Optical Lifetime Stability Methodology Development

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Optics damage of optical elements can be one of the main factors for optical systems to reach premature lifetimes. Optics damage threatens the lifetime of sensitive optics but also create a host of limiting performance issues including matching and downtime. The desired goal for inspection systems under continuous operation is 10 yrs with no changes in optical performance and minimal PM or downtime. This imposes many demanding challenges. This talk will give an overview of optics damage and the main challenges encountered in the 193 nm Rapid inspection system. This talk will also outline BKMs and suggest strategies to design for desired lifetimes.

I. Introduction

Only high-purity fused silica (FS) and high-purity crystalline CaF_2 are candidate materials for optics at 193 nm. High purity fluoride coatings are main choice for 193 nm. Nevertheless, these materials are known to degrade in the course of irradiation for the 10 years of their expected lifetime.

One main challenge is that the light sources used for inspection systems are typically not off the shelf systems and are typically developed during phase 2 of the PLC process. Nevertheless, one needs a stable well characterized source to be able to do optics lifetime qualification. Qualification of optics can take a long time. Without a stable, well characterized light source no early testing can be done. A second challenge is that optics and coatings are not designed for our light sources. Most laser-damage data to date in literature have been obtained with Excimer lasers used at higher peak power and fluences and at significantly lower pulse counts compared to our use case. Extrapolating from Excimer studies does not carry over to our high rep rate sources. The lack of well-established scaling to the high rep-rate, high-pulse-count regime is unreliable and reckless. To understand laser-damage behavior in the regime that is relevant, Rapid made a multimillion-dollar invested in laboratory to study failure modes. During the program development phase, we conducted hundreds of tests on bulk materials (FS and CaF_2). We performed tests on high purity FSs from Corning, Schott, Heraeus, Nikon and ShinEtsu.

II. Bulk Damage

Bulk damage degradation manifests itself through a few major physical changes: a loss in transmission, laser induced densification or compaction (observed only in FS), rarefaction, laser induced (LI) absorption, LI-birefringence, compaction and micro channeling. All of these effects were observed in our testing. The damage mechanisms have different origins. For example, transmission loss is caused by color center of the fused-silica network. Nevertheless, all effects adversely affect the performance of optical systems by changing either their transmission or light properties that affect system performance.

FSs did not show good lifetime with RAPID 193 nm optics. In addition, high purity FSs are very expensive. Published lifetime data predicts a 5 yr lifetime for intensities of up to ~1 W/cm2 for most high purity FS. Our desired use case was for intensities of up to 10'S of W/cm^2. For example, test showed lifetime ~ 4 Hrs @ 8 W/cm2 for 100mm thick sample high purity FS from Corning (See Figure 1).

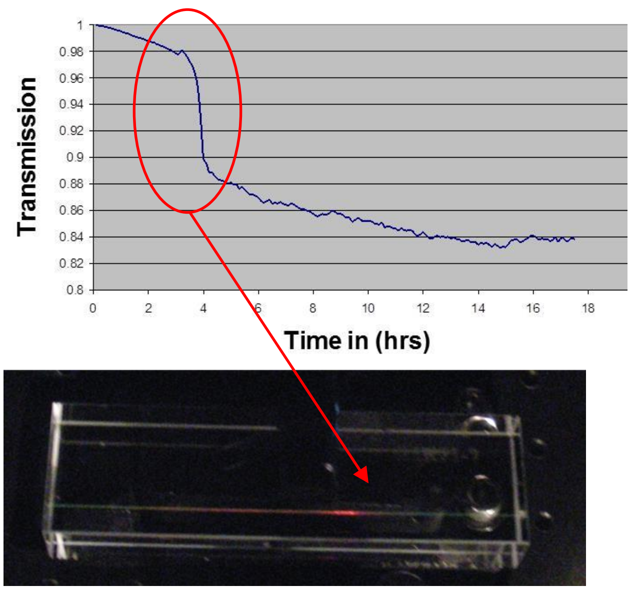


FIGURE 1. Damage occurred ~ 4 hrs ! at Ave intensity ~ 8 W/cm^2. Initial design was Ave intensity of up to 30 W/cm2

We found CaF2 to be far more robust and it could be used for intensities of up to 30 W/cm2 for 10 yrs without impacting performance. Without much effort we substituted FS with CaF2 optics with intensities higher than 1 W/cm2.

