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Exposure of photosensitive glasses with pulsed UV-laser radiation

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Abstract The photosensitivity in UV-range of some glasses can be used for micro structuring. The irradiated areas crystallize after a thermal treatment. Microstructures are achieved by wet-chemical etching of the crystallized areas. Interactions between UV-laser radiation of different wavelength and the photosensitive glass are investigated. The relationship between process parameters and geometry of microstructures is examined.

1 Introduction

Glass becomes an increasingly important material in micro systems technology. Especially glasses, that can be structured by a modified photolithographic process, are significant. Using such a material it is possible to produce any 2 1/2 dimensional structure. The photo structuring process (Fig. 1) with its steps UV-exposure, thermal treatment and etching arranges the production of micro structured glass components. In order to produce complex objects e.g. components for micro valves, micro actuators or sensors it is necessary to join glass with glass or various other materials. The use of glass as a material for micro technical applications requires technologies of structuring in the range of micrometers.

The exposure takes place with conventional mask aligners, where the optical components are adapted to the UV-range of light source. Disadvantages of this technique are high exposure times in consequence of low spectral power density of the light source and small flexibility.

The exposure with UV-laser radiation is an alternative method to this technique. Investigations are concentrated on the interaction between UV-laser radiation and the photosensitive glass. The destination is the determination of fields for important parameters of exposure with UV-laser radiation (e.g. wavelength of UV-laser radiation, energy or power density, number of pulses, pulse repetition frequency and local profile of laser beam).

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2 UV-lithography

First step of micro structuring photosensitive glass is the partial exposure with UV-radiation. The function of the exposure process is the partial initiation of nuclei. During the exposure a photochemical reaction takes place in the exposed areas (Fig. 1). The parameters of the exposure process depends on the material (e.g. spectral transmission (Fig. 2) and threshold energy densities) and on technology (e.g. wave length of the radiation, energy density, geometry of beam and masking).

3 Laser equipment

For the investigations pulsed lasers (excimer laser: 193, 248, 308 and 351 nm and (3ω) Nd:YAG laser: 355 nm) were used. The processing of photosensitive glass with pulsed UV-laser radiation were made at RWTH-Aachen Lehrstuhl für Lasertechnik. Figure 3 gives an example of such laser equipment with an excimer laser as a pulsed UV-laser radiation source.

For description of the interaction processes between UV-laser radiation and photosensitive glass it is important that the local beam profiles of excimer laser radiation and Nd:YAG-laser radiation are comparable. Therefore only a part of the excimer laser beam were used. The result was a local beam profile with nearly the same full width at half maximum like a Gaussian local beam prolile of a Nd:YAG-laser. The following process parameters for exposure of photosensitive glass with UV-laser radiation were used:

- Wave length of pulsed laser radiation: 193, 248, 308, 351, 355 nm
- Energy density: $\varepsilon_L < \varepsilon_{thr}$
- Number of pulses: $N = 1$
- Pulse duration: 10 ns $< \tau <$ 40 ns
- Diameter of the laser beam: 80 μm $< d <$ 100 μm

4 Designation of threshold energy densities

The knowledge of threshold energy density is important for exposure photosensitive glass. It is defined as the energy density at which the surface was not destroyed. In Fig. 4 are shown the threshold energy densities for the exposure of photosensitive glass with different pulsed UV-laser radiations.

