are adjusted to the desired frequency, each is removed and mounted in a ceramic package. This operation is performed using semi-automatic assembly equipment that punches out and picks up the crystal from the wafer while, simultaneously, dispensing conductive epoxy on the crystal package. The crystal is then positioned and placed in the crystal package cavity. (See Fig. 3.) This sub-assembled crystal is then hermetically sealed using a matching glass or ceramic cover.

V. Electrical Characteristics

Recall that an isolated mode of a crystal is modeled electrically as a capacitance C_0 in parallel with a series combination of an inductance L_1, a capacitance C_1, and a resistance R_1. Primarily what distinguishes an ultra-miniature AT crystal from its larger brethren is a larger series resistance R_1 and a smaller series capacitance C_1 (both due to the smaller area of the electrode [3]). In Table 2 we give the electrical parameters for three CX-4 AT crystals of three different frequencies. Using these values the values for their larger CX-1 counterpart (not given here), we find that R_1 is roughly two to three times the resistance of its larger CX-1 counterpart while C_1 is roughly one-half to one-third the value of the CX-1.

Table 2: Electrical Parameters of Some Ultra-Miniature AT-Cut Crystals

Frequency	C_0 (pF)	C_1 (fF)	L_1 (mH)	R_1 (Ω)
16 MHz	0.7	1.0	100	70
40 MHz	1.0	2.6	6.0	35
67 MHz	2.0	4.3	1.1	35

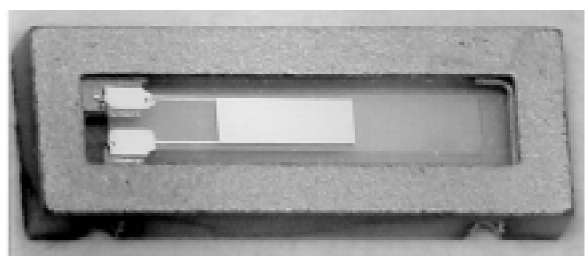

Figure 3: Ultra-miniature AT crystal resonator in CX-4 package (before seal).

That such small crystals can be well behaved electrically in the sense that their fundamental mode is well separated from other modes can seen in the impedance scan of an ultra-miniature crystal in Fig. 4. In a frequency band roughly 5% of the crystal's fundamental frequency only a single anharmonic mode is visible. This mode's resistance is sufficiently high and it is sufficiently far from the main mode (in frequency) that its effect is negligible.

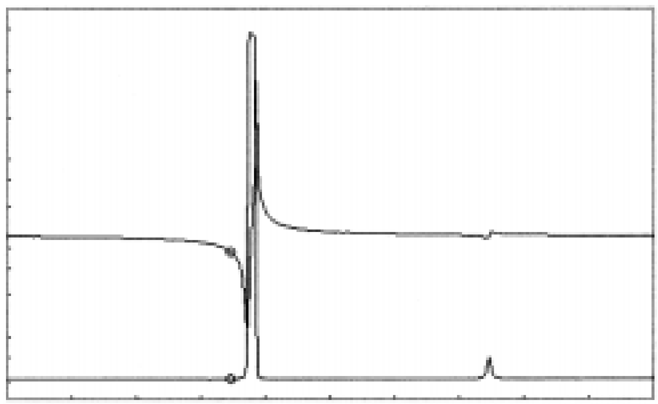

Figure 4: Impedance as a function of frequency for a (roughly) 16 MHz CX-4 (obtained using an HP 4194A). Note the lack of any significant anharmonic modes in this particular design.

References

[1] S. Chuang and P. N. Le, "AT Strip Resonator Manufactured by Using Photo-Etching Process," 14th Piezoelectric Device Conference and Exhibition, 1992, Vol II, pp. 1-4.

[2] Jim Varsovia and S. S. Chuang, "Wafer Backplating of Sub-Miniature AT quartz resonators," 17th Piezoelectric Device Conference and Exhibition, 1995, Vol I, pp. 40-44.

[3] Virgil E. Bottom, The Theory and Design of Quartz Crystal Units, McMurry Press, 1968.

A version of this Technical Note was presented at the 19th Piezoelectric Devices Conference and Exhibition, Kansas City, Missouri, August 20-22, 1997.