Quartz Crystal Microbalance for Real-Time Deposition and Clean End Point Monitoring

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1. INTRODUCTION

The Quartz Crystal Microbalance (QCM) (Figure 1) has traditionally been used for the monitoring and control of electron beam and thermal evaporation deposition of thin films. These methods of deposition are used extensively in the photovoltaic and OLED display manufacturing industries. In order to use in semiconductor manufacturing processes which are in high demand, QCM technology is now being adapted by optimizing the electrode material, body coating and improving crystal stability due to temperature changes, so that it can be used in front end semiconductor manufacturing to monitor process stability and chamber health in real-time.

2. APPROACH

The change in resonance frequency Δf of the quartz crystal is defined by Sauerbrey equation as: [1][2]

$$\Delta m = \left(\frac{N_q \cdot \rho_q}{\pi \cdot R_z \cdot f}\right) \cdot \tan^{-1}\left(\pi \cdot \frac{f_q - f}{f}\right)$$

Where:

Δm=change in mass per unit area in (g/cm^2)

N_q=Frequency Constant for AT-cut quartz crystal $=1.668 \times 10^5\ Hz \cdot cm = \frac{\sqrt{\rho_q \mu_q}}{2\rho_q}$

ρ_q =Density of quarts = 2.468 g/cm^3

f_q=Resonant frequency of unloaded crystal (Hz)

f = Resonant frequency of loaded crystal (Hz)

R_z=Z-factor of film material $= \sqrt{\frac{\rho_q \cdot \mu_q}{\rho_f \cdot \mu_f}}$ = Acoustic Impedance Ratio

ρ_f =Density of material (g/cm^3)

μ_q =Shear Modulus of quartz = 2.947×10^{11} (g・cm^{-1}・s^{-2})

μ_f =Shear Modulus of film material (g・cm^{-1}・s^{-2})

According to this theory, QCM monitors the film thickness increase in CVD and ALD. Plus, the QCM can monitor the mass change of deposition on the crystal caused by various of chemical reaction. [1][2]. We deploy this method to monitor the real time process accumulation and clean end point monitoring in a HDP (High Density Plasma) CVD chamber.

Comparing to typical application which is enough with a standard sensor and AT cut gold crystal, semiconductor processes are much more critical. In this case sensor body and crystal were coated by an alumina protection layer in order to extend the sensor life. Besides, SC cut alloy crystal was used to minimize frequency shift caused by temperature changes.

QCM sensors were adapted and fit into the chamber wall of a HDP chamber (Figure 2). This was to measure the real time deposition rate and chamber clean end point. QCM and process data was taken in real-time and correlated by FDC system (INFICON software FabGuard®).

3. RESULT

In this example, INFICON partnered with two Individual Wafers Manufacturers to develop and qualify QCM sensors for use in the HDP CVD chambers. From the result (Figure 3, 4), we can see the accurate frequency trace during film accumulation and removal (Deposition / Clean Cycles). Frequency going down when deposition is being accumulated on the crystal surface, then going up when the film is being removed from the surface. Besides, QCM can be used to monitor the clean end point, thus prevent loss of extra cost due to over etching, yield lost and unscheduled tool down time due to particles generation (Figure 5).

4. SUMMARY

The QCM sensor is not only giving a good insight to process on the wafer, but also an excellent indicator of what is happening at the chamber sidewall. This is very important, since the actual film thickness on the sidewall is often not well known but is the fundamental point for performing an in-situ clean as well as running production under well controlled conditions. In this way, the QCM gives a direct measurement of how much accumulation is on the chamber wall, and exactly when it is all cleaned off, in a way that other sensors cannot.

