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Full Aperture Laser Conditioning of Multilayer Mirrors and Polarizers

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Abstract

The Inertial Confinement Fusion (ICF) program at LLNL is beginning the design of a 1.8 Megajoule, 0.35-µm, laser system called the National Ignition Facility (NIF). In order to reduce cost, and increase performance, high damage threshold optics are essential. As a result of damage initiating defects, only a small percentage of current as-deposited optical coatings can meet the required damage threshold specification. Work has been conducted in the area of understanding the causes of these nodular defects and how they are related to laser damage. While it is not yes possible to produce defect-free coatings, it has been found that the damage threshold of some coatings can be increased by as much as 2 or more times as a result of pre-illumination at incrementally increasing fluences. This process, termed laser conditioning, has been associated with the ejection of the damage-initiating defects. With current damage thresholds, mirrors and polarizers for the NIF will have to be laser conditioned in order to meet the laser requirements for fluence propagation (Fig. 1).

LLNL has constructed a system dedicated to laser conditioning of meter-sized HfO_2/SiO_2 multilayer polarizers and mirrors. The optic is moved in a raster pattern through a stationary 10-Hz rep-rated, 1.064 µm beam with 10-ns pulses. A scatter measurement diagnostic allows on-the-fly evaluation of laser-induced damage during a scan. This system has been used to laser condition optics as large as 73 cm x 37 cm. Such optics are now being used on the Beamlet laser system at LLNL. A description of the conditioning process, its effect on the optic, and an analysis of its application to large areas is presented.

Keywords: laser conditioning, nodular defects, raster-step conditioning, scattered light

1. Laser Conditioning Review

LLNL uses two different techniques to produce the laser conditioning effect. The first is done with a rep-rated laser system in a sequence termed ramped conditioning, or R:1 (R on 1) conditioning. This means that fluence on a single site is increased in ramped manner, over several hundred rep-rated shots. This is the standard way of measuring a small spot conditioned threshold on a witness sample. The second method used is termed N:1 meaning a number of increasing fluences on a single site. This is used to describe conditioning that is not ramped. The conditioning is achieved by illuminating the site at increasing fluences, not necessarily over hundreds of shots, and not necessarily in a rep-rated mode. Shots may be separated unevenly in time, but the fluence is increasing with each step.

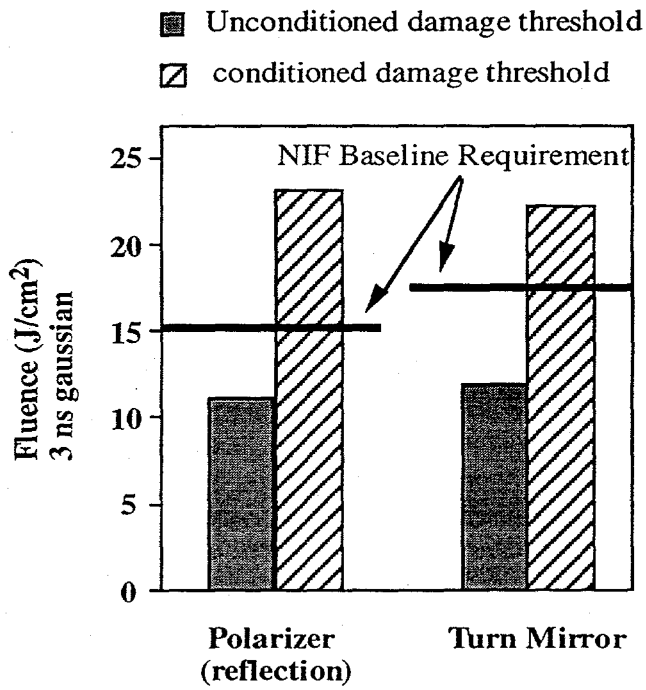

Fig. 1 Based on current damage thresholds, mirrors and polarizers on the NIF laser system would have to be laser conditioned

Since the optics to be conditioned are meter class in size, R:1 conditioning is not feasible. The N:1 technique can be applied using a large aperture laser system, or by using a small laser source and scanning the optic using a raster-step conditioning procedure. The procedure is shown in Fig. 2. The optic is translated through a stationary, rep-rated laser beam, at a velocity such that the optic has moved one 90% beam diameter between each laser shot. Moving the optic in a raster pattern ensures that the entire surface is illuminated at the set fluence. The fluence is then increased to the second conditioning step and the entire optic is scanned again. This procedure is done in six incremental steps beginning at one-half the measured unconditioned threshold (S:1) up to the desired performance level plus a 15% safety factor.

