Optical Damage Characterization of Pure and Yb^{3+}-doped Fused Silica

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Motivation—There are several nonlinear processes that limit the pulse energy that can be transmitted by an optical fiber. They include stimulated Raman and Brillouin scattering, self focusing, and permanent damage to the glass caused by the optical field. These all interact to some extent to limit the transmissible energy. However, optical damage is the process that sets an ultimate limit that cannot be avoided. It is also the least understood and quantified of the processes. The literature on the subject has many contradictory observations and claims. Our goal is to carefully characterize optical damage in pure silica and in the Yb^{3+} doped silica that is used in fiber lasers and amplifiers.

Accomplishment—We fine tuned a Q-switched Nd:YAG laser so it produced exquisite pulses that are highly reproducible from pulse to pulse and have a smooth, nearly Gaussian temporal profile of 8 ns duration, and a lowest order Gaussian spatial profile. Pulses of varied energy are focused to a spot approximately 15 μm in diameter in pure and doped fused silica samples, and the threshold for damage is measured. Bulk damage is observed when the focus is deep inside the sample, and surface damage occurs when the focus lies near the entrance or exit face.

We took micrographs of bulk and surface damage under various conditions. Examples of bulk damage at two energy levels near the damage threshold are shown in Fig. 1. Damage initiates at the point of focus which is the center of the upper bloom in the images. This takes place on a sub nanosecond time scale, and the remainder of the pulse energy causes upstream growth of the damage. The initial damage strikes a plasma at the focus which then absorbs incoming laser energy on the upstream boundary causing upstream damage grow.

Figure 2 shows that the transmitted light is cut off abruptly in less than a nanosecond when the plasma first reaches critical density. Further, as the pulse energy is increased the damage always occurs at the same power, indicating that there is a well defined damage irradiance threshold. The variation of the threshold is 5% or less from one pure silica sample to another. For fiber performs we measured damage thresholds in the cladding which is undoped and in the doped core and find the threshold is approximately 20% higher in the core.

Deriving the damage threshold from these measurements requires a substantial correction to account for self focusing. This is done using numerical models of beam propagation that includes self focusing induced by an instantaneous n_2 from the Kerr effect, to find the degree of irradiance enhancement on the beam axis near the focus. There is another, smaller contribution to n_2 from electrostriction as well.

Significance—A major goal of the fiber laser effort at Sandia is to extract as much energy as possible from a fiber amplifier in nanosecond pulses. Another Sandia application requires efficient transmission of multi-mJ, nanosecond pulses through silica fibers. Self focusing and optical damage limit the energy in this application as well. We have established the precise irradiance limits for pure and doped silica, and we have provided clear explanations of the damage mechanism. Surface damage is important to both of these programs as well, and will be studied next.

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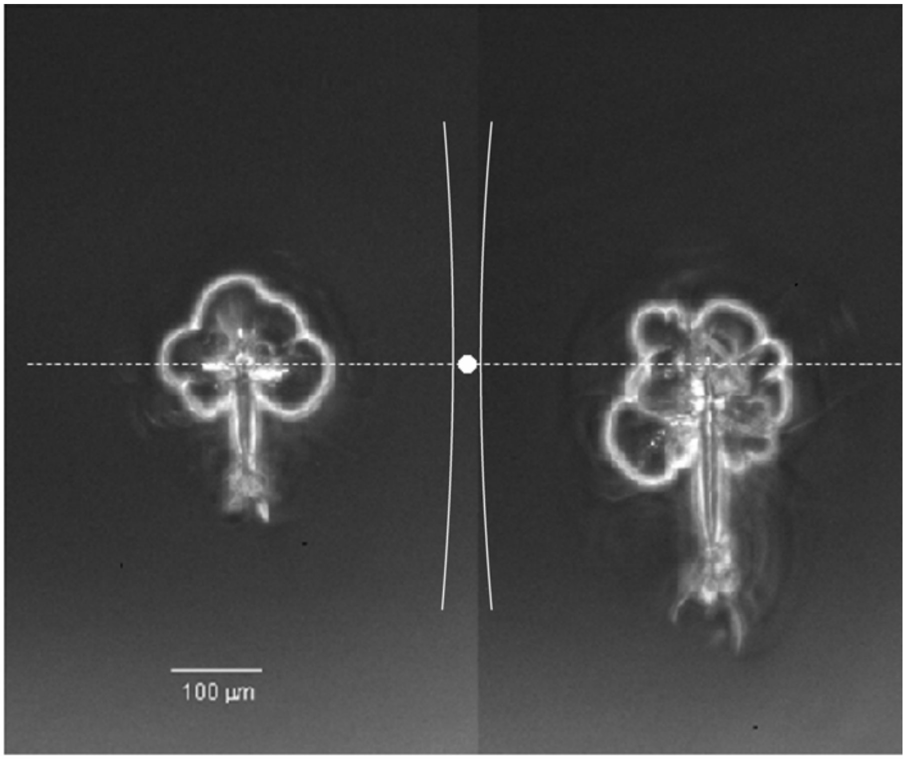

Figure 1. Damage morphology near the damage threshold. Light travels upward with the focal shape indicated by the curved lines. Damage starts at the beam waist and grows downward until the pulse passes or the plasma terminates due to weakening light away from the focus.

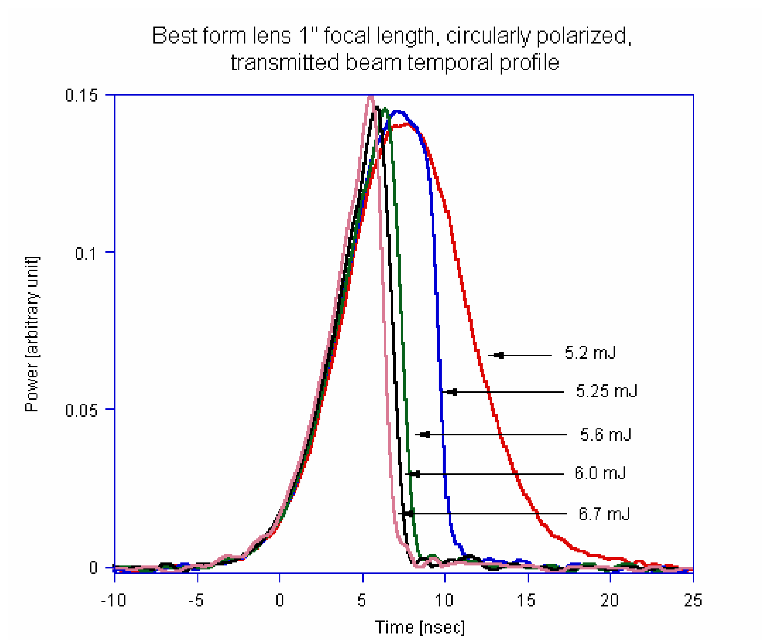

Figure 2. Time profiles of transmitted light pulses of various energy. Damage always occurs at precisely the same irradiance level.