Experimental Simulation of Damage in Spatial Filter Lenses

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ABSTRACT

The spatial filter lenses on the OMEGA laser system have required regular replacement due to bulk damage. When removed from the system, it was observed that many of the optics were contaminated with oil on their inner surfaces. Upon investigation, it was determined that oil from the mechanical pumps used to create a vacuum in the spatial filter tubes was the source of the contaminant. The oil is believed to have contributed to the formation of a type of damage morphology referred to as clamshell defects. The original purpose of the experiment was to recreate the clamshell morphology under controlled conditions. This proved to be harder to achieve than expected and the focus shifted to investigating how the oil contaminants affect the damage threshold of both sol-gel and hard oxide coated (HOCO) spatial filter lenses. Results showed that sol-gel coated lenses had a 15% lower damage threshold when contaminated than when clean. The difference of damage threshold between contaminated and clean HOCO lenses was negligible.

INTRODUCTION

Spatial filter lenses on the OMEGA laser system require regular replacement due to bulk damage in the optics (see figure A). It is believed that this behavior is caused by oil vapor contamination of the spatial filter tubes. This vapor originates in mechanical vacuum pumps used to create a vacuum inside the tubes (see figure B). If left unchecked, these damage sites could grow to the lenses' critical flaw depth, and implode under vacuum. This not only lowers the performance of the laser, but creates a situation dangerous to both OMEGA and the technicians that maintain it. In order to prevent such a situation, optics are regularly inspected for flaws.

Replacement due to damage is determined by the Half Critical Flaw (HCF) size of the optics. The HCF size is defined as half the depth of damage at which an optic will fail structurally. This depth is ascertained with a bending stress simulation, which combines the optics' physical characteristics (dimensions, density, Young's Modulus) with the load applied by the vacuum in the spatial filter tube, and calculates how deep of a flaw will cause the optic to crack and break. It is then assumed that the diameter of damage on the surface of the optic (measured tangential to the optic's surface) will be approximately twice the depth. A spatial filter lens will be replaced when half that diameter is reached to insure that the lens will not implode into the spatial filter tube. However, replacement of optics is undesirable due to the high expense and time wasted on realignments when new optics are brought into the system. Therefore an investigation was started into the cause of the defects found on spatial filter lenses, to make effective any strategy aimed at dealing with them.

Spatial filter lenses were first coated with a material called Sol-gel. Physically Sol-gel is a soft, extremely porous coating. The "-gel" portion of its name references its similarity to other gels, in that the slightest touch leaves a mark on the coating, ruining it for laser applications. But while this coating is more difficult to handle than a hard oxide (HOCO) coating, it remains today as the best reflection minimizing coating available.

The mechanism thought responsible for damage formation is as follows: Spatial filter lenses with Sol-gel coatings, when on OMEGA, were able to absorb the previously alluded to oil vapor found in the spatial filter tubes due to the porous nature of the gel. This vapor and Sol-gel combination found its way into micron-sized surface cracks in the lenses created by the grinding and polishing process. When combined, the oil and Sol-gel create a region of high refractive index, so high that upon exposure to laser light, this region gets much hotter than the surrounding oil-free area, and starts to cause cracks to the lens due to thermal effects. Upon further exposure to laser light, these cracks then grew into the observed damage sites. This mechanism is supported qualitatively by the following observations:

In the sol-gel coated lenses, a defect type known as clamshells have formed. These defects, which appear as slits on the surface, actually extend deep into the optic (see figure C). It is believed that tiny microscopic cracks in the optic (which have been observed in the past as a result of lens processing methods), when mounted on a spatial filter tube, are spread open on the vacuum surface due to bending stresses caused by the vacuum inside the tube. When the sol-gel then absorbs oil vapor, the contamination reaches into these cracks. When irradiated by laser light the oil burns and causes the clamshell defect to form. This theory is supported by a carbon residue found in the clamshell sites. A defect such as a clamshell has been shown to grow into larger damage sites when irradiated by laser light, similar to the kind found on damaged spatial filter lenses. However, no quantitative data has been generated supporting this theory, and is what this experiment was designed to do. It should be noted that although these lenses have now been replaced with hard oxide coated (HOCO) lenses, which are not porous and therefore do not absorb the oil vapor, it is still suspected that the oil on the surface might contribute to the damage of the lenses.