CaF2 doubles the cost of optics elements, but only a few elements were affected and only in a couple of modules. New types of FS (Haraeus) and other older types of FS like Schott Lithotec (currently known as the J-Fiber SQ-E193) with much lower cost were qualified and we were able to substituted in place of the expensive Corning & Nikon with minimal engineering effort to get a substantial CoGs impact.

III. Coating Damage

There are many mechanisms for optical coating damage. Durability of a coatings depends the coating material, the design, the purity of the coating material, defects, stress in the coating, polishing, substrate cleanliness, coating technology and coating processes. At shorter wavelengths, the substrate surface plays a significat role. For example, uncoated substrate contributes in the formation of the ensuing microstructure growth of the coating, which in turn influences scatter, stress, and mechanical stability. Polishing is crucial for high performance but specialize techniques are required to not produce subsurface damage. Contamination issues are extremely critical in the shorter DUV. Not only do absorption coefficients increase many folds, but also the energy per photon is greatly increased, leading to reduced lifetime for each optic.

Optical coating technology is dominated by coating material. These materials must have the appropriate optical constants n (index of refraction) and k (extinction coefficient) for spectral performance, stress compatibility in multilayer structures for environmental ruggedness, and appropriate molecular structure to survive laser pulse irradiation. Also significant are the deposition process techniques employed to produce these materials as thin film structures and to attain the overall desired functionality.

The individual absorption losses in each material layer as defined by the extinction coefficient (k). For example, choosing the material pair with the highest ratio of refractive indices, the number of layers required to reach the reflectance goal can be minimized and, due to a reduction in absorption and scatter losses, could provide an increase in the maximum reflectance. However heat induced by the laser can contribute to inter-diffusion. The number of layers also contributes to the laser damage threshold. The purity of the coating comes into play here. The chemical purity of vapor deposition materials influences not only the coating properties but also the way the material behaves during evaporation. We have shown that a purity of least 99.99%, is required for 193 nm systems Rapid systems.

Absorption in the film is one of the leading causes for damage. Absorption of films depends strongly on stoichiometry and impurities. High purity with minimum of 4N are required but 5N materials are recommended with impurity levels of about 1 ppm or less. Materials sintered or sublimed in vacuum are most suitable. Film stoichiometry has to be controlled as well as the substrate temperature and deposition rate.

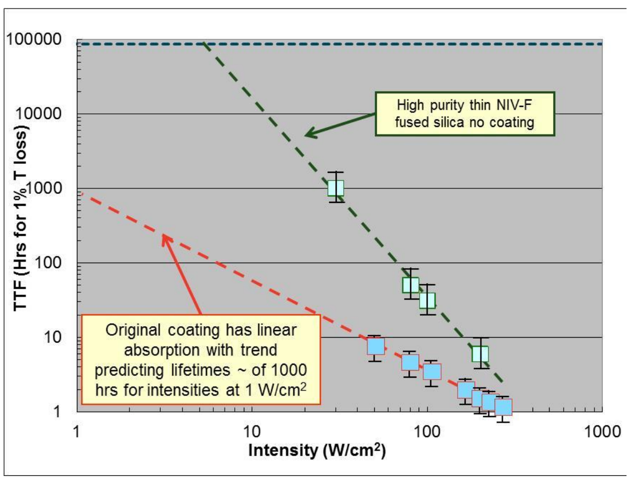
Absorption can also be influenced by amount of water in the coating chamber and by the oxygen partial pressure. These need to be monitor and controlled.

Even small concentrations of transition elements can have a marked effect on the transmission properties of dielectric layers.
Coating technology causes different amounts of stress in the coatings. IAD or IBS coating are the prefer coatings long term stability, but these

coating technologies also create higher stress in the coatings. Stress can be mitigated by coating design and temperature control of substrate during deposition. Reliving stress in the coating needs to be considered.

