SVC Topics

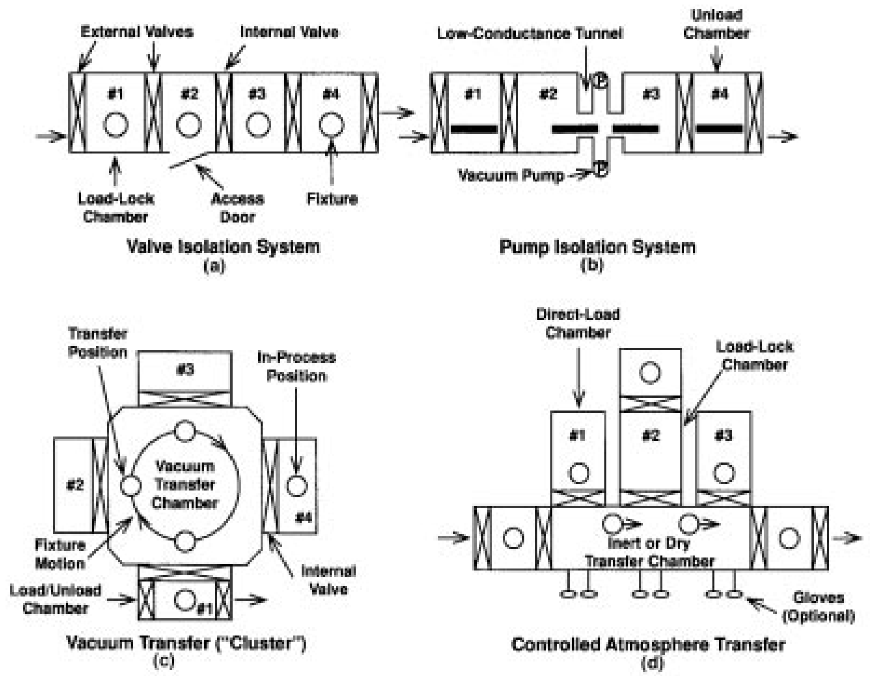
Donald M. Mattox
Technical Director
Society of Vacuum Coaters
71 Pinon Hill Place N.E.
Albuquerque, NM 87122
505/856-7188 • FAX: 505/856-6716
Internet: http://www.svc.org

PVD Processes: In-line Processing Systems

In-line processing systems use several processing chambers connected together to sequentially process the substrates. The system can, for example, clean the substrate, modify the substrate surfaces and deposit films or otherwise build structures or devices without exposing the substrate to the ambient environment between steps.

An in-line system may involve several different types of processing, such as physical vapor deposition (PVD) and subatmospheric chemical vapor deposition (SA-CVD). The in-line systems are characterized by having the substrates moving from chamber to chamber in one direction, so that a fixture can be under processing conditions in each module all the time. This can give very high product throughput of multi-process-built structure, particularly when the system is automated. Some in-line system designs have the capability of adding or changing process chambers with ease; others do not.

The processing chambers can be operating at different vacuums or they may use different processing gases. The processing chambers can be isolated from each other in several ways, as shown in the figure.



In-line processing systems—(a) valve isolation system; (b) pump isolation system; (c) vacuum transfer system; (d) controlled atmosphere transfer system.

Valve Isolation System

In the valve isolation system (a), there is a valve between processing chambers. The fixture is moved from one chamber to another, valves close and the process is physically isolated from the other processing chambers. After processing is completed, the chamber may be pumped out to remove the processing gases (if any), the valve is opened and the fixture is moved. Figure (a) shows a linear in-line system, where it is relatively easy to change or add more processing stages.

Pump Isolation System

In the pump isolation system (b), there is an intermediate chamber (or "tunnel") between the processing chambers. This tunnel has a low conductance for gas flow between chambers and the region is actively pumped to prevent gases from one chamber getting into the other chamber. An advantage to this system is that one end of a long substrate can still be in one chamber, while the other end is entering the next chamber. This type of design is common with systems used to coat architectural glass (10-ft x 12-ft panes) with solar control or low-E coatings. It is relatively easy to change or add more processing stages to this type of equipment.

Vacuum Transfer System

In the vacuum transfer system (c), the fixture is moved into and out of a transfer chamber that can be evacuated to a "rough," or even a "high," vacuum. The purpose of the transfer chamber is to prevent processing gases in one chamber from entering another by rapidly pumping the transfer chamber. In some cases, the transfer chamber can be at a higher pressure than the processing chamber, so that when the valve is opened, gas flows into the processing chamber from the transfer chamber to further prevent "back-flow" of the residual processing gases. In one application using SA-CVD, the pressure in the transfer chamber is 3 Torr when the valve is opened.

If the in-line system in figure (a) used a separate chamber to isolate two processing chambers, rather than for processing, it would be called a vacuum transfer system. The system shown in figure (c) uses a vacuum transfer chamber that is common to all the processing modules. This configuration is sometimes called a "cluster" in-line system. In one application of this system—the coating of automobile headlight reflectors with aluminum—the cycle time for each processing chamber is 30 sec. It is not possible to add more processing stages to this type of in-line system equipment.

