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Novel microstructures with high laser-induced-damage thresholds

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Materials with subwavelength textures can be etched or replicated directly into the bulk substrate of optical windows to provide ultrahigh-broadband antireflection performance.

The energy output and operational lifetimes of high-power lasers depend critically on eliminating reflections from the surfaces of their numerous windows and optical components. This is commonly achieved using multiple thin layers of dielectric (nonconducting) antireflection coatings deposited onto the external surface of the optics. Each layer can produce constructive or destructive interference for light propagating through the optic surface within a specific wavelength range. But the optical field amplitude present at each layer interface is large, leading to thermal gradients and rapid damage near coating defects that result in relatively low optical energy. Additionally, broadband antireflection coatings and narrowband high-reflective coatings require many film layers to widen the range of wavelengths over which reflections are suppressed, thus increasing the potential for unacceptable laser damage threshold levels.

We recently reported antireflective (AR) microstructures that can be etched, milled, or even replicated directly into an optical surface.[1–3] Their performance has been particularly noteworthy with reported average reflection losses lower than 0.2% over a four-octave range (400–1800nm), and a loss of less than 0.03% routinely achieved for narrowband applications. Because they are designed to provide a gradual change of refractive index at a material boundary, light can propagate without material damage at energy levels that are significantly higher, a clear improvement over thin-film interference-based coatings. For instance, a laser-induced-damage threshold (LIDT) of nearly 57J/cm^2 at 1064nm (20ns pulse) was shown for a borosilicate glass window containing AR microstructures. This threshold is two to three times greater than that of single-layer sol-gel AR coatings on fused silica.[3]

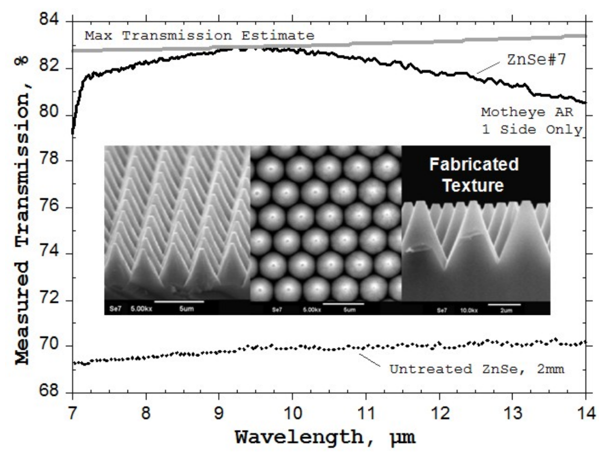

Figure 1. *Scanning electron microscope (SEM) image of a moth-eye anti-reflective (AR) texture etched in a zinc selenide (ZnSe) window and LWIR transmission spectrum.*

Microstructure antireflection technology

Some surface relief structures, commonly known as moth-eye textures, consist of subwavelength-sized features that can efficiently suppress the reflection of light.[1–3] We have developed a variety of AR microstructures, including moth-eye, random, and subwavelength structures (SWSs).

Figure 1 shows a periodic array of moth-eye-type structures etched into the front surface of a zinc selenide (ZnSe) window designed for the long-wave IR. The structures have an approximate height of 5μm with a grid spacing of 2.4μm. Also shown is the transmission of the treated ZnSe window over the 6–15μm range along with the transmission of an untreated ZnSe window with no reflection loss from one surface. The average reflectance loss over the 8–12μm band is less than 1.5%.

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Figure 2 shows a periodic array of holes that form an SWS AR texture on one surface of a fused silica window designed for near-IR (NIR) applications. A plot of the measured reflection from both treated and untreated fused silica windows is also shown. Ultrahigh performance is achieved with an average reflection loss of less than 0.03% over the 1290–1360nm range.

Finally, Figure 3 shows a random AR surface texture etched into the surface of a fused silica glass window. The dimensions of these features are clearly much less than the visible to NIR wavelengths that will pass through the window. Reflectance levels at normal incidence average less than 0.3% from 350 to 1000nm.