This experiment used actual E-input lenses, with both HOCO and sol-gel coatings, contaminated and damaged on OMEGA, to investigate the effects of oil contamination on damage and the causes of clamshell defects.

APPARATUS

In this experiment, a large area conditioning station (LAC) was used. It contains a Nd:YAG, 1064 nm, 1J laser that ran at 30 Hz pulses of 10 ns each (see figure D). To simulate OMEGA conditions, a cell was constructed that would hold E-input spatial filter mounts on both sides. This apparatus was connected to a Varian scroll vacuum pump and a gauge that would measure the pressure of the system. The lower the pressure, the better the vacuum. Three panels of filter glass and two panels of bead-blasted float glass were placed behind the cell to absorb and diffuse the laser light after it passed through the lenses. This cell setup was placed on the LAC1 Conditioning Stage (see figure E).

EXPERIMENT

The E-input spatial filter lenses for the experiment had all previously been used and contaminated on the OMEGA system. This was done so that the optics used for the experiment had months of exposure to contamination, an important consideration as the lenses require months to absorb the oil vapor. To insure the sol-gel coated optics used for the experiment were indeed contaminated with oil, a guided wave spectrophotometer scan was performed. This measured the amount of light being reflected off the surface of the optics over a range of wavelengths. The contaminated optics had a reflectance very similar to an uncoated piece of glass, meaning that the anti-reflective Sol-gel on them had failed. The sol-gel coated optics that were to be tested clean were chemically stripped of their contaminated coating and recoated with fresh Sol-gel. HOCO lenses from the system also had oil on their surfaces. After cleaning the original anti-reflective performance of the lenses returned, thus oil is believed to have not penetrated the HOCO coating.

Once clean and contaminated optics of each coating were collected, they were placed on the side of the cell that would receive the incident light. A clean sol-gel optic was used on the side of the cell where the light would exit. The vacuum was then pumped down to ~7 mTorr, a slightly lower pressure than in the Spatial Filter tubes on the OMEGA (~10 mTorr), to ensure that the bending stress would be equal to or greater than on the OMEGA. All scans were 30 mm diameter circles due to limitations of the stage diagnostics to monitor a scan. Multiple scans were made on each optic in places where there was no visible bulk damage from OMEGA. Scans were performed in both areas where there were no defects, and where there were clamshell defects. All testing was performed in an oil-free vacuum, any contamination on the optics was present prior to testing.

Contaminated HOCO and sol-gel coated optics were first scanned at increasing fluences until the damage threshold was reached. It was found that in using this method, any potential damage sites would grow rapidly into large pit morphologies, too quickly for quantitative data to be collected. This method did, however, provide the damage threshold of the optics. To try and allow for the more subtle clamshell growth, but at a more accelerated rate than on OMEGA, the contaminated optics were scanned repeatedly at fluences below their damage thresholds. No visible damage was seen after these scans. Due to time restrictions, the focus of the project was shifted to include the effect of oil vapor contamination on the damage thresholds of both HOCO and sol-gel coated lenses (see figure F).

