Chapter 4 – COATINGS

Technical developments in coatings for plastic optics have resulted in optical and durability characteristics once believed possible only with glass. These advances in coating technology include multilayer broadband antireflection coatings, narrowband laser antireflection coatings, coatings for front-surfaced mirrors used in the visible and infrared spectral regions, coatings for beam splitters and filters, transparent conductive films and abrasion-resistant coatings.

Full Reflective Coatings: Aluminized plastic formerly required a lacquer base coat that degraded surface quality and imaging. Now, high-precision parabolic, spherical and flat plastic mirrors are aluminized by vapor deposition without the need for basecoats, much in the manner that glass optical elements are coated. Mirrors produced for visible and infrared wavelengths are capable of meeting the reflectivity and hardness requirements of MIL-M-13508, thus giving them the same capabilities as glass for many applications.

Coating processes have been refined such that the mechanical integrity of the coating with temperature variation is limited only by the substrate material used, Fig. 4.1. Aluminum with a protective silicon-monoxide overcoat is the standard mirror coating for the visible spectrum; either aluminum or gold can be used for the infrared region. Additionally, vapor-deposited protective overcoats can be applied. For use in extremely harsh environmental conditions, and where image quality is not critical, organic oversprays such as lacquer can be used.

Typical applications for plastic optical mirrors include range-finder systems, aircraft heads-up displays, medical instruments, flight simulators and low-power laser mirrors. Since cleanability is equal to that of many glass mirrors, these coatings provide a long useful life.

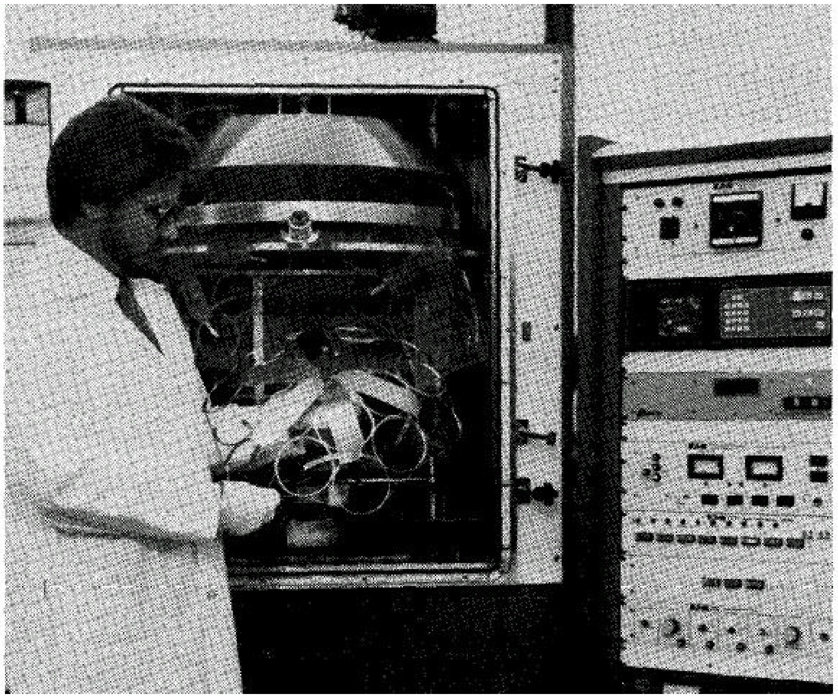


Fig. 4.1 - Like the plastic optics they process, coating pro-cedures and materials are highly sophisticated and proprietary.

For applications in the ultraviolet region, aluminum with a magnesium fluoride (MgF_2) overcoat is used. This process requires low subtrate temperatures; so the coating is soft, similar to ultraviolet aluminum on glass, and demands extreme handling care. These mirrors are recommended for use with wavelengths above 2400 Angstroms.

The cost for producing optical-grade plastic mirrors with MgF_2 coatings is similar to that of coating glass. The cost for smaller, high-precision lots would be higher than larger quantities because of the economics of scale. Although this coating may be costlier than the plastic substrate under some circumstances, the combined cost can be well under the combined cost of a glass with the same type of coating.

Antireflective Coatings: Since plastic optics are now used for fairly precise single and multiple-element lens systems, antireflection coatings on plastics are assuming an increasingly important function. Each plastic-to-air interface reflects a nominal 4% of incident light per surface, Fig. 4.2. Therefore, a 3-element lens has a light loss of 22% (.966). Not only does multiple surface reflection reduce light transmission, but it also causes lower image contrast and less definition. Several coating options are available for reducing reflection losses and increasing light transmission. Selection is based on wavelength, required efficiency (ratio of transmitted light to incident light), durability and cost.

