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Detection of Inherent and Laser-Induced Scatter in Optical Materials

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Detection of Inherent and Laser-Induced Scatter in Optical Materials

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Introduction

As Lawrence Livermore National Laboratory moves forward with the design of the National Ignition Facility (NIF) in the Inertial Confinement Fusion (ICF) program, issues relating to the detection and measurement of laser-induced damage on large optics must be addressed.

Currently, microscopy is used to evaluate surface quality and measure damage thresholds on small witness samples. In order to evaluate large areas, an automated system was constructed which can scan optics with dimensions as large as 1 meter and weighing as much as 400 pounds. The use of microscopy as the main test diagnostic has been replaced with an optical scatter detection system. Now large areas can be rastered, and maps can be generated, reflecting inherent and laser-induced scatter in multilayer optical coatings and bulk materials.

The integrated scattered light from a test piece is measured in transmission using a HeNe laser as the probe source. When the probe beam is overlapped on a pulsed, high power, Nd:YAG laser beam, damage related scatter may be measured. This technique has been used for: 1) mapping of inherent scatter in an optic, 2) on-the-fly damage detection during a high fluence raster scan of an optic, and 3) single site damage evaluation for the determination of a laser damage threshold. Damage thresholds measured with the scatter diagnostic compare within measurement error to those attained using 100 x microscopy.

Scattered light measurement system

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

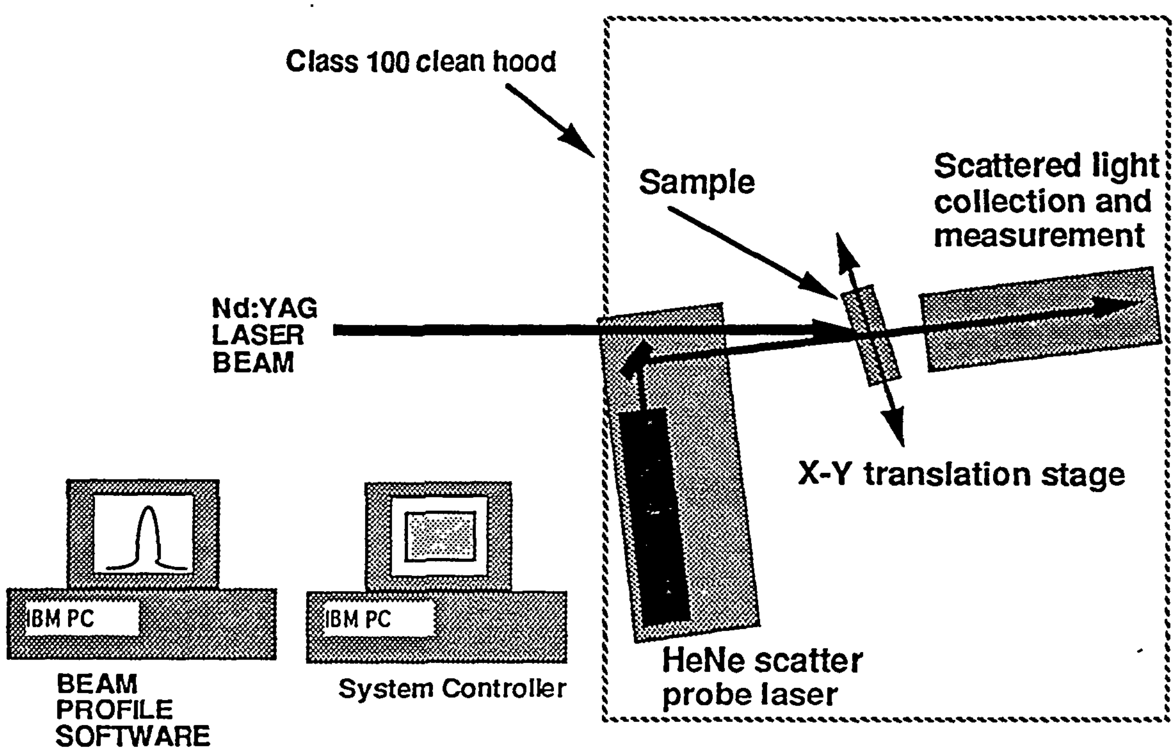

Fig. 1 The scatter measurement diagnostic has been integrated into the existing Large Area Conditioning system at LLNL.

