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Diagnostics for the Detection and Evaluation of Laser Induced Damage

Lynn Sheehan, Mark Kozlowski
and Frank Rainer

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Lynn Sheehan, Mark Kozlowski, Frank Rainer

Lawrence Livermore National Laboratory
P.O. Box 5508, L-484
Livermore, California 94550-9900

ABSTRACT

The Laser Damage and Conditioning Group at LLNL is evaluating diagnostics which will help make damage testing more efficient and reduce the risk of damage during laser conditioning. The work to date has focused on photoacoustic and scattered light measurements on 1064-nm wavelength HfO_2/SiO_2 multilayer mirror and polarizer coatings. Both the acoustic and scatter diagnostics have resolved 10 μm diameter damage points in these coatings. Using a scanning stage, the scatter diagnostic can map both intrinsic and laser-induced scatter. Damage threshold measurements obtained using scatter diagnostics compare within experimental error with those measured using 100x Nomarski microscopy. Scatter signals measured during laser conditioning can be used to detect damage related to nodular defects.

Keywords: functional damage threshold, laser conditioning, photoacoustics, scattered light

1. INTRODUCTION

As the Inertial Confinement Fusion (ICF) program moves forward with the design of the National Ignition Facility (NIF), an improved understanding of damage thresholds of large optics is required. Current small spot damage tests are conducted in areas on witness samples that represent only 0.01% of the area on a large ICF laser optic. As optical materials are manufactured with fewer and fewer defects, it is important to test a large enough area that the defects are included in the measurement.

In order to design the NIF, the damage threshold must be based on testing a larger area and considering the damage severity versus fluence. This new measurement is referred to as the functional damage threshold. That is, it represents the damage threshold of a ICF size optic, with the allowance of small amounts of pinpoint damage that has no effect on beam propagation.

The relation of this functional damage threshold to our standard small spot damage thresholds is shown in Fig. 1. The S:1 and R:1 damage thresholds are based on pinpoint damage which may have no effect on the functionality of the optic. The damage thresholds are determined on the basis of any observable change in the material with 100x nomarski microscopy. If the small pinpoint damage observed with microscopy is allowed up to a certain size, the threshold will be higher than the current numbers. Some literature suggests that damage on the optics as large as 300 μm is acceptable for a ICF laser(1). When a larger area is tested, the measured damage threshold is generally lower because the chance of irradiating a low threshold defect is increased.

Besides defining a new way of measuring the damage threshold, a quick turn around of results is also required. As new materials and material processing technologies evolve, the intrinsic and process dependent damage thresholds must be measured in a timely manner to provide feedback to their development. These requirements could not be met using our current procedure for damage threshold measurements. To meet these goals, an in-situ damage detecting diagnostic is required.

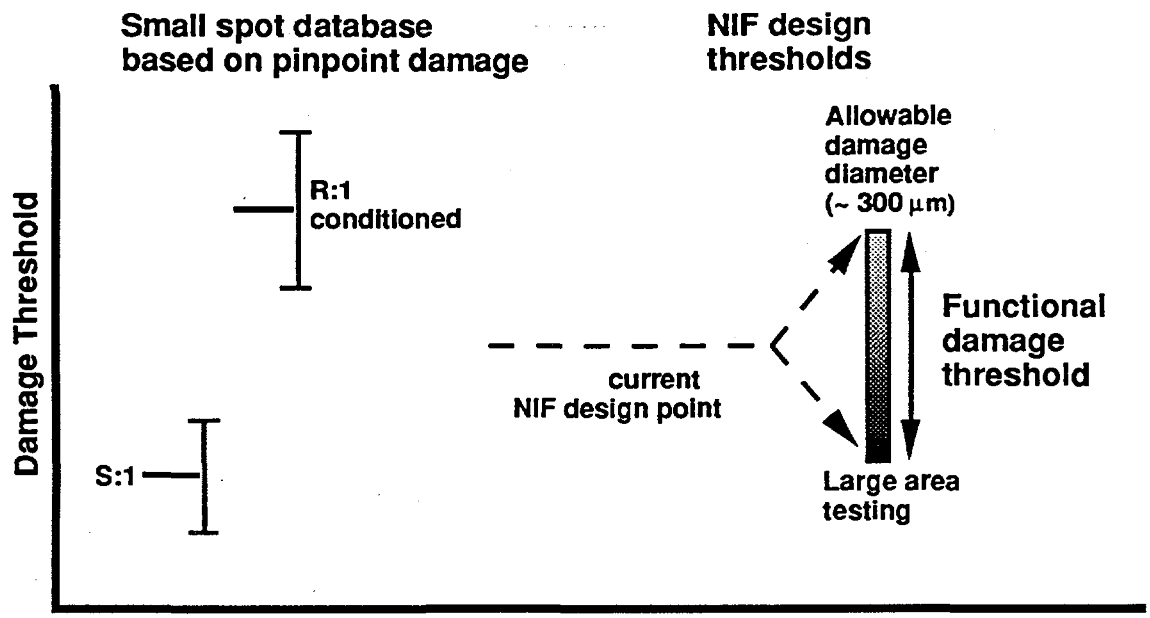

Fig. 1. The design of future ICF lasers will be based on a functional damage threshold derived from examination of a large area of the optic but allowing for some small damage points.

