

Effect of the repaired damage morphology of fused silica on the modulation of incident laser



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ABSTRACT

Local CO₂ laser treatment has proved to be the most promising method to extend the life-time of fused silica. However, previous experimental data show that some raised rims are observed around the mitigated sites left from the mitigation process, which will result in hazardous light modulation to the downstream optics. In this work, the morphology features of mitigated sites on the surface of fused silica optics were analyzed in detail. According to measured morphology features, a 3D analytical model for simulating the modulation value induced by mitigated site has been developed based on the scalar diffraction theory. The diffraction patterns at a discrete distance downstream from each mitigated site are measured. The influences of geometry, laser wavelength and refractive index of substrates on the modulation by repaired damage morphology at different distances are discussed, respectively. The analytical model is usable and representative to evaluate the hazardous modulation induced by repaired damage morphology to downstream optics. Results on this research suggest that the downstream intensification can be suppressed by controlling the morphology features of mitigated sites, which provides a direction for the development and improvement of the mitigated techniques of damage optics.

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1. Introduction

For large-aperture, high-power laser systems, laser-induced damage on the exit surface of fused silica remains today a key limitation for laser performance in terms of energy and focal spot. It's inevitable to introduce damage precursors such as structural defects [1,2] (e.g. scratches, craters) and contaminations [3] on the surface of fused silica during polishing and grinding processes. Research findings reveal that the interaction between high power laser beam and those damage precursors would result in obscuration that degrades the beam quality [4], and moreover, generate localized intensification that is very hazardous to surface damage resistance of fused silica [5,6]. Once the surface damage is initiated, it will grow exponentially upon further illumination and seriously shortens the lifetime of optics. In order to improve the life time of optical components, various proposals, such as chemical treatment [7,8], plasma etching [9,10] and CO₂ laser treatment [11–16] have been developed for a feasible mitigation process of damage growth.

CO₂ laser treatment is the most promising method to extend the life time of fused silica in those proposals, because it is used not only to increase the damage resistance by eliminating the structural defects and contaminants on the surface of fused silica [11–13], but also to mitigate the damage growth of fused silica by high temperature melting of initial damaged sites [14–16]. However, previous experimental data show that some raised rims are observed around the mitigated sites left from the mitigation process which will result in strong light modulation to the downstream optics [16–19]. Thus further investigation is very important to obtain theory model for simulating light modulation value induced by mitigated sites.

Under the simulation of previous work, the impacts of surface cracks or small mitigated sites on the modulation of light field mainly have been explicated based on using finite-difference time-domain (FDTD) algorithm [5,6,19–22]. However, FDTD algorithm is only applicable to a small-sized defect (<10 μm) because of the limitation of calculation amount. Recently, the scalar diffraction theory is applied to simulate the wavefront modulation properties of downstream beam propagation behind various mitigated sites [23,24]. In this paper, the profile parameters for each mitigated site

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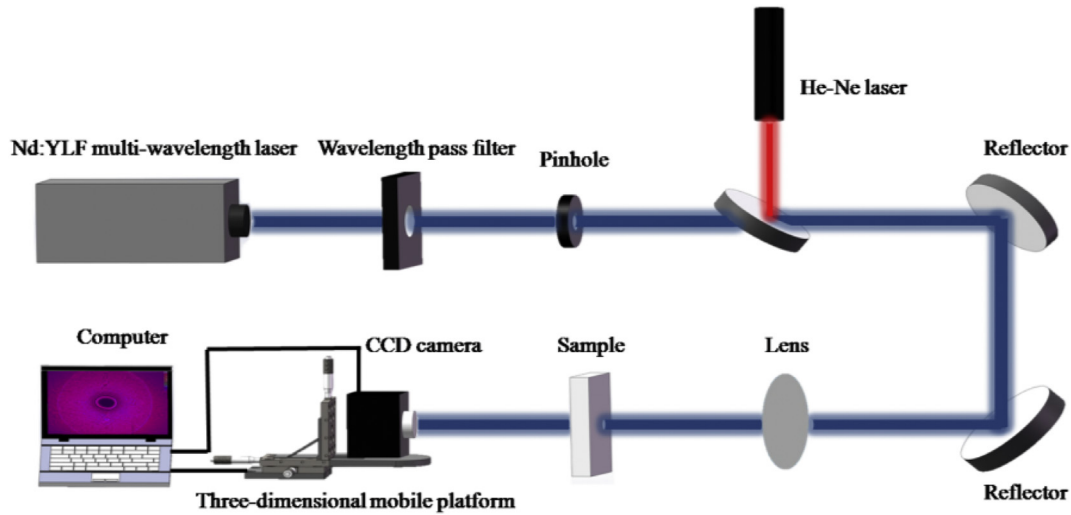


