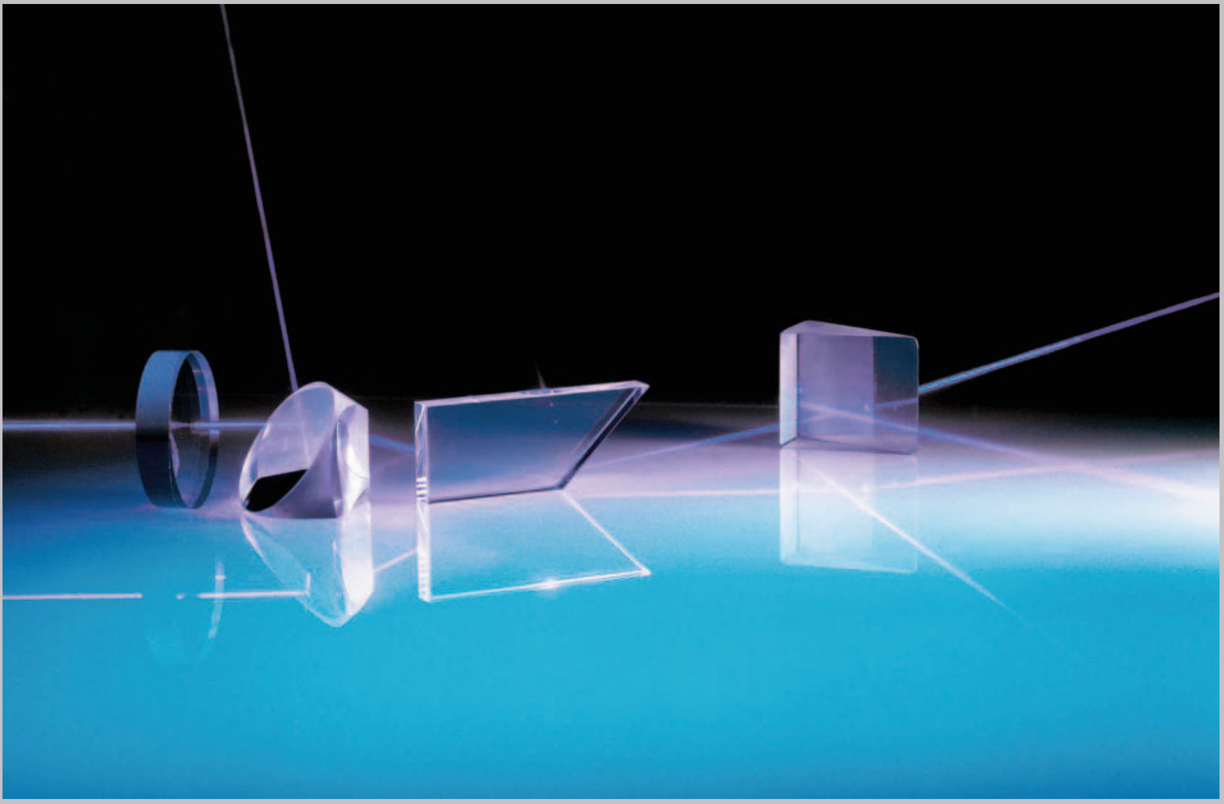
Heraeus

Fused silica for Excimer Laser Applications



Introduction

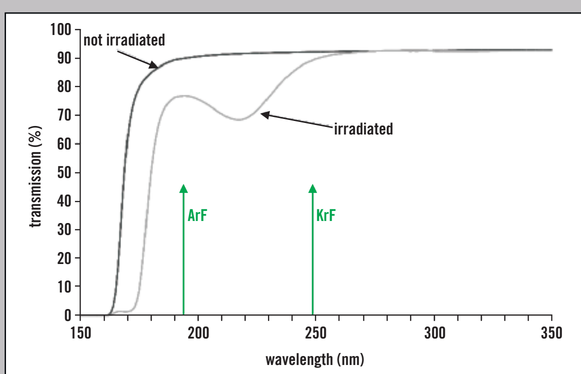
The use of excimer lasers in research and industry continues to grow. These intense UV light sources place a very high demand on the quality and laser damage behaviour of the optical materials used for beam transport and beam-shaping. This is based on the fact that the energy of the photons is close to the energy of the band gap of the optical materials, and the intensity of the beam is very high because of the short pulse length. It is exactly these properties of the excimer laser which make it of great interest for laboratory and industrial applications. For beam transport and beam shaping, usually fused silica and fluoride crystals are used, with each of these materials types having its own specific pro and cons.

