Film Thickness Measurements

Piezoelectric effect

Film thickness is measured using a Film thickness monitor, or FTM utilizing the piezoelectric sensitivity of a quartz crystal's added mass.

The FTM uses this mass sensitivity to monitor the deposition rate and control final thickness of a vacuum deposition. When a voltage is applied across the faces of a properly shaped piezoelectric crystal, the crystal is distorted and changes shape in proportion to the applied voltage. At certain discrete frequencies of applied voltage, a condition of a very sharp electro-mechanical resonance is encountered. When a mass is added to the face of the resonating crystal the frequency of the resonances are reduced. The change in frequency is very repeatable and is precisely understood for specific oscillating modes of quartz.

Frequency Change

Saurbrey [1,2] and Lostis noted in the late 1950's that the change in frequency, $\Delta F = F_q - F_c$, of a quartz crystal when coated with a material (or composite) and uncoated frequencies, F_c and F_q respectively, is related to the change in mass from the added material, M_f, as follows:

$$\frac{M_f}{M_q} = \frac{\Delta F}{F_q}$$

Where M_q is the mass of the uncoated quartz crystal

Substitutions lead to a film thickness, (T_f) proportional to the frequency change (ΔF)

$$T_f = \frac{N_{at} d_q \Delta F}{d_f F_q^2}$$

Where:
d_f is the density of the film
d_q is the density of single crystal quartz
N_{at} is the frequency constant of AT cut quartz
F_q is the frequency of uncoated quartz

Further developments in calculations by treating resonating quartz and the deposited film system as a one dimensional continuous acoustic resonator by Miller and Bolef [4] and development of Z matching equation by Lu and Lewis [5] has resulted in the more sophisticated equation

$$T_f = \left(\frac{N_{at} d_q}{\pi d_f F_c Z}\right) \arctan\left(Z \tan\left[\frac{\pi(F_q - F_c)}{F_q}\right]\right)$$

.

Where: $Z=(d_q u_q / d_f u_f)^{1/2}$ is the acoustic impedance ratio and u_q and u_f are the shear moduli of the quartz and film respectively. This refinement is not implemented in the Quorum coaters as it generally only affects thick films

Tooling Factor

Due to the non-uniformity of source deposition and that the sample is not placed directly next to the film thickness monitor (FTM), a correction factor must be applied (See Figure 1). This correction factor, named the Tooling Factor, accounts for the difference in thickness measured by the FTM and the thickness deposited on the substrate to ensure accurate deposition control. The tooling factor accounts for factors such as chamber geometry, the position of the substrate, position of the FTM and the material deposited.

Deposition Thickness T_d

$$T_d = \frac{\Delta F \times Tooling\ Factor \times 10^4 \times 166100 \times 2.69}{F_i^2 \times density\ of\ deposited\ material}$$

Where: $\Delta F = F_c - F_i$, of a quartz crystal when coated with a material(or composite) and initial frequencies, F_c and F_q, N_{at} =166100 Hz cm and d_q, density of quartz =2.649 gm/cm^3

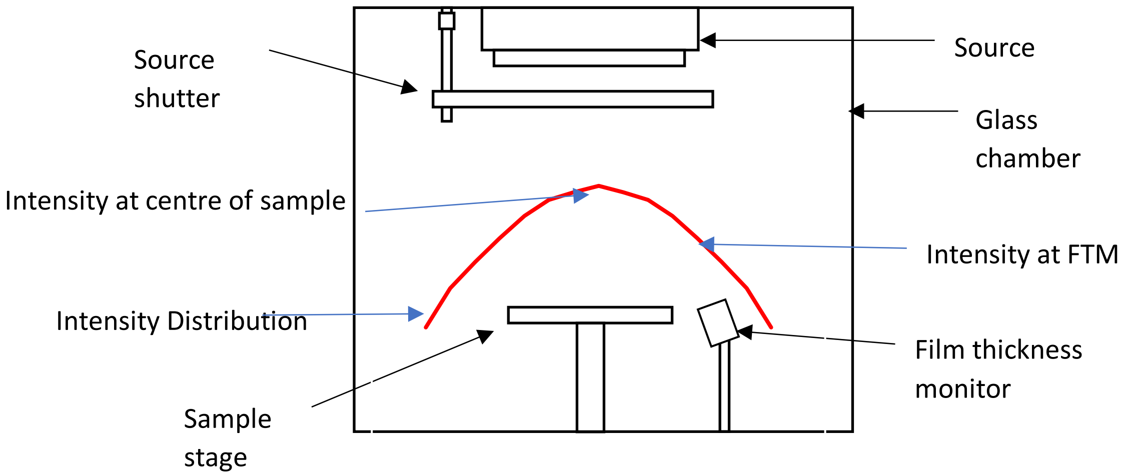

Figure 1

Determining the Tooling Factor

1) Place a Test Sample at the centre of the substrate holder
2) Make a short deposition and determine the actual thickness Typical methods are using a depth profilometer or ellipsometer
3) Calculate the tooling from the relationship;

$$\text{Tooling}(\%) = \text{TF}_\text{i}\left(\frac{\text{T}_\text{m}}{\text{T}_\text{x}}\right)$$

