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Investigation of Plasma Motion, Emission spectrum, and Induced Defects in Laser Back-Irradiation with Nanosecond Pulses

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Introduction. The laser backside irradiation (LBI) method involves focusing a laser beam onto an absorber attached to the backside of an optical bulk glass sample. This creates a localized heated zone inside the glass, causing it to absorb radiation from the laser source and initiating a plasma spark that propagates toward the light source. As the plasma moves, it modifies the material along its path, leaving behind a structurally altered trace. The process continues until beam defocusing lowers the laser power density below the modification threshold. The modified structures have significant potential applications in the manufacturing of optical components, integrated optics, and microfluidic channels [1,2].

Traditionally, this method has been studied using continuous-wave (CW) lasers; however, recent studies have demonstrated the feasibility of applying nanosecond laser pulses, offering greater control over the process and introducing distinct structural modifications, behaviors, and potential applications [3]. This study aims to further investigate the LBI method by analyzing plasma motion dynamics, emission characteristics, and their correlation with the resulting modified regions within the material.

The main part. In our study, we utilized an IPG YLPM-1 pulsed fiber laser (wavelength: 1064 nm, maximum power: 20 W, pulse duration: 200 ns, repetition rate: 10–1000 kHz) to induce plasma formation through laser backside irradiation (LBI). The laser beam was precisely directed using a Galvano scanning system equipped with F-theta focusing optics (focal length: 160 mm). The beam was focused onto a 100 μm-thick AISI 314 stainless-steel foil, which served as an absorbing layer. This foil was placed between an N-BK7 glass sample (dimensions: 3 × 2 × 1.1 cm) and a glass slide, held securely in position using a custom-designed jig. This configuration ensured stable experimental conditions and facilitated the desired interaction between the laser energy and the material. To capture the plasma propagation dynamics, we employed an AOS X-EMA high-speed camera with a resolution of 1280 × 75 pixels, operating at 10,000 frames per second (fps) with a 100 μs shutter time. The plasma spectral characteristics were analyzed at multiple positions under varying experimental conditions using an Avantes AvaSpec-ULS4096CL-EVO fiber-coupled spectrometer, which covered a detection range of 200–1100 nm.

The modified area left along the plasma path was then examined, with structural changes analyzed and compared to variations in plasma behavior.

Conclusions. High-speed video recording was conducted during nanosecond laser backside irradiation under varying experimental conditions, revealing a direct correlation between plasma propagation velocity and the applied average power density. The analysis of the recorded footage further showed that the plasma plume exhibited oscillatory behavior in both speed and size along its propagation path. A detailed examination of the resulting defect structures indicated a clear relationship between these structural modifications and the observed plasma oscillations. In certain regions of the modified area, periodic structural patterns were detected, suggesting a link between plasma dynamics and material response. Additionally, spectral measurements provided valuable insights into the plasma characteristics, including its temperature variations and changes in emissivity at different positions along its trajectory.

References:

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