Figure correction of borosilicate glass substrates by irradiation with an ArF excimer laser for production of precisely shaped reflective optics

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Unintentional deformation of optical substrates is a common issue in optics technology. A possible figure correction method is based on stresses induced by irradiation of a borosilicate glass substrate with an ArF excimer laser. We report on results regarding the distribution and stability of the induced stresses and the generation of antibiaxial plane stress components.

1 Introduction

Deposition of a thin film, e. g. a mirror coating, on a silicate glass substrate is a common procedure in optics technology. Figure errors of the substrate evolve from the mechanical stress of the deposited film or by other reasons. Recently, methods for correction of these figure errors have been developed that are based on the introduction of a plane stress field in the backside surface of the substrate. In [1], we demonstrated such an approach for tensile stresses generated inside the surface of a borosilicate glass by irradiation with an ArF excimer laser. Here, we report on additional results obtained on this figure correction approach.

2 Experimental

The samples, the irradiation procedure and the measurement of curvature and integrated stress are described in detail in [1]. We irradiated thin sheets of the glass Schott D263M with the light of an ArF excimer laser (193 nm, 20 ns) and laser spots with a flat top fluence distribution or a distribution of parallel, equidistant lines. By tactile profilometry, we obtained the curvature change of the samples due to the irradiation and subsequent processing steps. Height profiles of the irradiated surfaces were obtained by tactile profilometry and atomic force microscopy. Etching was done in a 1.000(2) mol/l aqueous KOH solution at a temperature of 80 °C. For annealing, we applied a muffle furnace.

3 Results

The integrated stress, calculated by the Stoney Eq. [2] from the measured change in curvature, in dependence on the KOH etch depth of the irradiated material is plotted in Fig. 1 for a sample irradiated with one pulse per position at a fluence of 1 J/cm^2. The integrated stress decreases with increasing etch depth and vanishes at a depth of about 650 nm, which therefore corresponds to the thickness of the stressed surface layer. At the applied fluence of 1 J/cm^2, the value of the integrated stress is already close to its maximum value for variation of the fluence [1]. Therefore, the obtained thickness presumably is close to the maximum thickness.

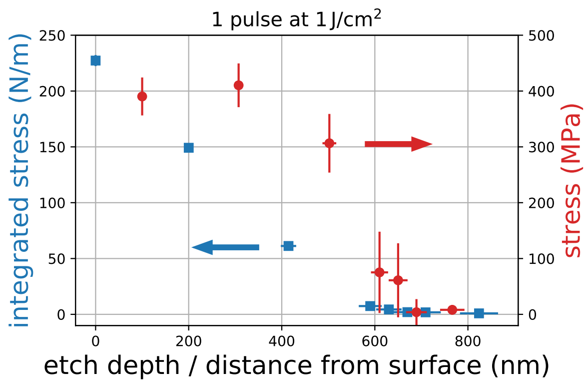

Fig. 1 *For irradiation with one pulse at a fluence of 0.99(5) J/cm^2, we measured the integrated stress (left ordinate) in dependence on the thickness of removed material by etching in KOH solution. From this data, we calculated the stress distribution in direction normal to the surface (right ordinate).*

By calculation of the central difference quotient of the integrated stress with etch depth, we obtained the stress distribution in direction normal to the surface (Fig. 1). On the first 500 nm from the surface, a tensile stress of roughly 300 to 400 MPa is observed. For larger depths, the stress rapidly declines to zero.

In [1], we demonstrated that the value of the integrated stress decreases for long-term storage in ambient atmosphere at room temperature. Fig. 2 shows the time dependence of the integrated stress for annealing at 100 °C in ambient air. The stress was induced by irradiation at a fluence of 1 J/cm^2 and one pulse per position. In Fig. 2, the integrated stress was normalized by the value obtained for a control sample which was simultaneously kept at room temperature. A faster decrease of the integrated stress than at room temperature is observed. This result might be used to stabilize the integrated stress via annealing after irradiation.