The scatter measurement system is similar to what has been evaluated within the damage community in the past.[2,3,4,5] 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 2). In this system the spatial resolution limit is approximately 10 µm to 20 µm due to the collection angle of the optical system. 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 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. 3.

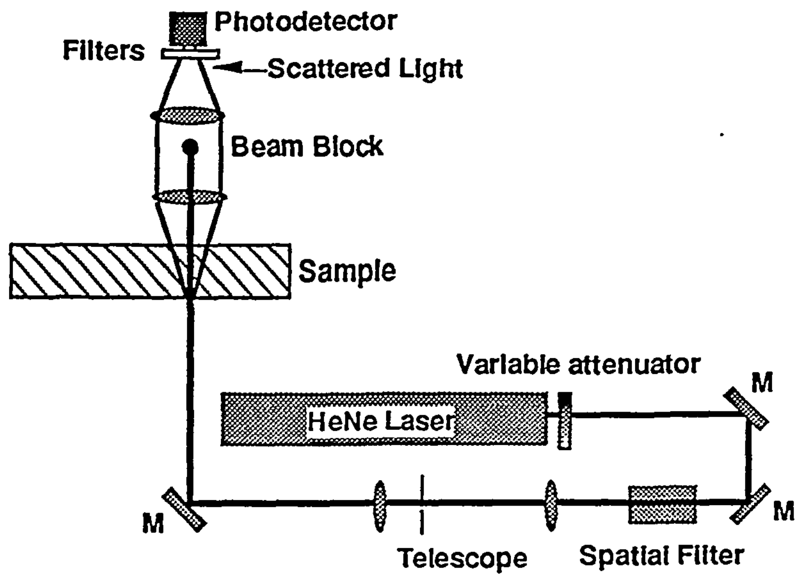

Fig. 2 Layout for measurement of optical scatter.

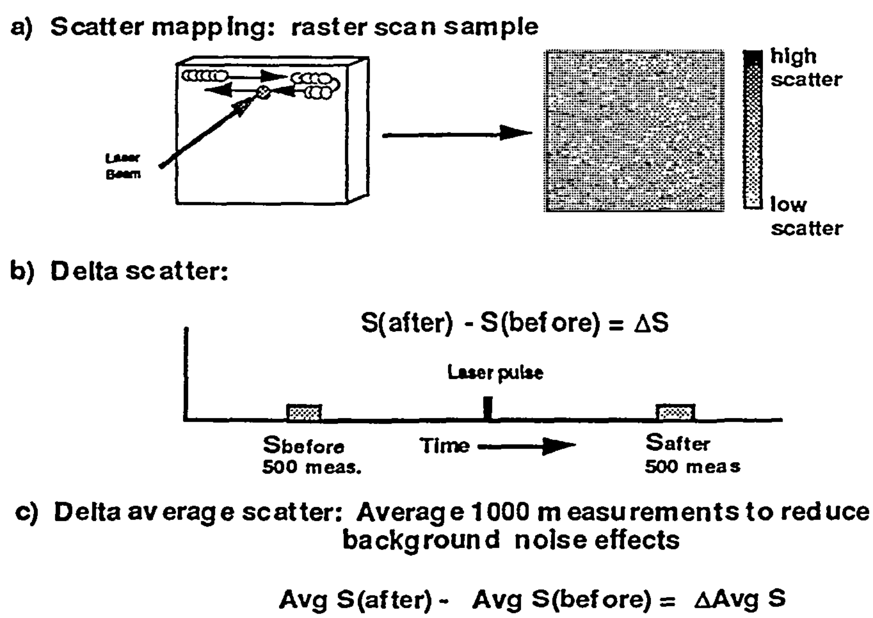

Fig. 3 The present scatter diagnostic system is capable of measuring both intrinsic and laser-induced scatter on single sites, or over large areas

Details of scatter light detection system

In order to understand the efficiency of this initial system, a detailed layout and subsequent CODE V modeling is presented. Fig. 4 shows a more detailed layout of the optical components that make up the transmissive scatter measurement.