The goal for damage test diagnostics is to be able to detect 5 μm diameter damage sites on optical thin films, be automated, and evaluate a damage threshold within 15% of that found with conventional 100x Nomarski microscopy. For laser conditioning, the goal is to consistently detect damage greater than 20 μm in diameter in a manner which lends itself to on-the-fly damage detection. This diagnostic will ensure that the small amount of damage caused by the large-area conditioning procedure is not large enough to interfere with optical performance[2]. Diagnostic development to date has focused on photoacoustic and scattered light measurements on 1064-nm wavelength HfO_2/SiO_2 multilayer mirror and polarizer coatings.

Since any new damage diagnostic must first be compared with nomarski microscopy, the new detection system is combined with the normal damage test system layout (Fig. 2). The damage beam is diagnosed using a beam profiler and energy meter. The test sample is mounted on a rotary stage which allows it to either be in the plane of the microscope, or the plane of the laser beam. Each test site is viewed and photographed with the microscope before and after irradiation in order to determine the number and size of any damage points.

2. PHOTOACOUSTIC DAMAGE DETECTION

The measurement of laser-initiated acoustic signals in has been documented in the literature[3]. The measurement relates an acoustic signal to the amount of damage incurred by the material under test. The minimum detectable damage point diameter must be determined in order to evaluate its performance against 100x microscopy, which is limited to a resolution of approximately 5 μm.

2.1 Photoacoustic measurement system

For the acoustic diagnostic, a piezoelectric transducer (PZT) was coupled to the side of the sample shown in Fig. 3. The output of the transducer was filtered and amplified, and was then read by a variety of instruments. An oscilloscope was used to view the actual acoustic signal in order to measure the peak to peak voltage (Vp-p). The RMS voltmeter was capable of integrating the entire acoustic signal in time and outputing the signal to a plotter so that the acoustic energy, Ea, could be determined.

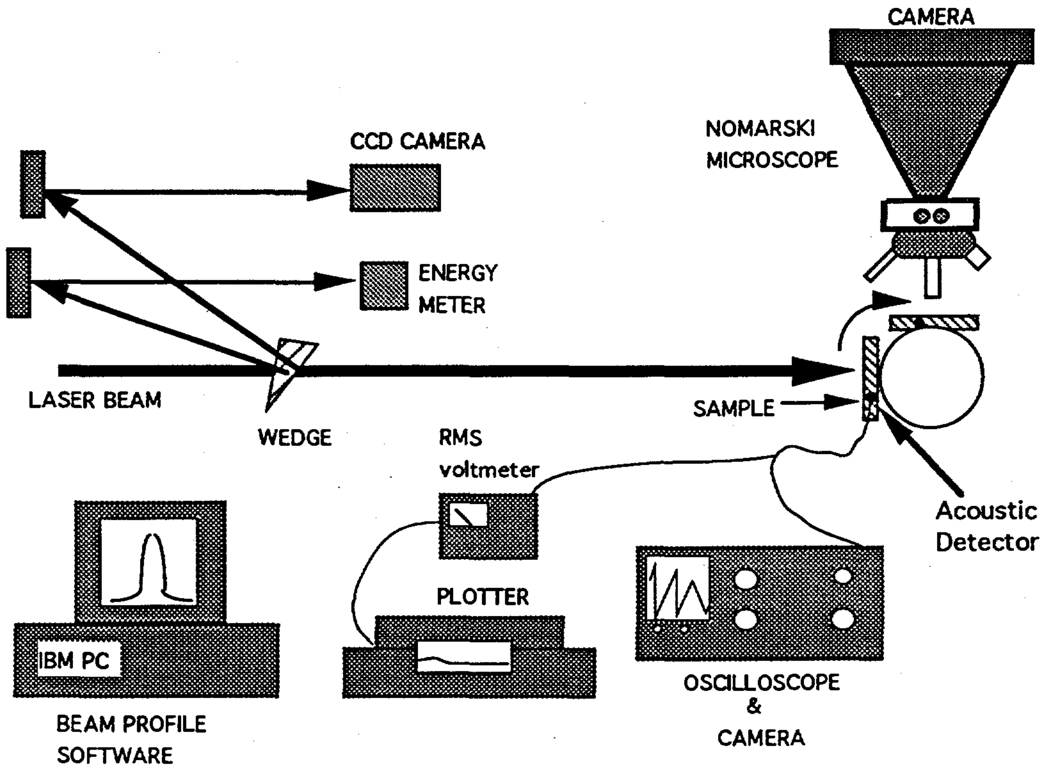

Fig. 2. Layout for the measurement of damage-initiated acoustic signals. The detection system is used in combination with the standard damage test system.

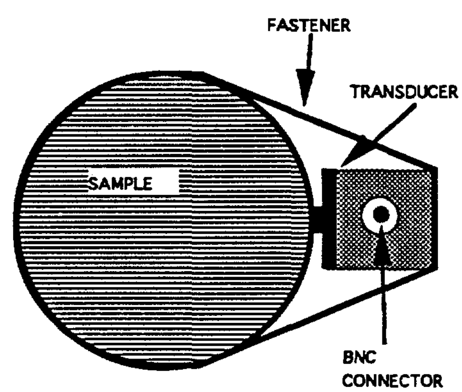

Fig. 3. Attachment of PZT to damage test sample.

