Specifying Coatings for Military and Aerospace Applications

Optics are employed in virtually every area of military operations, from vision systems and target designators used by troops on the ground, through guidance systems utilized in both manned and unmanned aircraft, to reconnaissance and surveillance packages carried by satellites in Earth orbit. These optics are often subjected to large variations in ambient temperature and humidity, as well as contact with abrasive or corrosive materials (such as sand or salt spray). Thin film coatings, which are almost universally required on military optics, must be able to physically withstand these stressors, as well as deliver their design performance in an environment where "failure is not an option." But, increasingly, achieving these ends must also be balanced with cost.

Coating Physical Characteristics

An optical thin film consists of one or more layers of coating material, with individual layer thicknesses typically ranging from a few nanometers to several microns. Achieving target performance requires tight control of deposition to produce the desired sequence, uniformity, material thicknesses and indices of refraction of these layers.

In the broadest terms, there are three basic technologies in use for producing the majority of optical thin films, namely: evaporation, sputtering and chemical vapor deposition. And, for each technology there are numerous vendor-specific variations. Each of these methods has its place, and there is no one approach that is best for every application.

DSI Coating Capabilities Comparison Overview

	MicroDyn® Sputtering	IsoDyn®LPCVD	Electron Beam Evaporation
Maximum film survival temperature	1000°C	1200°C	300°C
Abrasion resistance	Excellent	Excellent	Good
Humidity resistance	Excellent	Excellent	Excellent
Wet/dry spectral shift	None	None	None
Scatter & absorption	Fair	Excellent	Good
Survive LN2 dunk	Yes	Yes	Yes
Precision*	Good	Fair	Excellent
Laser damage	Good	Excellent	Fair
Cost in high volume	Good	Good	Fair
Available spectral range	Near UV — MWIR	Near UV — MWIR	MWIR — LWIR
Functionality	Narrowband and broadband AR, HR. beamsplitters & filters	Broadband AR and HR	Narrowband and broadband AR, HR. beamsplitters & filters

*The ability to duplicate the target design performance, particularly the placement of a band edge, in the actual film

Because of the different available variations, it's impossible to completely generalize the discussion of how various methods compare. So, instead we compare here the specific forms of the three basic technologies as currently utilized at Deposition Sciences, Inc. These are evaporation (in this case limited to mid-wave to long-wave IR materials), a form of reactive magnetron sputtering called MicroDyn®, and a low pressure chemical vapor deposition (LPCVD) technique referred to as IsoDyn®.

For most military applications, there are a few key parameters which are most critical to proper coating performance. The first of these is coating hardness. Hard coatings resist damage due to repeated cleaning or abrasion from particulates like sand. Here, there is a progression from evaporation, which produces the least dense and softest films, through to sputtering and LPCVD which both produce highly densified, hard coatings.

Higher coating density, or more precisely, lower porosity, also prevents water molecules from entering the film when it is exposed to high humidity. Moisture absorption changes layer refractive index, which shifts the coating performance curve to longer wavelengths. This so called "wet/dry shift" is generally not a problem in broadband coatings, such as antireflection (AR) and most high reflection coatings, but can have a serious impact on coatings intended for narrowband performance or those with a sharp band edge. Examples of these are bandpass filters, edge (short or long wave pass) filters and notch filters (which reflect a single laser wavelength and transmit everything else). These are all coatings widely employed in military systems, including target designators, multispectral imaging sensors, and countermeasures.

In general, evaporation does produce somewhat more porous coatings than either MicroDyn® or IsoDyn®. However, for the particular spectral range (mid-wave to long-wave IR) and materials involved in DSI military optics, wet/dry shift is not an issue in evaporative films, and all three technologies deliver acceptable performance for this metric.

Another issue is internal film stress. Coatings typically exhibit compressive residual stress, and more rarely, tensile stress. Generally, higher compressive stress correlates with better durability, unless it is so high that it overcomes the adhesion to substrate, which can result in catastrophic failure for thicker coatings. Evaporation, which is a lower energy process, produces coatings with the least stress, followed by the higher energy deposition methods of MicroDyn® and then IsoDyn®.