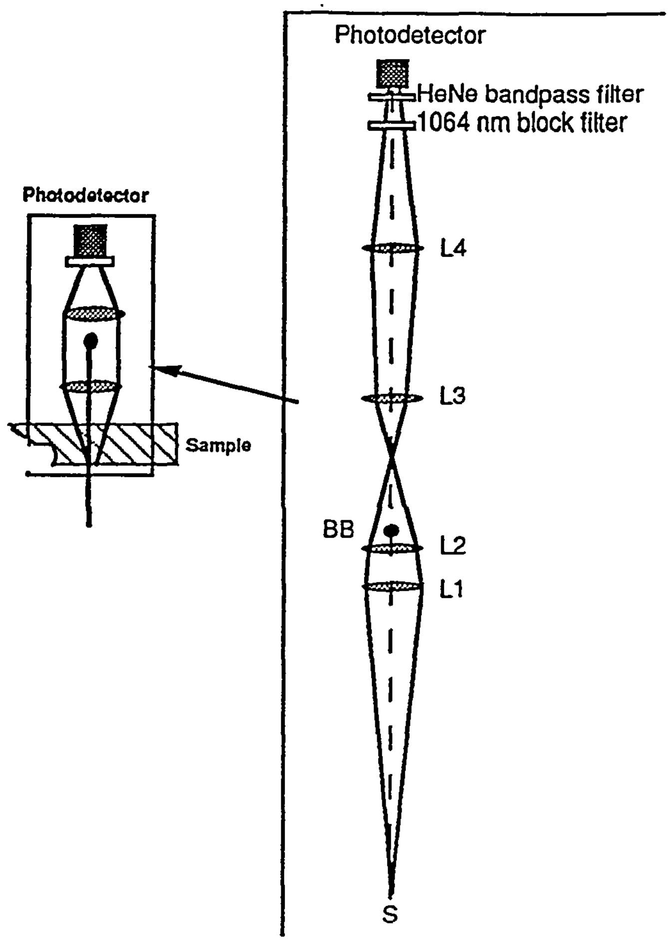

Fig. 4 Detailed layout of the transmission scatter measurement

The parameters of the optical components are shown in Table 1. The separation column represents the distance from the previous component to the listed component, where the sample surface is zero. So L1 is 265 mm from the sample surface, and L2 is 80 mm from the center of L1, and so on.

The Fig. 5 displays the Code V raytrace of the scatter detection system. The calculated magnification was about 1.6, so the field of view (FOV) at the sample surface is 16 mm. The largest high power beam diameter is 6.5 mm.

Table 1. Parameters for the optical system.

Component	material	diameter	thickness	focal length	Separation
Sample	varied	varied	varied	None	0
L1	BK-7	50 mm	8 mm	125 mm	265 mm
L2	BK-7	50 mm	9.4 mm	100 mm	80 mm
BB	------	200-1000 μm	------	-------	45 mm
L3	BK-7	50 mm	10.4 mm	88.3 mm	70 mm
L4	BK-7	50 mm	8 mm	125 mm	140 mm
Detector	------	10 mm	------	------	180 mm

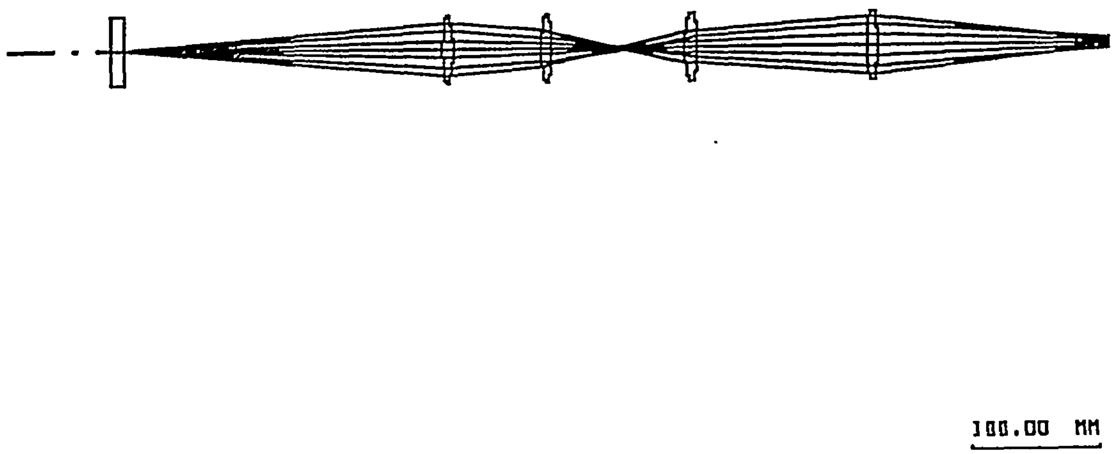

Fig. 5 Code V raytrace of high-angled scattered light through optical detection system

