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Original

Optical damage as a computer generated hologram recording mechanism

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Abstract

In this paper we report optical damage as a bulk glass recording process. We used a 10 Hz, 35 picoseconds, 5 mJ polarized Nd:YAG pulse laser focused using a 25 mm lens to create 50 μm average optical damage spots to record a computer generated hologram embedded in stress free BK-7 glass. It was observed that for the recording conditions the material surrounding the damage spot was induced birefringence altered producing a 70 μm pixel optimal separation.

Keywords: Optical damage; Micromachining of glass; Computer generated hologram

1. Introduction

Using high intensity laser pulses for locally confined permanent modifications inside transparent materials, like changes in the refractive index, are possible by nonlinear absorption mechanisms. If the energy falling into the material is sufficient, plasma formation sets in and material damage can occur (Loeschner et al., 2008; Wood, 1986). Laser optical damage refers to material processing by laser ablation on a material. In some cases it can be controlled to produce artwork or optical devices. Femtosecond laser processing has recently been used to produce material micromaching (Zoubir, Shah, Richardson, & Richardson, 2001), drilling (An, Li, Dou, Yang, & Gong, 2005), or diffraction gratings recording (Park, Cho, Kim, & Kang, 2011). Laser optical damage is produced by controlling the operational parameters, such as beam intensity, spatial and temporal pulse shape, wavelength, as well as the material characteristics. Depending on the material properties we can have either energy dependence for absorbent materials or peak energy dependence for transparent materials. In any case the ablation produces a local refractive index change and depending on the pulse duration we can observe shock wave effects depending on the mechanical properties of the material.

On a customarily uncorrelated field, holography involves the recording and reconstruction of waves (Goodman, 1996, chap. 9). The coded record of a wave is called a hologram. In optical holography, a wave front diffracted by the object propagates to the hologram plane, where it interferes with a reference beam. The resulting intensity pattern is recorded on photographic film or plate to form the hologram. To decode the information from the hologram and reconstruct the object wave, the reference wave is again used to illuminate the hologram. Computer generated holograms (CGH) provide a more flexible process (Juárez-Pérez, Olivares-Pérez, & Berriel-Valdos, 1997). A computer digital hologram (CGH) is the numerical representation of the interference pattern observed in a hologram obtained by the superposition of a reference beam and an object beam. On CGH a physical object is not needed, it is sufficient to have a mathematical description of the object. Customary the fabrication CGHs is performed by an enlarged sample of a plotted computed hologram followed by a photographic reduction with the desired final size. Supported by modern computational tools, it is a mature area and has displaced up to some extend the traditional holographic film recording procedure.

Combining both optical induced laser damage and CGH is possible to conceive optical damage as a recording mechanism. Similar recording methods are found on the literature (Fauzi, Kim, Kim, Jun, & Lee, 2012; Li, Dou, An, Yang, & Gong, 2005; Waedegaard & Balling, 2010; Waedegaard & Balling, 2011; Zhao et al., 2005). For instance, on Fauzi et al. (2012) the recording is done in the glass bulk using Lohmman CGH

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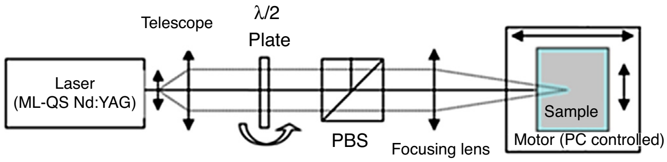

Figure 1. Setup used to control the optical damage. The intensity is controlled by a half wavelength plate. A 10 cm lens is used to focus the beam on the sample. The sample is displaced by a computer controlled stage.

code (Brown & Lohmann, 1966) in which each pixel is composed by an array of dots and the codification is done by the number of points recorded (amplitude) and position (phase). An advanced CGH code is found on Waedegaard and Balling (2011) but the recording is performed only on the surface.

In this paper we use optical damage using long laser pulses as a recording mechanism for writing an advanced CGH generation code inside bulk glass.

2. Optical damage experimental setup

In order to investigate optical damage in glass we used the setup shown in Figure 1. A Quantel 416 mode-locked-Q-switch Nd:YAG vertically polarized laser operating at 10 Hz producing 35 picosecond pulses delivering up to 35 mJ at 1064 nm is used to produce a small spot within the material. We used different lenses placed after a telescope to focus inside a solid $2 \times 2 \times 2\,cm^3$ cube of BK7 stress free optical glass. The intensity was controlled by a variable attenuator made by a quartz polarizing beam splitter (PBS) and a half wavelength retardation plate. The sample was moved by a computer controlled XYZ stage with controlled 200 nm resolution step motors (Newport ESP300).

