SVC Topics

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PVD Processes: Anti-reflection Coatings

Anti-reflection (AR) coatings are used on optical* lenses and windows to decrease the amount of radiation reflected, thereby increasing the amount of radiation transmitted through the surface. They are a necessity when there are multiple interfaces between optical components, such as in photographic lenses.

A type of uncoated 50mm lens that has several lens elements glued together, for example, has a transmission of 52 percent, while the coated lens has a transmission of 96 percent (at 0.5 microns wavelength). Germanium, which is widely used as an infrared optical material, has a single-surface reflectance of 36 percent in the uncoated condition, and AR coatings are highly desirable. An AR coating is formed naturally on some glasses by aging; this was noted by Lord Rayleigh in 1887. Chemical techniques for forming an AR coating were developed in 1896, and vacuum-deposited AR coatings were developed in the 1930s.

Optical Properties of Materials

Material	Refractive index (0.55 µm)	Refractive index (2 µm)	Useful wavelength region (µm)
MgF_2	1.38	1.35	<0.2–5
SiO_2	1.46	1.44	0.2–8
SiO	1.55–2.0	1.5–1.85	0.8–7
Al_2O_3	1.6	1.55	0.2–7
CeO_2	2.35	2.2	0.5–5
ZrO_2	2.1	2.0	0.25–7
ZnS	2.35	2.2	0.4–15
TiO_2	2.3	2.2	0.4–12
Si	–	3.3	0.9–8
Ge	–	4.0	1.3–35
Glass	1.5–1.8	–	0.3–2.5

(strong absorption at 1 µm by the FeO content of glass)

Index of Refraction Determines Design of Coatings

The index of refraction (refractive index) of a material is the ratio of the velocity of light at a specific wavelength in vacuum to that in the material. The index of refraction varies with wavelength, and the value for a physical vapor-deposited (PVD) material can be different from that of the bulk material, because of compositional and/or density differences. The accompanying table lists the approximate index of refraction of various substrate materials and some coating materials at wavelengths of 550 millimicrons (visible) and 2 microns (infrared).

The reduction in reflectance is primarily caused by interference phenomena, and is a function of the wavelength of the incident radiation and of the angle of incidence of the light on the surface. The design of an AR coating depends on the index of refraction of the substrate (n_s), the film material(s) ($n_{1,2,3,4...}$) and the surrounding ambient (n_o). For a single layer that is a quarter-wavelength thick, the reflectance (R_λ) from the surface at normal incidence and at a wavelength λ, is:

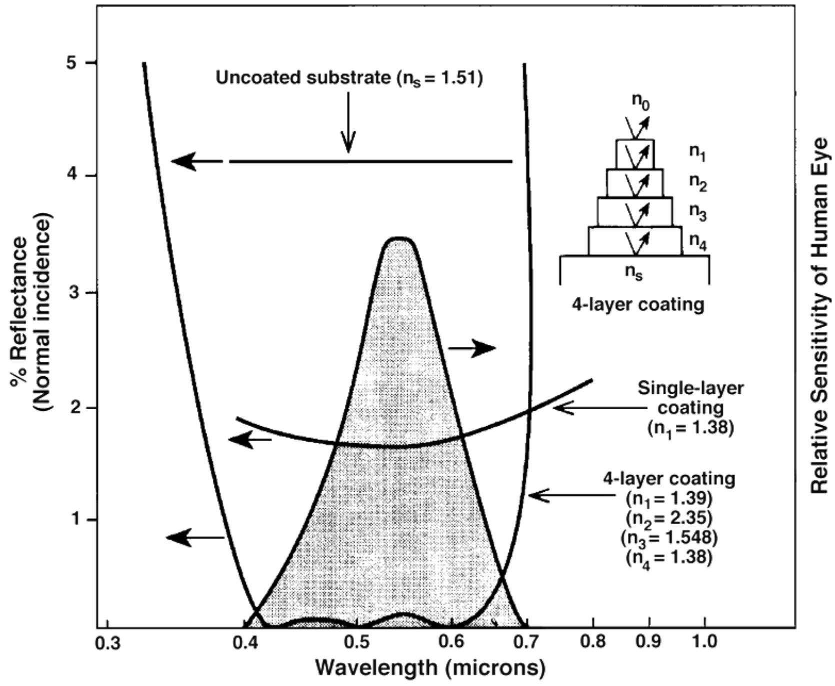
$$R_\lambda = ([n_1^2 - n_o n_s]/[n_1^2 + n_o n_s])^2$$