2.2 Photoacoustic damage detection results

As discussed above, the two measurements made were Vp-p and Ea. The correlation of Vp-p to the detected damage diameter is shown in Fig. 4. When more than one damage point was seen, the diameters where summed. Over a damage diameter range from 15 µm to 550 µm an increasing trend of the acoustic signal with increasing damage diameter can be seen. This increasing trend has a wide band in the signal level, making it difficult to correlate a particular damage diameter to a single acoustic signal. The smallest diameter detected with this test was 15 µm.

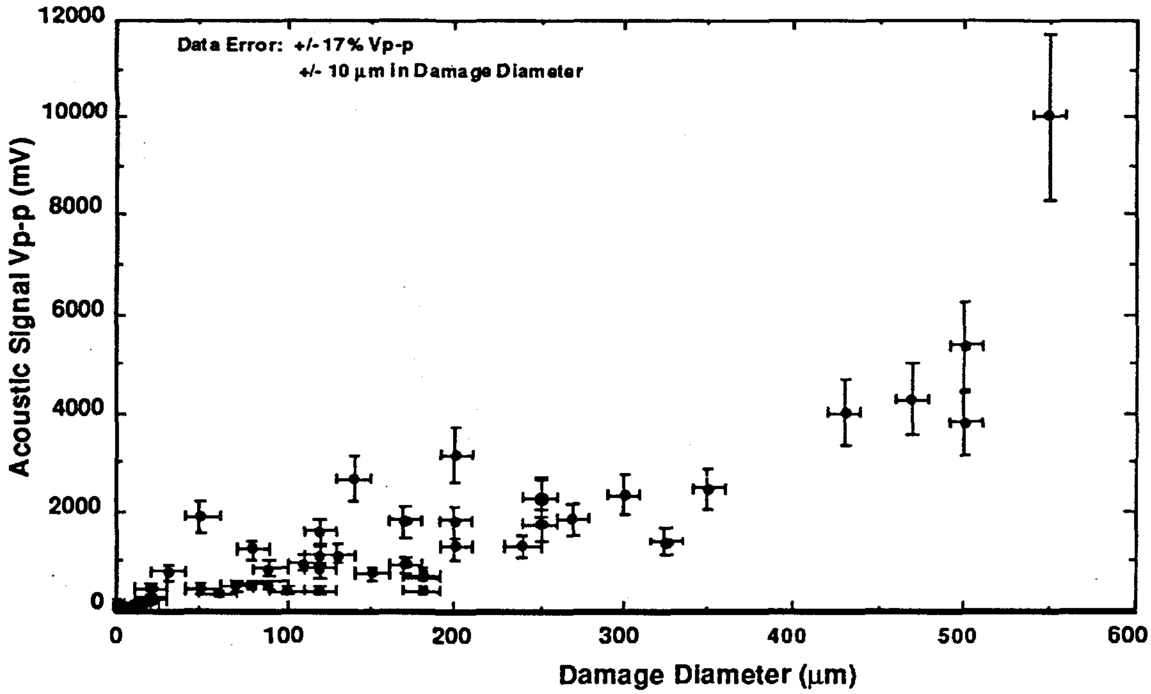

Fig. 4. Acoustic signal Vp-p increases with damage diameter.

The next measurement was total integrated acoustic signal, Ea. For the data shown in Fig. 5, only test sites where one damage point was detected where used in order to simplify data interpretation. This measurement showed a polynomial correlation of integrated acoustic signal and damage diameter. The smallest detectable damage diameter was 10 µm.

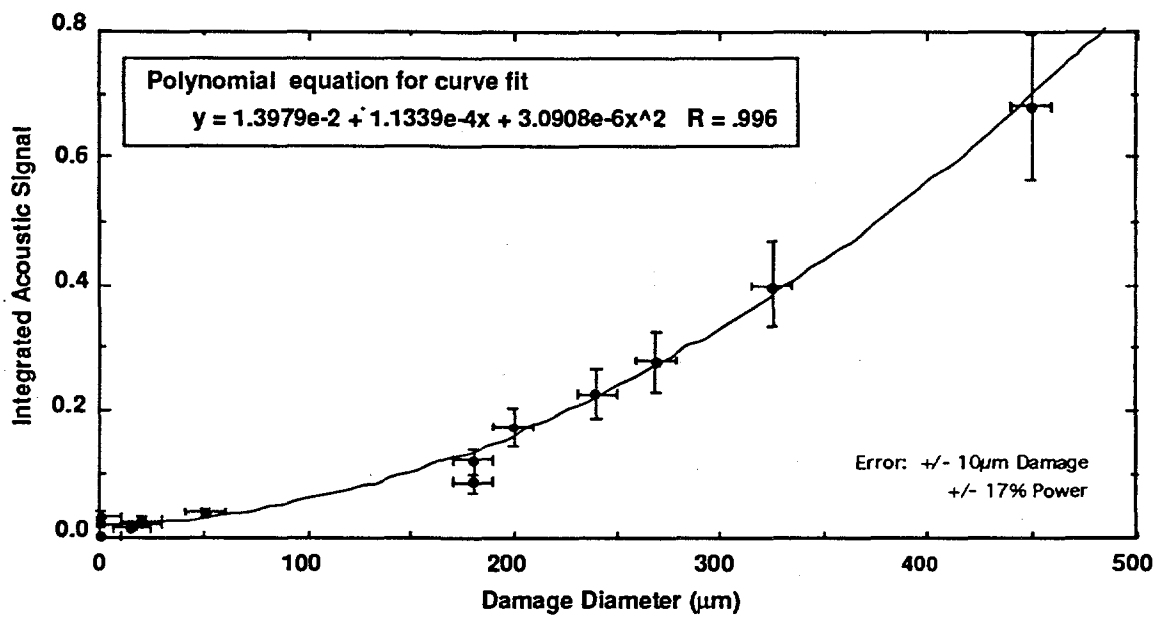

Fig. 5. For single pinpoint damage, there is a smooth curve correlating damage diameter and the integrated acoustic signal.