REFERENCES

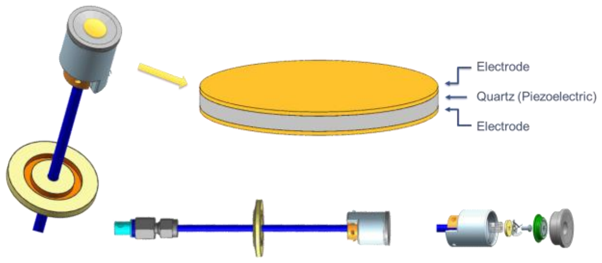


Figure 1. QCM sensor

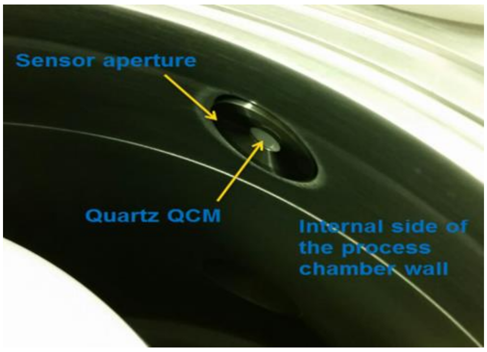
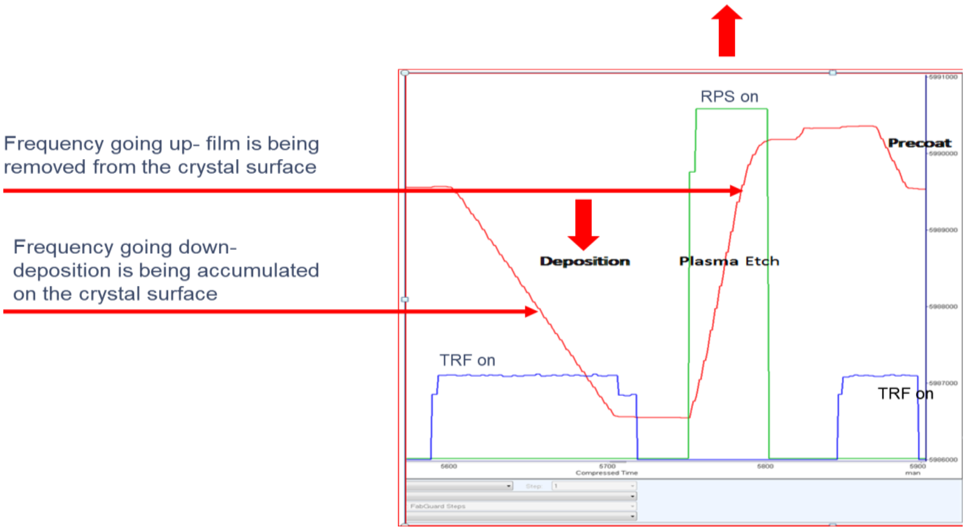


Figure 2. Location of QCM in a HDP chamber



Frequency going up- film is being removed from the crystal surface

Frequency going down- deposition is being accumulated on the crystal surface

Figure 3. QCM frequency trace during film accumulation / removal

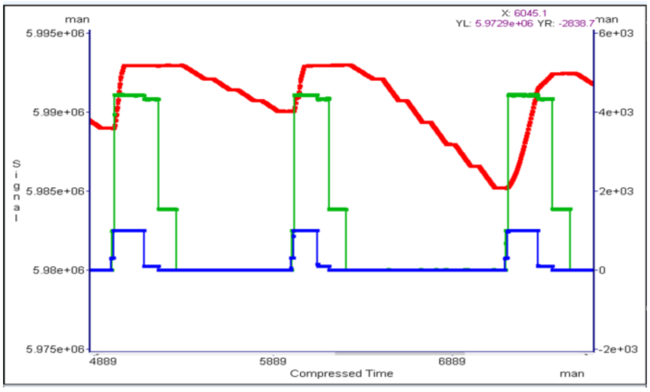
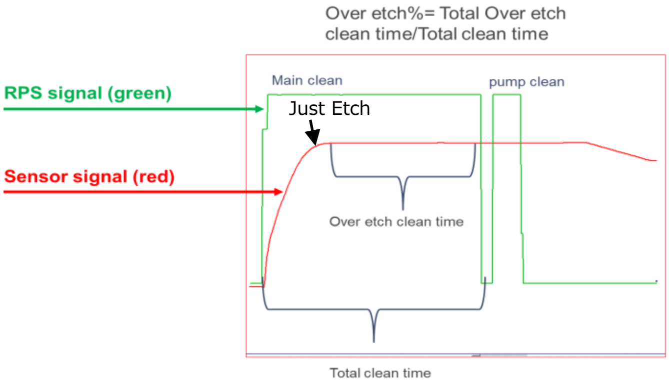


Figure 4. Deposition / Clean Cycles



Over etch%= Total Over etch clean time/Total clean time

Figure 5. Clean End Point Monitoring

[1] S. Okamura et al., “Real time monitoring system of Airborne Molecular Contamination in the clean room” ISSM2002

[2] S. Ito et al., “Real Time Detection of Chemical Contaminant from Equipments Using QCM Monitoring Technique” ISSM 2002