We observe catastrophic optical damage using pulse energies larger than 3 mJ per pulse using a 25 mm focal length focusing lens, in accordance with similar observations (Loeschner et al., 2008). Because of shot-to-shot fluctuation, the large energy per pulse and the relatively large pulse duration, the shot-to-shot damage was not uniform. We observed these fluctuations for individual damage spots with differences in shape and size under the microscope (Fig. 2).

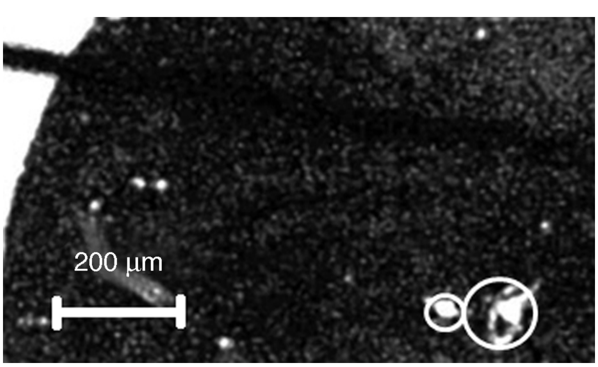

Figure 2. Frontal view of optical damage in a BK7 optical glass produced using a 25.4 mm focal length lens. We observe two spots with diameters of 60 ± 10 μm (left point) and 80 ± 10 μm (right point). Notice the non-uniformity in the spots shape.

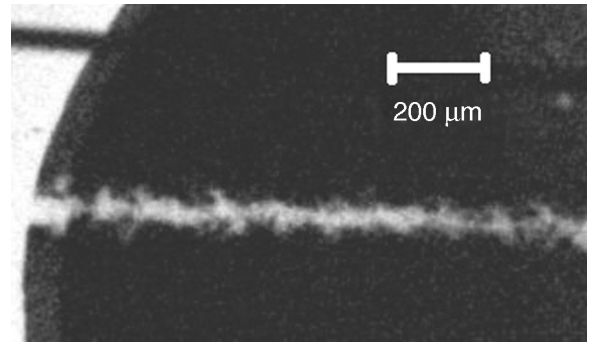

Figure 3. Lateral view of optical damage in a BK7 optical glass produced using a 250 mm focal length lens at 3 mJ per pulse. The width of the line is 60 ± 10 μm and has approximately 3 mm length. (not all line is shown). Notice the fluctuations in width along the line.

In most of the cases the damage was not localized and produced long strips in the material. Using long focal length lenses ($f = 250$ mm) we were able to produce lines as long as 3 mm due to a combination of ablation and temperature distribution (Fig. 3).

After the single spot average size was obtained, which was actually a line-hole in the material, a series of lines were recorded on the glass by laterally displacing the glass with respect to the beam direction. With the characterization in size and shape of the damage we decided to keep a 10 cm focal length lens which produce a 50 μm spot (on average) observed under a microscope. Keeping the glass for 5–10 shots we observed a line depth between 1 and 5 mm.

With the single damage points characterized, using a mechanical shutter to select the number of shots we recorded between 10 and 20 lines. Between each line we laterally displaced the glass cube by a given distance. For example in Figure 4 we observe a series of 11 lines separated by 100 μm.

The resulting damage recorded is a series of regular lines which irregularities both in length and width. These lines were illuminated using a He-Ne laser and observed in a screen 2 m

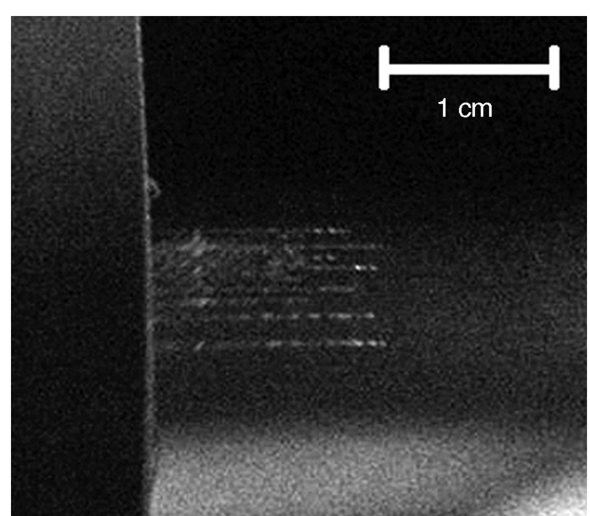

Figure 4. Lateral view of 11 lines separated 100 μm recorded with 10 shots each on BK7 using a 250 mm focal length lens to focus.