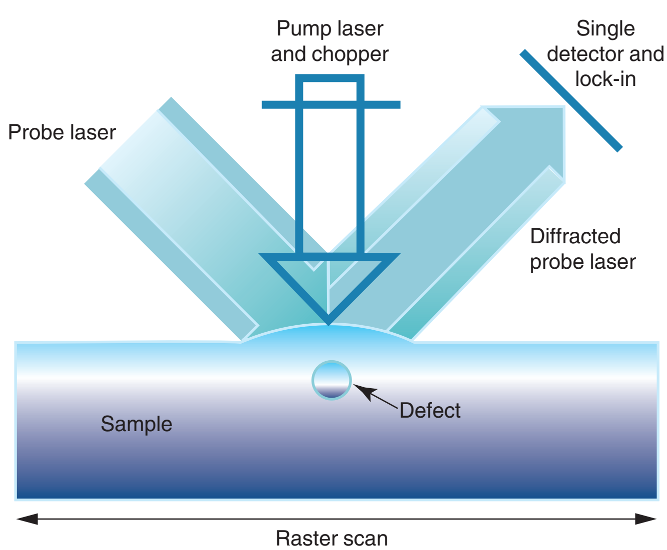
Faster Inspection of Laser Coatings

LASERS have been a Lawrence Livermore specialty almost since the first laser flashed in 1960. Dealing with the challenges that arise as these lasers get bigger and more powerful is, of necessity, a specialty too.

The process of creating an intense laser beam requires that the beam traverse many pieces of optical glass. Oftentimes, the glass requires highly reflective mirror coatings so that the laser's energy is not lost as it passes through. But during the coating process, miniscule defects—called nodules—inevitably occur. As lasers get larger, they require larger pieces of glass, and more defects occur. On a laser mirror a half-meter across, there may be as many as a million defects. While more than 99.99 percent of defects have no influence on optical performance, a few of the defects will limit the laser fluence (a measure of the energy passing through) that the mirror will survive; finding those few among a million is like trying to find the proverbial needle in a haystack.

In the mid-1990s, Livermore began to explore the best means for locating coating defects. Optical microscopy and atomic force microscopy can reveal nodules but cannot distinguish the thermal defects in thin films that arise during the coating process. Engineer Chris Stolz and others at Livermore began working with scientists at Eastern Michigan University who were experts in photothermal microscopy, an imaging technique that can locate and characterize both nodules and thermal defects in laser mirror coatings.



Defects absorb light from the pump laser and cause a surface bump to form. The probe laser detects the bump, and the photodetector records changes in the probe's optical diffraction caused by the deformation. The resulting signal indicates the amount of optical thermal absorption at the specified wavelength.

Finding the Needle

In photothermal microscopy, a pump laser set at a specific wavelength heats a surface. Surface and subsurface defects that absorb the light at that wavelength cause a bump to form on the surface, as shown in the figure below. A second laser beam, known as the probe laser, detects the change in the surface, and a photodetector records changes in the probe's optical diffraction caused by the bump, or deformation. The pump beam is "chopped," or interrupted periodically. The photodetector locks into the chopping frequency, and the resulting photothermal signal is an indicator of how much heat at the specified wavelength was absorbed.

The benefit of photothermal microscopy was made clear in its earliest tests, which examined a 9-millimeter by 9-millimeter area of coating. One defect, which had the highest photothermal signal, was not visible optically. Later, during laser damage testing, the defects with the highest photothermal signal proved to have the lowest damage threshold. (The damage threshold is the laser energy level that the material is designed to endure but beyond which damage will likely occur.) A high-energy laser needs glass with the highest possible damage threshold.

Studying various kinds of defects in glass coatings allowed the researchers to zero in on the few that reduce the damage threshold. Photothermal microscopy images also validated the use of laser conditioning—treatment of defects with a laser—as a way to reduce the absorption of defect fluences, as shown in the top figure on p. 18.

