Ultrafast Laser Half-Beam Writing Paradox

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Abstract: Contrary to common belief asymmetric imprinting, revealed as different modification thresholds for two halves of Gaussian beam, is demonstrated in amorphous silicon. The phenomenon is interpreted in terms of anisotropic transport produced by ultrashort light pulses.

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Interesting phenomena in ultrafast laser writing are the dependencies of material modification in the bulk of glass on the polarization [1] and writing direction [2] relative to the direction of intensity front tilt of ulrashort light pulse. The physical mechanisms of the phenomena are still not completely understood. Here we provide the first experimental evidence of the asymmetry in material modification by a laser beam with symmetric intensity distribution profile for thin film geometry. The experiments were carried out with hydrogenated amorphous silicon (a-Si:H) thin films, which are widely used for solar cell technology. The results are interpreted in terms of anisotropic transport produced by ulrashort light pulses with tilted intensity front.

Thin a-Si:H films of 0.3 μm thickness were deposited by PECVD from the mixture of 25% SiH_4 and 75% Ar on a silica glass substrate at 250°C. A series of lines was directly written in the films using an amplified Yb:KGW laser (Pharos, Light Conversion Ltd.) operating at 1030 nm, with pulse duration ranging from 300 fs to 800 fs and repetition rate 200 kHz. Tuning of the laser pulse compressor changed the pulse duration, which was accompanied with the change of the PFT at constant pulse energy. The PFT direction was identified using single shot FROG Grenouille (Swamp Optics). The laser beam with symmetric Gaussian intensity profile was focused with an aspheric lens of 0.16 NA about 80 μm above the film, producing about 15 μm spot size on the surface. The writing speed was 5 mm/s. After writing the structures were imaged with an optical microscope. Surprisingly, at a particular power of 120 mW the lines written with the increased pulse duration revealed an increased

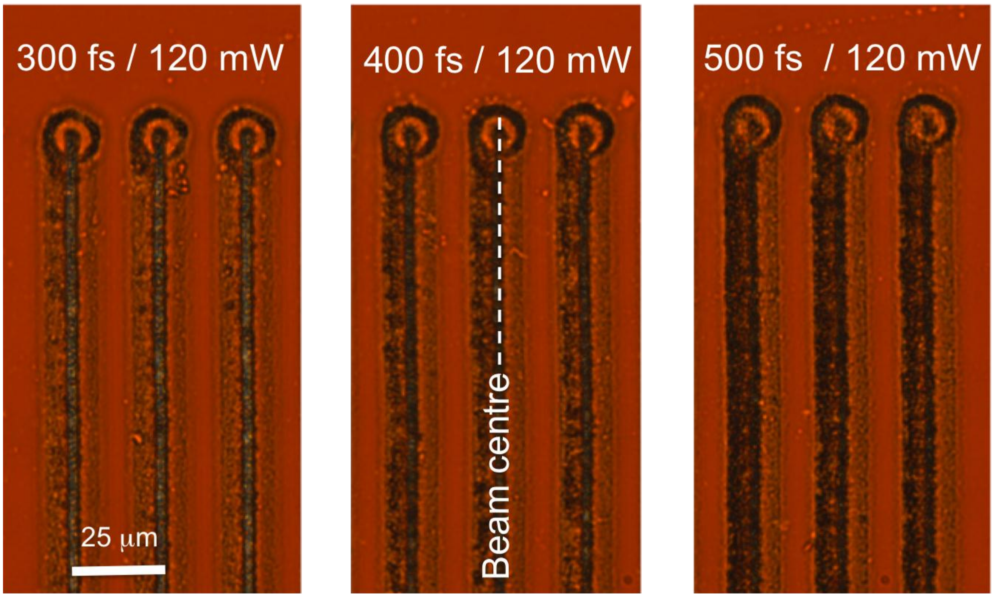

Fig. 1 Microscope images in transmitted light of the three series of line structures written with different pulse durations and the same average power. Paradoxically only half of symmetric Gaussian beam produces strong modification.

asymmetry in the induced modification (Fig. 1) Moreover, modification was much stronger exactly on one side from the center of the Gaussian beam. It looked like only *exactly one half of the beam* has been imprinted in the film.