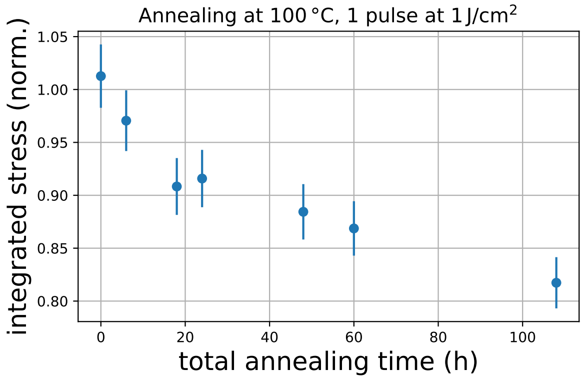

***Fig. 2** Annealing at 100°C in ambient air causes a faster decrease of the integrated stress with time than at room temperature. The obtained integrated stresses for irradiation with one pulse at 1 J/cm^2 after different total annealing times are normalized by the values for a sample kept at room temperature.*

If a large laser spot of uniform fluence distribution is applied, as was the case above, only equibiaxial plane stress components can be generated. In [1], we demonstrated that antibiaxial plane stress components can be generated by irradiation with a line pattern with a period of $d = 8\,\mu$m. The antibiaxial plane stress components cause an anisotropic deformation of the sample, which we characterized by the curvature ratio k_s/k_p of the curvature k_s in direction across the lines divided by the curvature k_p in direction along the lines. Fig. 3 shows this curvature ratio plotted in dependence on the depth of the trenches of the line pattern. It decreases with increasing structure depth. This behavior is qualitatively similar to the case of a stressed film that has been patterned into lines of a certain aspect ratio, as is analytically described by the theory of Wikström et al. [3]. In Fig. 3, this theory is plotted for a Poisson's ratio $\nu = 0.208$ of the sample material. The resulting curvature ratio lies below the experimentally obtained values.

A better match to the experimental values can be obtained, if an equibiaxial stress contribution of the trenches of the line pattern is considered by addition of the Stoney equation [2] for a continuous film:

$$\mathbf{k} = A\left[\underbrace{(1+\nu)\frac{b}{d}\mathbf{P}_s^{-1}\begin{pmatrix}1-\chi(\rho)\nu\\1-\chi(\rho)\\0\end{pmatrix}}_{\text{Wikström}} + \underbrace{\left(1-\frac{b}{d}\right)}_{\substack{\text{fraction of}\\\text{trenches}}}\underbrace{\begin{pmatrix}1\\1\\0\end{pmatrix}}_{\text{Stoney}}\right] \tag{1}$$

In Eq. (1), $\mathbf{k} = (k_p, k_s, 2k_{ps})^{\mathsf{T}}$ is the vector of curvatures, A a combination of parameters, that cancels out when the curvature ratio is calculated, b the width and ρ the aspect ratio (height/width) of the lines. Matrix $\mathbf{P}_s$ and function $\chi(\rho)$ are given in [3].

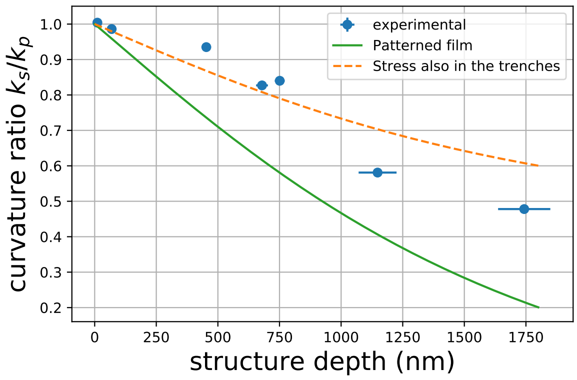

***Fig. 3** Irradiation with a line pattern leads to an anisotropic deformation of the sample. The curvature ratio k_s/k_p of curvatures in directions across and along the lines is plotted in dependence on the depth of the line pattern. The experimental results are compared to the Theory of Wikström et al. [3] for a stressed film patterned into lines and to Eq. (1), which additionally considers the generation of a stress in the trenches of the line pattern.*

4 Conclusion

Laser generated stresses can be used for the figure correction of glass substrates. For the borosilicate glass D263M and irradiation with an ArF excimer laser, a thin (<1 µm) layer of highly stressed ($\lesssim$ 400 MPa) material is generated. The decrease of this stress with time can be accelerated by annealing, which could lead to a mechanism for stabilization of the stress and thereby to more precise corrections. If a line pattern is applied, the degree of antibiaxial plane stress can be controlled by the aspect ratio of the pattern of the surface.

References

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