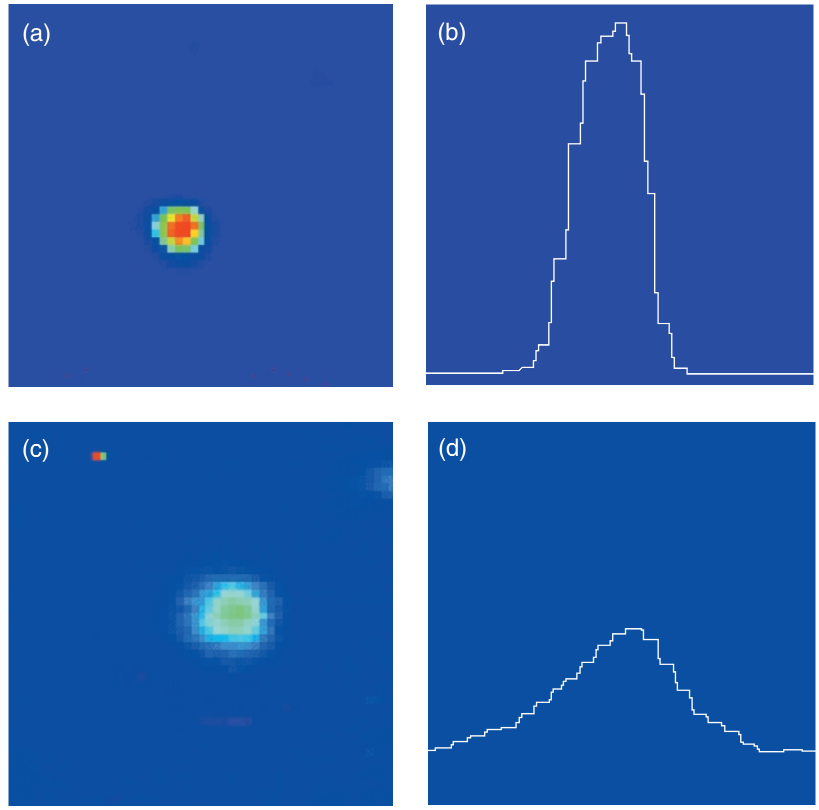
From Scanning to Imaging

The photothermal microscopy system worked well but, because it used a raster-scanning technique, was extremely slow. The results of raster scanning are what you see when the graphics on a Web site or other computer graphics gradually improve line by line or pixel by pixel. In photothermal microscopy, the pump and probe beams are raster-scanned while the detector collects data a single pixel at a time. Together, they generate a photothermal microscopic map of a given inspection area at a rate of 1 second per pixel. That speed is impractical for inspecting large surfaces of coatings.

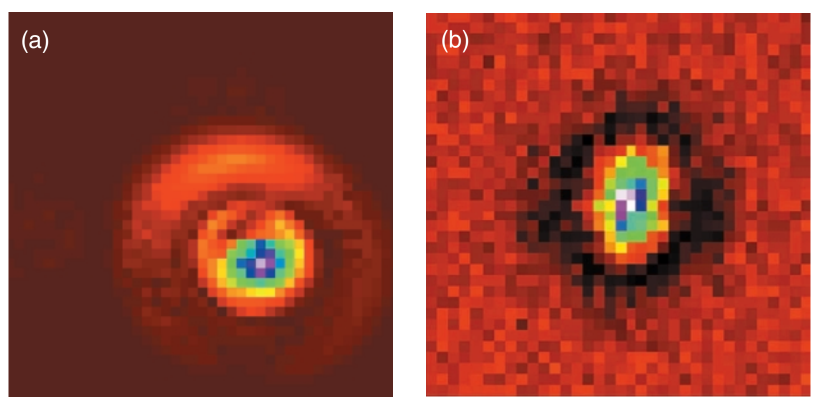
Recently, engineers Diane Chinn and Stolz, working with others at Livermore and Wayne State University, modified the scanning technology to create photothermal imaging microscopy, which is 10,000 times faster than the raster-scanning method. Using the imaging mode, photothermal microscopy can inspect a 1-square-centimeter area in just 2 seconds.

For photothermal imaging, Chinn and the others expanded the pump and probe beams to about 5 millimeters. They used a 1,024- by 1,024-pixel charge-coupled-device camera to detect the diffracted pump beam. In scanning mode, the detector was locked in electronically to the chopping frequency of the pump beam, but in the imaging mode, the collected images are phase-delayed relative to the pump beam to achieve optical lock-in.

The bottom figure at right compares images of a glass sample with an antireflective coating using both the raster-scanning and imaging modes. Aluminum dots were sputtered onto the glass substrate before coating. The two images showing aluminum absorption are comparable, but the time it took to produce them is not. The raster-scanned image took 35 minutes to obtain, while the one generated through the imaging mode took just 40 seconds.



(a) A photothermal microscopy image and (b) the diffraction signal of a nodule defect before laser conditioning. (c) The same defect after laser conditioning. (d) Its diffraction signal has been reduced by a factor of 125, which in turn reduces the likelihood that this defect would cause damage at the National Ignition Facility's fluence.



(a) A map of a sputtered aluminum dot under an antireflective coating using photothermal microscopy in the raster-scanning mode. It took 35 minutes to obtain this image. (b) The same dot imaged using photothermal microscopy in the imaging mode. Producing this image took just 40 seconds.

Applied to NIF

The team's proof-of-principle work was funded by Laboratory Directed Research and Development. Now, with project funding, the team is beginning to apply the process to optics for the National Ignition Facility (NIF).

When NIF comes on line in the next few years, it will be the largest, most energetic laser in the world as well as the largest optical instrument ever built. NIF will require lots of optical glass—7,500 large optics (as large as a meter along the diagonal) and more than 30,000 small optics. The primary task of these optics will be to separate and steer 192 laser beams through a 250-meter-long building and to amplify the laser energy before that energy is focused onto a fusion target the size of a dime.

Electron beam deposition lays down multilayer coatings of hafnia and silica on NIF optics. With the raster-scanning technique, imaging a 1-centimeter-square area of NIF optical coating at 10-micrometer resolution would take a full 278 hours. Inspecting the acres of coatings on NIF optics would have taken decades at that rate. The faster photothermal microscopy imaging technique, however, is a viable method for inspecting NIF's coatings.

One of a Kind

"We have proved that this new system can produce the fast, high-quality images we need to inspect NIF coatings," says Chinn. "And it is a capability that doesn't exist anywhere else in the world." Photothermal imaging microscopy will have other uses as well. Chinn sees it helping microtechnology engineers to assess computer chip lithographic techniques. It may also be useful for studying hard coatings and thermal barriers in the automotive and aerospace industries.

"If this system works in-house as we hope it will," continues Chinn, "we plan to move the technology into the coating vendors' shops for their use. This is a much faster method for identifying problem areas than anything else out there."

—Katie Walter

Key Words: laser glass, multilayer hafnia–silica coatings, National Ignition Facility (NIF), photothermal microscopy.

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