Application Note

TDMAT Precursor Monitoring with a Quartz Crystal Microbalance

Introduction

INFICON is an industry pioneer for semiconductor fault detection and classification (FDC) with the FabGuard® process monitor. INFICON is also the market and technology leader and innovator for quartz crystal microbalance (QCM) sensors, monitors and controllers. Leveraging these two core competencies and applying them to semiconductor applications offers an affordable monitor capable of verifying TDMAT delivery to TxZ chambers.

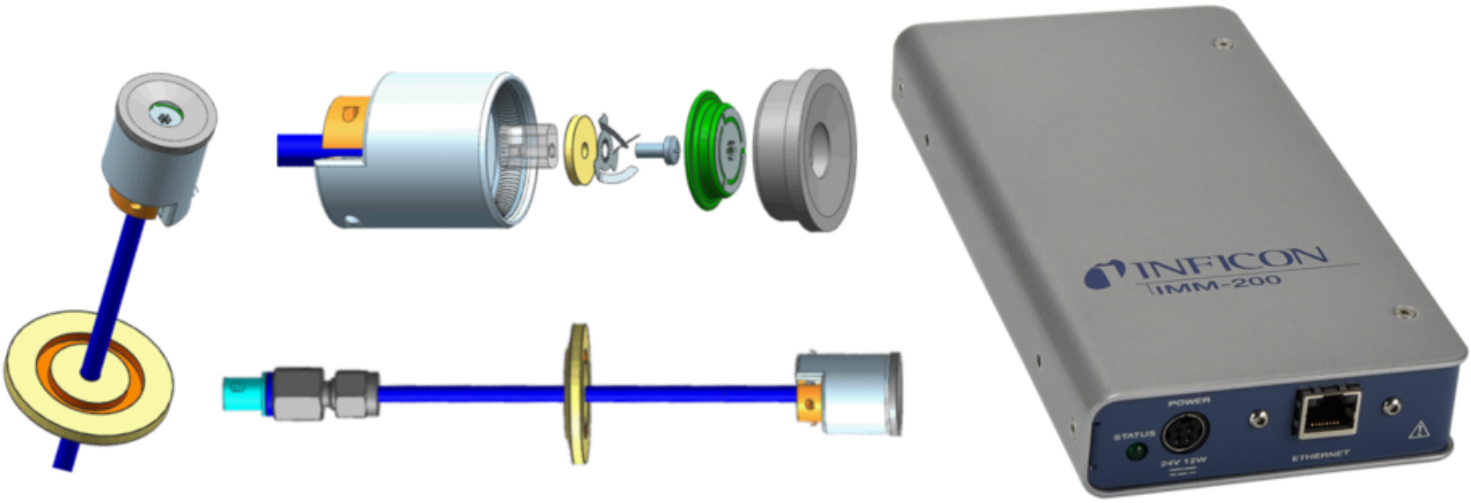
The TxZ Process

TxZ metal organic chemical vapor deposition (MOCVD) is a widespread process for depositing barrier metal films for semiconductor processing of both 200 mm and 300 mm wafers. TxZ chambers are typically found mounted to the transfer chamber of the Applied Materials® Endura® mainframe and are a CVD Evolution of traditional physical vapor deposition (PVD) of titanium nitride (TiN). PVD TiN uses a solid metal target of titanium as its source that is sputtered in the presence of nitrogen and deposited onto a wafer's surface. TxZ MOCVD, uses a liquid metal organic precursor, called tetrakis(dimethylamido)titanium (TDMAT), as its titanium source. This source uses a carrier gas to bubble through the liquid TDMAT precursor and carry the metal organic to the deposition chamber. The TDMAT is contained within an ampoule of finite volume that needs to be changed out frequently before depletion. Over the past decade many wafers have been scrapped worldwide due to low TDMAT ampoule levels, resulting in higher costs and yield losses for fabrication facilities.