Where T_m = Actual Thickness
T_x = Thickness read by FTM
TF_i = Initial Tooling Factor

4) Round off percent tooling to the nearest 0.1%
5) Enter the new value for tooling into the appropriate recipe or material property
6) Repeat the measurement up to 3 times to reduce errors

Corrections and Variables

The Tooling Factor is dependent on position of the substrate relative to the FTM. Any change in position of the sample relative to the source can affect the measured Tooling Factor

Different magnetron sources and target materials have different sputter yields which can affect the measured thickness. See Figure 2. showing the difference between sputtered yields, using a commercial magnetron source, for titanium and gold materials. See Figure 2. showing the difference between sputtered yields for titanium and gold. As an example, if the FTM is positioned greater than 1 cm from the center of the sample, (where Position 0 is the center of the sample) the tooling factor would be different for Ti and Au. If the FTM is at the center of the sample the tooling factors would be 1. Note that materials with higher sputter yields have a narrower angular distribution.

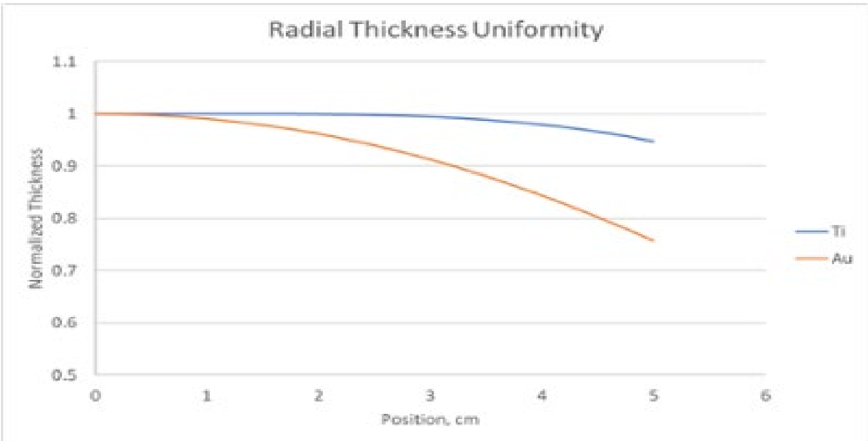

Figure 2

Different deposition pressures can affect the amount of scattering of the sputtered material and the sputter yield which can affect the measured thickness. See Figure 3.

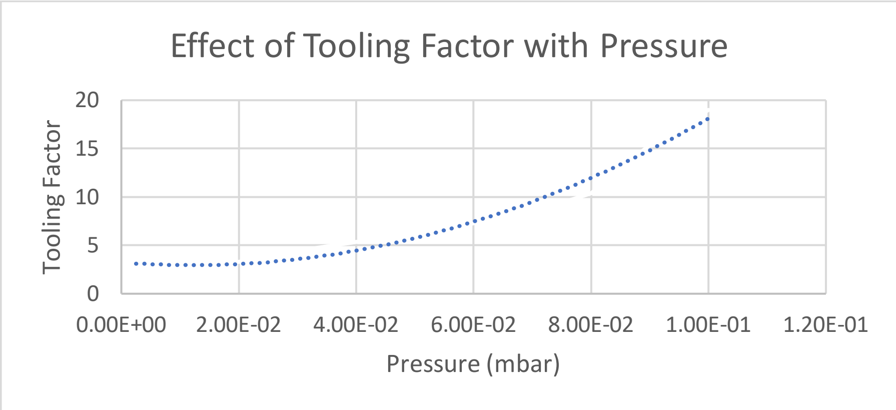

Figure 3

Summary

References:

1. G.Z. Sauerby, Phys. Verhand .8 193 (1957
2. G. Z Sauerby, Z. Phys. 155,206 (1959)
3. P.Lostis, Rev. Opt. 38,1 (1959)
4. J. G. Miller and D.I.Bolef, J.Appl. Phys. 39,5815,4589,(1968)
5. C. Lu and O. Lewis, J Appl Phys. 43, 4385 (1972)

Note: For a point source such as Carbon Rod, Cord and metals evaporation the Tooling Factor is 1 as the FTM “sees” the same intensity of material as the sample.