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PVD Processes: Vacuum Gauges for the Plasma Environment

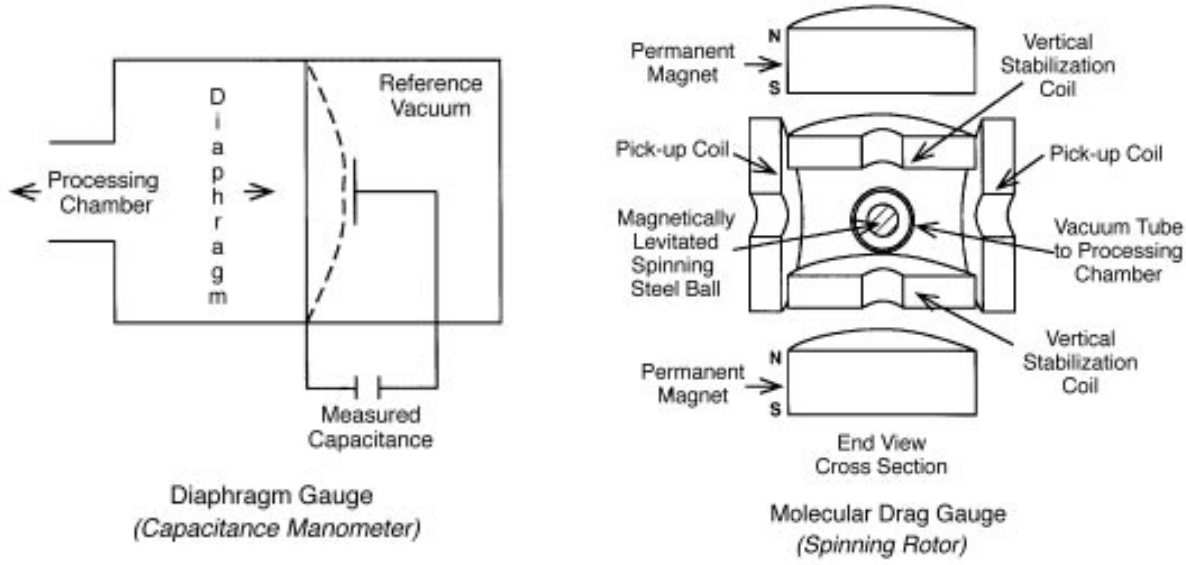
Plasmas for physical vapor deposition (PVD) processing generally use gas pressures in the pressure range of 2 x 10^{-2} to 10^{-4} Torr. Measurement of these pressures is complicated by the presence of ions in the plasma, heating from the plasma and heating from ion-electron recombination on surfaces. This makes the use of vacuum gauges based on ion generation and collection (*e.g.*, ion gauges and mass spectrometers) and thermal behavior (*e.g.*, Piriani gauges) difficult. The most common vacuum gauges used in production involving plasmas are the diaphragm gauge and the molecular drag gauge shown in the figure.

Diaphragm Gauge

In the diaphragm gauge, one side of the diaphragm (reference vacuum) is kept at a very low pressure, and the pressure difference causes the diaphragm to deflect (see figure). This deflection of the diaphragm can be measured by the change in capacitance, in which case the gauge is called a capacitance manometer gauge. The diaphragm can be mounted with only one plate electrode (as shown in the figure), or it can be mounted between two plates, whereby two capacitances are measured in a potentiometric arrangement. The deflection can also be measured using a strain gauge on the diaphragm, which is less common and less sensitive.

The sensitivity and range of the diaphragm gauge is controlled by the design of the sensor "head" and the properties of the diaphragm. Sensor heads are available that span the pressure range of about 10^{-6} Torr to atmospheric pressure, with a range for a single head being three to four orders of magnitude. A typical accuracy is about ±3 percent at 10^{-3} Torr. Because this gauge gives a direct pressure reading, the measurement does not depend on the gas species or gas temperature. The gas density, however, does depend on the gas species and temperature of the gas. The reading is sensitive to the temperature of the head, so for the best accuracy and precision, the temperature of the sensor head should be controlled.

The high vacuum side of the diaphragm may be provided by either a sealed chamber, or may be actively pumped by a small, high-vacuum pumping system, such as a turbopump. This latter arrangement allows the meter to be zero-set by pumping both sides of the diaphragm chamber with the diaphragm chamber blanked-



A single-element capacitance diaphragm gauge (left) and a molecular drag gauge.

off from the processing chamber. For the best long-term stability, the diaphragm chamber should be valved-off from the processing chamber and kept under vacuum when the processing chamber is let-up to atmospheric pressure. This prevents excessive stressing of the diaphragm during pressure cycling.

Metal fatigue, corrosion of the diaphragm, or changes in the reference volume pressure can cause drift of the gauge calibration. The gauge, therefore, should be periodically recalibrated. The diaphragm can be made of a corrosion-resistant material when the processing uses a corrosive gas or vapor. When using an AC capacitance-measuring technique, excessive contamination on the diaphragm can cause a change in the mass of the diaphragm, which can cause drift in the gauge calibration.

Molecular Drag Gauge

The molecular drag gauge (MDG)—also called a spinning rotor gauge—uses the frictional drag of the gas molecules to slow a rapidly moving surface. The rate of deceleration is a measure of the gas density. The usual configuration is a small steel ball, magnetically levitated in a nonmagnetic steel tube that is connected to the processing chamber. The ball is rotated at a frequency of 400 Hz by a moving magnetic field, formed by external electromagnetic field coils. When the inductive driving field is removed, the ball decelerates as a result of the frictional drag of the gas molecules on the surface of the ball. The deceleration of the magnetized ball induces a synchronous AC voltage in the pickup coils. The change in angular velocity is proportional to the gas density, and depends on the gas species and temperature, as well as some geometrical factors. The time over which the deceleration is measured depends on the pressure being measured.

In the pressure range of 10^{-2} to 10^{-6} Torr, the precision of the MDG is about ±1 percent. The short-term stability is very good and the long-term stability is a few percent. Because the gauge readings are affected by temperature, the sensor temperature should be controlled for best precision and accuracy. Readings can also be affected by vibration, so the system should be as free from vibration and changes in vibration as possible. In some processing applications, changes of the rotor surface can change the calibration. Reactive deposition of carbides with a hydrocarbon precursor, such as acetylene, for example, can result in gas phase nucleation of "soot." This soot can deposit on the rotor surface and change the frictional drag properties, thereby changing the calibration.

Minor corrosion of the rotor surface will also change the drag properties. This means that for the best long-term stability, the gauge should be valved-off when the processing chamber is being let-up to the atmosphere, or when there is excessive outgassing of corrosive vapors—such as water vapor—in the processing chamber prior to the processing stage.

The molecular drag gauge has been studied extensively, and is recommended as a secondary (transfer) standard for calibrating other vacuum gauges in the pressure range of 10^{-2} to 10^{-6} Torr.

Note: *Precision* is the ability to give the same reading repeatedly, under the same conditions, even though the reading may not be accurate. *Accuracy* is the ability to give a reading that is correct when compared to a primary standard. Precision is often the desired characteristic in production, where process reproducibility from run-to-run is the important concern. Accuracy, as well as precision, is often a desired characteristic in process development, where the values will be used to write the specifications for performing the process and transferring the technology. *Stability* is precision (or accuracy) over a period of time and/or repeated operation. **P&SF**

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