Scattered light detection results

Scatter mapping

An example of the scatter mapping capability of the system is shown in Fig. 6. 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 uniformity at normal incident 632 nm wavelength transmission.

Delta scatter mapping on-the-fly

The ΔS measurement is used during our laser conditioning process to identify small pinpoint damage that may occur. This measurement evaluates 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 the 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 damage incurred during scans of a polarizer coating are shown in Fig. 7. The first map of damage sites Fig. 7 a) was from a scan of the optic just above its damage threshold, and showed only a few damage sites. In Fig. 7 b) the fluence was twice the damage threshold of the coating, and many damage sites are detected. Since the coordinates of each of the detected sites is known, microscopic analysis of sites of interest can be made.

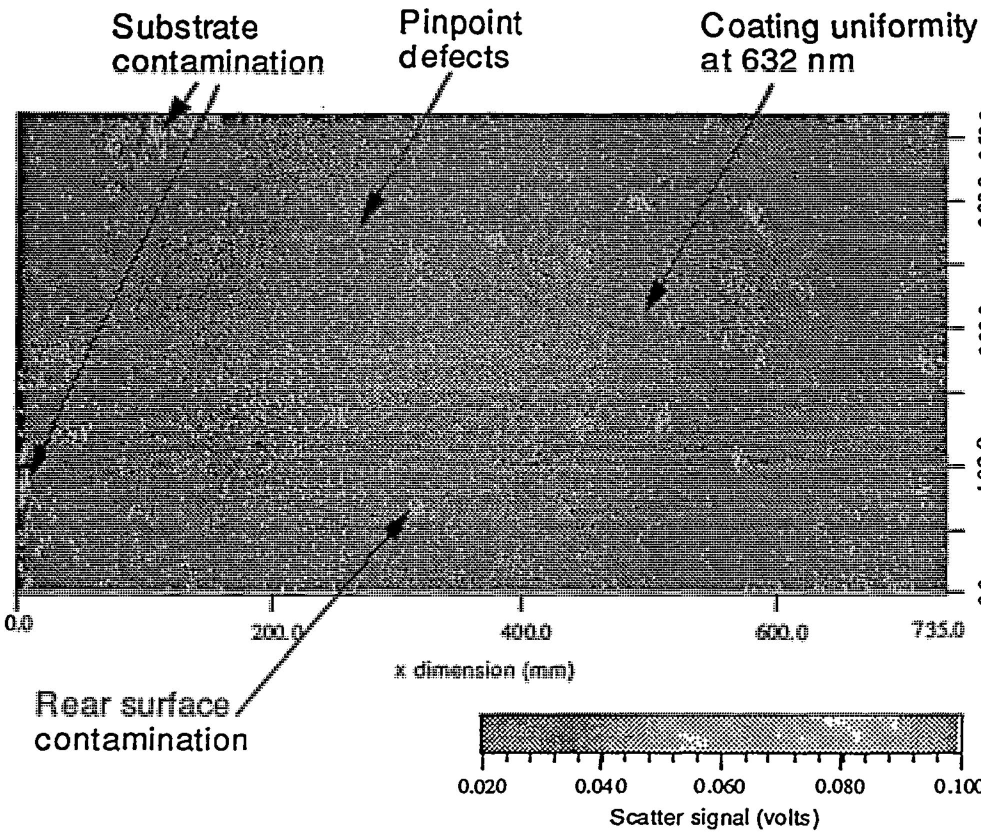

Fig. 6 By mapping the scatter signal from the entire optic, a variety of scatter sources can be seen. This map of a 74 cm x 36 cm polarizer shows the inherent scatter sources of a large optic.

