Detecting Microscopic Inclusions in Optical Glass

Our automatic system for detecting potentially damaging inclusions in optical glass can find and identify microscopic particles in the parts-per-quadrillion range.

For further information contact John Marion (415) 423-6788.

Lasers of high peak power, such as those used in fusion research and proposed for use in possible defensive laser weapons, require large glass optical components (10 litres or more of glass). These components must withstand laser intensities in excess of 1 GW/cm^2. Thus it is essential that they be free of inclusions, which can cause damage to the glass under high laser fluences.

At present, most glass optical components are melted and refined in platinum crucibles. These platinum crucibles are the source of the microscopic particles that can become included in the glass. When exposed to high-energy laser irradiation, these platinum inclusions partially vaporize and cause cracks within the glass that interfere with the propagating laser beam.

Our current research is directed toward reducing or eliminating these inclusions in future optical components (see the article on p. 12). Reliable detection of such inclusions is a prerequisite to developing optical components that are highly resistant to damage. Unfortunately, traditional detection methods have not been adequately successful. For the laser energies of interest, the size of the inclusions that cause damage are in the micron to submicron range—often too small to be reliably detected by conventional optical microscopy. Light scattering techniques also are unwieldy for inclusions at such low densities ($<10^{-4}$/cm^3) because spurious signals from bubbles, surface imperfections, and other scattering sources swamp the signals of interest.

We have developed a novel approach for optical inspection in which we use the focused output from a commercial, Q-switched, yttrium-aluminum-garnet (Nd:YAG) laser to scan the entire glass component for the presence of inclusions. The energy of the scanning laser beam is sufficient to partially vaporize the absorbing inclusions, producing a plasma ($\sim$10 000 K). These tiny inclusions are readily detected by the visible emission from this plasma; a photomultiplier tube is used to resolve the light emissions. A computer records these events and generates an inclusion map of the optical component. This scanning technique reliably detects micron-sized inclusions in large volumes of glass and greatly reduces the long times and human subjectivity inherent in previous visual inspection techniques.

One previous method of testing optical glass for damage, used by researchers elsewhere, was to focus a small (1-mm^2 or smaller) laser beam at high fluences on a few areas in a sample.[1] The results often were coupled with a statistical treatment of the data to yield an overall measure of defects.[2] Unfortunately, this method of inspection and damage assessment is completely ineffective for glass with a sparse distribution of defects. In another approach to inspection of large optics, we used the Nova laser to give high fluences over a large area[3]; however, these tests were restricted to several shots per day and required a subsequent optical inspection.

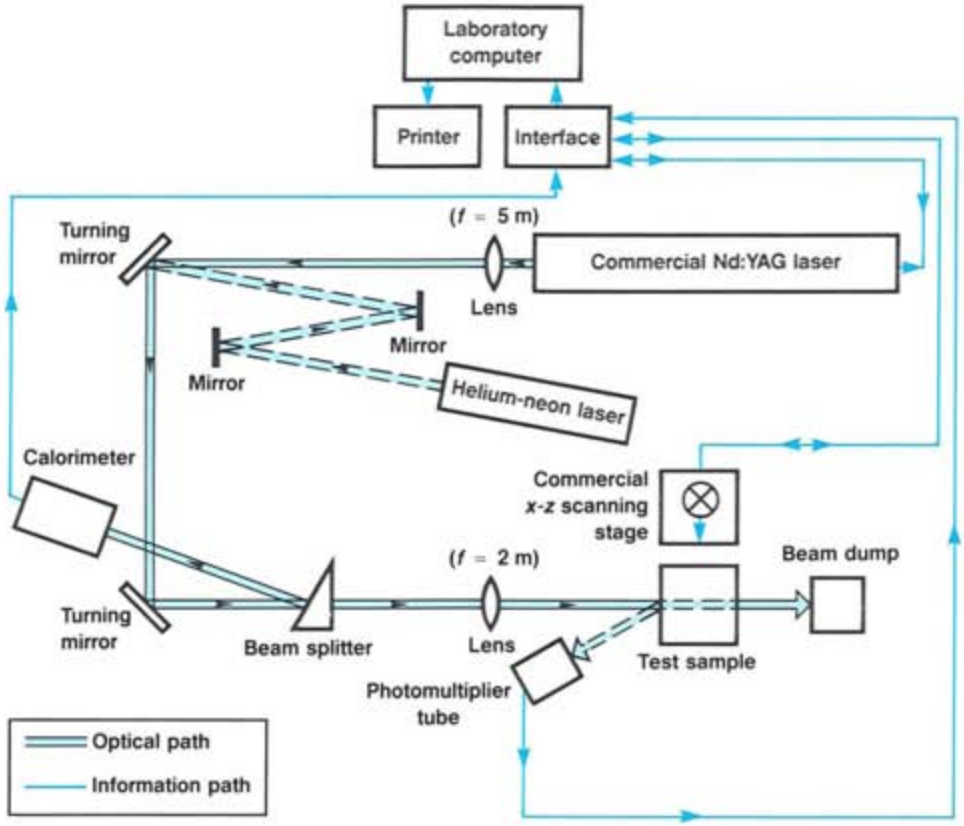
With our new rapid-scan inspection device, we have successfully inspected 10-litre ($>10^4$-cm^3) optical components and have detected inclusions at levels in the parts-per-quadrillion (10^{15}) range. The $100 000 cost of the entire assembly is modest, especially considering the cost of high-power lasers.

