Lifetime Modeling of Laser-Induced Density and Refractive Index Changes in Fused Silica Used in DUV Microlithography

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Dr. Johannes Moll

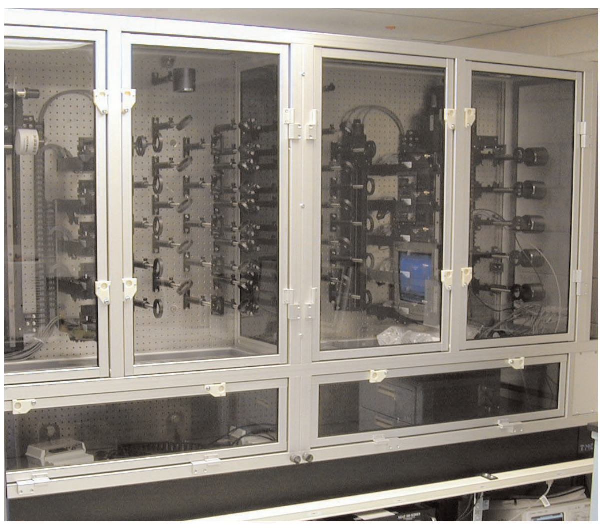
Laser Damage in Fused Silica:

Impact in Microlithography

- Absorption increase over lifetime:
  - transmission loss (reduced throughput)
  - lens heating (reduced imaging quality)
- Increased wavefront aberration over lifetime: reduced imaging quality

Laser-Induced Changes in Fused Silica

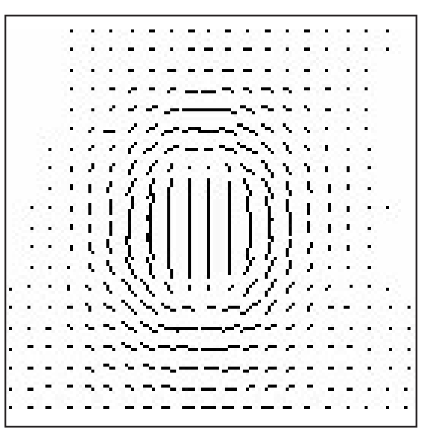
- Density change: could be positive (compaction) or negative (expansion), leads to change of index of refraction and stress-induced birefringence
- Photorefractive effect: increase of index of refraction in the material due to the formation of SiH and SiOH
- Absorption change: due to color center formation



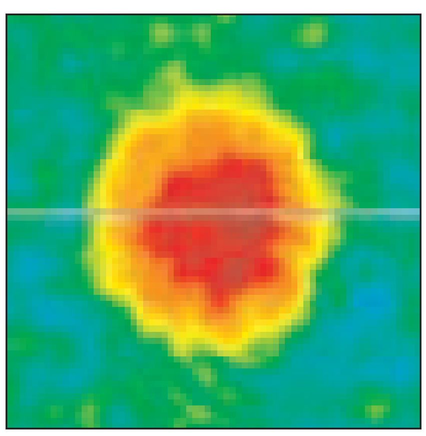
ArF Laser Damage System at Corning

Currently, in this system, up to 25 samples can be exposed at 2000 Hz.

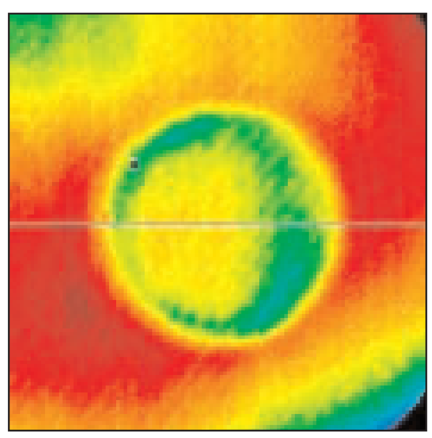
Example - Expanding HPFS® Sample



Line plot of birefringence in the damage spot. The lines indicate the direction of the slow axis of birefringence. The tangential pattern around the edge of the damage spot indicates that the sample density has decreased inside the exposure region.



Interferogram of the damage spot, measured using a 633 nm laser. The wavefront inside the damage spot is advanced, i.e., the optical pathlength at 633 nm has decreased.



Interferogram of the damage spot, measured using a 193 nm laser. The wavefront inside the damage spot is retarded, i.e., the optical pathlength at 193 nm has increased due to the larger contribution from the photorefractive effect at 193 nm.

Empirical Model For ArF-Laser Induced Wavefront Distortion

- Measured wavefront distortion: combined effect of density change (compaction, expansion) and a photorefractive effect.
- Compaction, expansion, and photorefractive effect each depend in different ways on exposure fluence and material parameters.
- The relative magnitude of the photorefractive effect (compared to the wavefront distortion due to density changes) is larger at 193 nm than at 633 nm.