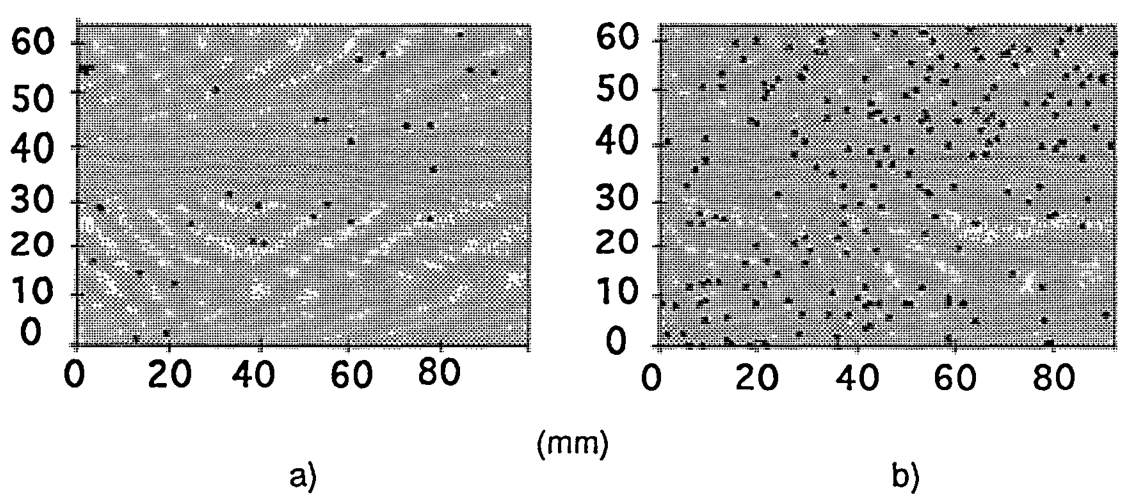

Fig. 7 Map of damage sites detected by ΔS measurement during a raster scan at a) 9.1 J/cm2 and b) at 16.8 J/cm2, a fluence that is 2x the damage threshold of the coating

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. 8. The first is the different inherent scatter properties of damage spots with the same diameter. 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. 9 shows the relation between ΔS and the size of damage observed. The data can be used to provide a indication of the size of damage, but not an absolute value.

Delta average scatter measurement

The data shown in Fig. 10 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.

Determining damage thresholds

Using both the ΔS and ΔAvgS measurements, damage thresholds of optics can be determined. A plot of damage thresholds of HfO_2/SiO_2 , 1064 nm mirror and polarizer coatings, identified by sample number, is shown in Fig. 11. Plotted are the damage threshold (S:1) 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 % measurement 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 as the ΔAvgS technique, its determined threshold was higher. Even with different resolution limits, both techniques compared well to microscopy.