This note deals with the behaviour and properties of fused silica under excimer laser irradiation using KrF excimer lasers @ λ = 248 nm and ArF excimer lasers @ λ=193 nm. The use of the term "fused silica for excimer laser applications or quartz glass for excimer laser applications always refers to the Heraeus synthetic fused silica grade Suprasil®.

Only Suprasil® ArF/KrF has the necessary extremely high purity and is produced with the well defined and tightly controlled process parameters necessary to keep the color center formation at a minimum. This in turn is the prerequisite for the high laser damage resistance Heraeus specifies for its Suprasil® ArF/KrF.

Transmission and induced absorption

The transmission of fused silica under excimer laser irradiation is determined by the reflection on the surfaces of the material, as well as the initial absorption and induced absorption in the material. Usually, the induced absorption is transient, decreasing after the light source is turned off. Thus it cannot – in contrast to the initial absorption –



be measured with a photospectrometer in a well defined way. Transmission losses under excimer laser irradiation @ 193 nm and 248 nm are mainly caused by the absorption band at 215 nm (the so called E'-center). Therefore the following statements are valid for both wavelengths.

The long term stability of fused silica is given by the creation rate of network defects per laser pulse. This creation rate is generally constant and thus leads, after a number P of laser pulses having an energy density per pulse ε and a pulse duration τ to an induced absorption.

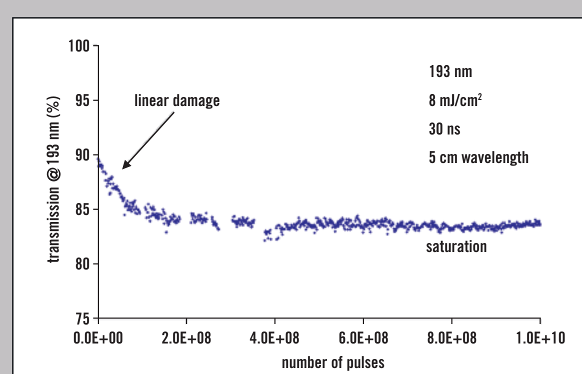
$$\alpha_{\text{induced}} = \alpha_0 \cdot \frac{\varepsilon^2}{\tau} \cdot P$$

(ε in J/cm^2, τ in ns, α in 1/cm to the basis e)

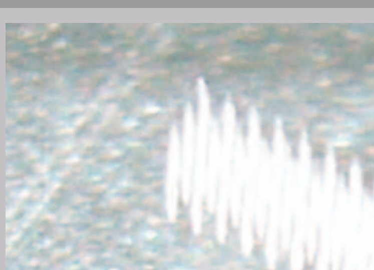
For Suprasil® ArF/KrF at 193 nm, one uses a typical value of $\alpha_0 = 6 \cdot 10^{-5}$, and of $\alpha_0 = 3 \cdot 10^{-7}$.

The network bonds can be broken with a certain probability using a high-energy laser pulse. The number of breakable network bonds (precursors) is a lot larger for high energy densities than the number of defects created during the lifetime of an optical element. In this case the linear damage-law is applicable.

For comparably low energy densities, a saturation of the induced absorption is observed. The specified internal transmission before the irradiation is at least 99.8 % @ 248 nm, and 99.3 % @ 193 nm.



