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Coating Materials News

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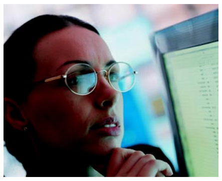
Selecting Materials for Specific Optical Coating Designs



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Optical surfaces are coated with functional multi-layer designs for a variety of purposes. The most common function is to reduce surface reflection. Another common coating is used for metal mirrors. High volume coating of architectural glass for thermal control is a major industry. These are but a small sample of the many functional applications for optical coatings. The materials suitable for a specific coating design are chosen according to the substrate material's properties, the environment in which the coated surface will be operated, optical performance, and cost of production. A table of materials and combinations appears in the *Photonics Handbook* [1]. Some general applications of thin films have been presented in a previous issues of *CMN* [2]. Here, we review some typical optical applications and the recommended materials.

AR Coatings for Glass and Plastics, Including Ophthalmic Applications

Inside:

The commonly used materials for AR coatings are silicon dioxide and titanium dioxide because they provide a high refractive index contrast and are easily evaporated or sputtered. The most efficient coating that covers the visible range, 420 nm to 680 nm, requires an index intermediate to the 2.2 and 1.44 values. This can be synthesized from the titania and silica, or by adding a third material such as aluminum oxide, yttrium oxide, or a mixed material. Strong adhesion to polymer surfaces requires special pre-processing of the surface, a step we have discussed in detail in past *CMN* issues. Briefly, a thin layer of an oxygen active material such as CrO_x may be used. Another procedure is to establish reactive bonds in the surface with an energetic plasma of oxygen or nitrogen, depending on the polymer chemistry.

Mirror Coatings

Aluminum is most frequently used in mirror coatings because of its superior long-term stability compared with silver. The metallization is on the back surface for protection of the soft metal. Millions of data and music CDs and DVDs are metallized with alloys of silver or aluminum. First-surface mirrors of great hardness and scratch resistance use chromium or rhodium, trading for the lower reflectance of these metals. Examples are the rear-viewing mirrors on cars. Active mirrors that change reflectivity in response to incident light level are used on the rear-viewing mirrors on some newer vehicles. These mirror structures include an electrically controlled layer whose transparency can be altered by changing the applied voltage. Spectrally selective mirrors produce colored reflections through the use of all-dielectric multi-layer designs that reflect a band of wavelengths within the spectrum. The transmitted energy in the remainder of the spectrum might be used in a system or absorbed. Such mirrors are known as 'dichroic' mirrors. A common application is to separate

continued on page 2

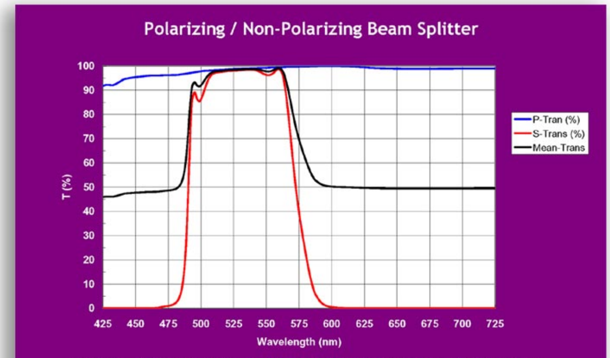

Figure 1. Beamsplitter that produces both polarized and unpolarized light.

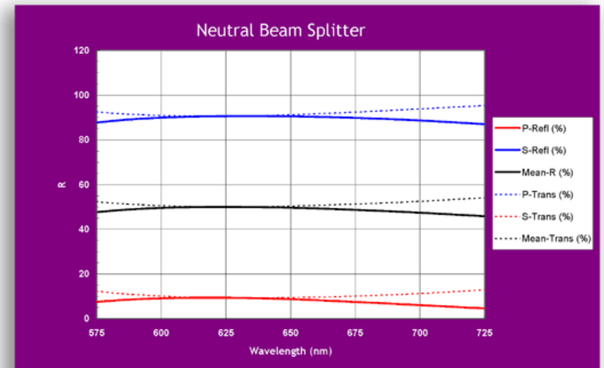

Figure 2. Neutral 45° beamsplitter with equal R (solid) and T (dashed) values.

Selecting Materials for Optical Coatings from page 1

useable visible light from the total irradiated energy that might contain a high proportion of infrared energy that, if passed would result in undesired heating. The varieties are 'hot'- and 'cold-mirrors'. Applications include dental mirrors and image projection systems. Here again, titanium dioxide and silicon dioxide layers are the materials commonly used for the visible region. Coatings intended for UV applications will substitute hafnium dioxide and silicon dioxide, which are non-absorbing to near 200 nm wavelength.

Bandpass Filters

If the reflected or transmitted band is narrow and spectrally centered, the multi-layer is known as a bandpass filter. Very narrow BPFs with high rejection of out-of-band energy are technologically the most advanced and difficult filters to produce. Wavelength division multiplexing filters (WDM) having sub-nm bandwidths are constructed of more than 100 layers.