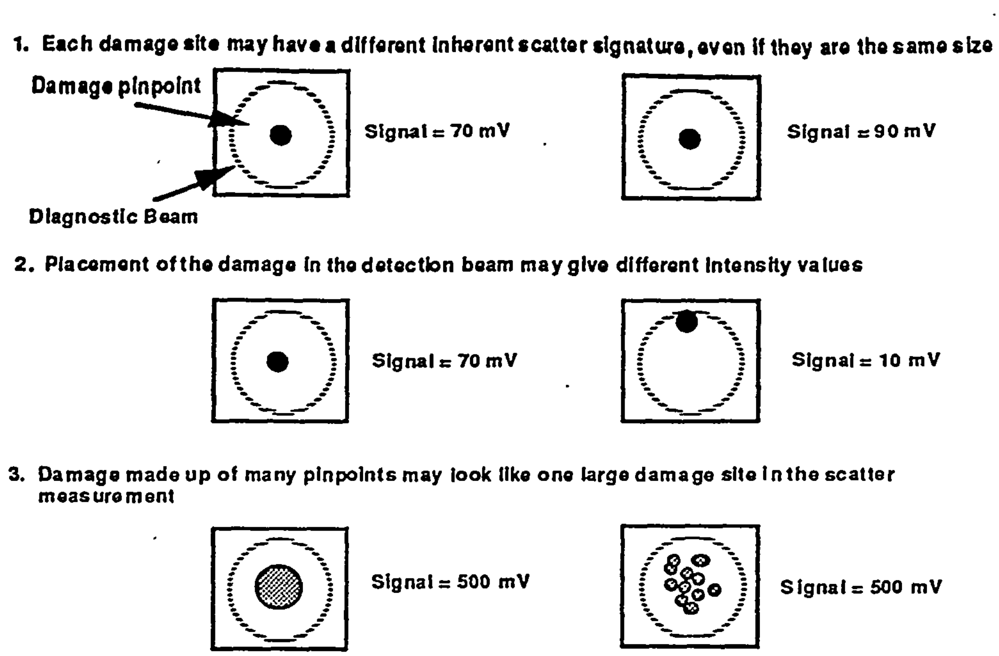

Fig. 8 There are several artifacts that make the correlation of scatter to damage morphology difficult.

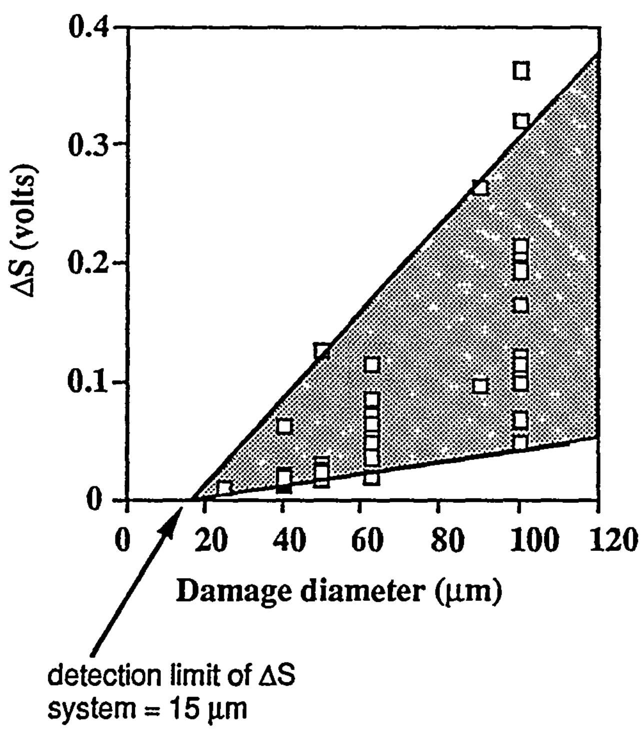

Fig. 9 The ΔS diagnostic provides some indication of the size of the damage incurred during a scan

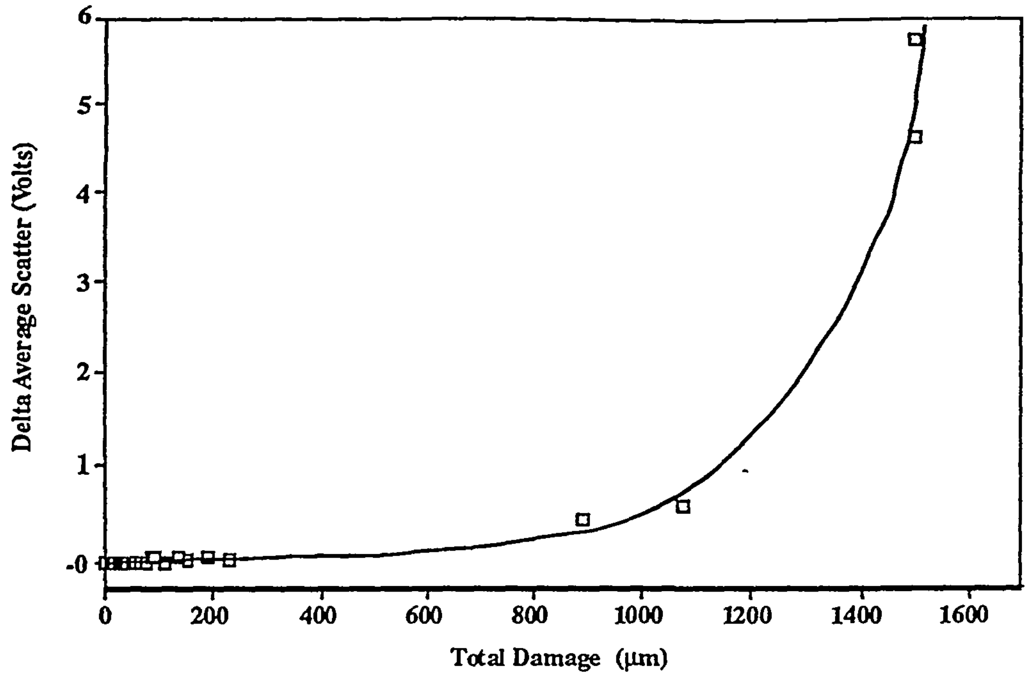

Fig. 10 There is some correlation between damage diameter and the change in scatter signal measured