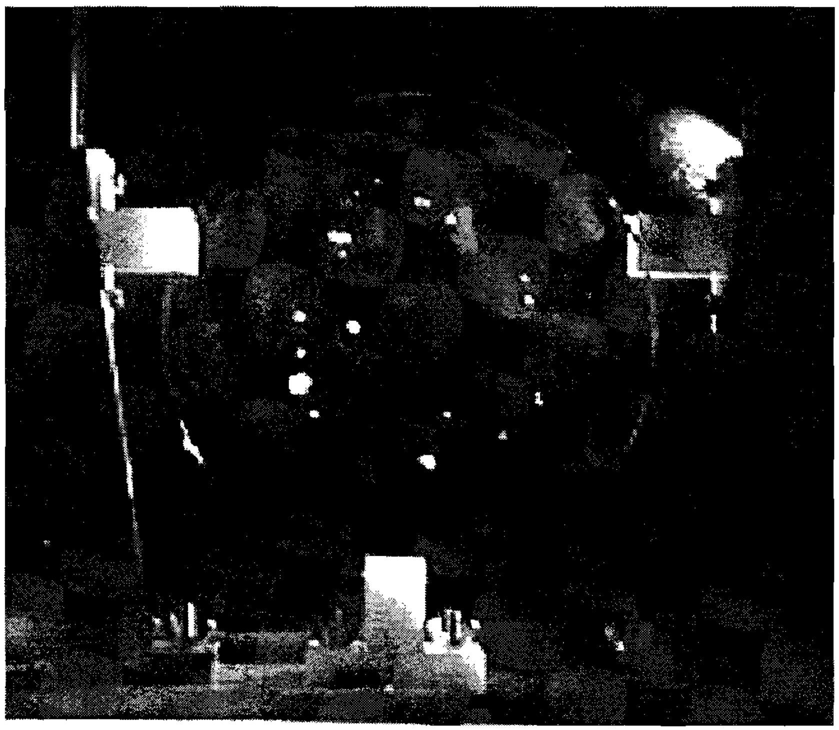
Clean HOCO and sol-gel optics were then tested for damage threshold. The clean sol-gel coating damaged at ~19 J/cm2 and at ~16J/cm2 contaminated. The clean HOCO damaged at ~16 J/cm2 whereas the contaminated HOCO damaged at ~15 J/cm2. These fluence values are calculated for a 3 ns pulse length. It should be noted that while the difference in sol-gel damage thresholds is significant, the difference between the HOCO thresholds is within the error range of the measurement and therefore negligible.

CONCLUSION

Results show that there is negligible difference between clean and contaminated HOCO optics' damage thresholds. Although the damage threshold of clean HOCO is the same as contaminated Sol-Gel, it does not lose its antireflective properties when exposed to oil vapor and is therefore the better optic for use in the contaminated spatial filter tubes.

Another benefit is the shorter amount of time needed to clean a dirty HOCO lens, as it does not need to be stripped of its coating, cleaned, then recoated as the Sol-Gel lenses do. HOCO coatings are durable enough that they can endure the entire cleaning process unaffected. In addition, oil filters have been placed on OMEGA to prevent further contamination. Additional study will be performed to assess the necessity of cleaning the current oil out of the spatial filter tubes on OMEGA.

Fig A.



Damage on spatial filter lens

Fig B.