The figure shows the wavelength sensitivity of the human eye (0.4 to 0.7 microns) and the ability of a single anti-reflection layer to decrease the reflection, at normal incidence, from the surface of a glass (n_s=1.51). The reflectance without the coating is 4.1 percent. In order to have a broad wavelength range of low reflectance, multiple layers (stack) of high- and low-index-of-refraction materials must be used to form the AR coating.

To design a multilayer AR coating, recursion relations must be calculated—computer models are available to do these calculations. The design is made to match the desired wavelength region and the angle of incidence of the radiation. The thickness of each layer is often a multiple of quarter-wavelength. The coating, therefore, may be a quarter-quarter stack, a quarter-half-quarter-quarter stack, etc. The figure shows the effect of a four-layer AR coating on the reflectance of a surface at normal incidence. Note

**The optical spectrum is defined as the visible and near-visible wavelengths (radiation); the extreme limits are taken as 0.1 micron (ultraviolet) and 30 microns (infrared).*

***The electrical resistivity (R) of a conductor is given by: R = ∂L/A where ∂ is the bulk resistivity in ohm-cm, L is the length of the conductor in cm, and A is the cross-sectional area of the conductor in cm². For a square of coating material of thickness (t) and side-lengths of (L), the cross-sectional area becomes L x t and resistance from side-to-side of any size square will be the same. This gives rise to the common thin film resistivity unit of ohms/sq (called the sheet resistivity). To obtain the resistivity of the coating material in ohm-cm, film thickness must be known, but is usually meaningless in a multilayer film system.*



The effect of a four-layer AR coating on the reflectance of a surface at normal incidence. Note that the reflectance increases sharply outside visible wavelength region.

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Multilayer coatings can be designed to transmit (or reflect) over specific wavelength regions. These are known as long-wavelength-pass filters, short-wavelength-pass filters, and bandpass filters. Coatings can be designed to reflect only the visible light and transmit the infrared. These coatings are used on “cold light mirrors” to reduce the heating by high-intensity lighting, such as that found in television studios and hospital operating rooms.

Optical materials can be deposited by thermal evaporation, rf sputter deposition, reactive sputter deposition, reactive ion plating or ion beam assisted deposition (IBAD), usually using oxygen ions. The IBAD process yields the most dense and highest-index films.

For environmentally sensitive optical materials, such as some infrared materials, the AR coatings also provide corrosion protection, so a dense film is particularly desirable on these optics. In depositing optical coatings, the reflectance or transmittance of the growing film stack can be monitored during deposition and used to control the deposition process by comparing it to the calculated model.

Anti-reflection films can be combined with electrical conductivity for coating on video display terminals to decrease the reflected light and provide electrical conductivity for an antistatic coating.

For high-transmission AR coatings, indium-tin-oxide (ITO) films are most often used. The antistatic, anti-reflection coatings can be combined with a contrast-enhancement structure that uses adsorption to enhance the image contrast. These multipurpose films can use electrically conductive nitrides or metals for the electrical conductivity. One such stack is:

air	SiO_2	SiN_x	$NiCrN_x$	Ag	$NiCrN_x$	SiN_x	glass
	570Å	200Å	16Å	80Å	12Å	300Å	

This coating has an 80-percent visible transmission with a flat transmission curve, an average reflectance <0.3 percent, and a sheet resistance of 30 ohms/sq**. The SiO_2 layer is abrasion-resistant, and the SiN_x layer prevents oxidation of the $NiCrN_x$ layer during deposition and improves mechanical durability. ***P&SF***

Reference

J. Wolfe, “Anti-static, Anti-reflection Coatings Using Various Metal Layers,” SVC *38th Annual Tech. Conf. Proc.* (1995), p. 272. SVC Publications ISBN 0737-5921.