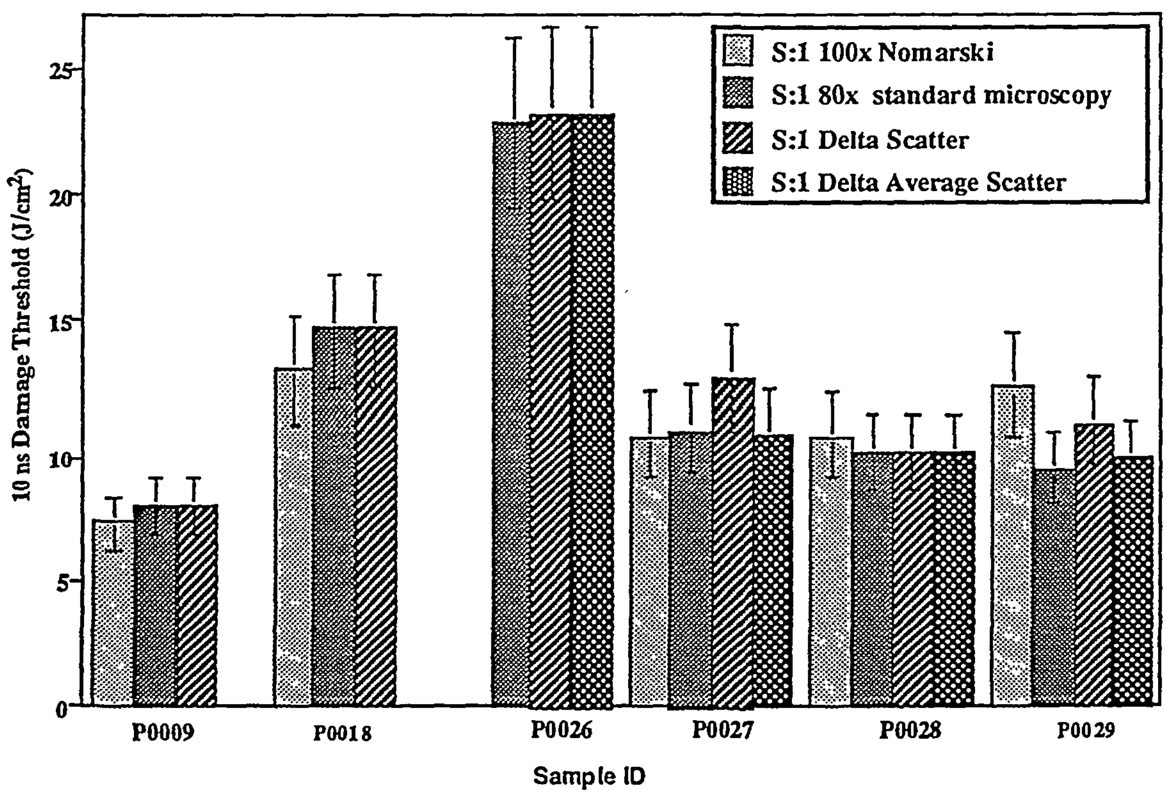

Fig. 11. Both delta scatter and delta average scatter measure damage thresholds of thin films within error of 100x nomarski microscopy.

Conclusions

An optical system has been demonstrated which can measure the integrated scatter from optical components in transmission. The system is capable of mapping inherent and laser-induced scatter in meter-sized optical components. A detailed design and results demonstrate the scatter collection system capabilities for such applications. The technique is capable of measuring scatter sources as small as 10-20 µm in diameter. When used to conduct measurements of laser damage thresholds of optical coatings, the results compare to those achieved with 100x microscopy.

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