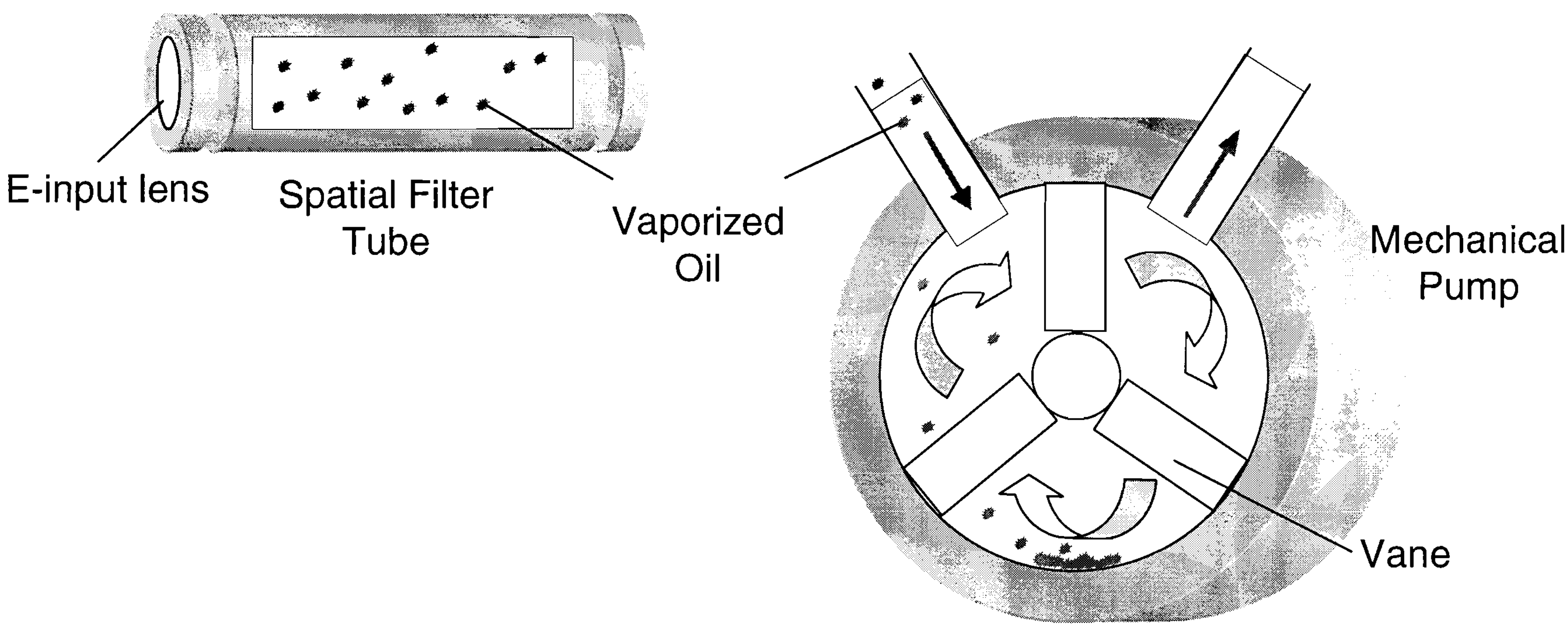
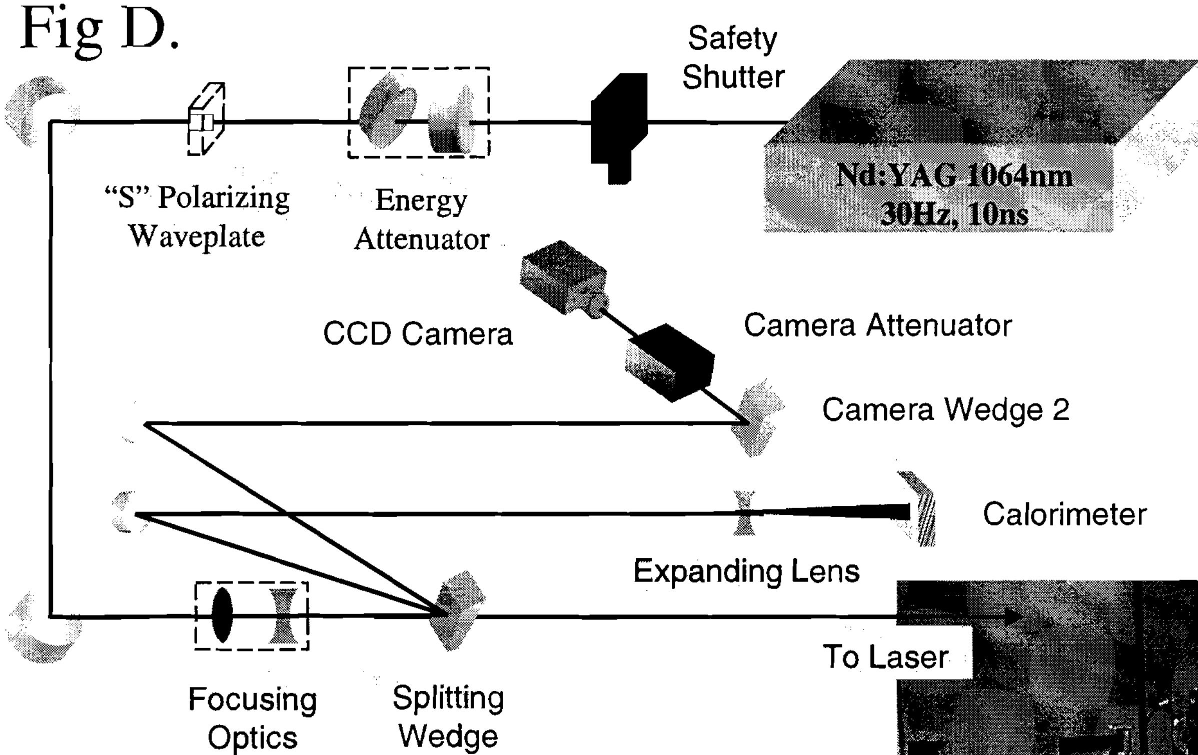