Quartz Crystal Microbalance (QCM)

The QCM is a piezoelectric quartz crystal transducer. By exploiting the reverse piezoelectric effect the quartz crystal is made to oscillate by the application of a voltage across the crystal faces. The frequency of oscillation depends on the crystal mass. Adding or removing mass changes the oscillation frequency. A properly designed QCM system allows nanogram sensitivity to mass changes. The system deployed for this application mounts the crystal into a sensor which holds the crystal in place and enables the frequency to be measured by IMM-200 quartz crystal frequency monitor. IMM-200 has a resolution of 0.003 Hz allowing easy detection of very small changes in mass.

This TDMAT Precursor Monitoring system is completed with the addition of FabGuard Process Monitor software. FabGuard integrates tool and process state data with frequency information from IMM-200, recording the overall frequency change profile for each wafer.



Comparison of In-Situ MOCVD Precursor Delivery Monitoring Methods

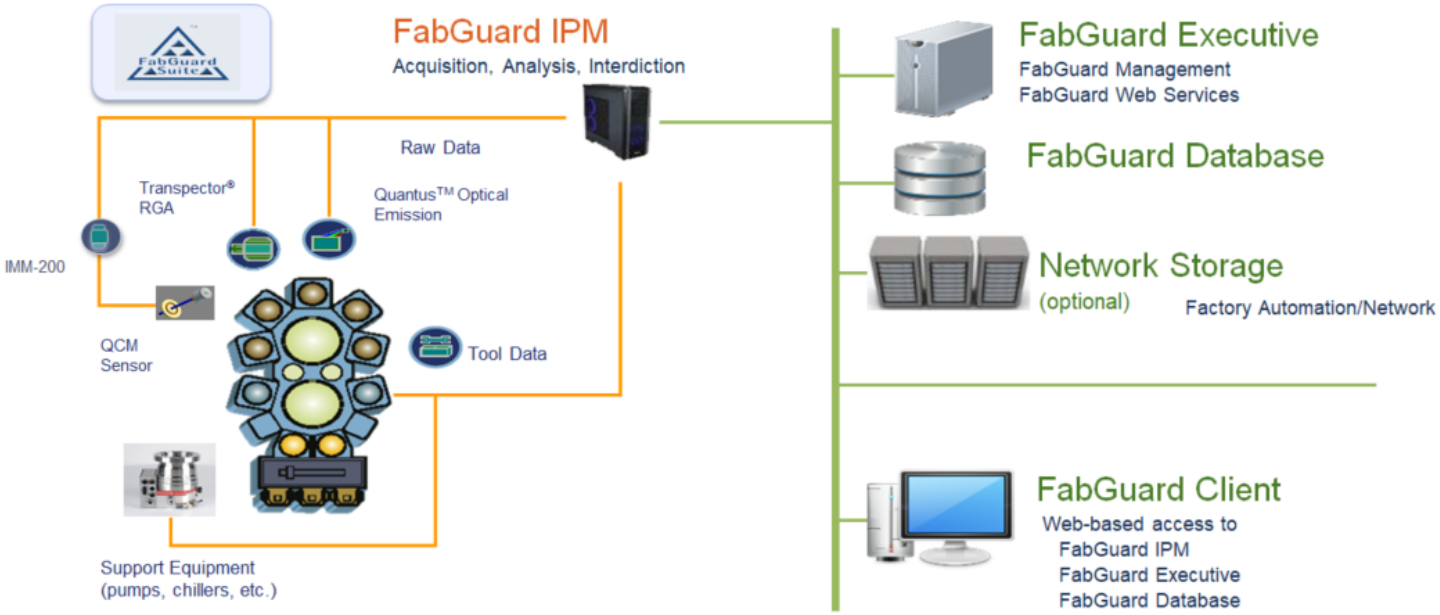
Existing methods to monitor TDMAT precursor delivery include time based consumption estimates, scales to measure the ampoule weight, internal sensors to measure the precursor levels and ultrasonic to measure the precursor level. All of these methods are intended to measure and/or predict that there may be precursor available in the ampoule. None of these methods can verify the in-situ delivery of precursor to the CVD chamber, which is the strength of QCM precursor monitoring.

