

SVC Topics

Donald M. Mattox Technical Director Society of Vacuum Coaters 440 Live Oak Loop Albuquerque, NM 87122 505/856-7188 • FAX: 505/856-6716 • Internet: http://www.svc.org

PVD Processes: Deposition Rate Monitors

The deposition rate is often an important processing variable in physical vapor deposition (PVD) processing. The rate can affect not only the film growth, but, along with the deposition time, the rate is often used to determine the total amount of material deposited. The quartz crystal deposition rate monitor (QCM) is the most commonly used *in situ*, real-time deposition rate monitor for PVD processing.

Quartz Crystal Monitors

Single-crystal quartz is a piezoelectric material, which means that it responds to an applied voltage by changing volume, causing the surfaces to move. The amount of movement depends on the magnitude of the voltage. If the voltage is applied at a high frequency (5 MHz range), the movement will resonate with a frequency that depends on the crystalline orientation of the quartz crystal slab and its thickness.

Quartz crystal deposition monitors measure the change in resonant frequency as mass (the film) is added to the crystal face. The change in frequency is directly proportional to the added mass. By calibrating the frequency change with the mass deposited, the quartz crystal output can provide measurements of the deposition rate and total mass deposited. The frequency change of the oscillation allows the detection of a change of mass of about 0.1 microgram/cm², which is equivalent to less than a monolayer of deposited film material.

The quartz crystal can be cut with several crystalline orientations. The most common orientation is the ATcut, which has a low temperature dependence of its resonant frequency



Single-beam atomic absorption deposition rate monitor.

near room temperature. Other cuts have a higher temperature dependence. Typical commercial quartz crystal deposition monitors have a crystal diameter of about ¹/₂ in. and a total probe diameter of about one in. The crystal is coated on both faces to provide the electrodes for applying the voltage and is generally watercooled to avoid large temperature changes.

The QCM Probe

Ideally, the QCM probe should be placed in a substrate position. This is not always possible because of the size of the substrate, fixture movement or system geometry, so the probe is usually placed at some position where it samples a portion of the deposition flux. The probe readings are then calibrated to total film thickness deposited. As long as the system geometry and vaporization flux distribution stays constant, then the probe readings are calibrated within a deposition run and from runto-run.

The QCM probe can be shielded so that it will sample the deposition flux from a small area. Several monitors can then be used to independently monitor the deposition from several vaporization sources close to each other. The output from the monitors can be used to control the vaporization rates, as well as the deposition time.

QCM Concerns & Considerations The major concerns with the use of QCMs are:

- Calibration with the actual deposition flux,
- Probe placement,
- Intrusion of the probe into the deposition chamber,
- Temperature rise, if the probe is not actively cooled, and
- Calibration changes associated with residual film stress and film adhesion to the probe face.

Probe positioning and calibration are particularly difficult problems in sputter deposition, where the sourcesubstrate separation is small and the areas are often large. The total residual film stress, which changes with film thickness, can change the elastic properties of the quartz crystal and, therefore, the frequency calibration. In some cases, the magnitude of the change can be more than the effect of the mass change.

The presence of film stress and its effect can be determined using two QCMs that have different crystalline orientations, which means they will have different elastic properties. If there is no film stress, then the probe readings will be the same during film deposition. If not, then film stress is probably a problem that has to be considered. Care must be taken in using this observation, because the stress in the film on the probe face may not be the same as the film stress present in films deposited on the substrates.

Often, QCM probes are used for several deposition runs. If the film deposited on the probe has absorbed gases or water vapor between runs, then desorptions of these gases and vapors during the deposition can affect the calibration.

Ionization Rate Monitors Ionization deposition rate monitors, although commercially available, are not commonly used. These monitors compare the collected ionization currents in a reference ionizing chamber and in an ionizing chamber through which the vapor flux is passing. By calibration, the differential in gauge outputs can be used as a deposition rate monitor.

In electron beam (e-beam) evaporation, the ions that are formed above the molten pool can be collected and used to monitor the vaporization rate. The optical emission of the excited species above the e-beam vaporization source can also be used for rate monitoring.

Atomic Absorption Spectrometry Some of the new commercial deposition rate monitors use optical atomic absorption spectrometry (AAS) of the vapor as a non-intrusive rate monitoring technique. In AAS, a specific wavelength of light, which is absorbed by the vapor species, is transmitted through the vapor flux and compared to a reference value.

A simple single-beam atomic absorption deposition rate monitor is shown in the figure. The light source is typically a hollow cathode gasdischarge lamp (HCL), with a cathode that is of the same material as the vapor to be measured, and an output that is the optical emission spectrum of the cathode material. The light source emits a spectrum of radiation and the bandpass filter (or monochrometer) eliminates all the radiation but the wavelength(s) of interest. Copper, for example, absorbs (emits) strongly at 324.7 nm and 327.4 nm in the near-ultraviolet. The amount of light absorbed by the beam depends on the density of the vapor flux along the light path.

Calibration is necessary to relate the absorption to the actual deposition rate. By using a feedback loop to the vaporization source, the vaporization rate can be controlled. Detection and control of deposition rates as low as 0.1 monolayer/sec have been reported. The technique is most sensitive at low flux densities (<10Å/ sec). By using several HCL light sources, several vapor species can be monitored at the same time.

The AAS rate monitoring technique has the advantage that it is nonintrusive, can be used in small volumes, in closely-spaced regions, and close to a surface. Problems with using the atomic absorption technique are in obtaining an HCL light source, calibration drift, changing transmission of the optical windows, light source instability, optical alignment shifts, and detector drift. Many of these problems can be avoided or minimized by using a two-beam ratio detection system and periodic calibration during the deposition.

NOTE: The optical spectrum is defined as the visible and near-visible wavelengths (radiation) and the extreme limits are taken as 0.1 microns (uv) and 30 microns (infrared), with the spectrum visible to the human eye being from about 0.45–0.7 microns. *Pasf*

Bibliography

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enforcement seems to exist. This should not, however, be an indicator to employers that there is not enforcement. Quite the opposite—OSHA looks at each situation independently and then decides how to proceed. They can always lean on the "General Duty Clause" as a means to cite an employer when they believe that all practical options to limit exposure have not been attempted.

In summary, the issue of which PEL or TLV to use for non-regular work shifts is a contentious one, even for the regulators. In this column, we have suggested a couple of options for modifying the PEL or TLV to accommodate extended exposure times. This, however, must be handled carefully because of the differences in how compounds may act upon the body. Close medical monitoring and emphasis on exposure control measures are strongly recommended. *Pasf*

References

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About the Columnist Philip Platcow is certified in comprehensive practice by the American Board of Industrial Hygiene. He graduated from Quinnipiac College in Hamden, CT, with a BS in environmental health technology and is a master's degree candidate in industrial hygiene at the University of Massachusetts. He has more than 12 years' experience in both industry and consulting. He has been employed by the Union Carbide Corp., the consulting firm of Hygienetics Environmental of Boston, and currently works for Sedgwick James, Inc., providing industrial hygiene, health and safety, and environmental services for a wide variety of clients. He is a member of the American Industrial Hygiene Association, the National Environmental Health Association, and is the assistant chairperson for AESF's OSHA Committee.