SAWYER

TECHNICAL BRIEF ALPHA MEASUREMENTS IN QUARTZ

Alpha Measurements in Quartz

The mechanical Q (electrical quality factor) of a resonator is a measure of the efficiency of the resonator in converting between mechanical and electrical energy. Resonator Q is dependent upon many factors, including blank geometry, resonator mounting, blank surface finish and drive level of the device.[1] Apart from such device considerations, resonator Q is also dependent upon impurity concentrations within the quartz material itself. This is sometimes referred to as the material Q.[2]

The determination of the material Q by the fabrication of standard resonators is a tedious process. The work of Dodd and Fraser[3] established a correlation between material Q measured with Warner design 5 MHz resonators[4] and infrared absorption measurements. This method was adapted for carbonate process crystals and established as an industry standard by Sawyer Research Products.[5]

The infrared absorption is usually expressed as an extinction coefficient, α, which is determined by the formula

$$\alpha = 1/t \log [T_{base} / T]$$

where t is the sample thickness in centimeters, T_{base} is the percent transmittance at a baseline wavenumber (nominally 3800 cm^{-1}) and T is the percent transmittance at the wavenumber of interest. Several wavenumbers in the OH absorption region have been used for this measurement.[6,7] Correlations have been established between Q and the α-values measured at the three most widely used wavenumbers - 3410, 3500 and 3585 cm^{-1}. The IEC has recognized all three as valid for the measurement of material Q.[8]

At Sawyer,the relationship between α at 3500 cm^{-1} and Q has been established as follows.

$$10^6/Q = 0.114 + 7.47\alpha - 0.45\alpha^2$$

The infrared absorption in quartz is a direct measure of the proton (H^+) impurities in quartz. These protons are bonded to oxygen atoms in the quartz structure and the infrared absorption develops from the stretching of the oxygen-hydrogen bond. Correlations have been established between proton concentrations and infrared Q.[2] Since the relative uptake of protons is dependent upon the growth rate of the crystal, measurement of α at different locations in the crystal gives a measure of the relative growth rate at those sites.

Sawyer has developed the α-graph as our standard method of infrared measurement. The α-graph (see Figure 1) is a measurement of percent transmission and α as a function of position along the major growth direction (Z) of the crystal. This not only depicts the uniformity of the crystal but also gives a measure of the relative growth rate at different points in the growth process itself.

Sawyer presently uses a Fourier transform infrared (FTIR) spectrometer with a custom sample handling and data collection system. The FTIR essentially looks at the entire spectrum (from about 400 to 4000 cm^{-1}) in one pass. In our technique, the entire spectrum is measured at a point, the sample is moved a small amount (0.5 to 1.0 mm) and the measurement is repeated across the entire width of the sample. Computer software is then used to select the wavelengths of interest at each point and this data is plotted versus position on the sample. The α-graph is thus generated.

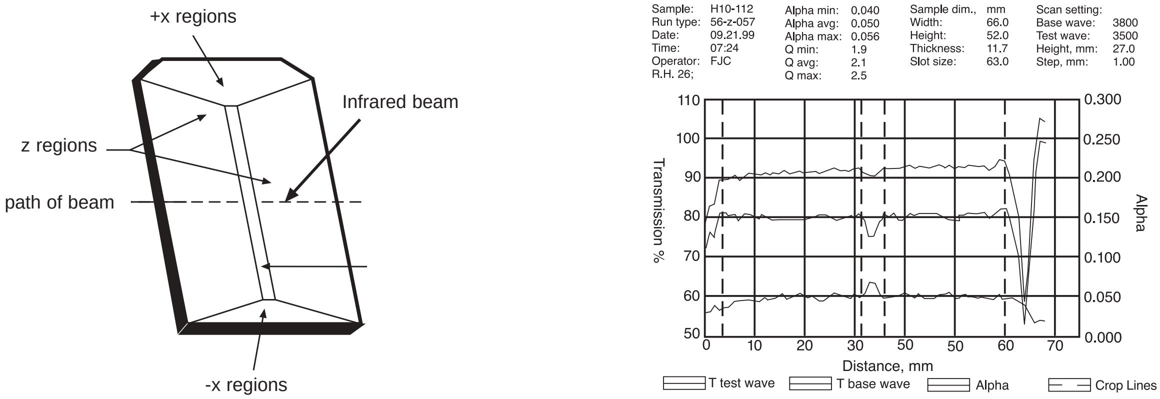

Figure 1. Schematic representation of Sawyer Research α-measurement technique and α-graph.

The IEC has set α rather than Q as the physical measurement used to control and specify quality in cultured quartz crystal. Below is a table showing the α-grades established by the IEC.[9] The corresponding Q-values are listed for continuity purposes.

Our experience with quartz applications over the years indicates that for devices requiring low absorption values (high Q's) or for devices highly dependent upon input crystal Q, it is also desirable to have the absorption uniform throughout the region of the crystal that will be used for the resonator.

Just as a resonator's Q indicates proper design and careful processing, Sawyer uses appropriate process control and infrared absorption monitoring techniques to guarantee the uniformly high quality of our cultured quartz products.

	Limit for Average α			
Grades	α_{3500}	α_{3585}	α_{3410}	Q / 10^6 units
Aa	0.026	0.015	0.075	3.8
A	0.033	0.024	0.082	3.0
B	0.045	0.050	0.100	2.2
C	0.060	0.069	0.114	1.8
D	0.080	0.100	0.145	1.4
E	0.120	0.160	0.190	1.0

References

[1] "Quartz Crystal Resonators and Oscillators for Frequency Control and Timing Applications - A Tutorial", John R. Vig, US Army Electronics Technology and Device Laboratory, SLCET-TR-88-1, 1990.

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[5] "Q Capability Indications from Infrared Absorption Measurements for Na_2CO_3 Process Cultured Quartz", B. Sawyer, IEEE Transactions on Sonics and Ultrasonics, SU-19, 41, 1972.

[6] J. C. Brice and A. M. Cole, 32nd Annual Symposium on Frequency Control, 1978.

[7] "Infrared Absorption in α-Quartz", J. C. Brice and A. M. Cole, Journal of Physics D: Appl. Phys., 12, 459, 1979.

[8] "International Round Robin in Infrared Alpha Measurements on Slices of Synthetic Quartz", B. Sawyer, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 41, 467, 1994.

[9] International Electrotechnical Commission Standard CEI/IEC 758, Second Edition, 1993-04.

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