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3. SCATTERED LIGHT DAMAGE DETECTION

This measurement is meant to evaluate the relation of a scatter signal to inherent scatter sources in a material and to the amount of damage incurred by the material under test. The minimum detectable damage point diameter is also of interest in order to evaluate its performance against 100x microscopy.

3.1 Scattered light measurement system

The current scatter measurement system is installed on the Large Area Conditioning facility at LLNL[2]. This facility allows raster scanning samples up to 1 meter in size with a high power Nd:YAG laser (Fig. 6). By integrating the scatter diagnostic onto this system, both inherent and laser-induced scatter phenomenon can be studied on small and large areas.

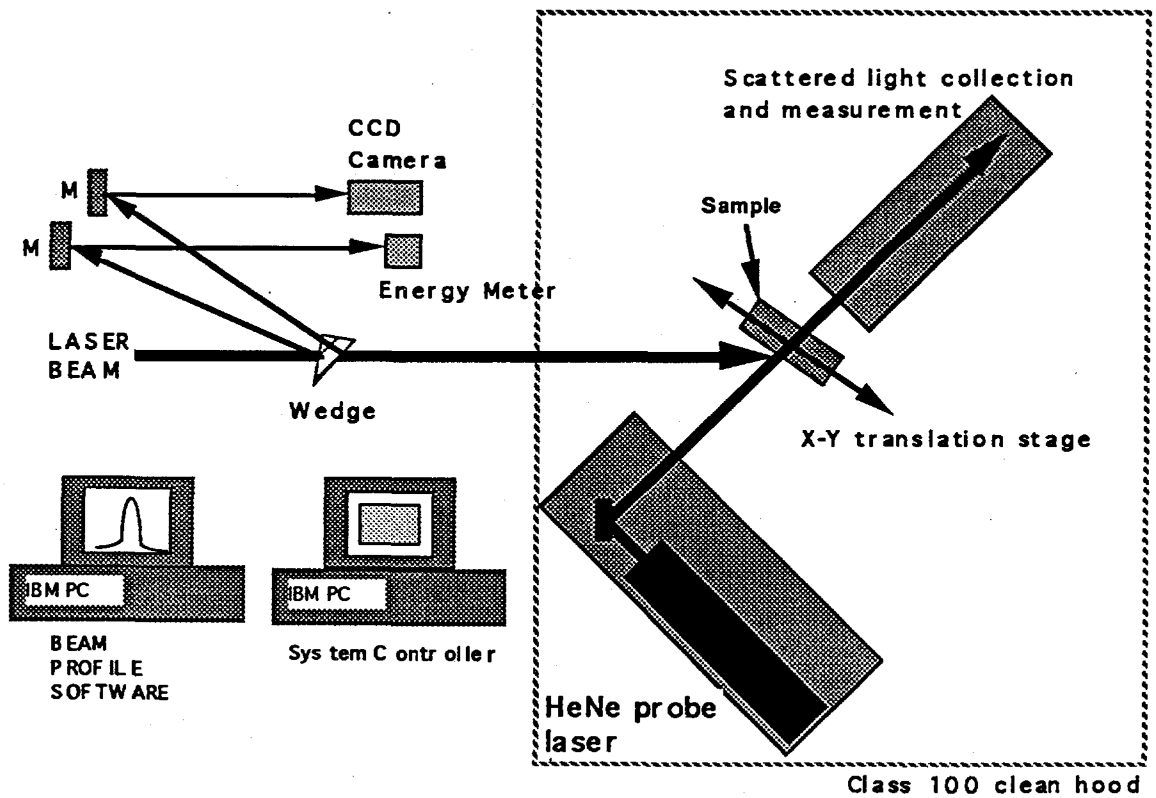

Fig. 6. The scatter measurement diagnostic was integrated onto the existing Large Area Conditioning system at LLNL.

The scatter measurement system is similar to what has been evaluated within the damage community in the past.[4,5,6] A 35 mW HeNe laser beam is sized such that its beam is larger than the damage test beam on the sample surface. The scatter detection system blocks the transmitted HeNe probe beam at a focus. Scattered light from the sample surface focuses beyond the beam block and is collected onto a silicon photodetector (Fig 7). The spatial resolution of the system is limited by the collection angle. In this system the spatial resolution limit is approximately 10 μm to 20 μm. The photodetector signal is amplified and filtered before being read by a computer controlled data acquisition system.

