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Micron and sub-micron gratings on glass by UV laser ablation

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Abstract

ArF excimer laser ablation is applied for the generation of surface relief gratings on various glass materials. At the laser wavelength of 193 nm even highly transparent borosilicate glasses exhibit sufficient absorption for the fabrication of precise, crack free ablation patterns. Gratings with periods down to 3 μm are created in a line by line process by projecting a laser illuminated slit onto the glass surface. Micron- and sub-micron-periodic gratings are made by projecting a transmission grating using a Schwarzschild objective. Such gratings can be applied for surface functionalization or diffractive marking.

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1. Introduction

High resolution patterning of glass by laser ablation is still a great challenge. Due to the low absorbance of glass materials in the visible and even in the near UV spectral regions, lasers emitting in the infrared (e.g. CO₂-laser at 10.6 μm) or in the deep UV are generally used for ablative laser machining of glass [1-3]. However, as the achievable resolution scales with the wavelength, CO₂ lasers are not suitable for the generation of micron or sub-micron sized structures. The use of femtosecond lasers utilizes multi photon processes to provide absorption and ablation, but the process speed is limited. Indirect ablation methods using an additional liquid or solid absorber material have been developed [4-6], but their industrial application is limited due to constraints concerning workpiece geometry and process environment. Thus, deep-UV lasers are the first choice for fast and high resolution patterning of glass. While some lead-containing glasses exhibit
sufficient absorption at 248 nm [7, 8], most standard glasses like borosilicate glass require a laser wavelength below 200 nm for efficient absorption. The ArF-excimer laser emitting at 193 nm is the optimum choice to obtain controlled, crack free patterns with high resolution. At this wavelength, gratings in doped borosilicate glass have already been successfully fabricated [9].

In this paper we demonstrate the fabrication of periodic line patterns with periods in the μm- and sub-μm range in undoped glasses. Such grating patterns have a number of applications, e.g. for surface functionalization or diffractive marking.

2. Experimental

Two optical arrangements are applied, one enabling a fast process with moderate structure resolution, the other one providing high resolution at reduced process speed. For the first one a slit is illuminated by the excimer laser beam and imaged onto the workpiece by a cylindrical quartz lens (Fig. 1). Using demagnification ratios of the order of 30:1, lines of more than 10 mm length and down to a few μm width can be irradiated with a fluence up to 2 J/cm². Line after line is generated applying the appropriate number of pulses. If one pulse per position is sufficient to obtain the required ablation depth, the pattern can be generated on the fly. In this case, synchronization of laser trigger and feed motion allows speeds in the range of a few seconds per cm².

For sub-μm periods a transmission grating is imaged onto the workpiece using a Schwarzschild objective (Fig. 2). These reflective imaging systems combine high UV-transmittance and high numerical aperture (NA) with a comparatively long working distance. With NA = 0.4 a pattern period of a few hundred nm can be obtained.

![Fig. 1. Optical setup for line by line processing](image1)

![Fig. 2. Optical setup for high resolution processing](image2)
3. Results and Discussion

Fig. 3 displays single lines created with the slit imaging method on borosilicate glass. Precise and smooth grooves without micro cracks are obtained. Debris originating from the ablation process can be easily removed using a commercial glass cleaning agent (Deconex 15PF, Borer Chemie). In Fig. 4 (a) a grating pattern made by the line by line technique is displayed. Fig. 4 (b) shows the diffracting character of this surface pattern. By adding a contour mask (“LLG”), the line pattern will only fill this contour leading to an opalescent mark.

![Fig. 3. Grooves made in borosilicate glass by slit imaging. Laser parameters: 193 nm, 1.1 J/cm², 2 pulses (a), (b) scanning electron microscope images; (c) optical microscope image](image)

Fig. 5 displays a grating with 400 nm period generated on a quartz glass surface using the Schwarzschild setup. As opposed to other glass types, for quartz glass the formation of cracks is frequently observed, especially if more than two or three pulses are applied at the same position. As a consequence, for the precise patterning of weakly absorbing quartz glass the use of an even shorter laser wavelength (157 nm) is advisable [10, 11].
Fig. 4. (a) 3-μm-period grating on a microscope slide made by slit imaging; (b) Opalescent mark made by slit imaging with contour mask.

Fig. 5. 400-nm-period grating on quartz glass fabricated with the Schwarzschild-setup (193 nm, 3.9 J/cm², 2 pulses).

Fig. 6. Ablation rates of various glass types at 193 nm measured in the case of plane ablation (without grating) [7, 12]: quartz glass and Schott glasses BK7 and SF11.
Fig. 6 displays the ablation rates of various glass materials measured at 193 nm [7, 12]. The lower the absorbance of the glass at this wavelength, the higher is the threshold fluence, and the higher is the ablation rate at the same fluence significantly above threshold. A few hundred nm per pulse is obtained at about 4 J/cm² in all cases, if the laser spot size is in the order of 300 μm. For sub-μm-gratings, thermal diffusion limits the modulation depth of the achieved grating relief [8, 13], so that their depth cannot be derived from the data of fig. 6. However, high diffraction efficiency for high contrast marks is obtained already with a modulation depth of a few hundred nanometers.

References


