Experimental Simulation of Damage in Spatial Filter Lenses

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ABSTRACT

Experiments were performed simulating the conditions of the stage E-input spatial filter lenses on the OMEGA laser system to determine whether vacuum pump oil, which has been shown to contaminate the lenses is a possible damage mechanism. Care was taken to grind 2" diameter Damage Testing Optics (DTO's) of crystalline fused quartz silica (CFQ) to a 4 mm thickness, rather than the normal 6 mm thickness, for bending stress simulation. E-input lenses were not used, due to their size and scarcity. Damage was inflicted prior to sol-gel coating, by both ball bearings and a diamond scribe. The DTO's were placed in vacuum cells that were either clean or contaminated with used vacuum pump oil. Finally, they were then raster scanned under stress by a Q-switched Nd:YAG laser emitting 1064-nm light with 10-ns pulse lengths. Results determined vacuum pump oil is a damage mechanism.

INTRODUCTION

The spatial filter lenses of the OMEGA laser system have required replacement due to large damage sites that form on the vacuum surface of the lenses, apparently aided by back streaming of oil from the mechanical vacuum pump. If left on the system, these defects can penetrate the optic deep enough to break it. This hazard not only affects the safety of the personnel, but of the rest of the system as well. The E-ins specifically must be removed from the system before reaching a point where they become weak enough to implode and strike the inside of the spatial filter as well as the lens at the other end of the vacuum, possibly continuing breakage. These damages are considered to generally form into the surface of the lens in a semi-circular, or halfpenny, shape. At OMEGA, the lenses are removed when a defect reaches one half of the calculated critical depth, which is the depth at which the lens will be in danger of breaking. This is calculated using the following formula, assuming a halfpenny defect where Y (the geometric factor of the flaw) = 1, and the depth = the radius of the flaw, where a_c = the critical flaw depth, K_c = the fracture toughness of the glass, and Þ = the bending stress [1].

$$a_c = \frac{(K_c)^2}{(pi)\,(Y\text{Þ})^2}$$

Replacement of the lenses is very expensive, and preferably avoided. When removed, heavily damaged optics smell of vacuum pump oil, leading to the speculation that the contamination assisted in the development of damage sites. Supporting this speculation is the effect of oil contamination on the index of refraction of sol-gel coating, causing the crystalline fused silica (CFQ) to behave as though not coated. The purpose of the performed experiments was to simulate all conditions existing on the OMEGA system, the control being optics tested under clean vacuum, and the experimental group being those tested under vacuum containing used vacuum pump oil vapor, to investigate oil vapor as a possible damage mechanism.

EXPERIMENTS

E-ins removed from OMEGA exhibit clamshell defects (see fig. 1a and fig. 1b) on their vacuum surface sides. Past experience has shown that these defects seem to grow into larger damage sites. These defects have not previously been duplicated off the system. The defects form in a 2-dimensional plane extending from the vacuum surface into the substrate, growing deeper in the shape of a clamshell. When tested, these dark-colored defects were found to contain carbon, which is a product of the laser light vaporizing the oil. One aim of this experiment was to create conditions under which clamshell defects could be replicated.

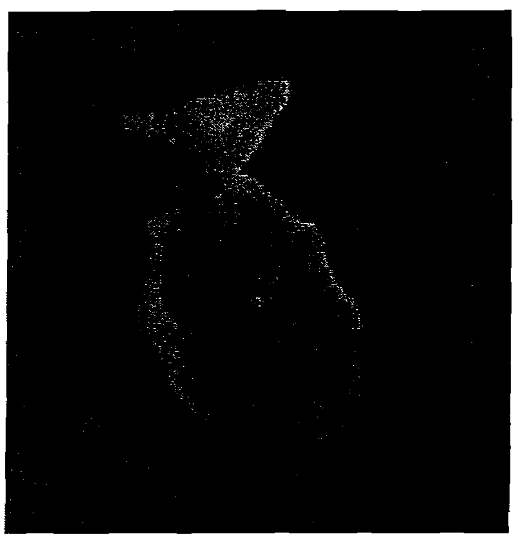


Figure 1a: A side view of a clamshell defect extending into the silica from the vacuum surface.

Figure 1b: A vacuum surface view of the clamshell defect that extends from this crack into the silica.

To simulate all conditions existing on OMEGA, bending stresses had to be similar. The bending stress is the tension that the substrate experiences due to the vacuum pressure. This tension on the vacuum surface may be a necessary factor in the formation of the defects, as it may assist in causing minor tension fractures, which allow the oil to condense. In the lab, we were able to obtain a vacuum pressure of ~20mTorr. Using the standard 6mm thick, 2" diameter Damage Testing Optic (DTO), this allowed for bending stresses of ~25 psi. The stage E-input lenses of OMEGA, which were used as a model, have bending stresses of ~232 psi, under a vacuum of ~10mTorr. It was calculated that if a 4mm thick DTO was used, then the bending stresses at the optic's clear aperture would average ~227 psi, under a vacuum of ~20mTorr. This was an acceptable value for the experiment.