There are 3 specific scatter measurements made with this system. The first is the mapping of both the inherent and laser-induced scatter from an optic. The second is a measurement of change in scatter based on 2 scatter

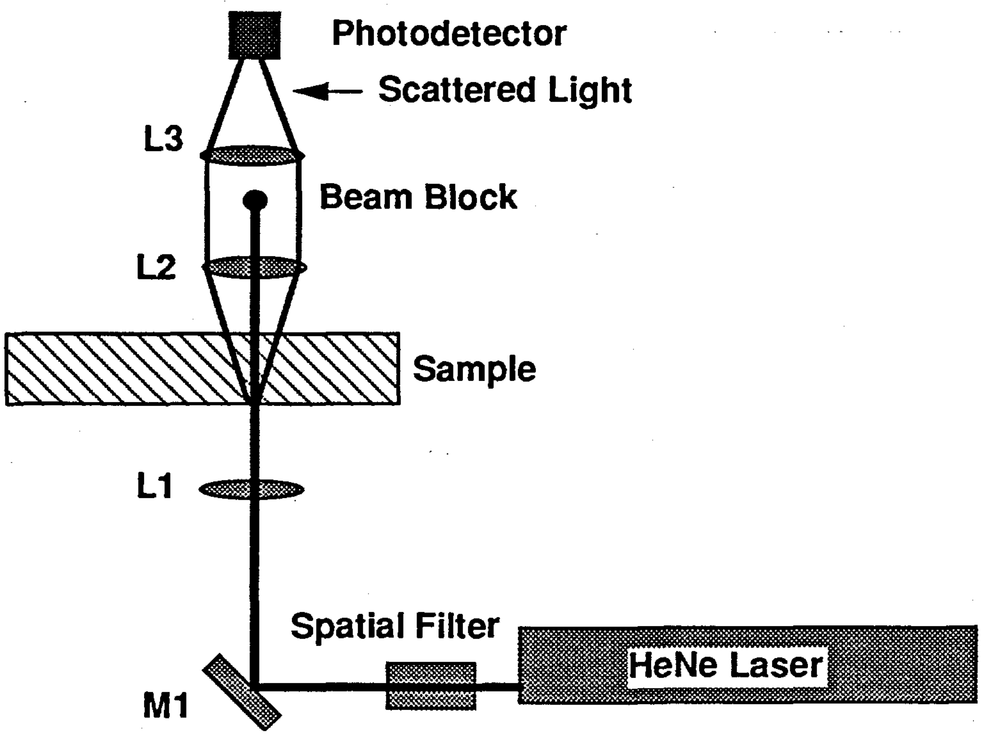

Fig. 7 Layout for measurement of optical scatter.

measurements at the same site, for use in detection of laser-induced damage. This measurement can detect damage at each site on-the-fly during a raster scan. The third measurement is a delta scatter measurement based on averaging of 1000 total measurements per site in order to reduce background noise effects. The graphical depiction of these measurements and the related equations and definitions of the measurements are shown in Fig. 8.

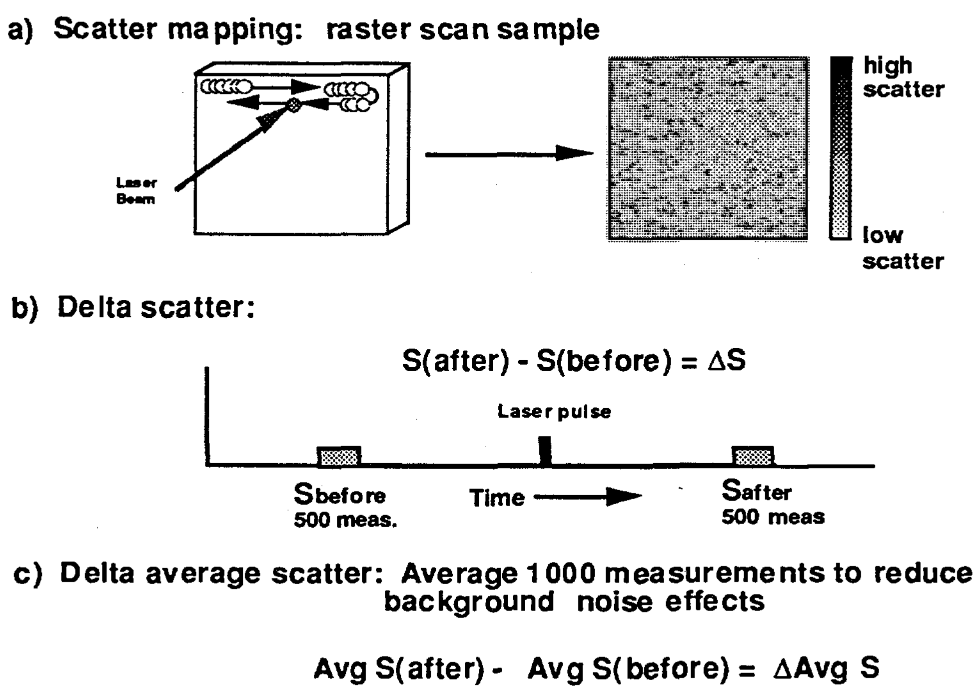

Fig. 8. The present scatter diagnostic system is capable of measuring both intrinsic and laser-induced scatter on single sites, or over large areas.

