

Optical and Structural Characterization of Modified Structures in K8 Glass Formed by Nanosecond Laser Back-Irradiation

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Abstract

Nanosecond laser back-irradiation through the rear surface onto a metal–glass interface produces a self-propagating emission zone in K8 glass and writes void-free tracks. We correlate propagation velocity with laser parameters using high-speed imaging, and characterize three track positions (focal, peak-velocity, deceleration) by SEM–EDX and polarization holographic microscopy. Strong Na/K enrichment in the recondensed core with an alkali-depleted ring appears in the peak-velocity region and weakens as the front slows. Polarization holographic microscopy reveals a central positive isotropic index change ($\Delta n \sim 10^{-3}$), peripheral negative zones, and pronounced retardance, indicating polarization-dependent stress/birefringence and potential for waveguiding.

Keywords

nanosecond laser back-irradiation; alkali-ion redistribution; polarization holographic microscopy.

Оптическая и структурная характеристика модифицированных структур в стекле К8, сформированных с помощью наносекундного лазерного обратного облучения

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Аннотация

Наносекундное лазерное обратное облучение через заднюю поверхность на границе раздела металл-стекло создает самораспространяющуюся зону излучения в стекле К8 и записывает дорожки без пустот. Мы соотносим скорость распространения с параметрами лазера с помощью высокоскоростной визуализации и характеризуем три положения дорожки (фокальное, пиковое по скорости, замедление) с помощью SEM–EDX и поляризационной голографической микроскопии. Сильное обогащение Na/K в реконденсированном ядре с обедненным щелочью кольцом появляется в области пиковой скорости и ослабевает по мере замедления фронта. Поляризационная голографическая микроскопия выявляет центральное положительное изменение изотропного индекса ($\Delta n \sim 10^{-3}$), периферические отрицательные зоны и выраженное задерживание, что указывает на зависимость напряжения/двойного лучения от поляризации и потенциал для волноводного эффекта.

Ключевые слова

наносекундное лазерное обратное облучение, перераспределение щелочных ионов, поляризационная голографическая микроскопия.

In previous work, we showed that nanosecond laser back-irradiation (LBI) enables crack-free internal modification in glass. In this approach, low-average-power nanosecond pulses at kilohertz repetition rates are focused through the rear surface onto a metal–glass interface, where localized heating increases absorption in the adjacent glass. This initiates a bright emission zone that propagates toward the laser source and leaves a modified track [1,2].

We subsequently investigated the propagation dynamics, material dependence, and geometry of the resulting structures in fused quartz (silica) and K8 glass. The emission front

exhibits oscillatory motion consistent with an optical-discharge-like regime and produces tracks that are structurally distinct from those formed under continuous-wave LBI (CW-LBI) [3].

The discharge dynamics and the resulting structures differ markedly between fused quartz and K8 glass. In K8, the emission zone accelerates after traversing the focal region and reaches peak velocities approximately twice those observed in fused quartz under comparable conditions, while producing void-free tracks. In this work, we characterize these tracks in terms of their structural and elemental modifications and their optical signature.

Nanosecond laser backside irradiation (LBI) was performed using an IPG YLPM-1 pulsed fiber laser (1064 nm, 200 ns, 2–100 kHz; up to 20 W). The beam was focused with an F-theta lens ($f = 160$ mm) onto a 100- μm -thick AISI 314 stainless-steel foil acting as an absorbing layer. The foil was sandwiched between a K8 glass sample (thickness 1.1 cm) and a glass slide and fixed in a mechanical jig.

The emission zone propagation dynamics were recorded with an AOS X-EMA high-speed camera (1280×75 pixels, up to 10k fps, 100 μs exposure time).

Cross-sections of the modified track were prepared and polished at three representative positions: (i) the focal region, (ii) the peak-velocity region, and (iii) the deceleration region near the track end. The sections were carbon-coated and examined by SEM–EDX (Zeiss EVO 50 XVP) to map the spatial distributions of the major elements in K8 glass.

Optical modifications were characterized using a polarization holographic microscope (PHM) based on a Mach–Zehnder polarization-sensitive interferometer, providing spatially resolved phase (refractive-index-related) maps and polarization-dependent optical response [4].

High-speed imaging of nanosecond laser backside irradiation in K8 glass under varied conditions reveals that the emission-zone propagation speed correlates with the applied laser parameters. While after traversing the focal region, the emission zone accelerates, and this acceleration becomes more pronounced at higher repetition rates and with deeper focal positions (from the glass-metal surface).

SEM–EDX analysis shows that elemental redistribution along the LBI-modified track is strongly position dependent. Near and before the focal region, no compositional change is resolved within the sensitivity of the method. In the peak-velocity region, Na and K are enriched in the recondensed core and depleted in a surrounding ring, with Si and O showing a complementary trend. Further along the track, the compositional contrast decreases as the emission zone slows, although residual Na/K redistribution remains detectable.

Polarization holographic microscopy (PHM) maps show a clear central modified track characterized by a positive isotropic refractive index change that decreases toward the periphery and can become negative in surrounding regions. In the present dataset, the core reaches Δn on the order of 10^{-3} , while negative values observed in some peripheral zones are consistent with the alkali-depleted ring. In addition, the PHM-derived retardance maps indicate a strong polarization-dependent (birefringent) material response in and around the modified track.

Overall, the data suggest that a transition occurring after the focal region coincides with the onset of strong alkali redistribution and the formation of a recondensed core–ring morphology. The measured Δn profiles indicate that the written structures may support waveguiding, motivating further quantitative mode characterization and loss measurements.

Literature

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