The Rapid-Scan Inspection Device

Our rapid-scan inspection device (Fig. 1) is located in a class-1000 clean room to reduce the likelihood of damage to the optics from dust contamination on the glass surfaces. The energy source, the Q-switched Nd:YAG laser, produces 800 mJ in 8-ns pulses at a 20-Hz repetition rate. The shot-to-shot stability of this laser (which has an oscillator/amplifier configuration) is excellent; more than 99% of the pulses are within 1% of the mean pulse energy. The 8-mm-diameter beam has a reasonably Gaussian profile to ensure that the sample is irradiated at the desired fluence (Fig. 2). The slightly diverging output beam is approximately collimated by a 5-m-focal-length lens (Fig. 1) and is directed toward the sample with dielectric-coated mirrors. A collinear helium-neon laser is introduced into the optical path for sample positioning. The beam is then focused by a lens with a 2-m focal length and enters a beam splitter whose front surface is coated to minimize reflection. The back surface of the beam splitter is imaged onto a calorimeter whose output is used to continuously monitor laser performance.

Fig. 1

Schematic drawing of the rapid-scan inspection system for automatically detecting metallic inclusions in optical glass.



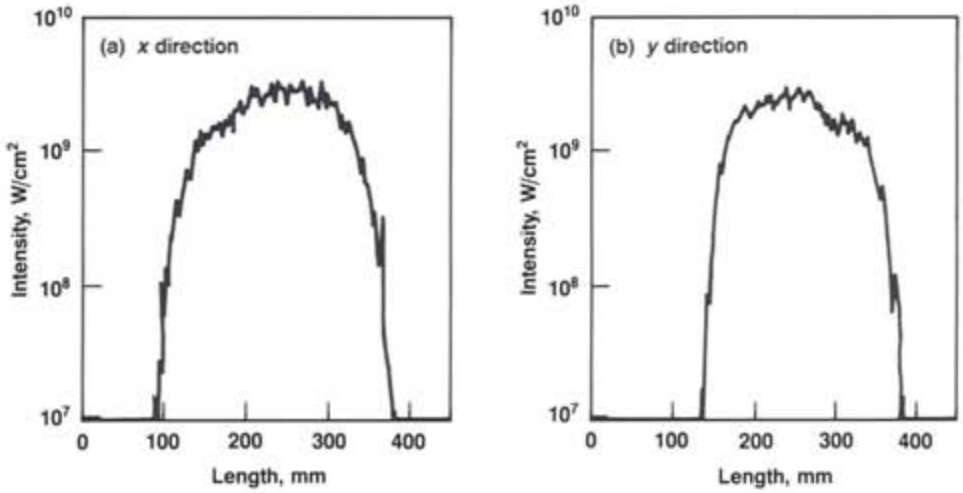


Fig. 2

Microdensitometer traces from a photograph of the Nd:YAG laser beam. Beam profile in the *x* direction (a) and *y* direction (b). The profiles are reasonably Gaussian.