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3.2 Scattered light damage detection results

The data shown in Fig. 9 shows the measured relationship between the detected damage diameters and the scatter signal. The detected damage is determined by summing all of the diameters of the damage points at a site and this is plotted against the ΔAvgS as defined above. There was an increasing trend of the ΔAvgS with increasing damage diameter. The smallest detected damage point was 10 µm in diameter.

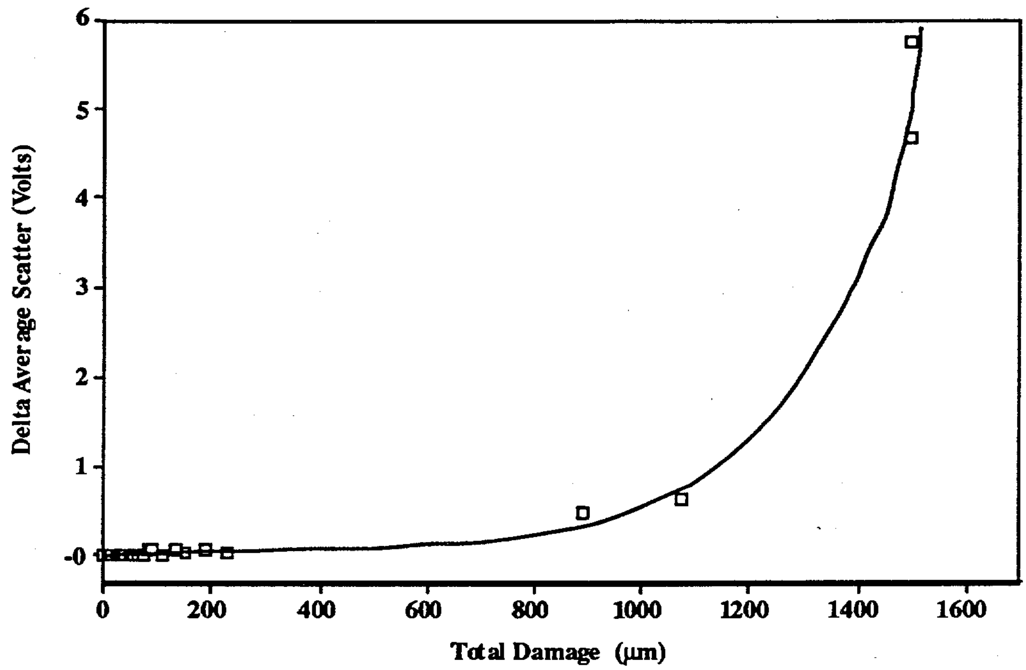

Fig. 9. There is some correlation between damage diameter and the change in scatter signal measured.

An example of the scatter mapping capability of the system is shown in Fig. 10. Shown is the inherent scatter signature of a 74 cm x 36 cm HfO_2/SiO_2 polarizer. In the map, many scatter signal sources can be identified: rear surface contamination, pinpoint defects, substrate artifacts, and also coating non-uniformity at normal incident 632 nm wavelength transmission.

The ΔS measurement is used during our laser conditioning process to identify small pinpoint damage that may occur. This measurement evaluates on-the-fly each irradiated site on the optic for damage. When a raster scan of an optic is complete, a map of the detected damage sites is available. By calibrating the ΔS measurement to detected damage diameter, a estimate of the damage incurred at each of these sites on the optic during conditioning can be made. A map of a polarizer coating after being scanned at 2x its S:1 damage threshold is shown in Fig. 11. Since the coordinates of each of the detected sites is known, microscopic analysis of sites of interest can be made.

There is some amount of difficulty in relating the detected scatter signal to the damage size or morphology. The three main artifacts found during this work are shown in Fig. 12. The first is the different inherent scatter properties of damage spots with the same diameter. Though with the microscope they look similar, but the detected scatter signal is different. The second artifact is the influence of the gaussian spatial shape of the HeNe probe beam and the location of the damage site. The scatter signal level will be less if the damage point is in the wings of the profile versus the peak. The third is that the scatter signal for large damage points and clusters of small damage points may be similar.