The coating materials used to make filters for the visible region are titanium dioxide and silicon dioxide. For wavelengths above 900 nm, tantalum pentoxide is the preferred high-index material because titania has some absorption in the 900 to 1100 nm region and because the morphology (crystallinity) of Ta_2O_5 is easier to control than that of TiO_2. Oxide compounds can be used to near 2000 nm wavelength before their bonds begin to absorb significantly. Some are useable in thin layers to wavelengths ~9 m. Examples include hafnium dioxide, tantalum pentoxide, yttrium oxide, and aluminum oxide. Silicon dioxide is also useable when its layers are grown with techniques that result in low intrinsic stress.

Beam Splitters

Diagnostic and analytical instruments use dichroic beam splitters that divide the spectrum into reflected and transmitted parts, but the compact portable digital projection industry is the largest user. The beam splitters can be in the form of plates or immersed in a cube, and they might have specific polarization requirements for the separation / combination optical paths in projectors. The polarizing beamsplitter separates incoming light into linearly polarized components: S reflected and P transmitted. There are limitations and trade-offs to be made with regard to spectral bandwidth, degree of polarization separation, and acceptance angle. Very high polarization ratios can be achieved for narrow bandwidth (20 nm) and small incidence angle (<1°). The refractive indices of the high and low layers and the glass substrate are important variables that impact the achievable performance. Commonly Al_2O_3 and SiO_2 are used. An interesting example of a beam splitter that produces both highly polarized and unpolarized light is shown in Figure 1.

The design of Figure 1 has only 15 layers and is immersed in a fused silica prism. The extinction ratio is >18,000:1 near 650 nm, and the polarizance is 99.99%. At 530 nm, the residual polarizance is <0.2%. The acceptance angle is ~1°.

Neutral Beam Splitters

Often an equal division of light intensity is required to be sent into two directions. For this purpose, a beamsplitter that reflects and transmits beams equally over a wide spectral region is desired. Thin metal films of nickel or nichrome with approximately spectrally neutral absorption are frequently used. Dielectric films can be added to both sides of the film to assist in flattening the spectrum. Shown in Figure 2 is a 5-layer all-dielectric beamsplitter with equal T and R values over a limited spectral region and absorptance =0. The acceptance angle is ~1°.

There are countless examples of thin-film coating designs but only limited choices of suitable coating materials. Selecting the proven combinations saves development time for the coater.

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Deposition and Film Growth Processes

Faithful readers of *CMN* who are practitioners in the technology of thin film coatings are well aware that deposition processes are as important as material selection. We review here the highlights and refer readers to previous discussions. The growth from the vapor state of dense, stable thin film layers that possess the desired optical properties and physical durability is actually a complicated process, as we have discussed in *CMN* [3]. The surface onto which the vapor species condenses must have the correct surface energy to promote chemical and physical bonding. In addition, the vapor adatoms must arrive with sufficient energy to provide free mobility on the surface. The surface cannot contain contaminants that tie up potential bonds that are intended for the adatoms condensing on it. Energy required for mobility and often for cleaning is present in the higher energy deposition processes that involve ions; these include sputtering (~1-10 eV) and Ion Assisted Deposition, IAD, (50 – 200 eV). Thermal processes such as resistance-heated and electron-beam evaporation are low energy (<1 eV) processes, and generally require substrate temperatures higher than 200° C to achieve strong adhesion and dense growth. *CMN* has discussed the topic of ion beam assisted deposition previously [4].

Much work has been published relating the advantages of high-energy ion processes and the mechanisms involved in improving film microstructure and with that the optical and mechanical properties. IAD growth kinetics are easily visualized with thin metal depositions, for example with silver film growth [5]. Low energy deposition promotes crystallite island formation in the early stages of nucleation due to low surface mobility. The addition of kinetic energy through ion bombardment causes these islands to grow as mobile adatoms are captured. With sufficient surface energy, mobility is high enough to promote coalescence to a continuous film of small thickness, thus increasing the packing density. If the kinetic energy delivered to the surface is below a certain threshold and the ion current density is low, mobility is limited and empty zones can develop around the larger crystallites as local adatoms are captured. This leads to porous films.

The parameters important in IAD processes are: the ion energy and the ion-to-atom (I/A) arrival rate ratio or current density. Ion energies >~500 eV result in etching/sputtering of some materials, creating pores. Ion/atom rates will vary with the amount of inert and reactive gas used. For pure oxygen, I/A should be >0.1; for Ar, ~0.25, however this parameter is not independent of the other parameters.

Another technique for producing high quality films, i.e., layers with high packing density, stable optical properties, and strong, low-stress mechanical behavior is to deposit materials that tend to grow in non-crystalline structures. As we have seen, materials that condense to grow columns — a propensity for refractory oxides, fluorides, and sulfides / selenides — have a microstructure that is not densely packed. There is a large internal void volume that can absorb moisture, resulting in unstable optical and mechanical properties. The desirable alternative is an amorphous microstructure that inherently is denser, in similarity to IAD-grown films. It has been shown that starting with “doped” materials produces film layers that are amorphous or amorphous-like, and thus exhibit superior properties. Many mixtures of materials that produce a range of refractive indices are available for the coating designer.

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