This raster conditioning technique has shown to be useful for increasing the threshold of the optical coatings to as much as 2 times their unconditioned threshold. Although the damage threshold of the optic is increased, the amount is dependent on the highest conditioning fluence used. The conditioning process is a permanent effect, but there is some damage incurred during the procedure. Fig. 3 shows some of the results found when raster conditioning areas on an optic. The conditioning process also lessens the severity of damage incurred at high fluences, shown in Fig. 4.

Literature has shown that the conditioning effect for HfO_2/SiO_2 multilayer coatings is related to the removal of nodular defects in the coating(1). The pit that remains has a higher threshold than the original nodule, and the damage threshold is increased. Damage as large as 100 μm has been observed

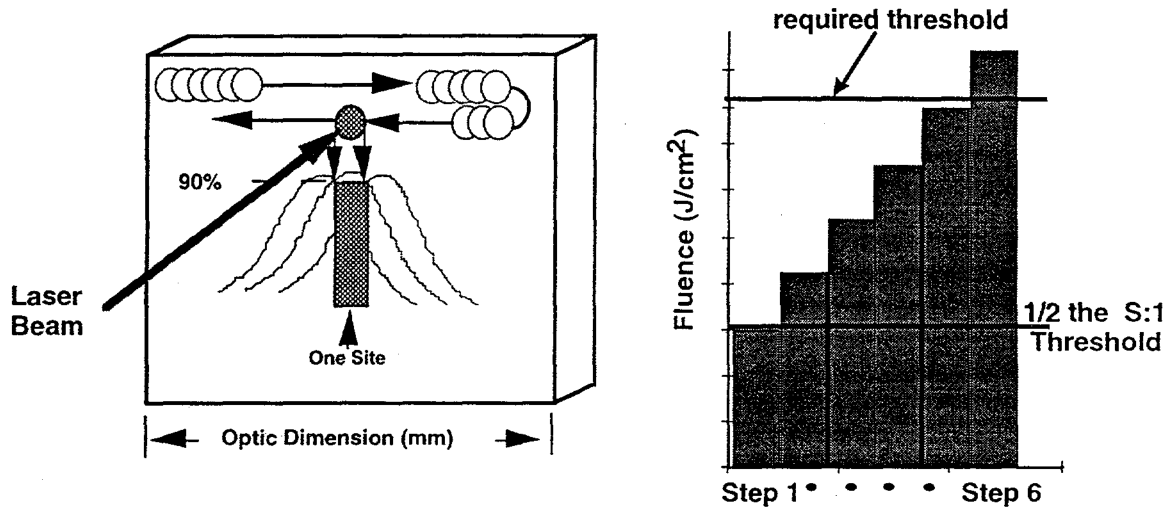

Fig. 2 Raster-step conditioning is similar to N:1 type conditioning. The entire optic area is raster scanned once at each of the fluence levels shown to the right.

when conditioning optics to twice their S:1 threshold, which suggests there may be a limit to the level that a coating can be conditioned and incur only benign removal of nodules. This 100 μm pinpoint type damage has not been found to cause performance problems on large optical systems such as the Beamlet laser at LLNL.

2. Large Area Conditioning (LAC) system

A system has been constructed which is dedicated to laser conditioning of meter-sized HfO_2/SiO_2 multilayer polarizers and mirrors. The optic is moved in a raster pattern through a stationary 10-Hz rep-rated, 1.064 μm beam with 10-ns pulses. A layout of the system is shown in Fig. 5. This system has been used to laser condition optics as large as 73 cm x 37 cm. A scatter measurement diagnostic allows on-the-fly evaluation of laser-induced damage during a scan(2). The system can also map the inherent scatter in a optical component.

