With the variety of choices available, it can be a daunting task to specify and choose the right optic for a given application. Manufacturers offer most optical components in an array of shapes and sizes and even off-the-shelf catalog components have many features that should be taken into consideration before an order is placed. Specifications of significant concern include outer diameter, damage threshold, bandwidth, angle of incidence, polarization, and reflectivity.

An easy decision can end up being the wrong decision if factors such as clear aperture, angle of incidence, and access to suitable mounts are not taken into consideration. A typical 1-in.-diameter optic, for example, will have a clear aperture of about 22 mm at normal incidence, accommodating any beam smaller than that. The same optic used at an incident angle of 45° will only accommodate a round beam up to 15.5 mm in diameter. The obvious choice might be to use elliptical or rectangular substrates for all applications at 45°, but for substrates in shapes other than round, polishing costs are higher and the selection of mounts is limited, making them a poor choice for many applications (see figure 1). Unless there is a spatial constraint to the optical setup, a suitably large round substrate can generally meet the requirements with lower cost and shorter lead time.

For imaging and laser focusing applications, surface quality and surface figure need to be clearly defined to meet damage threshold, wavefront, and scatter loss requirements. Most high-energy laser systems require substrates with a surface quality of 10-5 or better, meaning that the polished surfaces will have no scratch greater than 10 μm in width and no dig greater than 5 μm in diameter. An uncoated fused-silica lens polished to a 10-5 surface can withstand energies of more than 40 J/cm² at 1064 nm. Commercial-grade optics with scratch/dig specs of 60-40 or 40-20 cost less and may be perfectly suitable for research and low-energy applications.

**Antireflection Coatings**

Coatings can be used to enhance the performance and lifetime of an optical component. For transmissive optics such as lenses, windows, waveplates, and prisms, a thin-film dielectric antireflection (AR) coating can increase the overall transmission through the optic by as much as 4% per surface, while minimizing stray light and back reflections throughout the system.

The Fresnel equation gives the reflectance \( R \) in air \((n = 1.0)\) off an uncoated glass surface at normal incidence as:

\[
R = \left(\frac{n - 1}{n + 1}\right)^2
\]

where \( n \) is the refractive index of the substrate material. For BK7 glass at 633 nm, \( n = 1.5151 \), so \( R = 4.2\% \); this results in a total loss of more than 8% of the initial power. An AR coating can reduce the reflectance per surface to 0.1% to 2.0%, depending on the design chosen.

Three types of AR coating designs are most often used. Multilayer V-coatings, which take their name from the V-shape of the reflectance, are narrowband, durable, and damage resistant (see figure 2). They can be designed for use at almost any UV/near-IR (NIR) wavelength to achieve reflectance below 0.25% per surface at normal incidence.

Broadband multilayer AR coatings are used to optimize transmission over several wavelengths or wavelength regions within a limited range. These coatings provide an average reflectance of less than 0.5% per surface over 100 to 200 nm, depending on the substrate material and wavelength region being covered, which...
improves overall transmission by more than 7% through two surfaces. The most broadband of the three readily available options is a single-layer magnesium-fluoride (SLMF) AR coating. With $n = 1.38$, the SLMF coating is an excellent and inexpensive coating choice for use on high-index materials such as sapphire and SF10 glass. An SLMF coating on these materials can easily achieve normal-incidence reflectance of less than 0.25% without sacrificing either durability or bandwidth.

Dielectric and metal coatings can be applied to flat and curved substrates in order to reflect, redirect, or focus light. Metal coatings such as gold, silver, and aluminum are primarily useful for reflecting very-broadband light sources with low energies (less than 100 mJ/cm²) over incident angles ranging from 0 to 60°. These coatings often have a protective dielectric layer to increase the durability and lifetime of the coating, and can be enhanced with a multilayer dielectric stack to increase reflectivity in the UV or visible regions. Metal coatings are still sensitive to moisture and/or scratches, so they are generally not used in abrasive environments or systems in which the optics require frequent cleaning or handling.

High-energy laser mirrors use all-dielectric coating stacks to achieve very-high reflectivity at a single wavelength or over a narrow bandwidth and incident angle. Depending on the substrate material and wavelength of operation, damage thresholds of 10 to 20 J/cm² and reflectivity of greater than 99.5% are standard for normal-incidence mirrors (see figure 3). At 45°, S-polarized light reflects more and is more broadband than P-polarized light, so it is important to identify the correct component and polarization state when ordering or determining optical component specifications.

When bandwidth is a higher priority than damage threshold, alternate coating materials can be used in the visible and NIR spectral regions to create highly reflective mirrors with low dispersion and minimal pulse distortion. Coating designs can also be modified to create mirrors with high reflectivity at two distinct wavelengths or over much broader bandwidths or angles of incidence than can be achieved with "single-stack" designs.

Polarization Optics
When polarization is a concern, linear and birefringent polarizers can be used to remove, reflect, or refract one of the polarization components. The choice between a calcite polarizer, a thin-film plate polarizer, or a polarizing beamsplitter cube depends on the bandwidth and energy levels of the input light. A cemented beamsplitter cube works well for low-energy applications in which both components of light are to be utilized. These are available at many wavelengths, from the UV to the NIR, in both narrow and broadband varieties with damage thresholds up to 100 mJ/cm² and transmitted extinction ratios of 1000:1. Higher extinction ratios on the order of 10⁵:1 over very broad bandwidths can be achieved using birefringent calcite or magnesium-fluoride Rochon polarizers. Damage thresholds on these vary from 10 mJ/cm² to 1 J/cm² depending on whether the rejected beam is absorbed or removed through an escape window, and whether the assembly design is cemented or air-spaced.

For fluences of a joule or more, a plate polarizer or an optically contacted polarizing beamsplitter cube can be used to avoid damage due to cement or tracking within calcite material; both types of polarizers reflect the S-polarized light and can be used for high-energy laser applications. Plate polarizers exhibit group-velocity dispersion and so are often used in ultrafast systems, but usually need to be angle tuned to maximize transmission and extinction ratio. Polarizing beamsplitter cubes require no angle tuning and the transmitted and reflected beams are separated by 90°, but they are often more expensive and limited to dimensions of an inch or less.

To get the most from your optical component budget, give consideration to functionality and manufacturability as well as the mechanical and optical specifications of each component.

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