Figure 2: The apparatus for dropping ball bearings onto DTO's

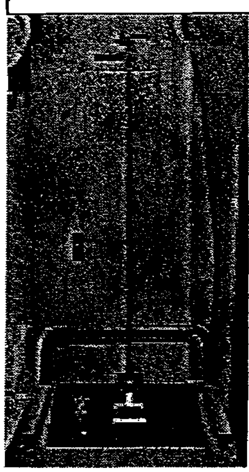
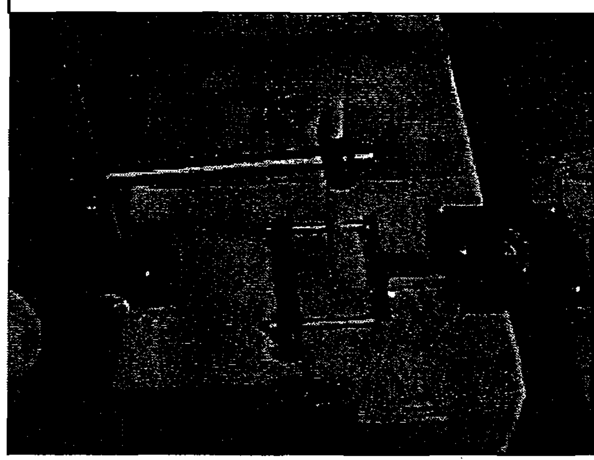


Figure 3: The diamond scribe on tip-tilt base used to damage DTO's. (Shown here with witness substrate.)



After being thinned, the optics were damaged in two different ways (see fig. 2 and 3). Some test sites were touched with a diamond scribe on a tip-tilt base to initiate a very small damage site. Other damage sites were created by dropping ball bearings from a calculated height to damage the optic, without breaking it. This was done to create a surface crack that might deepen into a clamshell defect. Some test sites were left undamaged prior to coating. The optics were damaged prior to coating due to

RESULTS

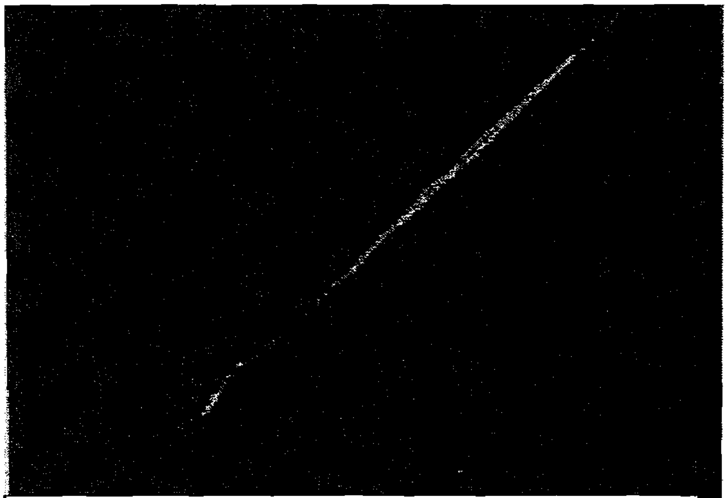


Figure 4: A vacuum surface picture of a clamshell defect from a removed OMEGA lens.

Figure 5: A vacuum surface picture of a defect created in an oil-contaminated DTO.

In vacuums not contaminated with vacuum pump oil, large, shallow, shatter-morphology damage sites were observed on the vacuum surface, which is typical of CFQ substrates coated with an AR (antireflective) coating such as sol-gel. Meanwhile, in vacuums contaminated with used vacuum pump oil, deep, thin damage sites propagated from the vacuum surface into DTO. In uncontaminated samples, the average fluence at which growth starts is 35 $^{J}/_{cm^2}$. That is significantly higher than the average starting fluence of 29 $^{J}/_{cm^2}$ which was observed under vacuums contaminated with oil, showing that the oil is a damage mechanism.

CONCLUSION

Samples contaminated with vacuum pump oil vapor showed damage initiation at lower fluences than clean samples, and damage morphology on Damage Testing Optics under vacuum differed between those with and without oil vapor. These results speculation that damage growth on OMEGA might form from minor damages in the grinding process before the optics are coated. The DTO's were then coated with sol-gel, an anti-reflective coating. This is the coating on OMEGA lenses whose refractive index changes when contaminated by vacuum pump oil vapor.

Once coated, the optics were put at either end of a vacuum cell and pumped down to a pressure of ~20mTorr. The thinned, damaged, and coated DTO's were put at the side of the cell which would receive incident laser light, while a standard thickness, sol-gel coated DTO was put on the side of the cell where the laser light would exit. The front DTO's were the heavily observed, and each one was divided into four testing sites. These testing sites were either ball bearing damaged, scribe-damaged, or not intentionally damaged. For each above described damage condition, there were DTO's tested in an uncontaminated vacuum, and others tested under vacuum containing vacuum pump oil vapor.

To assure contamination, used vacuum oil was put into the vacuum cell before it was sealed off with the DTO's. The cell was then pumped down to pressure with the DTO's in place, so that the oil would reach vapor pressure. Once vapor pressure was reached, the liquid oil would decrease in visible volume, but enough liquid was added in every case that saturation at pressure was obtained with extra liquid pump oil remaining. Thus, the oil vapor saturation level was reached for ~20mTorr prior to each contaminated sample testing. When the proper pressure had been reached, the optics were raster scanned.

suggest that vacuum pump oil contamination is at least one factor in causing the OMEGA spatial filter lenses to damage. Experiments will be continuing to further determine the oil's behavior as a damage mechanism.

ACKNOWLEDGEMENTS

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