Inert Transfer System

In the inert (or controlled atmosphere) transfer system (d), the transfer chamber is at atmospheric pressure, so hermetically sealed gloves can be used. In the transfer chamber, measurements and procedures, such as mask alignment or C-V measurements, can be performed between processing steps. The gas in the transfer chamber can be dry air if the product is moisture-sensitive, or an inert gas, such as argon or nitrogen, if chemical reaction is a problem. The individual processing chambers can be of a "direct-load" design, where the processing chamber is opened to the transfer chamber during each cycle, or of a "load-lock" design, where there is a chamber between the transfer chamber and the processing chamber. In the transfer chamber, the product may be packaged in an appropriate container before being exposed to the ambient.

Several types of valves can be used in the in-line system. If one side of the valve is at atmospheric pressure while the other is at a good vacuum ("external" valve), the sealing pressure is from the pressure differential and the valve can be a simple plate that seals against an elastomer seal. These can be used for the load-lock chamber and for access doors to individual chambers. Door movement should be such that the sealing surfaces are pressed "metal-to-metal" on sealing. Common polymer seals and their recommended maximum operating temperatures are:

- Buna-N (100 °C)
- Viton (200 °C)
- Silicone (250 °C)
- Spring-loaded Teflon™ (350 °C)

The "internal" (isolation) valves have no large pressure differential during the process sequencing. They can be simple "flap-valves," which have little sealing pressure but just restrict the conductance of gas flow between chambers, or they can be valves that have a positive sealing pressure provided by mechanical means. The latter is desirable if the processing gases used in one process would be a contaminant if they were to get into another processing chamber, or if high vacuums are required for processing.

In-line systems are meant to operate continuously, so heat buildup is a consideration. If high temperatures are desired in the processing chamber, it may be best to design a vacuum oven using radiant heaters to heat the fixture and have water-cooled surfaces facing the chamber walls. Because there is no convective heating in the vacuum chamber, heating of the chamber walls is minimized. It may be desirable to actively cool seal areas if heat buildup is a concern. This can be done using cooling coils on the exterior of the chamber. If the fixture has attained a high temperature during processing, it may be necessary to have an exit chamber that is actively cooled by flowing gas to reduce the temperature to an acceptable level before the fixture leaves the in-line system.

Generally, each chamber is provided with an access door(s). This allows easy cleaning, maintenance and repair. Processing hardware, such as sputtering cathodes or ion guns, can be mounted on the access door.

Vacuum pumping of each chamber can be accomplished with individual pumping “stacks,” or the chambers may be joined to a common vacuum manifold. The chambers often use a common roughing manifold and each chamber has an individual high-vacuum pump. This can result in limitations on the use of the system. If two chambers at different pressures are opened to the roughing manifold at the same time, for example, gases from the higher-pressure chamber tend to enter the lower-pressure chamber. This may not be acceptable.

Transfer mechanisms are driven from outside the vacuum chamber by rotary-motion vacuum feed-throughs. The drive can be a positive mechanism, such as gear-and-sprocket, or it may be a friction drive, such as powered rollers. For tall fixtures, such as a vertical pallet fixture, it may be desirable to stabilize the moving fixture by having a fixture guide at both top and bottom. Transfer mechanisms and drive trains are often the operational weak points of an in-line system.

Sometimes a back-and-forth motion is desirable in the processing chamber. For example, the fixture might need to have multiple passes in front of a planar sputtering cathode and a linear ion gun, both in the same chamber. This allows periodic “atomic peening” of the growing film structure by inert gas ion bombardment to densify the film without requiring a bias on the substrate. Use of reactive ions allows reactive deposition by depositing a few monolayers of metal, followed by bombardment with a reactive species, such as oxygen or nitrogen. A back-and-forth motion requires the necessary chamber length, drive mechanism and position sensors.

Position sensors allow a “fail-safe” operation of the transfer mechanism. The fixture must be in the correct position for the process to begin or for a valve to close. Position sensors may operate by optical, mechanical, electrical or magnetic sensing.

Sensors in the system enable software to be programmed to allow automation of the motion and the processing. In high-throughput systems, movement of fixtures from one processing chamber to another or into or out of a transfer chamber are often coordinated to maximize efficiency. This can lead to an inflexibility in system use. This can be important if the system is also going to be used for development or process characterization. If this is a consideration, the software should be such that it can be reprogrammed easily. It may even be desirable to run the system in a manual mode, yet leave the fail-safe sensors operative.

In some modules, the substrates may be electrically isolated, or “floated,” so that a bias voltage can be applied to the fixture/substrates, or so a uniform self-bias can be created on the surface of a dielectric material. ***Note:*** *A dielectric surface that is being subjected to a flux of charged particles and is being held in a grounded metal fixture will often have a different surface potential near the edges than at the center because of surface charge leakage. This effect can be minimized by electrically isolating the fixture from ground.*

Electrical isolation can be provided to the entire fixture and transfer assembly or just to the part of the fixture that holds the substrates. If the entire fixture and transfer assembly is biased, the total area can be very much greater than just the substrate area. This wastes power and may cause operational problems. Electrical contact to just an area on the fixture that is electrically isolated from the rest of the fixture and the transfer mechanism can be done using brush-contacts or mechanically loaded make-break contacts that release before the fixture is moved.

Sometimes, redundant processing volumes, such as long processing chambers or dual cooling chambers, may be needed to allow for more processing time than is required by other processes. The cycle time-limiting processes need to be carefully considered in the design of the in-line processing system. P&SF