We worked with highest-quality optics suppliers around the world who already had experience with 193 nm and conducted hundreds of tests for coating damage. Nevertheless, all vendors had poor coating lifetime when tested with the 193 Rapid laser. In the figure 2 below, is an example for a coating vendor. The damage thresholds for substrates were first measure. A thin substrate with much high damage thresholds is then chosen to test the coating. The damage threshold for high purity thin NIV-F FS no coating shows a slope of 2 representing an expected two photon process.

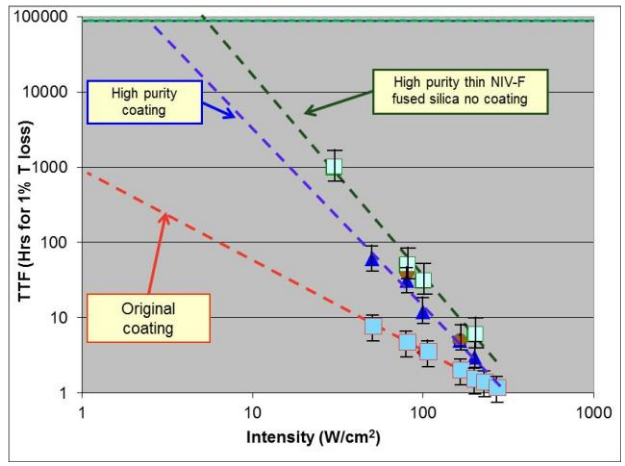
However, the coating test clearly shows a much different behavior. In this case the slope is attributed to single photon absorption. The coating for all vendors limited the lifetime of the optical components. For most vendors the lifetime was for our use case was on the order of 3 months.



Main issues found across all vendors were: 1) contaminants and ineffectively cleaned polishing residues, 2) impurities in the coating, 3) deposition chamber cross-contamination, 4) Coating design not optimized for high power, 5) Cross-contamination of target materials, 6) Cleaning, handling and packaging procedures not adequate.

The Solutions: Assist vendors in identifying problems, and helping them develop high purity coatings and design for high intensity 193nm applications. Together we developed, tested, and successfully produced qualified high purity coatings. We also helped vendors improve their cleaning recipes and improved process controll.

Once these issues were identified and addressed, the coating lifetime for all vendors improved by many orders of magnitude for our use case (see figure 3). By the end of the development phase all of our optics lifetimes were well above the 10 yrs and in most cases lifetime projectes were above 20 yrs.



Prevention and Design approach

Lifetime of optical components used in inspections systems needs to be approached from a systems engineering point of view. A clear understanding of optical and system performance must be established. In addition desired and acceptable lifetime of optical elements or subsystems needs to be recognized. An important step in predicting the lifetime of an inspections systems one must have good understanding of the damage mechanisms. With these factors in mind one is able to design accelerated tests that will accurately project actual tool conditions.

The following is an outline of the many steps that need to be includes as part of a successful design approach:

- An appropriate way to define end of optics life time is by defining the time to failure (ttf) as time when optical element or subsystem fails to satisfy critical specification parameters or certain performance metrics that are initiate from aberrations, wavefront distortion, Strehl, induced birefringence, Beam waist modification, Transmission, Uniformity, Scatter/Flare etc cause by light interaction.

- Understand damage mechanisms for wavelength and materials concidered to be able to design accelerated tests.

IV. Conclusion

Optics lifetime of optical elements induced by EUV,VUV,DUV and IR is a significant concern in leading-edge reticle and wafer inspection systems. A systematic approach to predict and establish sensible optics lifetime is presented. The systematic method needs be approached from an understanding of system engineering and systems performance metrics. Understanding the damage mechanisms are crucial for lifetime predictions. Overdesign of the system will lead to too stringent requirements, and will lead to high COO. Inappropriate requirements will lead to system and components failing in the field.

V. Bibliography

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- Determine the damage threshold for all optical components and environment spec.
- Identify and rank vendors for optics lifetime.
- Estimate the lifetime of modules and make engineering trade-offs for either PM, or make critical components indexable or make them FRU's.
- Cost models also need to be considered.

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