Fig. 1. Experimental setup for light modulation measurement.

were measured by the contacted stylus profilometry. In Section 2, the experimental setup used to measure the diffraction patterns at different distances is presented. In Section 3, analytical modeling and numerical simulation have been developed based on the scalar diffraction theory to give a theoretical description on the principle of modulation by mitigated sites. In Section 4, the dependence of modulation value induced by mitigated sites on geometry, laser wavelength and refractive index of substrates are discussed in detail, respectively.

2. Experimental method

The fused silica samples (Corning HPFS 7980) with a size of $50 \times 50 \times 5 \text{ mm}^3$ are used in the experiment. The samples are first etched in the buffered hydrofluoric acid (HF) solution for 10 min to remove the re-deposited layer and reveal the defects before the experiment. Then a series of damage sites are created in the rear surface of samples irradiated by Nd:YAG pulse laser with 355 nm wavelength. The effective pulse duration (at 1/e) is 7 ns with the

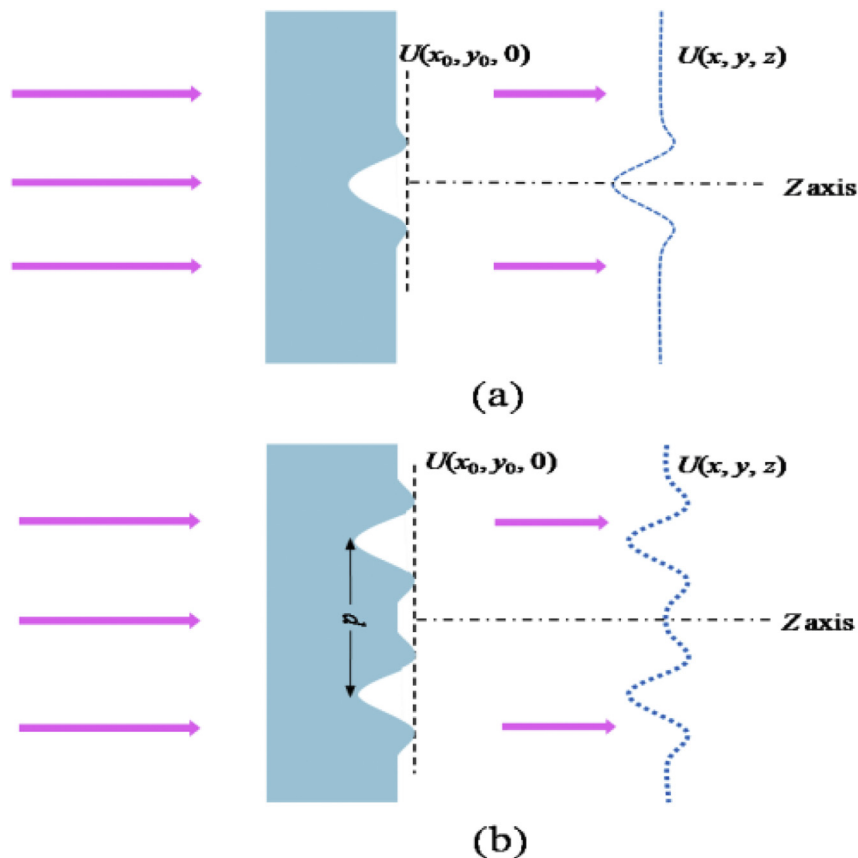


Fig. 2. Schematic diagram of transmitted beam modulation model for mitigated sites: (a) single crater (b) double craters.

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