Appendix: Inficon Quartz Crystal Monitor Resolution

A QCM measures frequency, and converts the frequency change into thickness using the well-known QCM equation. Rate is computed by dividing the thickness change during a measurement period by the length of the measurement period.

The ability of a QCM to resolve frequency is determined by the length of the measurement period and material density. Calculated values for the SQM-242 card are shown below.

Measurement Period	Frequency Resolution	D_m=1 Rate Resolution	D_m=10 Rate Resolution
0.25 sec	0.12 Hz	.59 A/s	.059 A/s
0.50 sec	0.06 Hz	.15 A/s	.015 A/s
1.0 sec	0.03 Hz	.04 A/s	.004 A/s
2.0 sec	0.015 Hz	.01 A/s	.001 A/s

Tooling Factor also effects rate resolution. Using the material of D_m=1 in the table above, the effect of tooling factor is shown below:

Measurement Period	Frequency Resolution	Tooling=50 Rate Resolution	Tooling = 200 Rate Resolution
0.25 sec	0.12 Hz	.295 A/s	.118 A/s
0.50 sec	0.06 Hz	.075 A/s	.030 A/s
1.0 sec	0.03 Hz	.02 A/s	.008 A/s
2.0 sec	0.015 Hz	.005 A/s	.002 A/s

At low rates, these considerations can significantly impact deposition control loop performance. At a measurement period of .5 sec, a density Dm=1, and a tooling factor of 100, the rate resolution of the SQM-242 is .15 A/s. That means that 4 counts of measurement noise will generate a rate variation that is 30% of setpoint at 2 A/s! The control system will try to reach setpoint, but it can never control better than from 1.7 A/s to 2.3 A/s.

Increasing the measurement period to 1 sec, and moving the sensor closer to the source (say Tooling = 25), increases rate resolution to .01 A/s. With the same 4 count measurement noise, a 2 A/s rate can theoretically be controlled between 1.98 A/s and 2.02 A/s.

Other factors can swamp these theoretical considerations:

Output Resolution: The SQM-242 card uses a 15 bit (plus sign) DAC in its source control output circuit. That 300uV resolution is adequate for most deposition systems. However, if a system has high power versus rate gain, a single output voltage step may create large rate changes.

Material Properties: If a material is not uniformly molten or properly wetting the crucible, it can cause large and unpredictable rate variations during deposition. This is especially true at low rates, where the power versus rate curve may be quite non-linear.

Temperature: QCM crystals are optimized for operation at 25ºC. Heating above 50ºC will create a frequency change that is interpreted as rate (usually negative rate). This is a problem mainly in sputtering and high temperature applications.

PID Control Loop: Tuning a PID control loop is more art than science. The main compromise is fast response versus stable control. Thermal systems are relatively stable, moderately slow responding, with a long delay time. Slow (over damped) tuning is usually best. Fast (under damped) tuning can cause unnecessary “searching” for setpoint because of the system’s long time delays. PID tuning is also very dependent on material properties and source/sensor configurations. Each material/configuration may require unique PID values, especially if fast response is desired.

Other considerations:

Density does effect resolution - if the material density REALLY increases. A material with a Density of 10 has ten times the resolution of one with a density of 1. But you can't just jack up the Density number to get more resolution.

Similarly, Tooling improves resolution if the sensor is really moved closer, so that it sees more material per measurement period. But just changing the tooling number does no good.