Creation of Microchannels

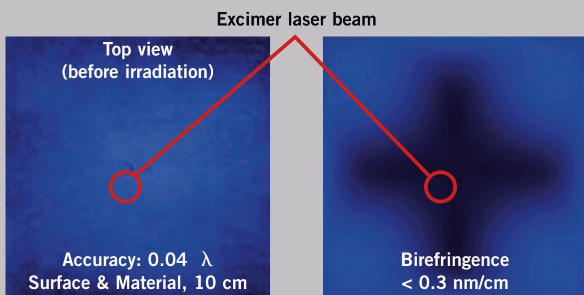


For optical elements having a long optical path length and being exposed to excimer laser radiation with large gradients in the energy density, the creation of so-called microchannels can be observed. This is comparable to the damage caused by exceeding the damage threshold for single pulses.

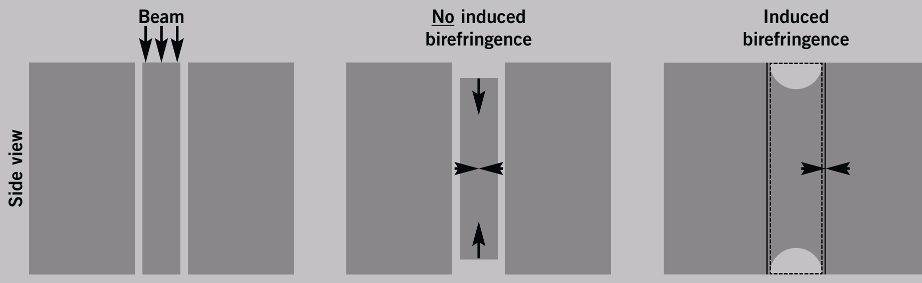
Because of the rather unusual conditions needed for the creation of microchannels, this defect can normally be neglected/disregarded for the applications.

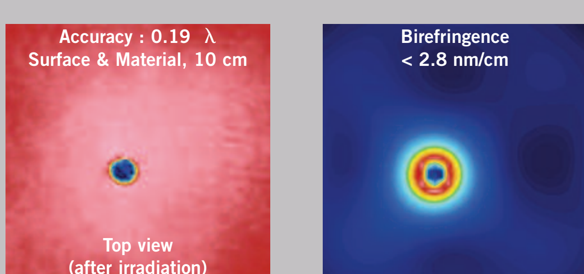
Induced birefringence and change of the index of refraction under irradiation

Changes in the network structure caused by excimer radiation lead to an increase in the density of the material and therefore to an increase in the index of refraction within the irradiated volume. This effect in the material is known as compaction and can be observed in all fused silica types in various degrees. If the material is irradiated inhomogeneously, this will lead to mechanical stress between the more strongly and less strongly densified areas. Here, fused silica will become birefringent.



As an example, a cuboid with sides polished to 0,04 λ is shown. The sample is illuminated by a circular beam with a homogenous energy density. Because of the irradiation, a compaction/ densification / contraction is observed in the illuminated area. Since the surrounding volume does not contract as much as the irradiated volume, one can observe stress-induced birefringence on the boundary between these regions.





The degree of densification depends upon the irradiation parameters and on the material. In this example, a stress-induced birefringence of ~ 3 nm/cm and a material inhomogeneity (difference in optical path length) of 0,15 λ was generated in Suprasil® ArF/KrF. Thus, this example demonstrates very well the need to take radiation-induced effects into consideration in the design of an optical element that is exposed to excimer laser radiation.

The change in the index of refraction can be described as a function of energy density, number of pulses, and temporal pulse width.

$$\Delta n = C \cdot \left(\frac{\varepsilon^2 \cdot P}{\tau} \right)^{0,6}$$

(P: number of pulses; ε: energy density in J/cm^2; τ: time pulse width)

For Suprasil® ArF/KrF for 193 nm, a typical value for C is C = 4.4 10^{-8}, for 248 nm it is C = 6.6 10^{-9}.

For very low energy densities, a lowering of the index of refraction can occur (not described in this note). The induced birefringence depends strongly on the beam geometry and is usually calculated with the finite element method. Therefore, a dose-dependent densification without boundary conditions is chosen and the volume is surrounded with material that is not densified.

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