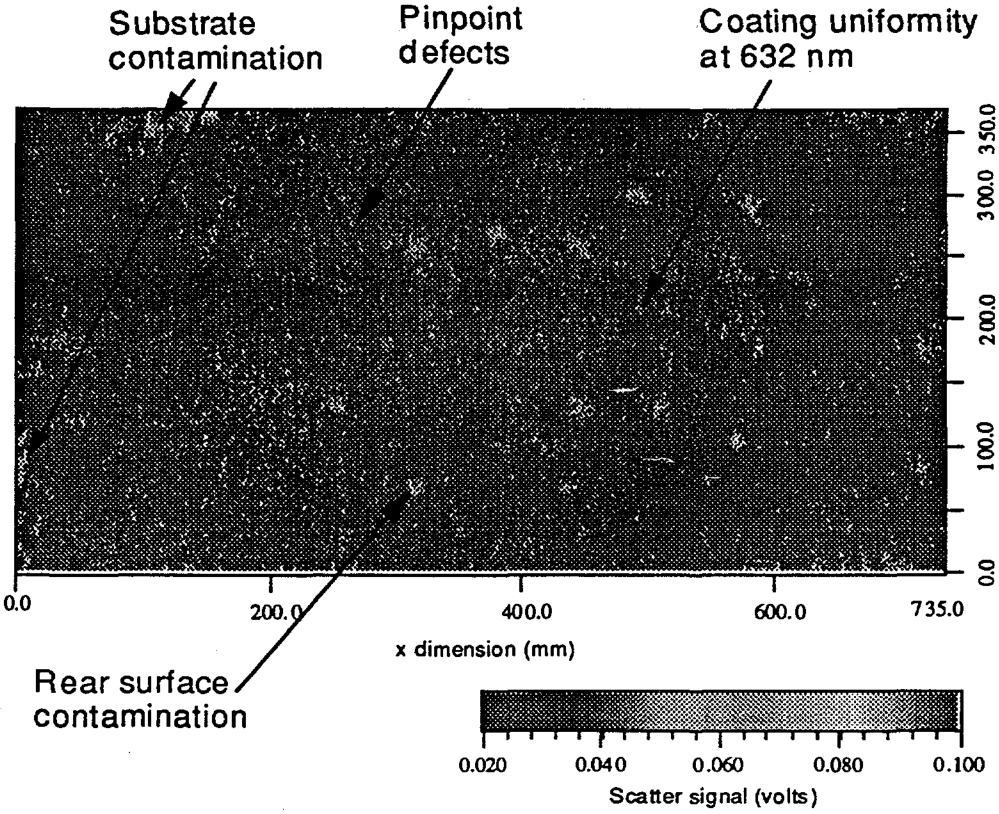

Fig. 10. By mapping the scatter signal from the entire optic, a variety of scatter sources can be seen, and change due to testing can be seen. This map of a 74 cm x 36 cm polarizer shows the inherent scatter sources of a large optic.

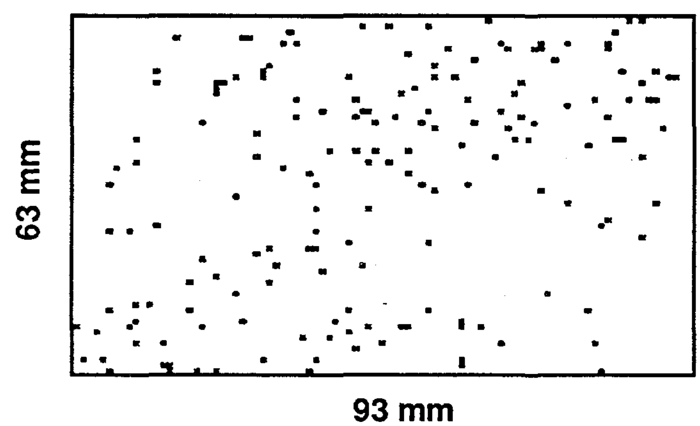

Fig. 11. Map of damage sites incurred during a raster scan at a fluence that is 2x the damage threshold of the coating.

Using both the ΔS and ΔAvgS measurements, damage threshold of optics can be determined. A plot of S:1 damage thresholds of HfO_2/SiO_2 , 1064 nm mirror and polarizer coatings, identified by sample number, is shown in Fig. 13. Plotted are the damage threshold results found using 100x nomarski microscopy, 80x standard backlite microscopy, ΔS, and ΔAvgS. The correlation of the scatter measurement techniques to microscopy where well within the ± 15 % error bars. The only notable difference between the two scatter measurement techniques is found on sample numbers P0027 and P0029. For these particular samples, the damage threshold was based on small pinpoint damage. The damage morphology was small pinpoints up to much higher fluences. Since the ΔS measurement is not as sensitive to very small pinpoints, its determined threshold was higher than that of the ΔAvgS technique, which is very sensitive to small pinpoints. Even with different resolution limits, both techniques compared within error to 100x nomarski.

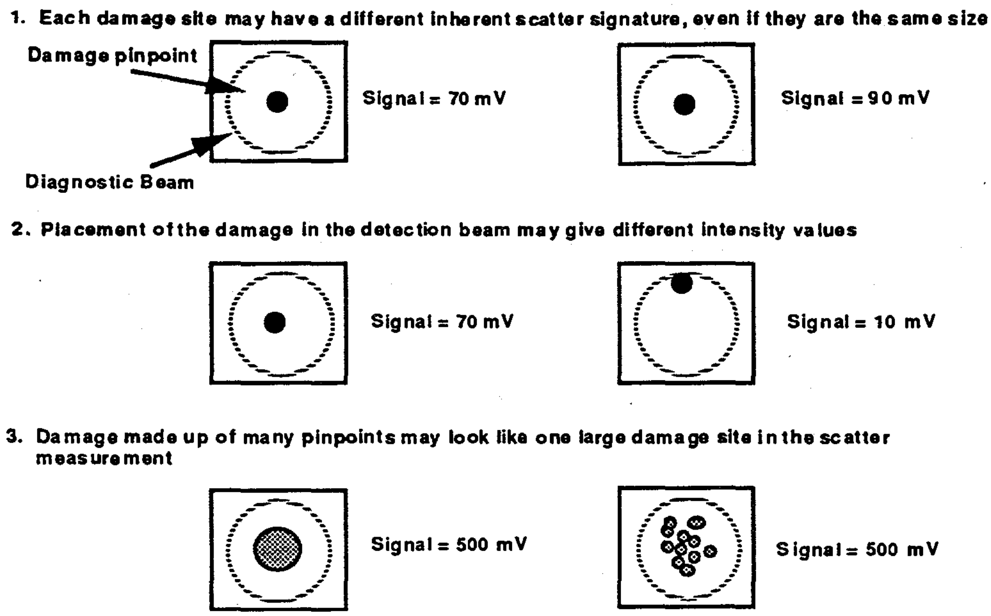

Fig. 12. There are several artifacts that make the correlation of scatter to damage morphology difficult.