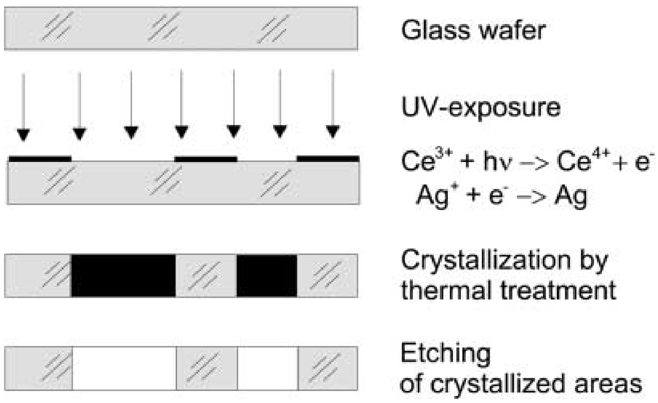

Fig. 1. Standard process of photo structuring

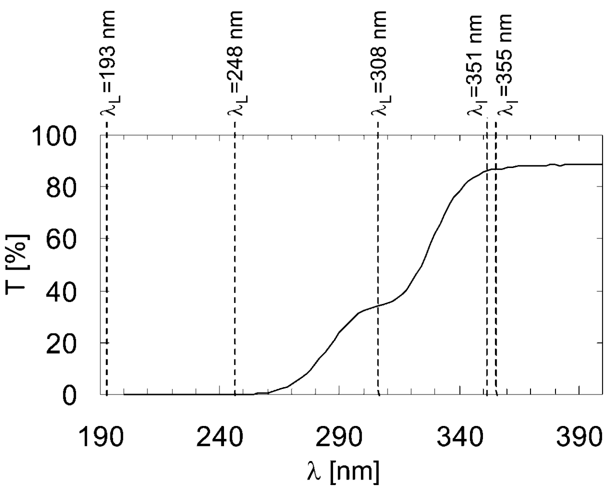

Fig. 2. Spectral transmission of photosensitive glass

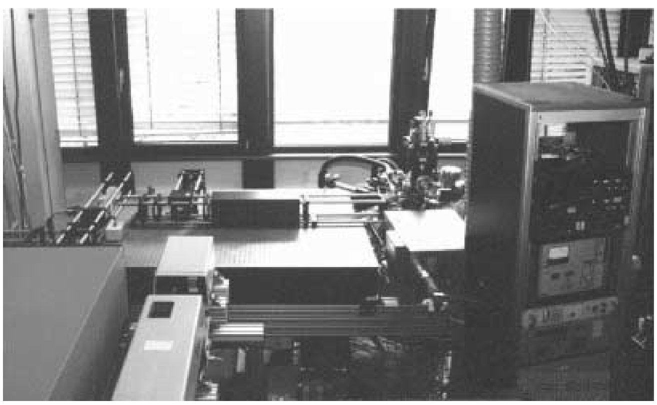

Fig. 3. Excimer laser equipment

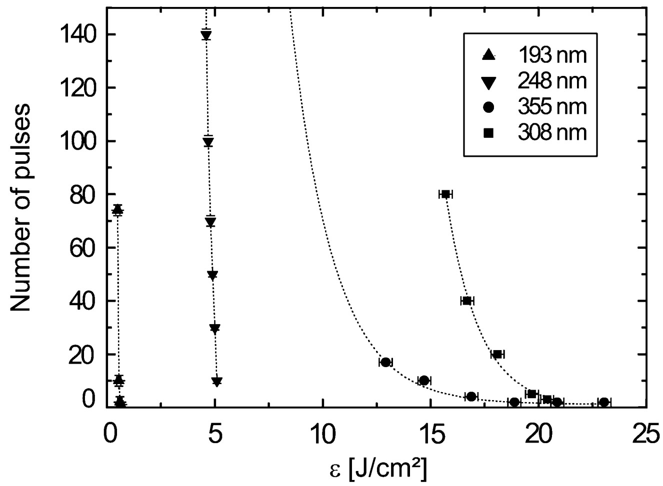

Fig. 4. Threshold energy densities of different pulsed UV-laser radiations

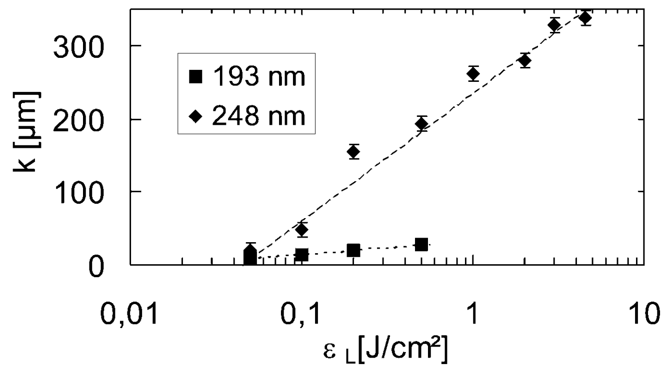

Fig. 5. Crystallization depth k dependent on the energy density ε_L and the wave length of laser radiation λ_L

The position of the threshold energy densities depends on absorption mechanism in photosensitive glass. There are two possibilities for absorption of UV-radiation in glass. One part of the radiation will be absorbed by the surrounding electrons of the oxygen ions (bridge ions) in glass. Another part will be absorbed by polyvalent elements with a band in UV-range of the electromagnetic spectrum (e.g. Ce^{3+}-ions in $\lambda = 310$ nm) (Scholze, 1988). With the exception of the XeCl-excimer laser radiation ($\lambda_L = 308$ nm) the threshold energy densities are situated on higher energy densities with higher wavelength of laser radiation. The reduction of the threshold energy density with higher number of pulses especially for the exposure with laser radiation $\lambda_L = 355$ nm and $\lambda_L = 308$ nm can be attributed with modification of the glass structure (Ashkenasi, 1999). Exposures of photosensitive glass were made below this threshold energy densities. The parameters wavelength of laser radiation and energy density were varied.

5
Results

The research of exposed samples by UV-laser radiation took place at Ilmenau Technical University. The exposed samples were partial crystallized during constant standard thermal treatment ($\upsilon = 590$ °C, $t = 60$ min).