Precursor Delivery Monitor	Measurement Type	Advantages and Disadvantages	Precursor Chamber Delivery Verification
Time/flow based	Time/volume flow through ampoule	Inexpensive, but can lead to depletion or waste due to early replacement	No in-situ chamber delivery verification
Scales	Tare weight vs. content	Simple sensor, outside of ampoule, installed on most tools, requires some maintenance/validation during preventive maintenance (PM)	No in-situ chamber delivery verification, only ampoule status
Internal sensors	Float switch or optical	Long-term more expensive than scales, needs to be installed on the inside of an ampoule, can stick/fail	No in-situ chamber delivery verification, only ampoule status
Ultrasonic	Point or continuous	More expensive than scales, needs to be installed inside of an ampoule, can stick/ fail	No in-situ chamber delivery verification, only ampoule status

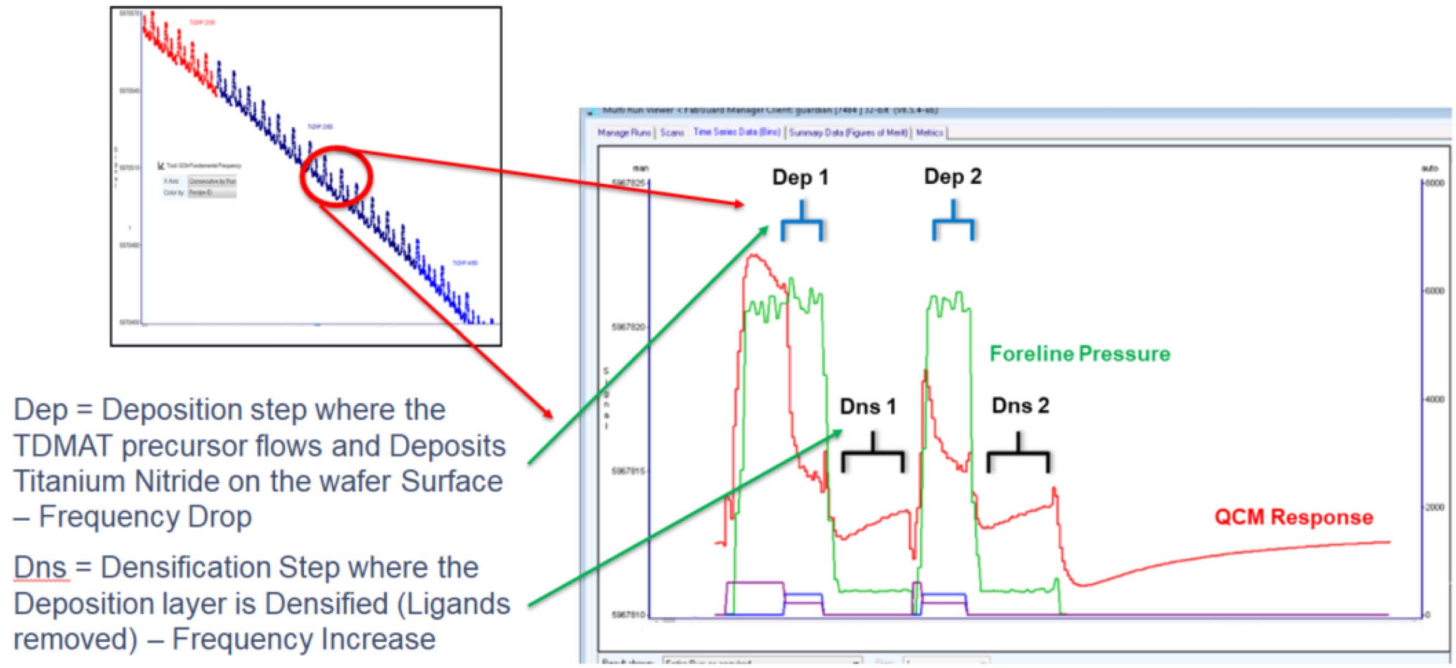
Precursor Delivery Monitor	Measurement Type	Advantages and Disadvantages	Precursor Chamber Delivery Verification
QCM Precusor Monitor	QCM frequency shift during deposition process	Low cost of ownership, easy, exhaust line installation, maintenance can be done during normal PM, precursor delivery verification	In-situ chamber delivery is verified