The asymmetry in modification was absent at lower and higher powers than the critical power 120 mW (Fig. 2). Moreover the induced modifications *did not depend on the pulse duration* for all powers

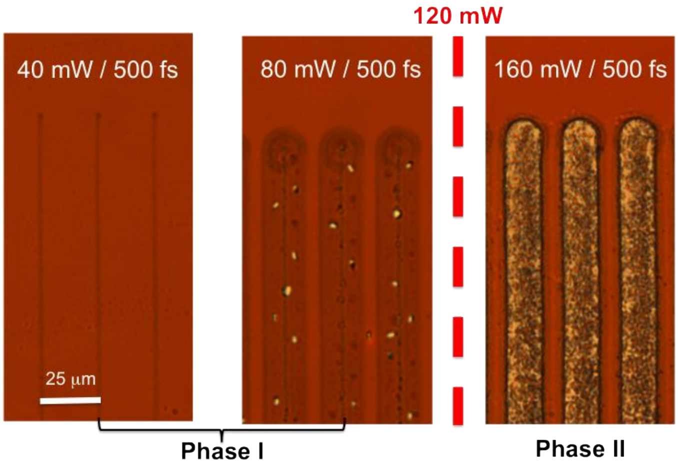

Fig. 2 Microscope image of a series of lines written with same pulse duration and different powers. All structures are symmetric regardless of pulse duration, which is in contrast to structures produced at critical power of 120 mW.

different from the critical value. It is also clear from the power dependence of the induced modifications that two modification phases could be produced with two distinct transitions (Fig. 2): one transition at about 40 mW, corresponding to the onset of crystallization in the film (phase I) and the second transition at about 120 mW, corresponding to the transition from the crystallization (phase I) to the melting (phase II) in the film modification. The observed critical power for the half-beam modification *coincided* with the power for the transition from the phase I to the phase II.

The results indicate that an anisotropic transport is involved in the observed phenomenon. Indeed, the gradients in intensity distribution from two sides of the Gaussian beam produce equal currents, e.g. due to diffusion or gradient force. Additional drift current uniform across the beam produced most likely by the gradient a tilted intensity front of the pulse or a spatial chirp (Fig. 3). The resulting

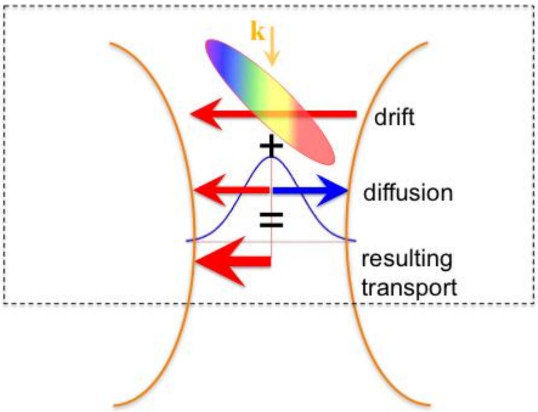

Fig. 3. The illustration of the mechanism of the half-beam writing phenomenon. The drift transport produced by the pulse front tilt breaks the symmetry of transport produced by symmetric gradients of the Gaussian distribution.

anisotropic transport of species, e.g. electrons or excitons, *reduces the threshold* of modification from phase I to phase II *only on one side* from the beam center. This mechanism is supported by the fact that the half-beam asymmetry increases with the pulse duration increase, which is accompanied by the increase of the spatial chirp and the pulse front tilt. Overall the observed phenomenon produces the first unambiguous evidence for the directional transport in ultrafast laser material processing and opens interesting opportunities in harnessing light induced modifications.

References

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