Vacuum Technology: In-Line Processing Systems

“In-line” processing systems use several processing chambers connected together to sequentially process the substrates. For example, the system can 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 Sub-Atmospheric 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 structures, 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 Figure 1.

In the “Valve Isolation” system 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 process is physically isolated from the other 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 1a shows a linear in-line system where it is relatively easy to change or add more processing stages.
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 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), and spring-loaded Teflon™ (350°C).

The "internal" (isolation) valves have no large pressure differential during the process sequencing. They can be simple "flap-valves" that 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 get into another processing chamber or if high vacuums are required for processing.

In-line systems are meant to operate continuously, so heat build-up 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. Since there is no convective heating in the vacuum chamber, this will minimize heating of the chamber walls. It may be desirable to actively cool seal areas if heat build-up 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 done with individual pumping "stacks," or the chambers may be joined to a common vacuum manifold. Often the chambers 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. For example: If two chambers at different pressures are opened to the roughing manifold at the same time, gases from the higher-pressure chamber will 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 feedthroughs. 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 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,
attention to the Russian work (Appendix I) that describes 2-layer AR coatings and providing the translations given in Appendix I.

References


Additional references:
5. P. Baumeister, communication 2003
10. R. Kanthack, p.5 in The Making of Reflecting Surfaces, A Discussion of The Physical Society of London and The Optical Society, 26th November (1920), Fleetway Press.

Appendix I

May 3, 2004
To: Don Mattox (by E-mail)
From: George Dobrowolski
Below is the Russian original and the English translation of the contents of the title page of the book which I am also appending in the form of a file for your interest:

Academician I.V. Grebenshchikov, A.G. Vaslov, B.S. Neporent, N.V. Suikobskaya


The book consists of 212 pages and is organized in 9 chapters with headings:
1. Physical basis for the antireflection effect
2. Mathematical theory of the antireflection effect of thin films
3. Physical properties of antireflection coatings and their control
4. Antireflection coating of silicate glasses using an etching method
5. Antireflection of glasses by deposition of silicon-organic solutions
6. Deposition of antireflection coatings through the deposition of fluoride vapors in a vacuum
7. Antireflection though the deposition onto the surface of a glass of monomolecular layers of organic materials
8. The manufacture of glasses with an enhanced reflection coefficient through the deposition of titanium dioxide layers
9. Antireflection coating through the deposition of two-layer coatings.

It contains 99 illustrations (some of equipment), tens of tables, and over a hundred references. Very impressive for a book which must have been written during the Second World War, if it was approved for publication in March of 1946 and came out later in the same year.

Mark Your Calendar!
Society of Vacuum Coaters 48th Annual Technical Conference
April 23–28, 2005
Adam’s Mark Denver Hotel, Denver, CO
Deadline for Abstracts is October 1, 2004