QCM Precursor Monitor Advantage

Existing methods to monitor TDMAT precursor delivery focus only on the TDMAT ampoule and its status/fill level. Existing methods do not validate if the TDMAT precursor is delivered to the CVD process chamber. QCM precursor monitoring is different and provides many advantages compared to existing methods. First, the QCM system is integrated with the FabGuard process monitor for full tool integration. This allows the system to be aware of wafer process start, recipe IDs, wafer IDS, and recipes steps, such as deposition and densification.

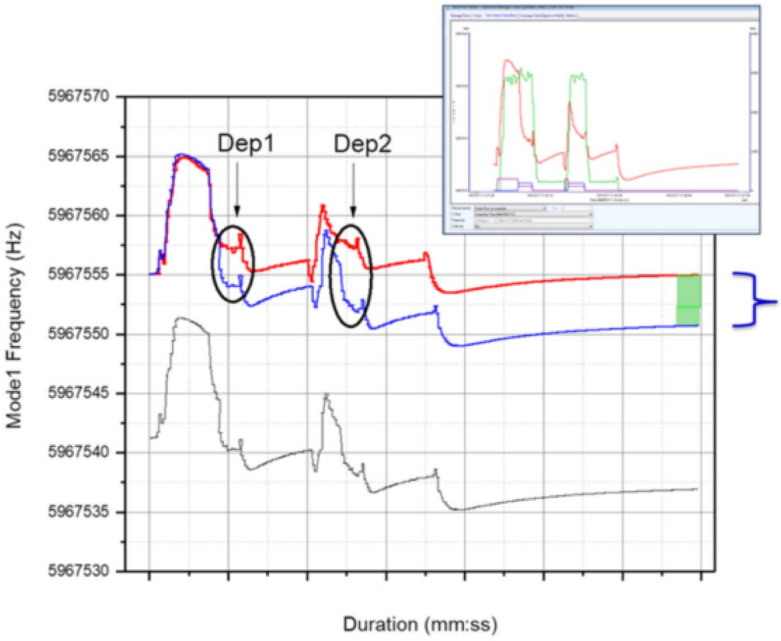


Second, the sensor is installed in the foreline of the process chamber. Since this is downstream from the process, what is detected by the QCM has come from the process chamber. When the QCM detects deposition (a decrease in the QCM frequency) during the deposition steps, it validates precursor delivery. Due to the high QCM resolution of 0.003 Hz and the typical change in frequency during the TxZ deposition of 0.4 Hz to 8 Hz, depending upon the process recipe, QCM precursor monitoring can easily detect deposition vs. no deposition. No deposition indicates a failure of the precursor delivery.



Dep = Deposition step where the TDMAT precursor flows and Deposits Titanium Nitride on the wafer Surface – Frequency Drop