Coating surface roughness and bulk scatter characteristics are an additional consideration. Scatter produces stray light, which lowers optical efficiency, reduces image contrast and lowers signal-to-noise ratio. In this case, MicroDyn® tends to deliver films with greater surface roughness than evaporation, while IsoDyn® again provides the best characteristics.

Included with this article is a table that summarizes the key characteristics of DSI's fabrication technologies for military applications. While IsoDyn® appears to deliver the best results in nearly all cases, it's also important to note that it utilizes a small material set and has coating thickness constraints due to the high stress inherent in its deposition process. This limits its use principally to broadband antireflection coatings and high reflectors, as it does not readily produce bandpass filters, edge filters or other complex designs with tight design tolerances that require a large number of layers. IsoDyn® also utilizes high processing temperatures, which does increase durability but limits the selection of substrate material that can be coated.

Optical Performance vs. Cost

In the most general terms, coatings become more expensive to fabricate as the number of layers increases and/or the index and thickness tolerances on those layers become tighter. Obviously, the goal of the coating specifier is to ensure that the component meets its performance targets, but it's important to make sure that specifications are framed in a way that doesn't needlessly drive up cost.

One area where this sometimes happens is with narrow and wide bandpass filters and edge filters (long wave pass and short wave pass filters), which are all utilized extensively in military applications. Two of the key specifications for edge and wide bandpass filters are the half-power point (HPP) placement tolerance and the slope steepness. For narrow bandpass filters, it is center wavelength (CWL) and full-width at half-maximum (FWHM).

Another key performance requirement is out of band blocking (OBB). This may be specified to start at the first 1% or 0.1% point on either side of the bandpass, or sometimes at a given wavelength away from the half-power point, or even at a particular wavelength. It may be specified as a maximum value, average value, or total integrated power within the blocking range. These and other relevant parameters for edge and bandpass filters are defined in Figures 1 and 2.

For mid-wave IR and long-wave IR edge and wide bandpass filters commonly produced at DSI for military uses, a HPP (or CWL) tolerance of ±0.5% (of the wavelength value) or higher is relatively routine, while tighter specifications tend to drive up cost. Similarly, slopes of 2% or greater are standard; smaller (steeper) values are more difficult. Thus, if there is a large separation between the wavelengths to be passed and rejected in a system, it's important not to put arbitrarily tight constraints on these values.

The out of band blocking specifications can also drive cost. Here it's necessary to state whether the blocking specification is an average value over the entire blocking band, or a mini-

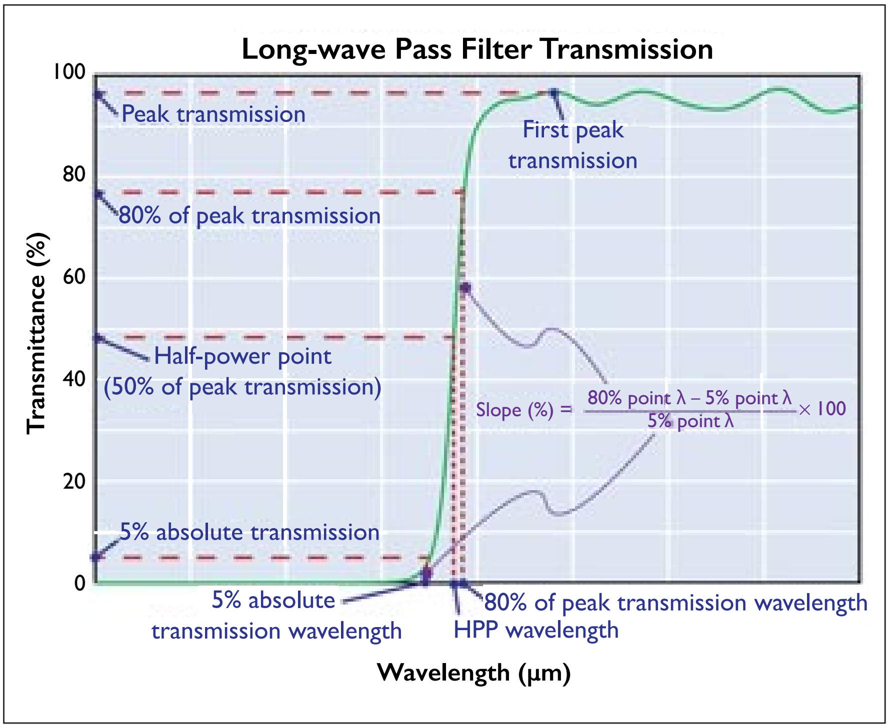

Figure 1. Definitions of edge filter performance parameters.

