6.5 Optical-Coating-Deposition Technologies

The coating process takes place in an evaporation chamber with a fully controlled system for the specified requirements. Typical systems are depicted in Fig. 6.6. There are several basic technologies for coating optical elements. Each technology has its advantages and disadvantages, and suits different kinds of coatings. The technology is chosen by the coaters according to the stated optical and durability requirements of the coating. The following sections describe the technologies.

6.5.1 Evaporation (deposition) methods

Evaporation is a common method of thin film deposition. The source material is evaporated in a vacuum chamber after removing almost everything other than the source materials. The vacuum allows vapor particles to travel directly to the target object (the substrate to be coated), where they condense back to a solid state.

Evaporation involves two basic processes (Fig. 6.7) wherein a hot source material evaporates and condenses on the substrate (similar to how liquid water gathers on the lid of a boiling pot). However, the gaseous environment and heat source are different. In high vacuum, evaporated particles can travel directly to the deposition target without colliding with the background gas (by contrast, in the boiling pot example, the water vapor pushes the air out of the pot before it can reach the lid).

Any evaporation system includes a vacuum pump. It also includes an energy source that evaporates the material to be deposited. Many different energy sources exist, depending on the method.

- **Thermal evaporation method**: Metal wire is fed onto heated ceramic evaporators called "boats" due to their shape. A pool of melted metal forms in the boat cavity and evaporates into a cloud above the source.

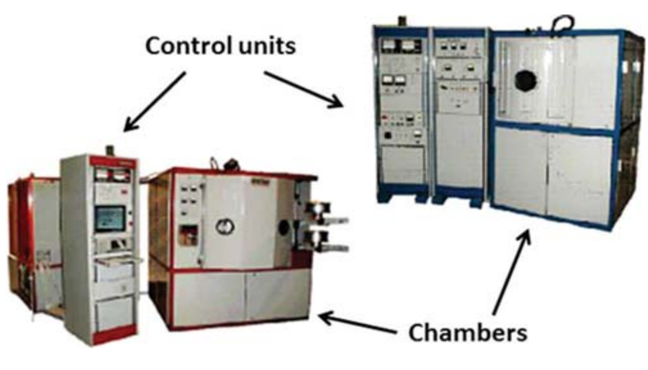

Figure 6.6 Typical systems for optical coatings. Image reprinted courtesy of Vecor, all rights reserved.

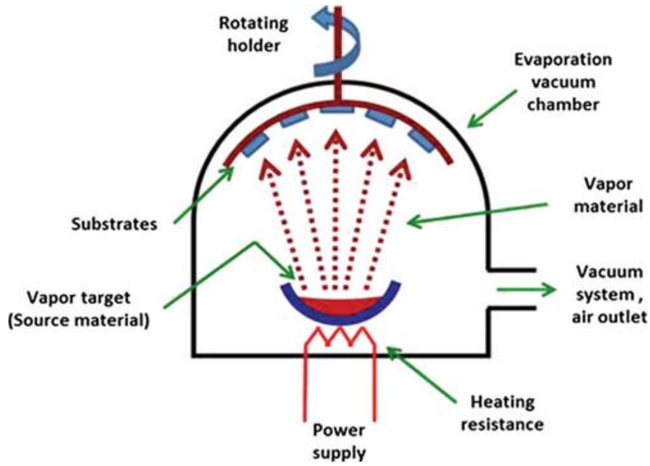

Figure 6.7 Evaporation of a common method of thin-film thermal deposition in a vacuum chamber.

Alternatively, the source material is placed in a crucible, which is heated by an electric filament.

- **Electron-beam evaporation method**: The source is heated by a single- or multi-crucible electron beam source with energy up to 15 kW. The use of multi-crucible electron beam sources allows the deposition of multi-layers of four or more materials; a quartz-crystal-thickness controller is used to program the multilayer as well as to automatically control the thickness and deposition rate of each layer. The system is normally equipped with a turbo-molecular pump of suitable pumping speed to evacuate the chamber to the high vacuum or ultra-high vacuum range. Optionally, an electron beam evaporation system can be equipped with an additional ion beam source for bombarding the substrates during deposition, i.e., **ion-beam-assisted deposition (IBAD)** or **ion-assisted deposition (IAD)**. In this technique, the coating material is produced using a high-power electron beam. Components are placed in the vapor, and individual coating atoms or molecules condense and stick on the surface of the component to form the coating. Simultaneously, highly energetic ions (100–2000 eV) are produced and directed at the component surface. The component is situated at the intersection of the coating material and ion beam.
- **Flash evaporation method**: A fine wire of source material is fed continuously onto a hot ceramic bar and evaporates on contact.
- **Resistive evaporation method**: This method is accomplished by passing a large current through a resistive wire or foil containing the material to be deposited. The heating element is often referred to as an "evaporation source."

Some systems mount the substrate to be coated on an out-of-plane planetary mechanism. The mechanism rotates the substrate simultaneously around two axes to reduce shadowing and create a uniform coating.

6.5.2 Sputter deposition methods

Sputter deposition is a physical vapor deposition process for depositing thin films; "sputtering" means ejecting material from a target and depositing it on a substrate. The target is the source material. Substrates are placed in a vacuum chamber and are pumped down to a prescribed process pressure. **Resputtering** is re-emission of the deposited material during the deposition process by ion or atom bombardment. Sputtered atoms ejected from the target have a wide energy distribution. The sputtered ions ballistically fly from the target in straight lines and energetically impact the substrates or vacuum chamber (causing resputtering). Alternatively, at higher gas pressures, the ions collide with the gas atoms that act as a moderator and move diffusively, reaching the substrates or vacuum chamber wall and condensing after undergoing a random walk. The sputtering gas is often an inert gas, such as argon. Reactive gases can also be used to sputter compounds. The compound can be formed on the target surface, in-flight, or on the substrate, depending on the process parameters. The availability of many parameters that control sputter deposition make it a complex process but also allow experts a large degree of control over the growth and microstructure of the film.