Diagram of Mechanical pump and spatial filter tube contamination

Fig C.

Clamshell defect found on Sol-Gel lens

Fig D.



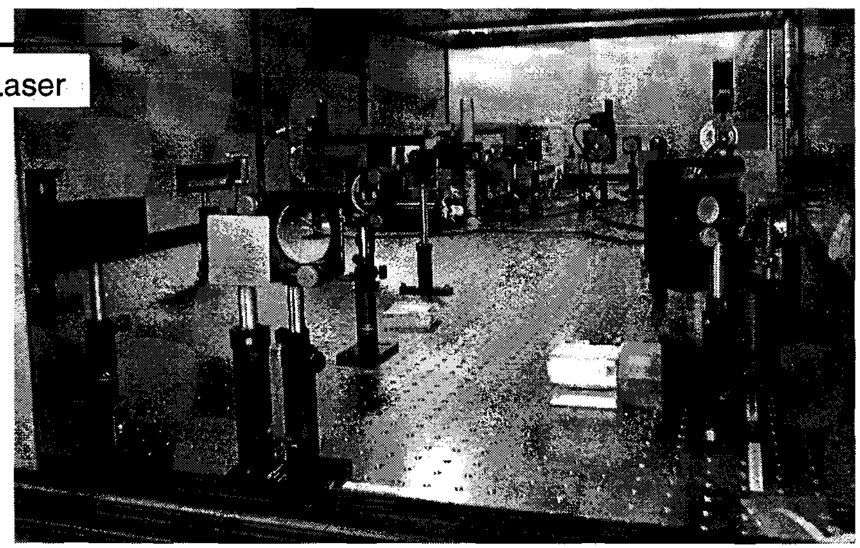
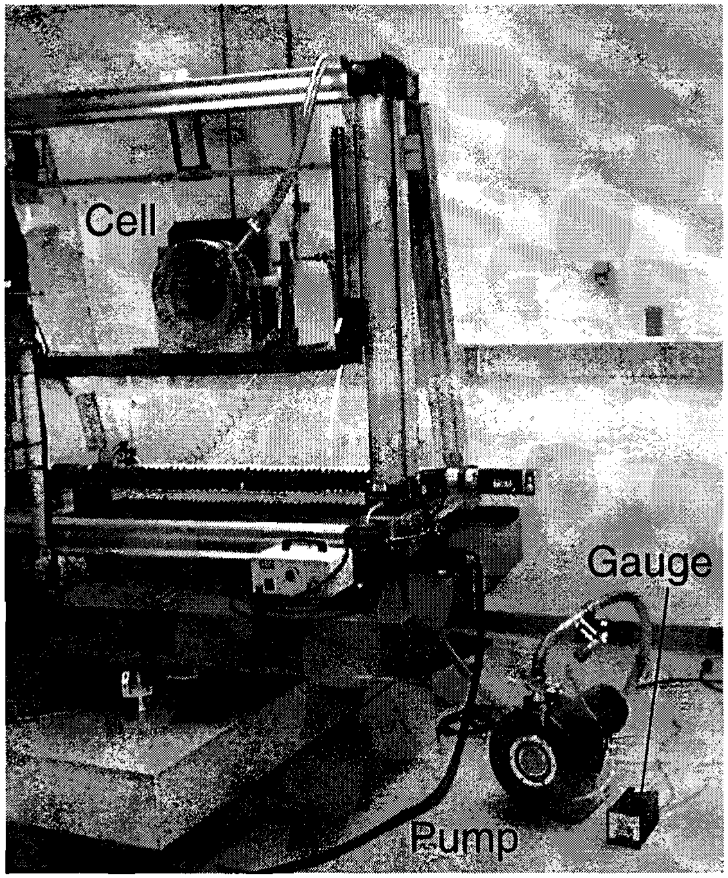


