UV-laser fabrication of sub-micron hole arrays in glass by phase mask projection

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Parallel processing of sub-µm holes in a glass surface using ArF excimer laser ablation at a wavelength of 193 nm by phase mask projection is demonstrated. Holes in soda lime glass are made by direct laser ablation; fused silica is processed by depositing a SiO_x-film on SiO_2, patterning the SiO_x by ablation, and finally oxidizing the remaining SiO_x to SiO_2.

1 Introduction

High-resolution laser patterning of glass materials is still a challenging task. As glass is transparent in the visible and the near UV spectral range, for the ablative structuring of glass preferably deep-UV lasers are applied. Some lead-containing glasses exhibit sufficient absorption at 248 nm [1]; most standard silicate glasses require a laser wavelength below 200 nm for efficient absorption [2,3]. The ArF-excimer laser emitting at 193 nm is the optimum choice to obtain controlled, crack free patterns with high resolution. In this paper we demonstrate the parallel fabrication of periodic hole arrays with sub-micron pitch and hole diameters down to 250 nm [4].

2 Phase mask projection

An ArF excimer laser (wavelength 193 nm) is used in combination with a mask projection setup for parallel hole processing. A phase mask is applied to minimize losses at the mask. This mask is projected on the glass surface with a Schwarzschild type reflective objective (25x demagnification, NA = 0.4). The phase mask consists of a surface relief grating on fused silica containing a binary crossed grating pattern [5]. The duty cycle of the crossed grating lines and spaces is adjusted in a way that the intensity in the zeroth diffraction order is largely suppressed. A beam selector blocks all diffraction orders except the four pure first order beams (+1/0, 0/+1, -1/0, 0/-1), so that in the image plane a four beam interference leads to a two dimensional array of intensity spikes. At sufficiently high laser fluence, this intensity array creates an ablated hole array.

3 Soda lime glass

Fig. 1 displays a scanning electron micrograph (SEM) of a hole array in soda lime glass generated by two pulses of 2.2 J/cm² peak fluence. The hole diameter is around 250 nm and the pitch amounts to 500 nm. The hole depth of 120-150 nm is determined by atomic force microscopy (AFM) as displayed in Fig. 2. This corresponds quite well to the measured ablation rates of standard glass materials at 193 nm [3,4].

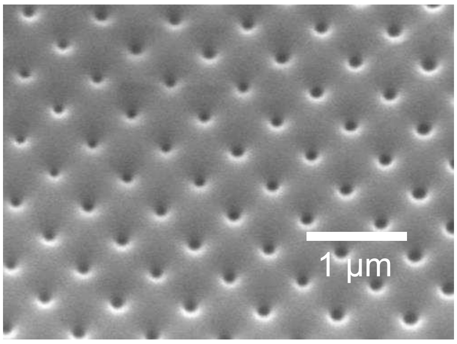
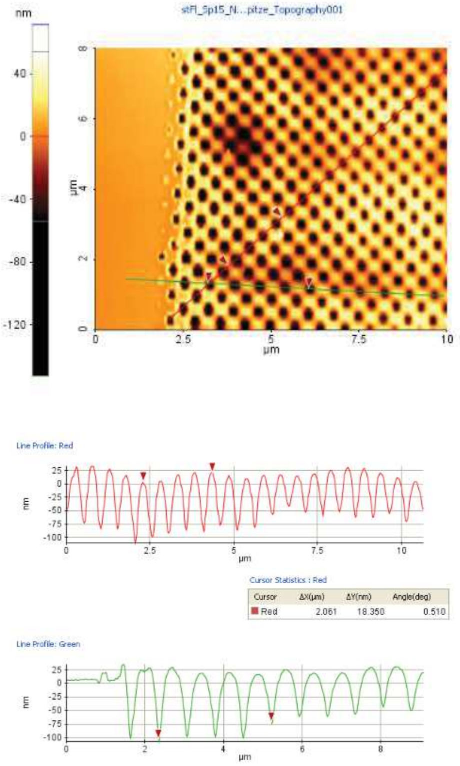


Fig. 1 *SEM image of a hole array in soda lime glass made by two laser pulses of 2.2 J/cm² peak fluence at 193 nm.*



Cursor Statistics : Red

Cursor	ΔX(µm)	ΔY(nm)	Angle(deg)
🟥 Red	2.061	18.350	0.510

Fig. 2 *AFM image of a hole array in soda lime glass made by two laser pulses of 2.2 J/cm² peak fluence at 193 nm.*

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4 Fused silica

The ablation threshold of fused silica at 193 nm of about 3 J/cm² is significantly higher compared to that of soda lime glass [6]. Furthermore, the ablation of fused silica at this wavelength is accompanied by crack formation. To overcome these problems, an alternative process scheme is chosen: The hole array is generated in strongly UV-absorbing SiO_x, which is afterwards oxidized to SiO_2, as displayed in Fig. 3 [7]. SiO_x-films ($x \approx 1$) are deposited on fused silica by vacuum evaporation. The generation of hole arrays is then performed with the same setup as described above. Fig. 4 (a) shows a pattern fabricated with a single laser pulse at 1 J/cm² peak fluence in a 150 nm thick SiO_x-film. The hole depth is 150 nm, as the ablation process stops at the fused silica substrate [8]. A high temperature annealing process leads to complete oxidation to SiO_2.

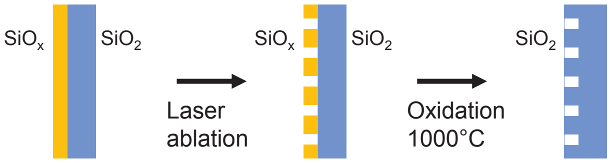
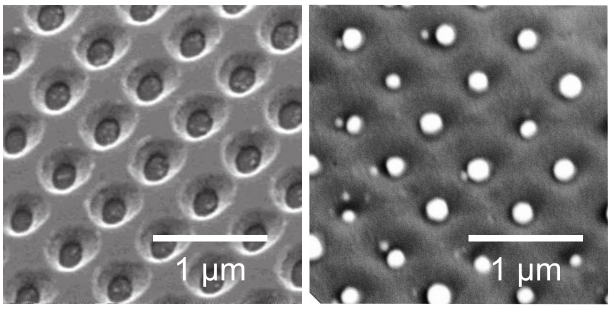


Fig. 3 *Process scheme of the fabrication of hole arrays in fused silica.*



(a) (b)

Fig. 4 *(a) SEM image of a hole array in fused silica made by a single laser pulses of 1 J/cm² peak fluence at 193 nm according to the scheme of Fig. 3. (b) SEM image of a hole array in fused silica filled with gold nanoparticles.*

5 Templated dewetting

There are various applications of sub-micron hole arrays like diffractive marking, nanofluidics, or sensor platforms. One specific application area is templated dewetting. Metal nanoparticles can be generated by high temperature annealing of deposited films leading to dewetting and particle formation. A pre-patterned substrate supports the formation of regularly arranged particles [9].

Fig. 4 (b) displays a hole array in silica glass, where each hole is filled with a gold nanoparticle of 100-200 nm diameter. This arrangement was fabricated in the following procedure:

1. Vacuum deposition of a SiO_x-film on fused silica
2. Fabrication of a hole array in the SiO_x film by single pulse laser ablation at 193 nm
3. Oxidation of SiO_x to SiO_2 by thermal annealing at > 1100 K
4. Deposition of 10 nm gold and subsequent rubbing off the loosely sticking gold
5. Dewetting of residual gold by thermal annealing at > 1100 K

This method may show a way to fabricate plasmonic devices without the need for complex lithographic processes.

Acknowledgements

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