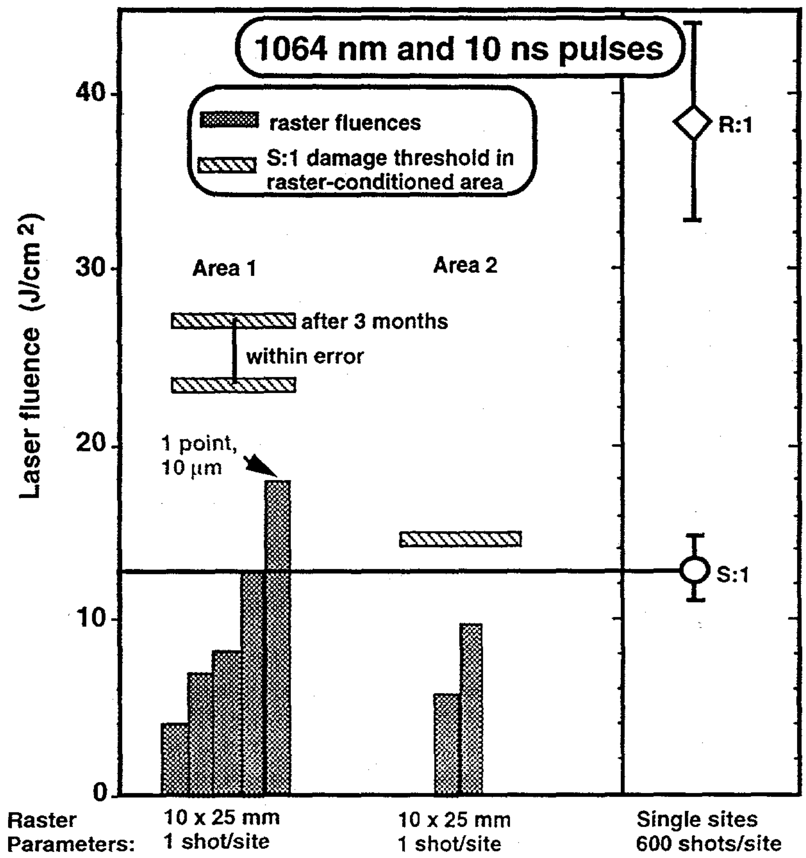

Fig. 3 The conditioning process results in a permanently increased threshold. The amount of increase depends on the peak fluence used to condition. Some damage does occur when conditioning large areas.

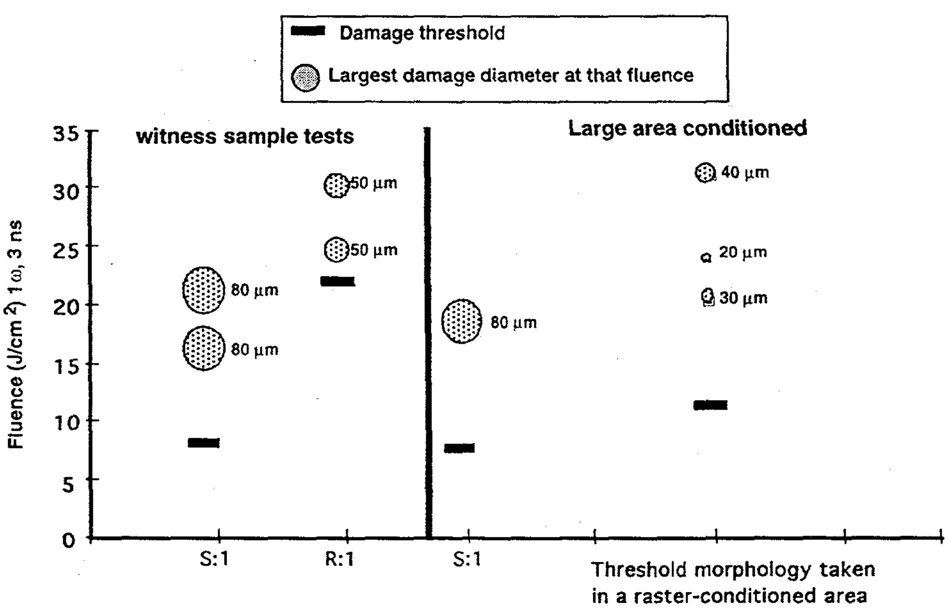

Fig. 4. Laser conditioning either in R:1 form or raster conditioned, decreases the damage morphology at high fluences.