Diagram of LAC1 conditioning laser

Fig E.

LAC 1 Conditioning Stage



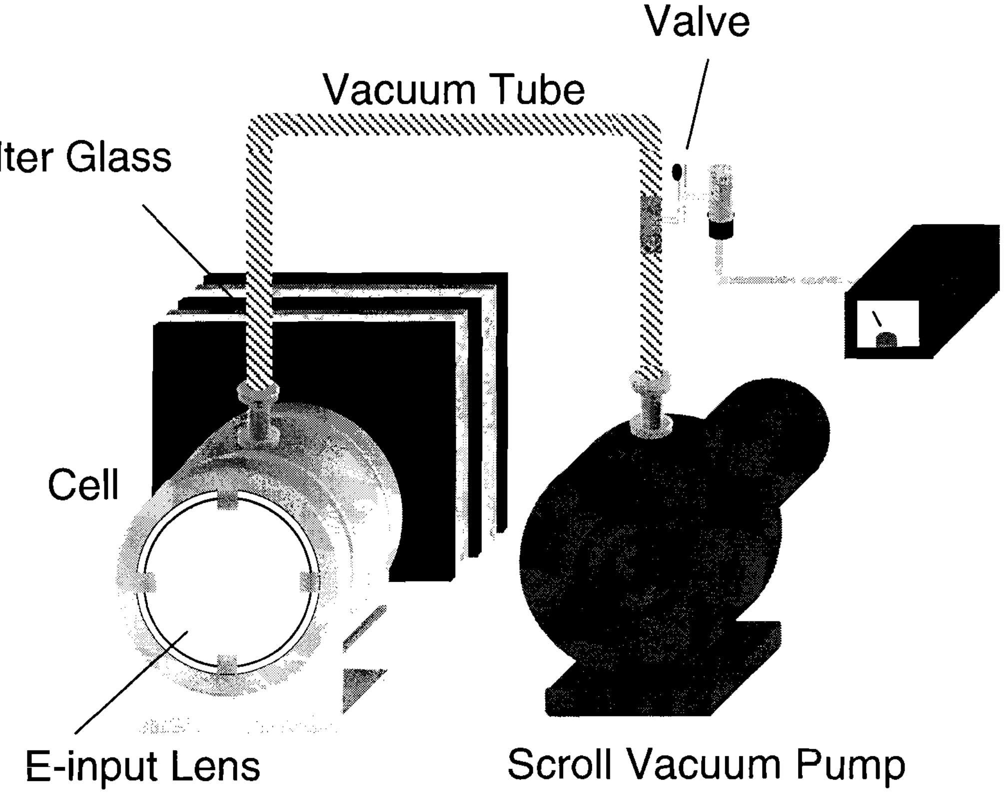
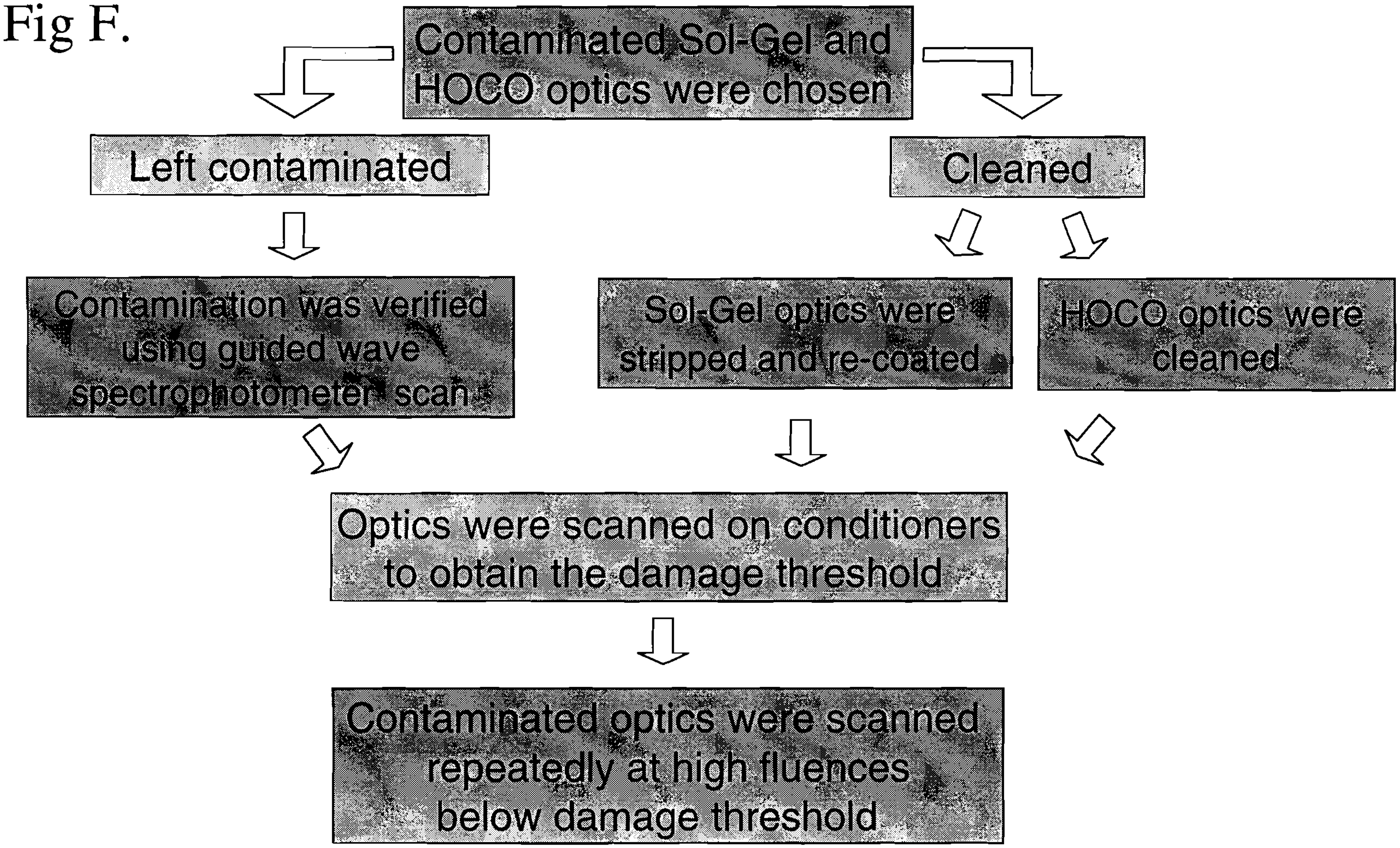


Diagram of experimental apparatus

Fig F.



Experiment flow chart

***All scanning was done in 3 cm diameter circles due to restrictions of the laser**

Fig G.

Damage Threshold at 3 ns pulse*

	Sol-Gel	HOCO
Contaminated	**~16 J/cm²**	
Clean	**~19 J/cm²**	**~16 J/cm²**

***To convert to equivalent OMEGA fluences, multiply value by 0.68**

Results of experiment