The crystallization depth of structures were higher than 700 µm for the exposure with $\lambda_L \geq 308$ nm and different energy densities. The crystallization depth of structures

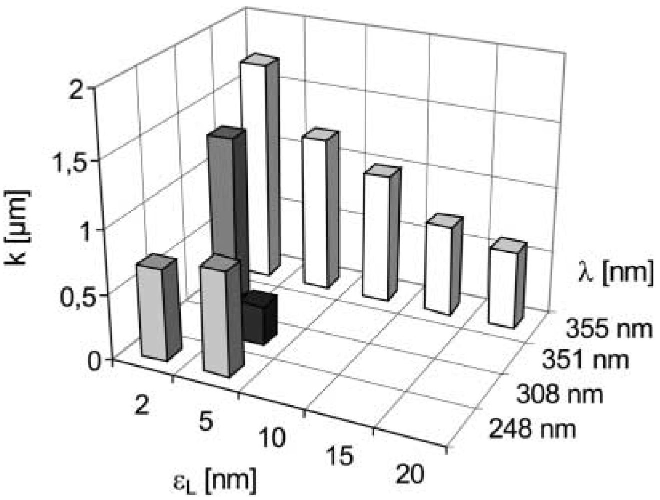

Fig. 6. Crystal size dependent on wave length of laser radiation λ_L and on energy density ε_L

exposed by laser radiation of $\lambda_L < 308$ nm is shown in Fig. 5.

Important for using photosensitive glasses as material for micro technical applications is the size of the $Li_2O \times SiO_2$ crystals. It influences the geometrical form and roughness of surface of structures. In Fig. 6 is shown an overview about the dependence of crystal size on the wave length of laser radiation and on the energy density.

The crystal size depends on the quantity of the nuclei. The crystal size is minimal for the exposure with $\lambda_L = 308$ nm. The photochemical reaction (Fig. 1) takes place with high efficiency by reason of the band of Ce^{3+}-ions in $\lambda = 310$ nm. A maximum of nuclei will be initiated during the exposure. Moreover the generation of different crystal sizes depending on parameters of the UV-laser exposure is possible. This is important for fabrication of different surface qualities in micro structures for instance for fluidic systems and tribological applications.

Figure 7 shows examples of structures after exposure with pulsed UV-laser radiation, thermal treatment and wet chemical etching. These simple structures can be combined to complex applications. The exposure with UV-laser radiation is an alternative to the exposure with a mask aligner. It is possible to expose photosensitive glass with masks (static or dynamic) and also by printing exposure. There is a high potential of flexibility in the field of micro structuring photosensitive glasses.

6
Summary

The exposure of photosensitive glass by pulsed UV-laser radiation in the range of $\lambda_L = 193$ nm until $\lambda_L = 355$ nm is possible. The laser radiation of different wavelength have characteristic threshold energy densities. Below this threshold energy densities exposures with varied laser parameters (wavelength of laser radiation and energy density) bring on differences in crystallization depth and crystal size of $Li_2O \times SiO_2$ crystals. A speciality is the exposure with $\lambda_L = 308$ nm. There is the highest threshold energy density and the crystal size is minimal. The dependence of crystallisation parameters on exposure parameters is important for fabrication specific surfaces in microstructures, e.g. fluidic systems and tribological applications.

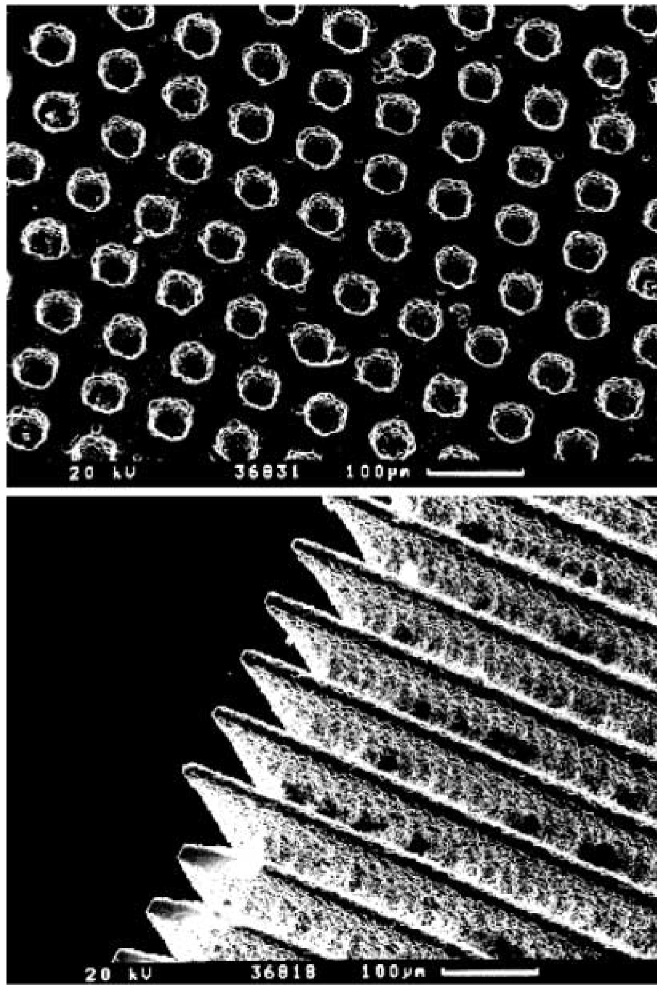

Fig. 7. Microstructures after exposure with the (3ω) Nd:YAG-Laser (355 nm), thermal treatment and wet chemical etching (on top: holes, below: trenche)

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