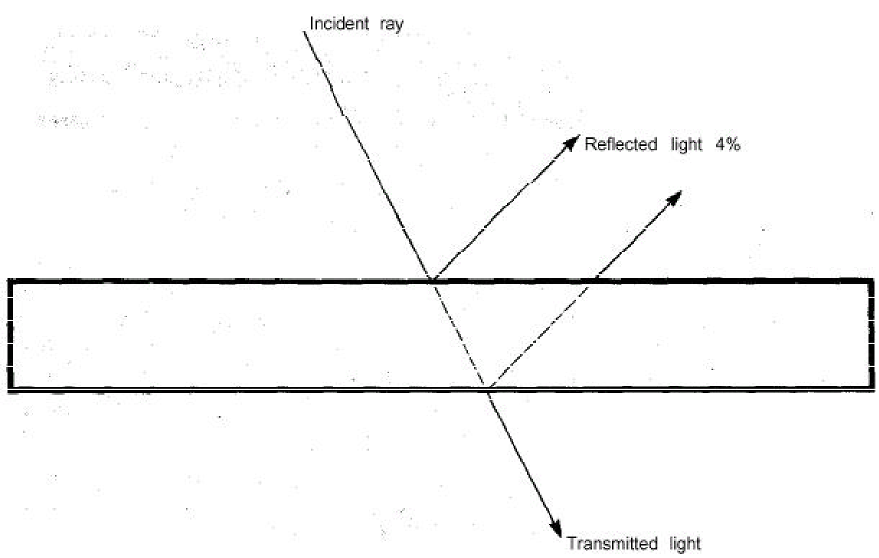
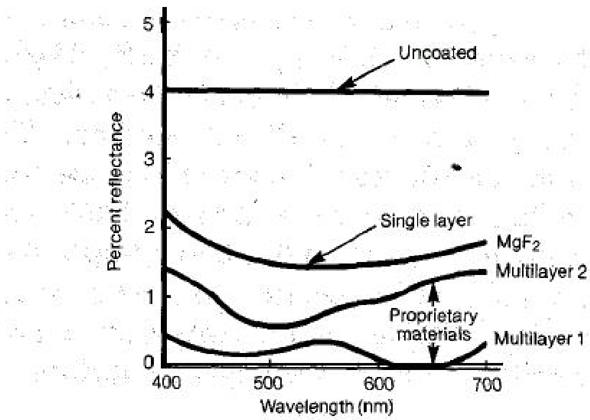


Fig. 4.2 Each plastic-air interface reflects a nominal percentage of incident light.

The simplest way to reduce surface reflection is to coat the optic surface with a single layer of MgF_2. MgF_2 has a refractive index of 1.38 and thus reduces the reflection loss of acrylic to approximately 1.6% per surface. Although this film is not highly efficient, it does reduce the total loss of a 3-element lens system from 22% to 9.1%, which is more than adequate for most applications. MgF_2 films tend to be extremely soft when deposited on plastic; and, therefore, consideration must be given to whether the optic will be sealed or exposed. Cleaning the coated surface is a difficult process which requires extreme care. MgF_2 can be deposited very economically, and therefore is applicable to low-cost systems requiring coatings.

Another option for reducing surface reflection is using a multilayer approach. Materials and processes used for multilayer coatings are largely proprietary and no detailed information is available. One proprietary coating has reflectance characteristics equal to that presently used on the most sophisticated glass optical elements. This coating reduces reflection losses to 0.5% or less. Although cost could be higher than that of the plastic element to which the coating is applied, the combined cost is still less than that of an expensive glass lens with the same coating.

Reducing reflectance to 0.5% or less per surface reduces the total reflectance of a three-element lens to 3%. This reduction is equivalent to a light transmission gain of over 20%, while the transmission-to-reflection ratio increases from 78:22 to 97:3. The durability of a multilayer antireflective coating is excellent. Although the coating cannot pass an eraser rub test, it will pass a cheesecloth test repeatedly. (The eraser rub test per MIL-C-675 uses an eraser mounted in a spring loaded fixture that provides a 2 lb. pressure. The eraser is rubbed over the lens surface 20 times. The cheesecloth test per MIL-M-13508 uses a l/2 in. thick pad of 3/S in. diameter cheesecloth rubbed on the surface with a l-lb force 50 times.)



Fig; 4.3 - A variety of coatings are available for meeting different spectral response, cost efficiency and durability requirements.

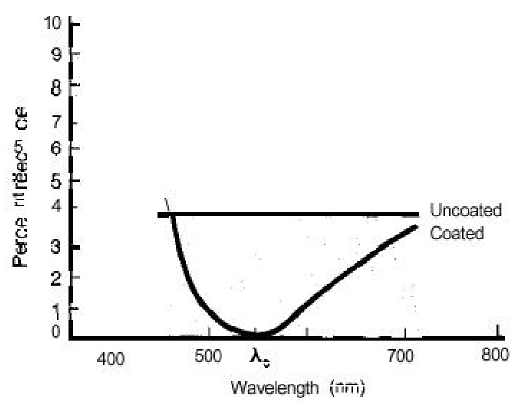


Fig. 4.4 - Narrowband coatings enhance optical transmission characteristics within specified wavelengths.