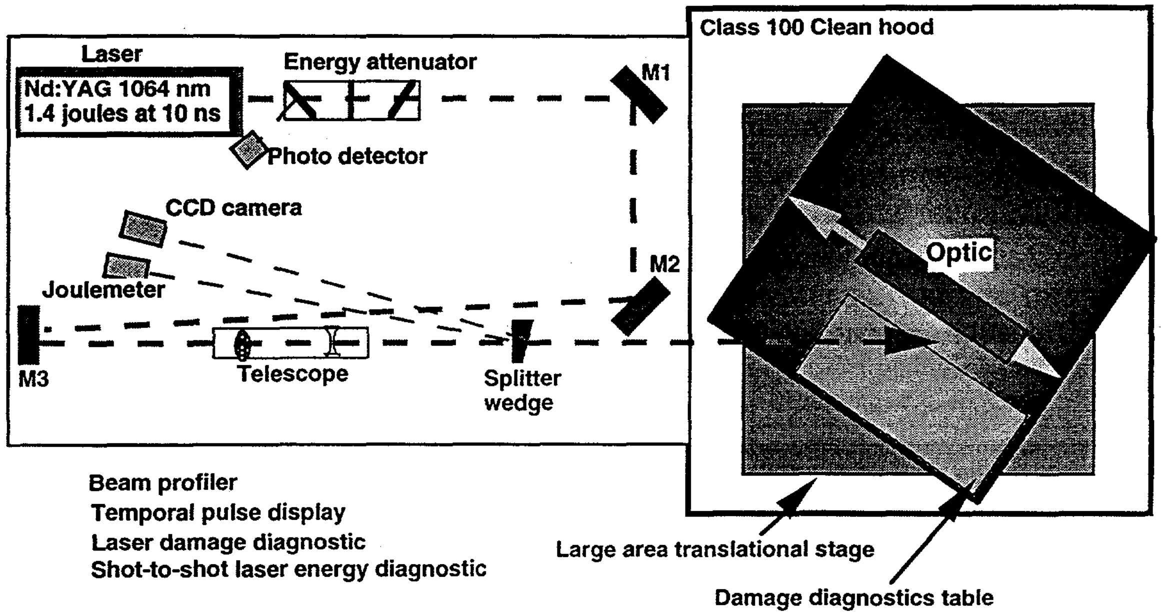

Fig. 5 Large Area Conditioning (LAC) facility layout

3. Results of the laser conditioning procedure

Several HfO_2/SiO_2 multilayer polarizers and mirrors have been conditioned to twice their unconditioned threshold as shown in Fig. 6. The optics have been used in large laser systems and have showed no influence on performance, and have survived fluences up to the conditioned levels.

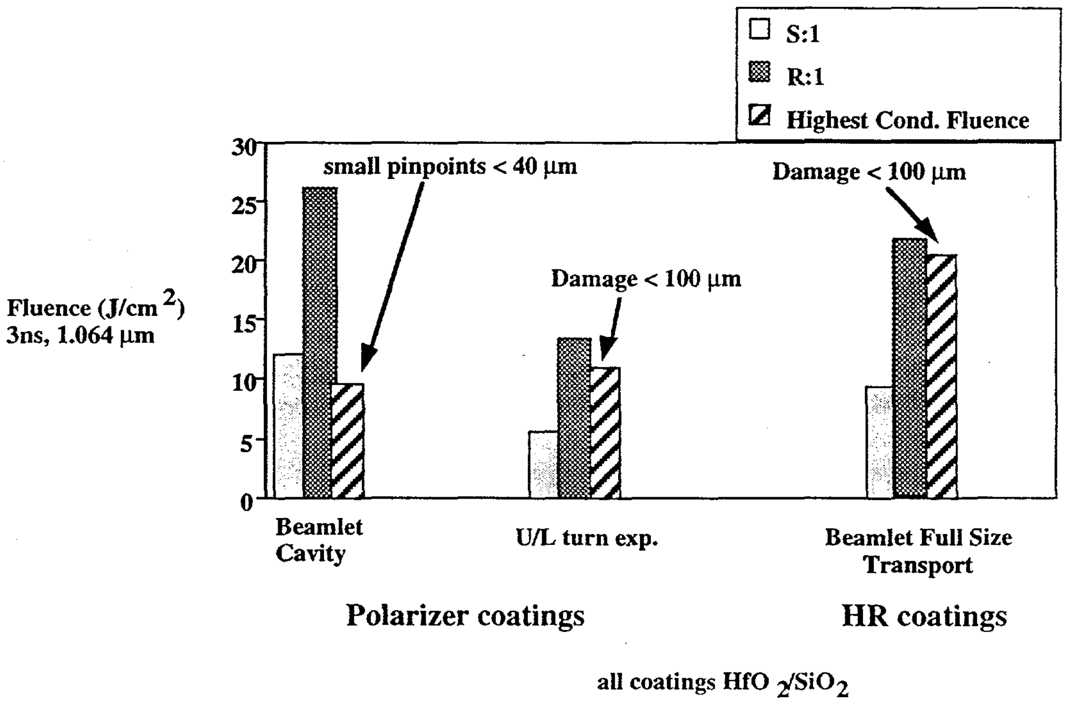

Fig. 6 Peak fluence levels as high as twice the intrinsic threshold where used to condition large optics for the Beamlet laser system.

The scatter detection diagnostic is used to map out the laser-induced changes in the coating due to laser conditioning. Fig. 7 shows the before and after conditioning maps of a 9 cm by 6 cm polarizer coatings conditioned to twice the unconditioned threshold of 8.4 J/cm^2 at 10 ns. Fig. 7a shows the inherent scatter of the coating before illumination. Fig. 7b shows the change in the scatter from the coating after conditioning to a peak fluence of 16.8 J/cm^2. The increased scatter is due to pinpoint damage no greater than 100 µm in diameter. This optic was used during a Beamlet test campaign and performed well.

