Parameters used in E-beam deposition system

Basic information

The Edwards FTM7 Film-Thickness Monitor is a microprocessor-based frequency counter. The FTM7 detects frequency changes caused by materials being deposited on the face of the crystal, and uses the change in frequency to calculate the deposition rate and thickness of the material being deposited. The sensor element for the FTM7 is a quartz crystal oscillator. It mechanically vibrates at a frequency of approximately 6 MHz when it is newly installed.

Definition of parameters

Density:
It is the density of the material (given in g cm^{-3}).

Z-value:
It is the acoustic impedance of the deposited material (given in Pa s m^{-1} or 10^5 g cm^{-2} s^{-1}) or the quartz crystal. The acoustic impedance Z is the ratio of sound pressure P to velocity v in a medium. The Z-value of quartz crystal is 8.834×10^5 g cm^{-2} s^{-1}. The acoustic analysis of the film material leads to the following equation:

$$T_\mathrm{f} = \frac{D_\mathrm{q}}{D_\mathrm{f}} N_\mathrm{q}\, T \frac{Z_\mathrm{f}}{\pi Z_\mathrm{q}} \tan^{-1}\left\{ \frac{Z_\mathrm{q}}{Z_\mathrm{f}} \tan\left[\pi \left(1 - \frac{T_\mathrm{q}}{T} \right) \right] \right\} \tag{1}$$

where T_f is the deposited film thickness (cm), D_q and D_f are the density of quartz and deposited film (g cm^{-3}), respectively. N_q is the frequency constant for the quartz crystal oscillating in the thickness mode (Hz cm). T and T_q are oscillation periods of loaded and unloaded crystals, respectively (s). Z_f is the acoustic impedance of the deposited film, and Z_q is the acoustic impedance of quartz (10^5 g cm^{-2} s^{-1}).

For very thin films, $T \approx T_\mathrm{q}$, then:

$$\tan\left[\pi \left(1 - \frac{T_\mathrm{q}}{T} \right) \right] \approx \pi \left(1 - \frac{T_\mathrm{q}}{T} \right) \tag{2}$$

$$\tan^{-1}\left\{ \frac{Z_\mathrm{q}}{Z_\mathrm{f}} \tan\left[\pi \left(1 - \frac{T_\mathrm{q}}{T} \right) \right] \right\} \approx \tan^{-1}\left\{ \frac{Z_\mathrm{q}}{Z_\mathrm{f}} \pi \left(1 - \frac{T_\mathrm{q}}{T} \right) \right\} \approx \frac{Z_\mathrm{q}}{Z_\mathrm{f}} \pi \left(1 - \frac{T_\mathrm{q}}{T} \right) \tag{3}$$

Equation (1) thus becomes:

$$T_\mathrm{f} = \frac{D_\mathrm{q}}{D_\mathrm{f}} N_\mathrm{q} \left(T - T_\mathrm{q} \right) \tag{4}$$

This implies that the Z-value only becomes important for heavily loaded crystals.

***Tooling factor*:**
Because the positions of the sample and the sensor relative to the evaporation source are not exactly the same, the thicknesses of the films deposited on the sample and the sensor are different. The tooling factor is defined as the ratio between the film thicknesses on the sample and the sensor:

$$\text{Tooling factor} = \frac{\text{Deposited film thickness on the sample}}{\text{Deposited film thickness on the sensor}}$$

A tooling factor of 1.00 implies that the sample and sensor receive the same deposit thickness.
A tooling factor > 1.00 implies that the sample receives a thicker deposit than the sensor.
A tooling factor < 1.00 implies that the sample receives a thinner deposit than the sensor.

We have calculated the tooling factor by an experimental deposition process and have determined this number to be 36% for our e-beam system.

Density and *Z*-value of some materials

Material	Symbol	Density (g cm^{-3})	Z-value (10^5 g cm^{-2} s^{-1})
Silver	Ag	10.5	16.68
Aluminum	Al	2.70	8.17
Titanium	Ti	4.50	14.05
Gold	Au	19.3	23.17
Palladium	Pd	12.0	24.72
Platinum	Pt	21.4	36.06
Nickel	Ni	8.91	26.66
Ruthenium	Ru	12.2	48.50
Silicon dioxide	SiO_2	2.20	8.25
Chromium	Cr	7.20	28.94
Titanium oxide	TiO_2	4.26	Not available
Germanium	Ge	5.35	17.10
Indium	In	7.30	10.49
Magnesium fluoride	MgF_2	3.00	Not available
Silicon	Si	2.32	12.39
Tantalum oxide	Ta_2O_3	8.20	Not available
Zinc oxide	ZnO	5.61	15.87

Reference:
Instruction Manual of FTM7 Film Thickness Monitor, Edwards High Vacuum International, UK