After passing the splitter, the laser beam strikes the sample. The sample, mounted on a commercial stage drive capable of movement along both *x* and *y* axes, is scanned continually as it is moved in front of the laser beam. The entire rapid-scan detection system is controlled by a laboratory computer and interfaced through a general-purpose data-aquisition controller.

With our present detection system, the irradiated area of the sample is imaged onto a photomultiplier tube, and the output is digitized and monitored by the computer. Optical signals emitted by the plasma (from the heated inclusions) are combined with *x*- and *y*-position coordinates and used to generate an inclusion map (Fig. 3).

Before we developed our new detector system, we inspected for inclusions by exposing each point in the component to ten shots at more than twice the damage threshold for platinum inclusions in glass.[4] After the inclusions were irradiated, the resulting damage was sufficiently large that we could detect the sites by visual inspection using side illumination of the sample. This new detector has greatly streamlined our inspection of optical glass.

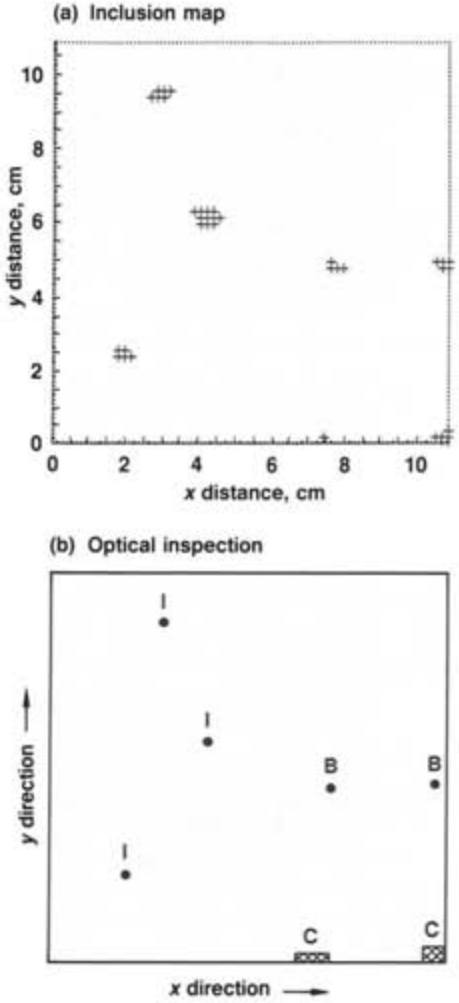


Fig. 3

Example results of inspection for inclusions in optical glass: (a) computer-generated inclusion map produced by the rapid-scan inspection device, and (b) map showing findings in the subsequent optical inspection. Sites marked "I" are platinum inclusions, sites marked "B" are bubbles, and sites marked "C" are chips at the edge of the sample.

Additional Applications

Our new testing device is also being used by the Laboratory's Laser program to study the effects of multiple laser shots on various types of defects. With this rapid-scan system, we can readily accumulate data on the growth rate of damage from individual defects for numbers of shots far exceeding projected requirements.

The rapid-scan system may also find applications in chemistry and materials science for the detection of small concentrations of microscopic inclusions or defects. To do this, two requirements must be met. First, the host material must be substantially transparent at a wavelength accessible by high-power lasers, and, second, the defect or inclusion of interest must absorb light significantly at that wavelength. Our method could be used, for example, with a Raman-shifted argon laser to detect metallic inclusions in semiconductor devices. It could also be used with a Raman-shifted Nd:YAG laser to detect silicon or carbon inclusions in Si_3N_4 or SiC structural ceramics.

Summary

We have devised a simple system to inspect large optical components for potentially damaging microscopic metallic inclusions. Our rapid-scan detection device, which can detect inclusions in the parts-per-quadrillion concentration range, uses a Q-switched Nd:YAG laser focused on the optical component, which is continually scanned during the test. The energy from the Nd:YAG laser causes any metallic inclusions in the glass to partially vaporize; these

plasma emissions are detected by a photomultiplier tube, whose output is monitored by a computer. The computer uses the output to generate an inclusion map. With our new detection system, it is now possible to inspect large optical components rapidly, reliably, automatically, and at moderate cost.

Key Words: damage—materials study, optical component; glass—inspection, laser, optical; laser—Nd:YAG; Nova, Q-switched; platinum inclusion.

Notes and References

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