Influence of heat accumulation on femtosecond laser written birefringence inside silica glass

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1. Introduction

Femtosecond (fs) laser direct writing of birefringent structures in silica has been used to generate unique optical devices that can manipulate and characterize the spatial polarization properties of light. So far, devices including spatial polarization converters [1] and polarization sensitive cameras [2, 3], and geometric phase holograms [4] have been demonstrated. Recently, a number of high power fs laser sources at high repetition rates (1-100 MHz) have become commercially available. As a result the use of high repetition rate fs laser sources has become a popular choice to increase the throughput of direct fs laser writing systems.

However, the throughput is often limited by the accumulation of thermal energy in the illuminated materials, which becomes dominant when the time between successive laser pulses becomes comparable to the thermal diffusion time [5]. An investigation of heat accumulation effects and the mechanism behind these is important to fully understand the limitations arising from the use of higher repetition rates and to help identify potential techniques that circumvent these limitations. This study reports on the investigation of the influence of repetition rate of fs laser induced birefringence inside silica and discuss the relation between the magnitude of the induced birefringence and the repetition rate, supported by simulations of thermal diffusion.

2. Methods

Birefringent dot structures were generated inside fused silica glass plates by focusing linearly polarized fs laser pulses (Light Conversion Ltd., PHAROS) using an aspheric lens of NA=0.65 (Newport). The wavelength of the fs laser pulses was 1030 nm, the pulse duration was 190 fs, and the repetition rate was varied from 100 kHz to 1 MHz. The level of birefringence (retardance) in the laser written dots was measured using a polarization microscope with a phase retarder (CRi, Abrio).

3. Results

Figure 1(a) shows birefringence images of two dots written by focusing twenty (20) fs laser pulses inside a silica glass plate. In this case the pulse energy was 140 nJ. For a given number of pulses (20), the retardance in the laser written dots is observed to decrease with increasing repetition rate (Figure 1(b)). When the pulse energy was 120 nJ and 140 nJ, the retardance dropped ~50 % for increasing repetition rate (100 kHz to 1 MHz). This drop of the retardance suggests that the birefringence is partially erased due to heat accumulation during laser irradiation at higher repetition rates. Evidently, at 100 nJ, the retardance remained almost unchanged. This apparent smaller sensitivity to the repetition rate suggests that the temperature increase in this case is not high enough to erase the laser induced birefringence.

To investigate the relationship between the retardance and repetition rate, the temperature change at the center of the photoexcited region during laser irradiation was simulated based on the thermal diffusion model [5]. Figure 2(a) shows the simulated temperature change for repetition rates of 1 MHz and 500 kHz. The simulation indicates that the heat accumulation becomes significant when the repetition rate is higher than 500 kHz. Figure 2(b) shows the temperature change just before each shot at different repetition rates. The temperature increase after 20 pulse irradiation is 30 times smaller at 100 kHz compared with that at 1 MHz. During the conference, we will discuss possible methods for how to mitigate the effects of heat generation.

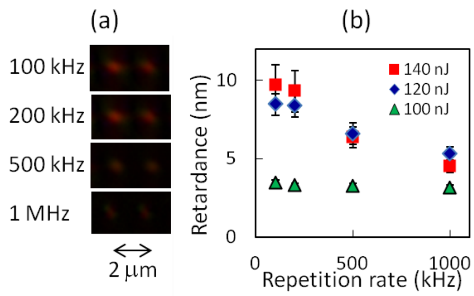

Fig. 1. (a) Birefringence images of two dots written by fs laser irradiation at different repetition rates. (b) Retardance of fs laser written dots plotted against repetition rate of fs laser pulses.

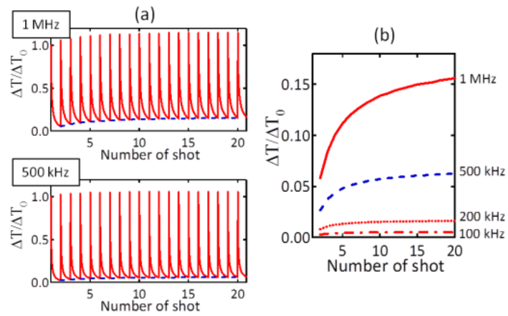

Fig. 2. (a) Simulated temperature change during laser irradiation in silica at 1 MHz and 500 kHz. (b) Temperature change just before each shot.

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