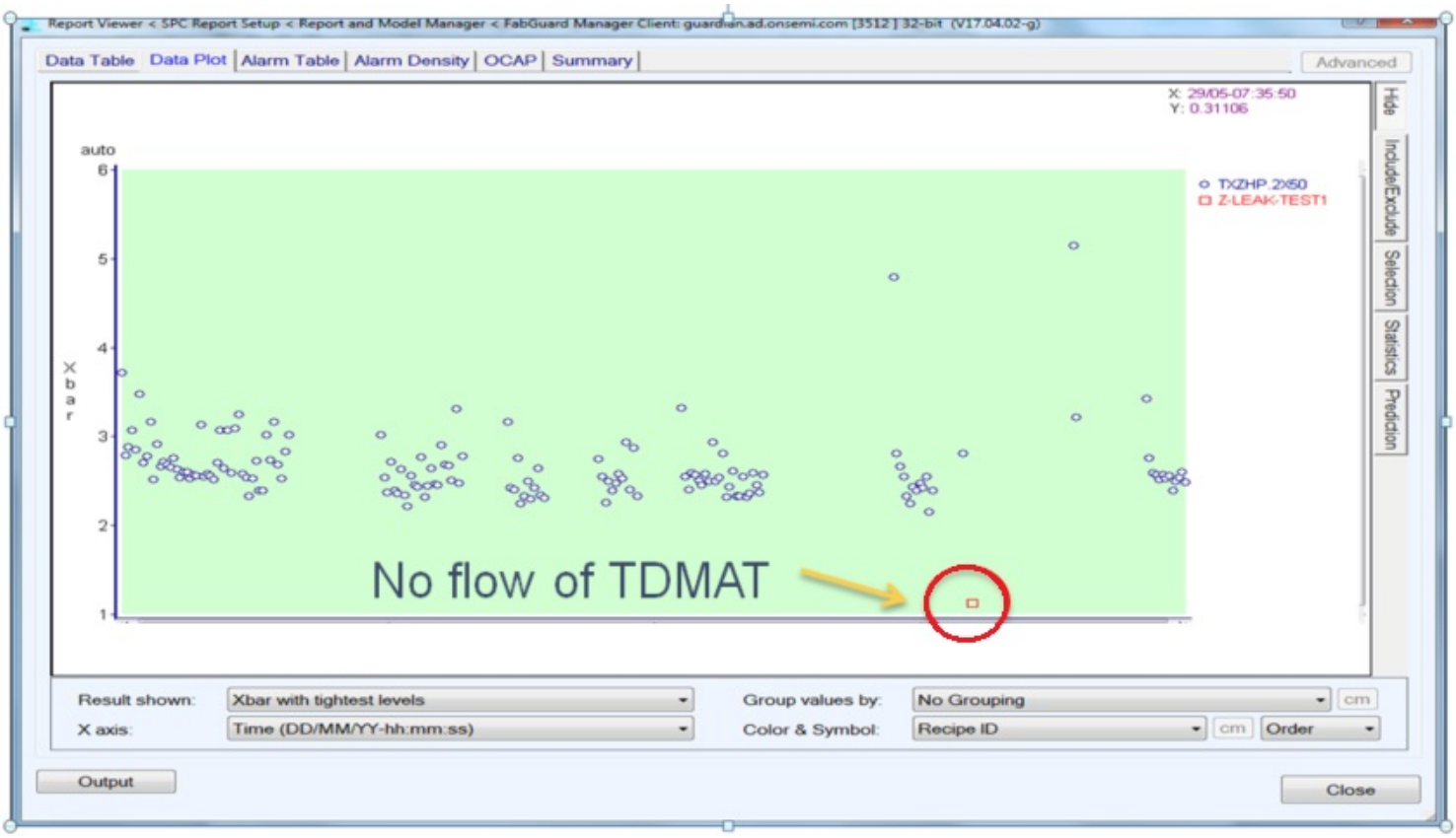
Dns = Densification Step where the Deposition layer is Densified (Ligands removed) – Frequency Increase



The difference between no Deposition (**no net Frequency change in Hz from the start to finish of the wafer process**) and normal Deposition (**3-5Hz drop per wafer**) is easily measured by the QCM with its resolution of **0.003 Hz**

No Frequency Change = No Precursor Delivery

In the event that no deposition is detected, the QCM system can provide multiple levels of action such as alarms, emails and full interdiction (halting) of the process tool. With real-time, in-situ process monitoring by the QCM precursor monitoring system, wafer scrap can be reduced to as little as one wafer in the event of a precursor delivery fault. The system also offers SPC controlled run-by-run wafer monitoring and interdiction.



QCM Precursor Monitoring for TxZ Conclusions

TxZ MOCVD process modules are widely used across 200 mm and 300 mm wafer processing for barrier seed deposition. Though these chambers do have some optional ampoule monitoring options, none of the existing commercial systems provide in-situ precursor delivery verification to the process chamber. The QCM precursor monitoring system fills this missing process monitoring gap and provides a low cost go/no go signal to the tool and the fab based upon real-time precursor delivery detection.