Other available broadband, antireflection coatings vary in efficiency, cost, hardness and other characteristics. The choice is based on user cost and durability requirements. Fig. 4.3 shows spectral curves for the MgF_2 single-layer film, a multilayer coating for meeting MIL-C-14806 optical reflectance requirements and another coating option.

whose cost, efficiency and durability lie between those of the other two materials. These antireflection coatings are presently used for cathode-ray tube, light-emitting diode and gas-discharge displays, plastic-lens systems for photography, printers and optical assemblies, and for computer and aircraft instrument windows. Antireflection coatings are also used for narrowband work such as in laser applications, which operate with a specific wavelength of light. The purpose of a narrowband coating is to reduce the reflectance of the specific wavelength down to 0.25% or less per surface, Fig. 4.4. The peak desired in the visible or near-infrared spectrum can be shifted to the desired wavelength by adjusting the composition of the coating. Typical wavelengths used are 436nm, 561nm, 633nm, 694nm, 870nm and 1.06 microns. A coating of this type can withstand over 100 rubs of the cheesecloth test in addition to a scotch-tape test on most substrates.

Beam Splitters or Partial Mirrors: A beam splitter is an optical device coated to reflect part of an incident beam while transmitting the balance. If the coating is metallic, it absorbs some of the light energy. The ratio of light to be reflected versus the amount transmitted is controlled by process parameters.

Beam splitters are specified by the reflectance/transmittance ratio. For example, a 30/70 beam splitter reflects 30% of the incident light and transmits 70%. A 50/50 beam splitter divides the light beam in half. Durability of these types of coatings is similar to that of a flat surface aluminum mirror on glass. Cost depends on the amount of light to be reflected, since a higher reflection dictates a more complicated filming process.

Transparent Conductive Coatings: These coatings are not a primary concern in most optical system designs. However their need does arise in some special applications.

EMI/RFI shielding: In some applications a lens, CRT display or meter bezel can admit radio frequency or electromagnetic interference to sensitive electronic circuits. In these cases, the optical elements can be coated with a material that can be grounded to the rest of the instrument while still exhibiting high light transmittance. By coating the element with an extremely thin vapor-deposited gold him in combination with other proprietary materials, it is possible to obtain a surface resistance of 15 ohms per square while transmitting 75% of incident light. Electrostatic shielding is also provided by sputtering indium tin oxide (ITO) coatings onto the plastic to get 100 ohms per square surface resistance at an 85% transmittance. Similar films have been reported giving 10 ohms per square with 80% light transmittance.

Antistatic evaporated films are- effective for reducing surface resistance to 1 megohm per square or less while maintaining a neutral color and approximately 85% transmittance. This process is a permanent solution to the prob-lem of static charge. However, high cost may be prohibitive for some applications.

For highly cost-sensitive applications, a commercially available dip or spray antistatic agent may be the best solution. Although these destaticizing agents are not permanent, they can be reapplied with an impregnated cloth. These agents should not be applied over other optical coatings, however, since they can change their optical characteristics.

Abrasion-Resistant Coatings: Most development activity for antiabrasion coatings has concentrated on coatings for large sheet substrates. Some coatings reportedly withstand steel-wool abrasions without damage. The materials used either harden the substrate surfaces or lower surface friction to minimize scratching.

This same technology has been used on curved surfaces. These coatings are applied mainly by spraying, dipping or spinning. They are generally not applied to precision optical surfaces. Unless extreme care is exercised, these processes are vulnerable to the accumulation of congealed particles, dust and coating build-up around the edges and near the apex of the curved surfaces.

Other methods under development for coating smaller, more precise surfaces include evaporation, sputtering and chemical vapor deposition. Successful evaporation techniques have been developed for applying anti-abrasion coatings to some plastic substrates. Precise thickness control eliminates film variation and, because of low process temperatures, lenses can be uniformly coated without changing their configuration or optical characteristics. Hardness of some abrasion-resistant coatings approach that of glass. Although vapor-deposited coatings are more expensive than a dipped coating, they are an undeniable asset for many high-quality lens systems. Exotic or very special coating requirements are more often satisfied by the coating specialist rather than the optic supplier.

It is recommended to consult with several coating companies at an early stage in the optical system development. Moreover, the user should direct all inquiries to companies whose sole interest is coatings for plastic optics, which is a highly specialized technology not shared by all coating firms. The coating specialist can provide information regarding the various materials available, together with their optical, chemical and mechanical characteristics and cost. New technologies and development work is expected to continue to advance the state-of-the-art of optical coatings for plastics.