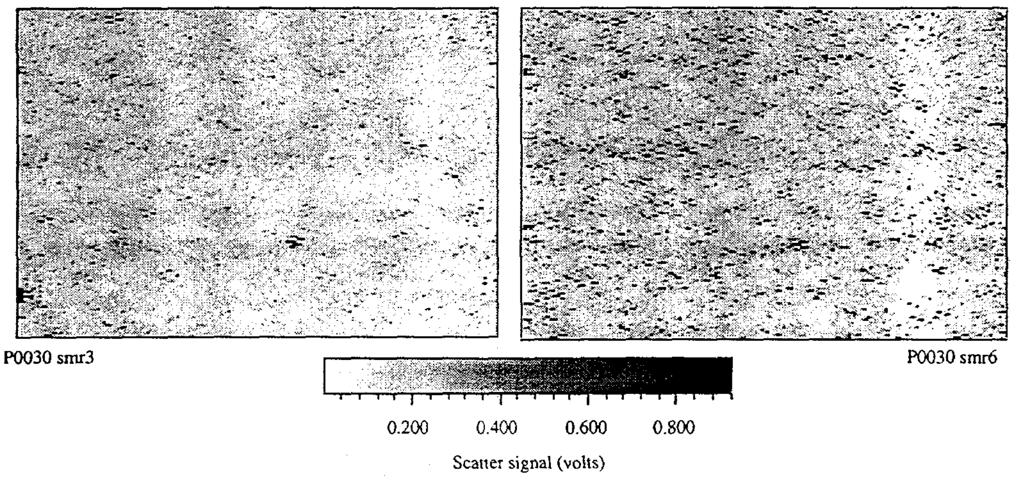

Fig. 6 a) Inherent scatter in polarizer coating, b) scatter map of coating after conditioning to twice the unconditioned threshold

4. Correlation of nodule ejection and laser conditioning of large areas

As mentioned previously, literature suggests that the laser conditioning effect is due to the benign removal of nodules in the optical coating. In order to investigate this observation over a large area, a one inch square on a 45 degree HfO_2/SiO_2 multilayer mirror was raster-conditioned to twice its original threshold. The area was then investigated with an Atomic Force Microscope (AFM) which delivers high resolution topographic information. Two areas where observed, conditioned, and unconditioned. In the unconditioned area, there were many nodules and only a few pits. In the conditioned area, the reverse was true, there where many pits and only a few nodules. Fig. 8 shows the statistics for the two areas, collaborating the presence of nodular ejection. Research has shown that nodules with very little height do not damage, and the nodules found in the conditioned area fell into the definition of low height [3].

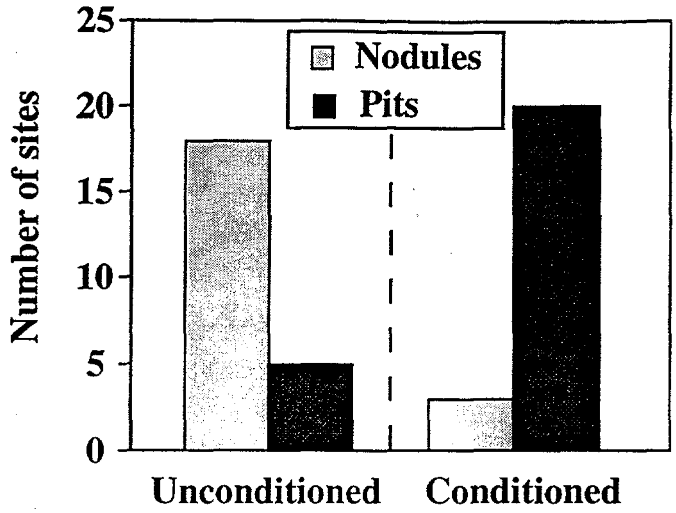

Fig. 8 AFM analysis of raster conditioned and unconditioned areas on a optical coating reveal the nodule ejection phenomenon.

5. Conclusions

The damage threshold of HfO_2/SiO_2 multilayer polarizers and mirrors can be increased by raster-step conditioning to as much a twice their original threshold. Coatings have been conditioned to their measured R:1 conditioned values as well. During the conditioning procedure, damage as large as 100 μm was observed. This damage has been found not to effect the performance of the Beamlet laser at LLNL. The tests concurred with literature that the conditioning effect is related to the removal of nodulàr defects in the coating.

6. Acknowledgements

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7. References

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