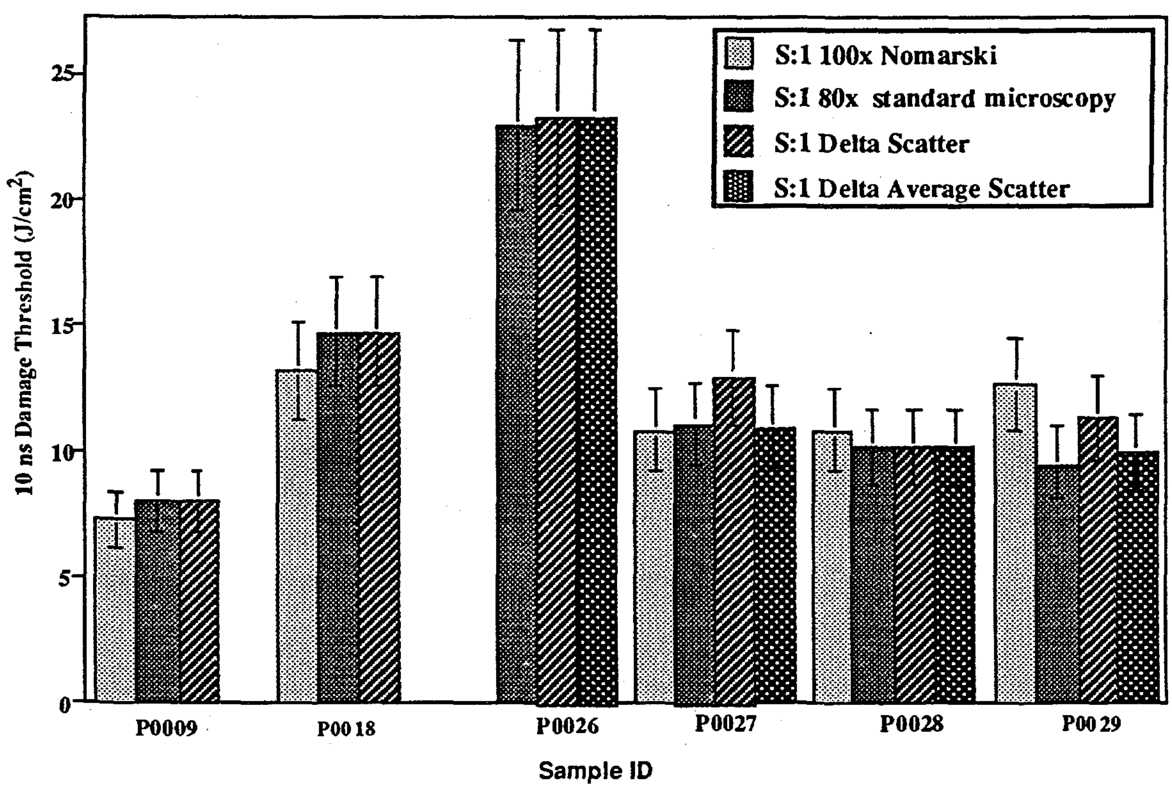

Fig. 13. Both delta scatter and delta average scatter measure damage thresholds of thin films within error of 100x nomarski microscopy.

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4. CONCLUSIONS

- Both acoustic and scatter diagnostics have been designed which can resolve 10 μm diameter damage points
- Scatter measurements using a scanning stage, map both intrinsic and laser-induced scatter
- Scatter signals measured during laser conditioning appear to be related to nodular defects
- Damage thresholds measured using scatter diagnostics compare within error with those measured using 100x nomarski microscopy

5. ACKNOWLEDGMENTS

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6. REFERENCES

1. Hunt, J., Manes, K., Renard, P., "Hot Images from Obscurations", Applied Optics, vol. 32 No. 30, 1993.

2. Sheehan, L. et al., "Large-Area Conditioning of Optics for High-Power Laser Systems", Laser Induced Damage in Optical Materials: 1993, SPIE vol. 2114, 559, 1994.

3. Mann, K. Gerhardt, H., "Setup of a Damage Testing Facility for Excimer Laser Radiation", SPIE vol. 1023, 136, 1989.

4. Seitel, S., Babb, M., "Laser-Induced Damage Detection and Assessment by Enhanced Surface Scattering", Laser Induced Damage in Optical Materials; 1986, NBS Spec. Pub. 752, 83, 1987.

5. Frank, J., et al., "Automated Pulsed Testing Using a Scatter-Probe Damage Monitor", Laser Induced Damage in Optical Materials; 1984, NBS Spec. Pub. 727, 71, 1985.

6. Moran, M., Kuo, R., Marrs, C., "Scatter Intensity Mapping of Laser-Illuminated Coating Defects", Laser Induced Damage in Optical Materials; 1986, NBS Spec. Pub. 752, 235, 1987.