TEST talk

Scattered Thoughts

Understanding the nuances of a scatter measurement may be the key to an accurate stray light simulation.

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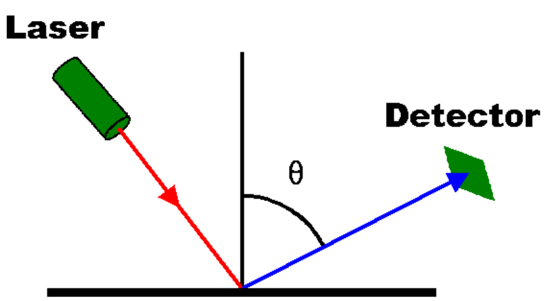
Every optical device, regardless of its complexity, is affected by stray light to one extent or another. The ghost images and contrast reduction we experience visually provide us with compelling evidence of its negative impact. It should come as no surprise that sophisticated optical instruments are every bit as susceptible to the effects of stray light as are our eyes. Consequently, stray light analysis has become an increasingly important ingredient in the design process

Optical scatter plays a major role in stray light simulations. An essential element of any scatter simulation is the bi-directional scatter distribution function (BSDF), which describes the angular distribution of light scattered from an optical or mechanical component. Incident angle, wavelength, and a host of material properties dictate the observed pattern. Depending upon sample type and application, the BSDF can be either transmissive (BTDF), reflective (BRDF), or some combination of both.



In a scatterometer, a light source illuminates the surface under test at a fixed angle while the system scans a detector over the selected hemisphere.

The optics community has been quite successful in developing a set of BSDF models that faithfully represent the scatter patterns generated by the microscopic scratches, machining marks, and sub-surface defects common to all optical surfaces. These "smooth" surface models obey reciprocity rules, meaning the incident and scattered angles can be reversed with no effect. The Harvey model is the most notable with its specular peak and exponential falloff. Most paints and diffuse surface finishesapplied to opto-mechanical parts are well-described with a symmetric polynomial, which also obeys reciprocity; certain paints and surface preparations exhibit enhanced specular behavior near grazing incidence, however, thus violating the reciprocity condition. The best-fit model then becomes some superposition of conventional models. Transmissive optical elements combine surface scatter with a volume-scatter component induced by bulk inhomogeneities. Diamond-turned optics exhibit anisotropic scatter patterns as a direct result of the periodic nature of the process.

Stray light analysis software can provide the tools necessary to take into account the complex issues involved in optical scatter simulations. Order-of-magnitude assessments of system degradation can routinely be made based upon representative data. In some cases, a back-of-the-envelope estimate is sufficient to make a pass-fail determination. However, critical performance evaluations may be unreliable unless actual measured data is incorporated into a simulation.

BSDF is measured using an instrument called the scatterometer. A light source illuminates a surface at a fixed angle of incidence while a detector is scanned over the appropriate hemisphere (see figure). Data taken in this fashion maps scatter angle to incident angle. Since the dynamic range required often exceeds 60 dB, a modulation is impressed upon the light source and data acquired through a lock-in amplifier. Modulation in excess of a few thousand hertz shifts the signal to a frequency range where $1/f$ noise is negligible. Detector aperture effects should be taken into account when the solid angle exceeds the minimum-required angular resolution for any analysis being performed.

The fact that a scatterometer consists of optical elements that themselves scatter light causes each instrument to display a signature unique to its elemental and geometric makeup. A refractive instrument, by virtue of greater surface count and transmissive nature, exhibits a signature plagued by ghost paths that tend to image various scatterometer components at the detector. The single advantage of refractive systems over their reflective counterparts is an absence of off-axis aberrations. A reflective layout provides a lower signature due to its minimal surface count, absence of ghost paths, and the fact that the best lens probably has more scatter than the best mirror.

When having scatter measurements performed, be sure to get more than just the data. Request detector aperture size and an instrument scan without the sample in place at minimum. **oe**

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