Empirical Model For ArF-Laser Induced Wavefront Distortion

$$\left.\frac{\Delta(nL)}{L}\right|_{measured} = A1*\left[1-e^{-\frac{\left(\frac{NI^2}{\tau}\right)^{C1}}{B1}}\right] + A2*\left[1-e^{\frac{-NI}{B2}}\right] + A3*\left[1-e^{\frac{-NI}{B3}}\right]$$

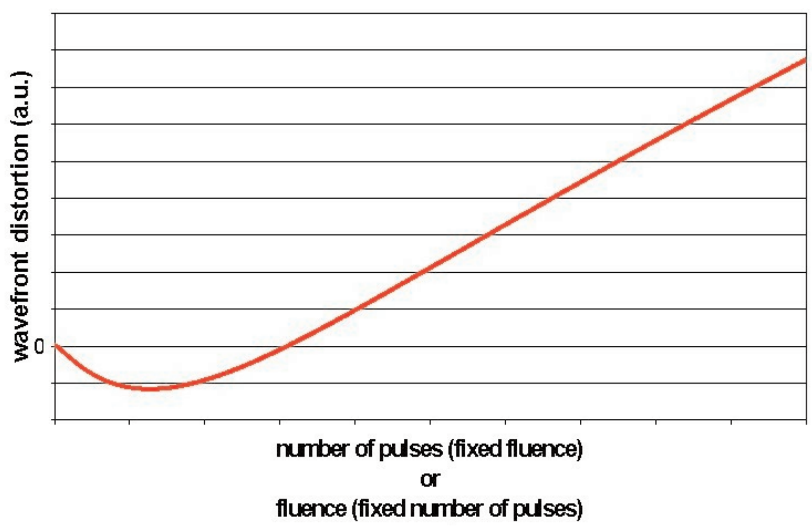
density increase — density decrease — photorefractive index change

$\left.\frac{\Delta(nL)}{L}\right|_{measured}$ = measured wavefront distortion

N = number of pulses (million)
I = fluence (mJ/cm2/pulse)
τ = pulse length (integral square, ns)

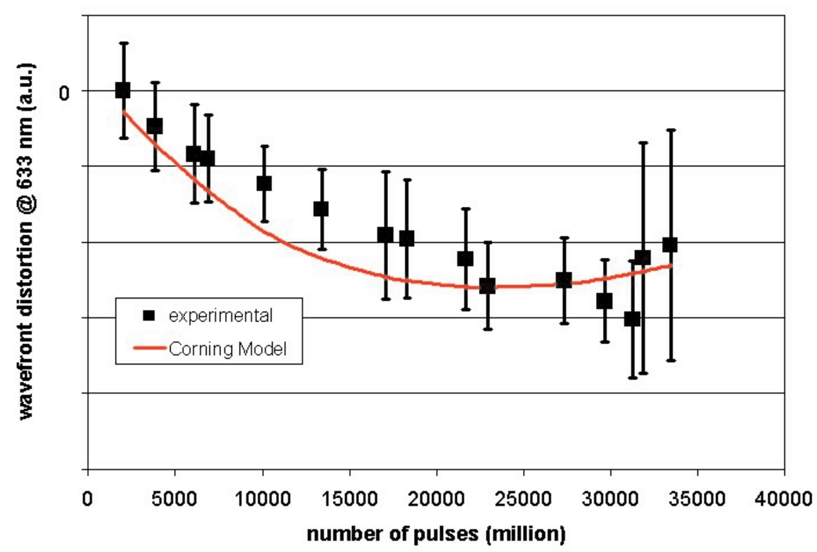
Prefactors A1, A2, A3 depend on material grade and measurement wavelength. A1 and A2 also depend on exposure geometry (constraint by surrounding unexposed material).

Empirical Model For ArF-Laser Induced Wavefront Distortion



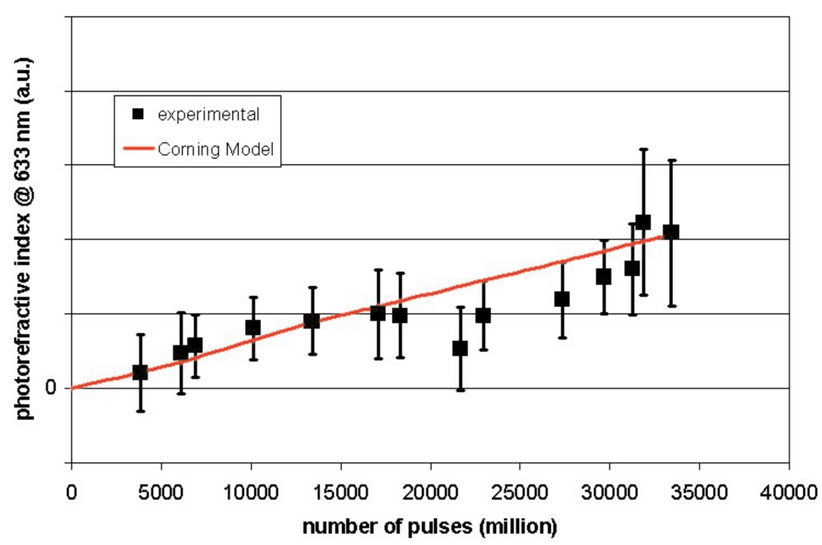
The graph shows the qualitative dependence of laser induced wavefront distortion as a function of exposure pulses or fluence. The material shows wavefront advancement (negative wavefront distortion) at low pulse count or low fluence, then crosses over to wavefront retardation at higher pulse count or fluence. The cross-over point depends on material grade, exposure, measurement wavelength, and sample/beam size.

Empirical Model For ArF-Laser Induced Wavefront Distortion



The model calculation agrees well with the total measured laser induced wavefront distortion (measured at 633 nm).

Photorefractive Effect



The magnitude of the photorefractive effect can be determined from the difference between the results from wavefront (interferometer) and birefringence measurements. Wavefront distortion results from both density change and photorefractive effect, but birefringence is independent from the photorefractive effect.

Summary

- Marathon testing of HPFS® samples is performed to verify material performance close to the actual use conditions.
- Results demonstrate that the measurement of wavefront distortion at the typical test wavelength (633nm) is not sufficient; testing is required at the wavelength of use (193 nm).
- Accurate birefringence measurements are necessary to correctly model the relative magnitudes of density and refractive index changes.
- Corning has developed models for density and refractive index changes in HPFS®.

Acknowledgments

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