Deep-ultraviolet (DUV) industrial and medical laser systems operating at 193 nm rely on high-performance multilayer-dielectric (MLD) coated optics to deliver optimum performance and lifetimes exceeding millions, and in some cases billions, of pulses. Accurate characterization of these coatings is key to obtaining optimal system performance, lifetime, and reliability, but the process is often misunderstood. To achieve peak optical performance, it is imperative to measure both transmission and reflection of the coated optics in order to evaluate the amount of inherent loss within the coating. A measurement of transmission alone can help to determine the center wavelength and relative bandwidth of a coating, but it will not indicate the amount of absorption that could lead to premature failure and unnecessary system downtime in the field.

Since MLD coatings produce relatively narrow reflecting bands in the DUV, it is also important to measure the coated optics at the laser wavelength and the angle of incidence at which the optics will be used. In addition, specific applications, especially at wavelengths at or below 193 nm, often dictate different operating environments for DUV optics. For example, a photoelectrorefractive keratectomy system used in a medical office would typically operate at atmospheric pressure (air). In contrast, a photolithography exposure system may operate under nitrogen-purge, while other applications may require operation in a vacuum. Coating characteristics can change under these varying conditions; therefore it is important to measure the coating performance in an environment that simulates as closely as possible the actual environment of the application.

Test results illustrate the importance of measuring both transmission and reflectance as a quality control (QC) procedure to more fully characterize a coating (see figure). To obtain the results above, we measured all three mirrors using a computerized automated spectrophotometer, capable of measuring percent reflectance and percent transmission from 120 nm to 600 nm, at angles ranging from 0° to 70°. In addition, the system can measure samples under vacuum, nitrogen-purge, or at atmosphere to simulate the actual operating environment for a specific application. For the data shown here, we initially measured all three mirrors under vacuum and achieved nearly identical transmission levels of about 0.1%. These results suggest that the mirrors should achieve near total reflectance. Subsequent reflectance scans, however, revealed that the mirrors actually had different reflectance characteristics and ultimately different absorption levels. Mirror A yielded 97.5% reflectance, while Mirrors B and C featured 94.5% and 89.5% reflectance, respectively. Total losses for B and C were about 5.4% and approximately 10.4%, respectively.

We then exposed all three mirrors to 225 mJ/cm² of 193-nm laser radiation at a 100-Hz repetition rate for laser-induced damage and lifetime testing. We continuously monitored mirror reflectance at 193 nm for a 45° incident angle during the laser exposure to determine the effective lifetime of the mirror being tested. The lowest loss coating demonstrated much greater resistance to laser damage and ultimately the longest useful lifetime. Mirror B damaged reached catastrophic damage levels relatively quickly, while Mirror C damaged almost immediately. For an industrial laser company, this could mean the difference between replacing optics every three months and replacing them once a year; in other words, Mirrors B and C may not be suitable for industrial laser systems.

There are many factors that affect laser damage resistance, but one of the key contributors to mirror failure in DUV laser systems is absorption. We recommend a QC procedure that includes both percent reflectance and percent transmission measurements at the laser wavelength, angle of incidence, and operating environment that best simulate the application.

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