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High Damage Threshold Ultrafast Laser Nanostructuring in Silica Glass

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A new type of birefringent modification (oblate nanopores or type X) with high optical transmission (>99%) was recently reported in silica glass using ultrafast laser writing [1]. This enables low-loss geometric phase (GP) flat optical elements with controlled phase shift by birefringence patterning. Here, high damage threshold of type X modification is demonstrated and compared with type II modification (nanograting type).

The experiments were carried out with a Yb:KGW mode-locked regenerative amplified femtosecond laser system (PHAROS, Light Conversion Ltd.) operating at 1030 nm with a repetition rate of 200 kHz and pulse duration tenable from 300 fs to 600 fs. Squares of type X and type II modifications (100 µm × 100 µm, azimuth angle 0°) were firstly imprinted via a 0.16 NA aspheric lens in silica glass sample using pulses of 600 fs pulse duration with 0.8 µJ pulse energy and 300 fs with 0.74 µJ respectively. The modified regions were overwritten by 50 µm × 50 µm areas (300 fs, azimuth angle 90°) in the middle of the structures with various pulse energies and scanning speeds (Fig. 1a). Under certain overwrite conditions (intensity of 7.5 TW/cm^2 and scanning speed of 0.02 mm/s), the birefringence of the modified area was erased, suggesting oblate nanopores were reshaped to isotropic nanostructures, which was further confirmed by optical phase difference (OPD) measurements (Fig. 1b) in two orthogonal directions (along the optical axes of the birefringent modification) by a phase imaging camera (SID4-HR, Phasics).

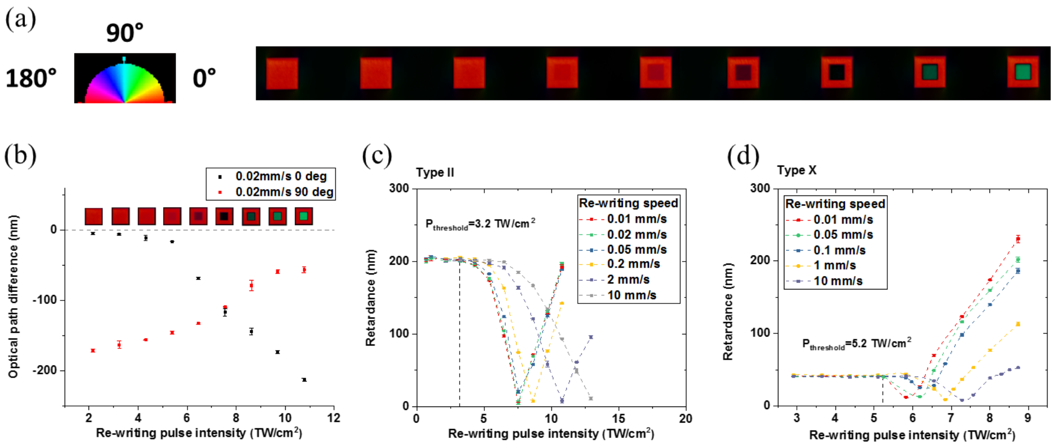

Fig. 1 (a) Illustration of the damage threshold test. (b) OPD of modified region by orthogonal linearly polarized light. Retardance degradation for type II (c) and type X (d) modifications.

The damage threshold was estimated when the retardance ceased to degrade with decreasing pulse intensity and scanning speed. The measured retardance under different conditions for type X and type II modifications was compared (Fig. 1c and 1d). It is evident that type X modification has a higher degradation threshold of 5.2 TW/cm^2 (comparable to the damage threshold of pristine silica glass of 7 TW/cm^2 for pulse duration of 300 fs) than type II modification (3.2 TW/cm^2), which could be attributed to more uniform nanostructures and lower defect concentration in type X modification. Moreover, the demonstrated damage threshold is much higher than that of liquid crystal GP elements [3].

Besides, we observed the retardance of initial modified region begins to decrease and then increase with higher laser re-writing intensity, which could be caused by the overwriting of nanogratings or nanopores [4]. For the retardance close to zero in the modified region (Fig. 1c), the isotropic nanostructures emerged during the overwriting process and the corresponding re-writing pulse intensity was smaller for higher pulse density at slower scanning speed. Furthermore, high-efficiency GP elements, such as prism, lens, and polarization converters, were fabricated in silica glass sample. Their performance was characterised and will be presented.

References

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