- **Ion beam sputtering**, also called IBS deposition (Fig. 6.8), is a method in which the target is external to the ion source. They are then accelerated by the electric field emanating from a grid toward a target. As the ions

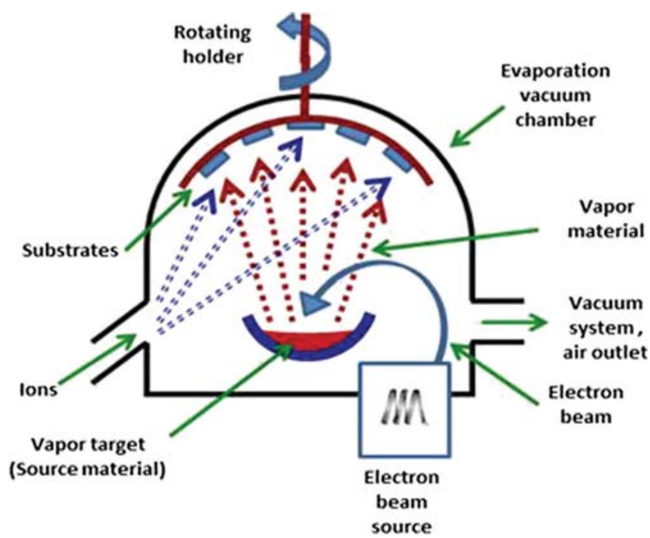

Figure 6.8 Ion-beam-sputtering deposition.

leave the source, they are neutralized by electrons from a second external filament. IBS has an advantage in that the energy and flux of ions can be controlled independently. Because the flux that strikes the target comprises neutral atoms, either insulating or conducting targets can be sputtered. A pressure gradient between the ion source and the sample chamber is generated by placing the gas inlet at the source and shooting through a tube into the sample chamber.

- **Magnetron sputter deposition** employs a **magnetron** that utilizes strong electric and magnetic fields to confine charged plasma particles close to the surface of the sputter target (the target is the source material). Substrates are placed in a vacuum chamber and are pumped down to a prescribed process pressure. Sputtering starts when a negative charge is applied to the target material, causing a plasma or glow discharge. Positively charged gas (such as argon) ions generated in the plasma region are attracted to the negatively biased target plate at a very high speed. This collision creates a momentum transfer and ejects atomic-size particles from the target. The sputter gas is typically an inert gas, such as argon. The extra argon ions created as a result of these collisions leads to a higher deposition rate.

6.5.3 Advanced plasma reactive sputtering (APRS)

APRS uses a magnetron to energetically remove atomic particulate from the surface of the target material. This technique results in a high level of control over the rate and energy of the deposition process, as well as enhanced structural characteristics in the coating itself. With this level of control, the APRS system is capable of producing precise optical coatings with over 200 layers.

The different names for the same methods can be confusing. The multiplicity is due to developments and improvement of the basic methods by coating-systems organizations or by the users of those systems. The coating process is generally not important for customers. What the coating specification requires is the optical and durability requirements, not a specific method.

6.6 Requirements

Requirements for optical coatings are stated in the drawing of the optical element or in the coating specification, and they are based on the functionality of the element and the environmental conditions of the operation. The drawing or the specification may include some of the following requirements:

Optical requirements

- Angles of incidence,
- Percentage of transmission at a specific wavelength,
- Average or absolute transmission at given wavelengths,

- Percentage of reflection at a specific wavelength,
- Average or absolute reflection at given wavelengths,
- Photonic transmission at a specific wavelength, and
- Percentage of improvement due to coating.

Durability requirements

- Adhesion,
- Humidity,
- Abrasion (moderate or severe),
- Temperature,
- Humidity,
- Salt spray,
- Salt solubility,
- Water solubility,
- Dust and sand,
- Rain erosion,
- Windscreen wiper action,
- Solvent resistance (solubility and cleanability),
- Fuel and oil resistance,
- Fungus, and
- Threshold laser damages.

Safety requirements

Some coating materials (Th_2F_4) may be radioactive. The best solution avoids these materials entirely. Such a preventative requirement should be stated in the coating specification. If for some reason dangerous materials are allowed, special considerations should be taken, i.e., procedures for handling optics containing dangerous materials.

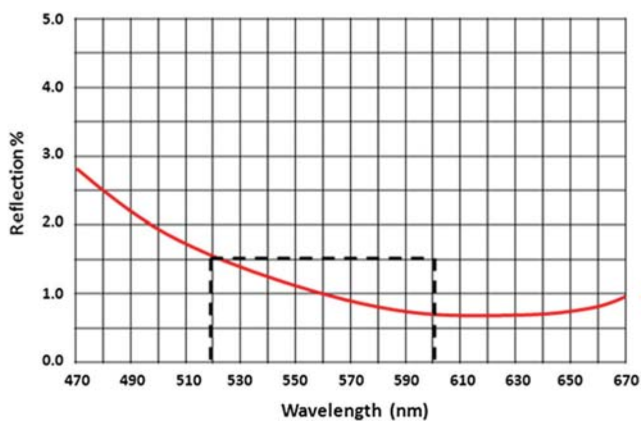

Figure 6.9 Reflection curve of an AR coating from one coated surface. The dashed line defines the specification's requirement of the maximum 1.5% average reflection at wavelengths between 520 nm to 600 nm.