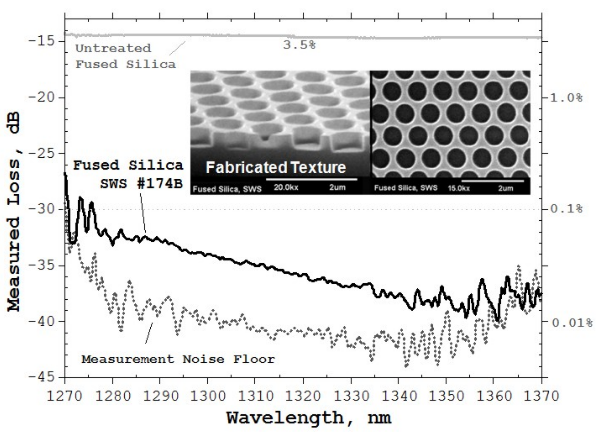

Figure 2. *SEM images of a moth-eye, random, subwavelength (SWS) AR texture etched in a fused silica window and NIR reflection spectrum.*

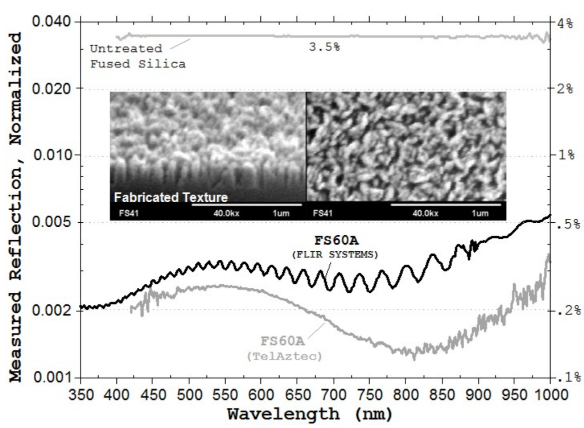

Figure 3. *SEM images of a random AR texture etched in a fused silica window and near-UV-VIS-NIR reflection spectrum. FLIR: FLIR Systems Inc.*

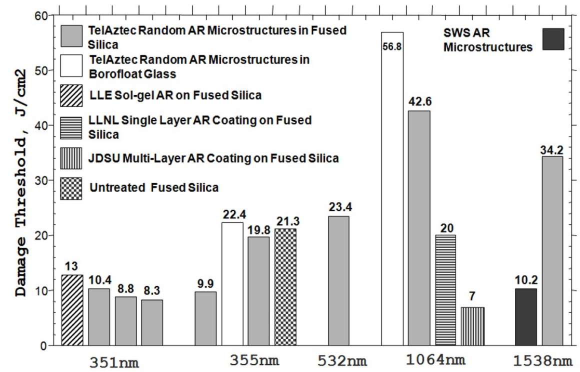

Figure 4. *Summary of our LIDT test results compared to results reported elsewhere.*[4–8] *LLE: Laboratory for Laser Energetics. LLNL: Lawrence Livermore National Laboratory. JDSU: JDS Uniphase Corp.*

Deciding which AR structure type to use depends on a variety of factors, including desired wavelength range, size of optic or window, and cost.

LIDT measurements

To date, we have fabricated these novel high-performance AR structures in a variety of visible and IR materials such as fused silica and Schott borofloat glass. LIDT testing has been conducted at five wavelengths ranging from the UV to NIR (1064, 532, 1538, 355, and 351nm). High pulsed-laser damage thresholds were found, particularly at 1064 and 355nm. The results suggest performance that is uncommon in the literature and may even be unprecedented. Surface structures etched directly into the bulk substrate show a damage threshold at least two times greater than comparable single-layer thin-film AR coatings at 1064nm. In the near UV, both short (0.5ns) and long (10ns) pulse lengths have damage thresholds near 10J/cm^2. Figure 4 compares our test results (TelAztec) to LIDT data reported in the literature. We plan to keep fabricating and testing AR surfaces in various materials, such as arsenic sulfide and barium borate crystals, for use at different wavelengths.

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