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AGING PERFORMANCE IN CRYSTALS

Introduction

Aging is the change in crystal frequency over time. This frequency change over the life of the part has to be accounted for in the application. Understanding the causes of aging, and the methods used to measure it, enables a method of predicting the rate over the life (10 to 20 years) of the device.

Cause of aging

There are two main causes for aging, mass transfer and stress.

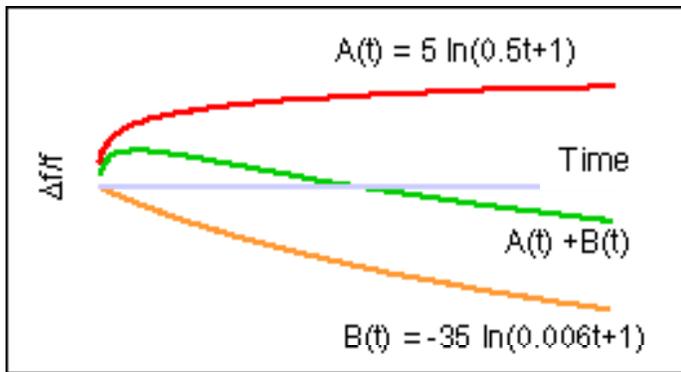


Table 1

In table 1:
 A(t) shows stress relief
 B(t) shows contamination effects
 A(t) + B(t) is the combination.

If a design is dominated by stress, the aging curve will approach A(t). Likewise, if the design is dominated by contamination, the aging will approach B(t).

In the real world both mechanisms are present. By looking at the above curves, it is important to point out the logarithmic nature of the curves. Crystals age at a fast rate early in their lives, but tend to settle down with time.

Mass transfer

Quartz crystals change frequency as mass is added or removed from the wafer. Unaccounted for material on the wafer or in the package can deposit or leave the surface of the quartz and change the frequency of the device. In practice, the crystal fabrication process is designed to keep all materials as clean as possible. If contamination equal in mass to 1-½ monolayers of quartz is added or removed from the surface, then the frequency will change 1ppm per megahertz of the device's frequency [2]. It is critical that the crystal process is as clean as possible to achieve good aging performance.

Stress

Quartz crystals will change frequency when stress is applied. This stress can come from any or all of several sources. Package and mounts, epoxy connection, metal films, and the quartz itself can be sources of stress. If the stress is constant over the life of the part, frequency will stay constant. However, in the real world, stresses relax with time hence, stress related aging occurs.

Package and Mounts

Package materials (metal or ceramic) have different coefficients of expansion than quartz. When quartz is cemented to the mounts, it is usually cured at an elevated temperature. When the part is cooled, thermal expansion puts the quartz under stress. Proper mount design can help reduce this.

Epoxy

Conductive epoxy or glue is used to make electrical connection to the package. During cure, the epoxy shrinks and puts stress on the quartz through the joint. Softer epoxies and silicon can be used to reduce this effect. However, the epoxy (due to outgassing) is a significant source of potential contamination.

Quartz

Stress in quartz can come from the growing process of the bars or the machining process of cutting, lapping, and polishing into wafers.

Synthetic quartz is grown in an autoclave from seed material. The quality of the seeds, and the consistency of temperature and pressure during the growing cycle impact the number of defects in the bar. These defects, whether contaminates or dislocations in the lattice structure, can be points of stress.

Quartz is a brittle material. The cutting, grinding, and lapping processes results in small surface cracks coming from the abrasive particles used in the process. These small cracks produce stress in the quartz. Processes using chemical etching can greatly reduce or eliminate this stress in the surface [3].

Measuring Aging

To improve aging performance, or to insure spec compliance, accurate measurements are key. There are several methods that can be used, each allowing for trade offs of time, cost, and accuracy. The true aging of a device can only be measured by placing it in circuit and frequency over the life of the product. This is impractical. So a method to simulate 10 or 20 years of life is necessary to insure aging performance. Accelerated aging at an elevated temperature was developed to accomplish this.

Accelerated Aging

By increasing the temperature above the normal operating temperature, aging in crystals can be accelerated. Military specifications [4] have used 85°C for 30 days and 105°C for 168 hours as an equivalent of one year at 25°C. Other industry standards use 85°C for 1000 hours for first year aging. The accuracy of the test is better for the longer time, lower temperature scenario [6]. Connor-Winfield uses 85°C for 1000 hrs as its standard for qualification.

Passive vs. Active

Now that we have established the time and temperature, the next question is how to collect the data. Two methods are currently used.

The first method is passive aging. Parts are serialized and measured at room temp in the measurement system before and after the bake. This is the lowest cost option but it sacrifices accuracy. Passive age can screen fliers and act as a process control, which alerts the manufacturer to problems.

The second method is active aging. This is performed by placing each crystal unit in an oscillator circuit so that frequency measurements can be made while the part is in the bake oven. Measurements can be made several times a day so that a data curve can be made for each unit. This curve can be mathematically fit and then projected out over time allowing for a long-term prediction [7]. Active aging methods result in better accuracy but at a higher cost.

Another benefit of active aging is the effects of driving the crystal. Actively vibrating the crystal during the test is truer to real world conditions. Passive aging does not drive the crystal during the test.

[1] John Vig, "Quartz Crystal Resonators and Oscillators For Frequency Control and Timing Applications, A Tutorial", July 2001

[2] John Vig, "Resonator Aging", *Ultrasonic Symposium Proceedings*, pg. 848, 1977

[3] R N Castellano, TR Meeker, RC Sundahl, "The Relation Between Quartz Surface Morphology and the Q of High Frequency Resonators" *Frequency Control Symposium*, 1977

[4] MIL-PRF-3098

[5] JR Gerhke, R Klawitter, "Experimental Results on Aging of AT-Cut Strip Resonators", *42nd Frequency Control Symposium* 1988, pg. 417

[6] M R Miljkovic, G L Trifunovic, V J Brajovic, "Aging Prediction of Quartz Crystal Units" *42nd Frequency Control Symposium* 1988

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