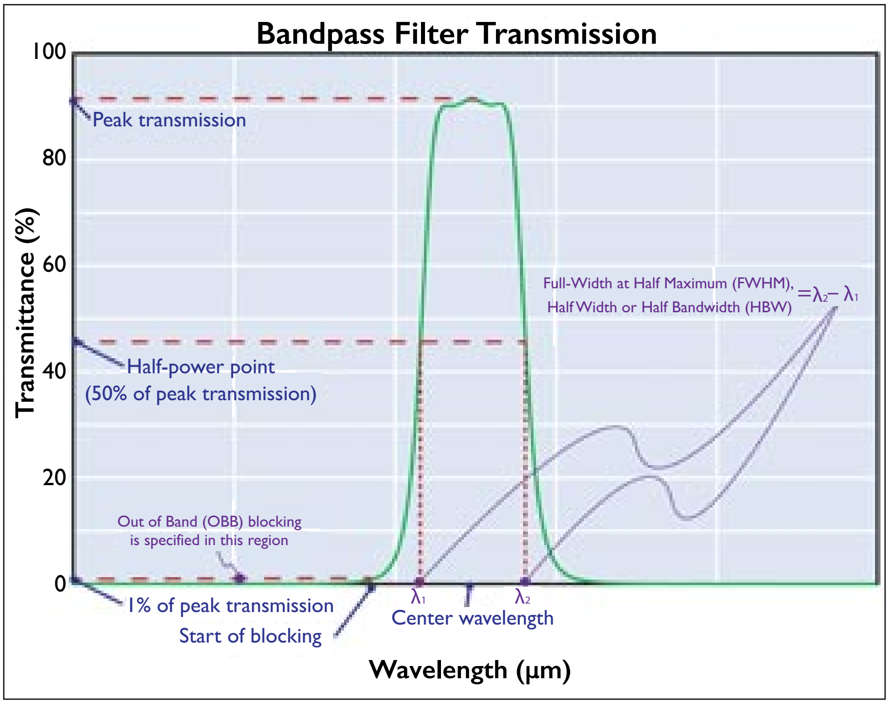

Figure 2. Definitions of narrow bandpass filter performance parameters.

mum threshold value. In many military systems, what is really required is blocking just at certain key wavelengths or wavelength bands. In this case, these are what should be called out, and it should be made clear that blocking at other wavelengths isn't as critical. This can simplify the coating design and lower the fabrication cost.

Another important — and often misunderstood — specification for coated optics is flatness. First, it's important to realize that virtually all optics vendors nominally specify component flatness prior to coating. The mechanical stress inherent in optical coatings (which, again, is typically higher in denser, harder coatings) can easily degrade the surface figure of a nominal λ/10 flatness component by an order of magnitude.

There are a couple of additional important considerations when defining flatness specifications. First, if an optic is being used solely in transmission, the surface flatness shouldn't be specified at all. Rather, the relevant specification is wavefront distortion on transmission, a parameter which is much less sensitive to degradation caused by coating stress.

The other factor to be aware of is that flatness tends to be much more of an issue with certain specific types of coatings. In particular, it's most pronounced when there are coatings with substantially different thicknesses (and therefore stress characteristics) on two sides of a thin optic. So, a window which has the same antireflection coating on both surfaces usually does not experience a problem. But dichroic beamsplitters, which have a thick long (or short)-wave pass filter coating on one surface and a much thinner antireflection coating on the other surface do often exhibit significant flatness degradation due to the differential stress effects between the two sides of the optic. Here it's not uncommon to add layers to the antireflection coating which change its mechanical stress characteristics without altering its spectral performance. However, producing such components in practice typically requires an iterative series of test runs in order to optimize the performance, and this adds cost.

Conclusion

Military optics have a lot in common with commercial optics. However, although their performance and environmental specifications are similar, the requirements for military applications are generally more stringent and the need to rigorously hit the target with those parameters is more critical. An understanding of how optical coatings are made and how they are best specified can reduce the impact these more stringent requirements have on the cost of the optics.

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