

# Viscoelastic deformation of glass substrates by laser patterned stressed films

## Abstract

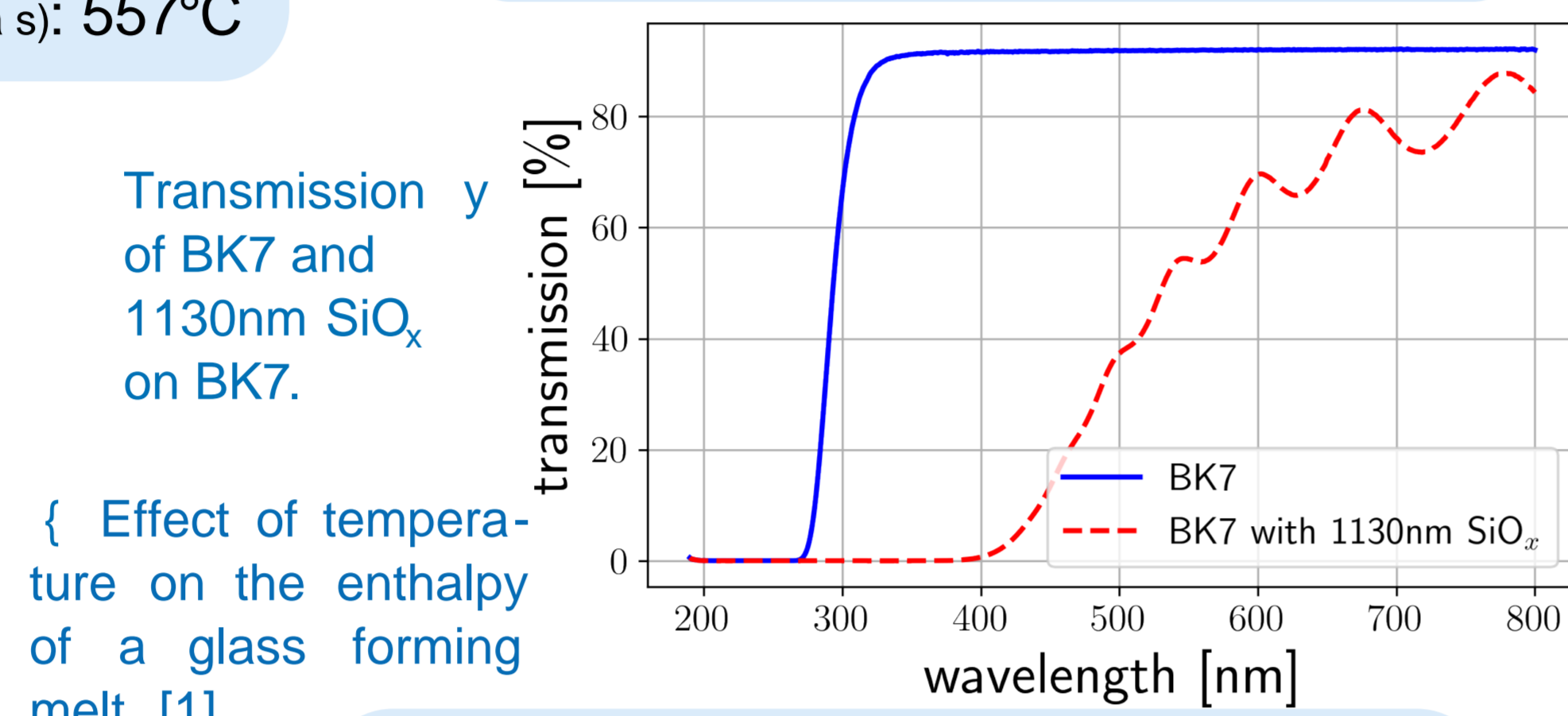
Thin films are often used to change the reflection or transmission behavior of surfaces and optical components. However, they can also have an influence on the underlying substrate and deform it, for example by viscoelastic flow through thermal treatment. In order to utilize this effect for active forming, the process should be better understood. For this purpose, the deformation of the optical glass substrate Schott-BK7 with a thin silicon suboxide layer is investigated. The deformation results mainly from the thermal stress on the thin film generated by annealing after deposition. By irradiating the sample with a XeCl laser before heat treatment, part of the thin silicon suboxide layer is ablated in order to specifically modify the deformation of the substrate during annealing.

## Materials

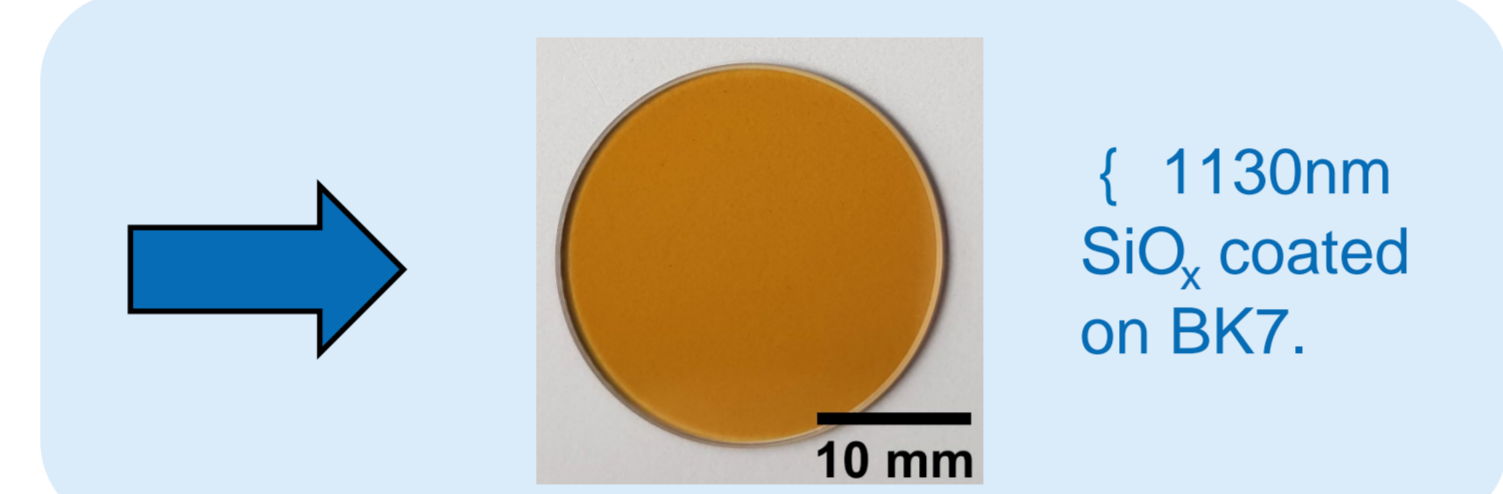
### Schott BK7

- commercial, often used optical glass
- strain point  $\dot{\epsilon} \approx 13.5 \text{ Pa s}$ : 524°C
- annealing point  $\dot{\epsilon} \approx 12 \text{ Pa s}$ : 557°C

- Silicon suboxide ( $\text{SiO}_x$ )
- strong UV-absorption
- heating leads to oxidation to  $\text{SiO}_2$

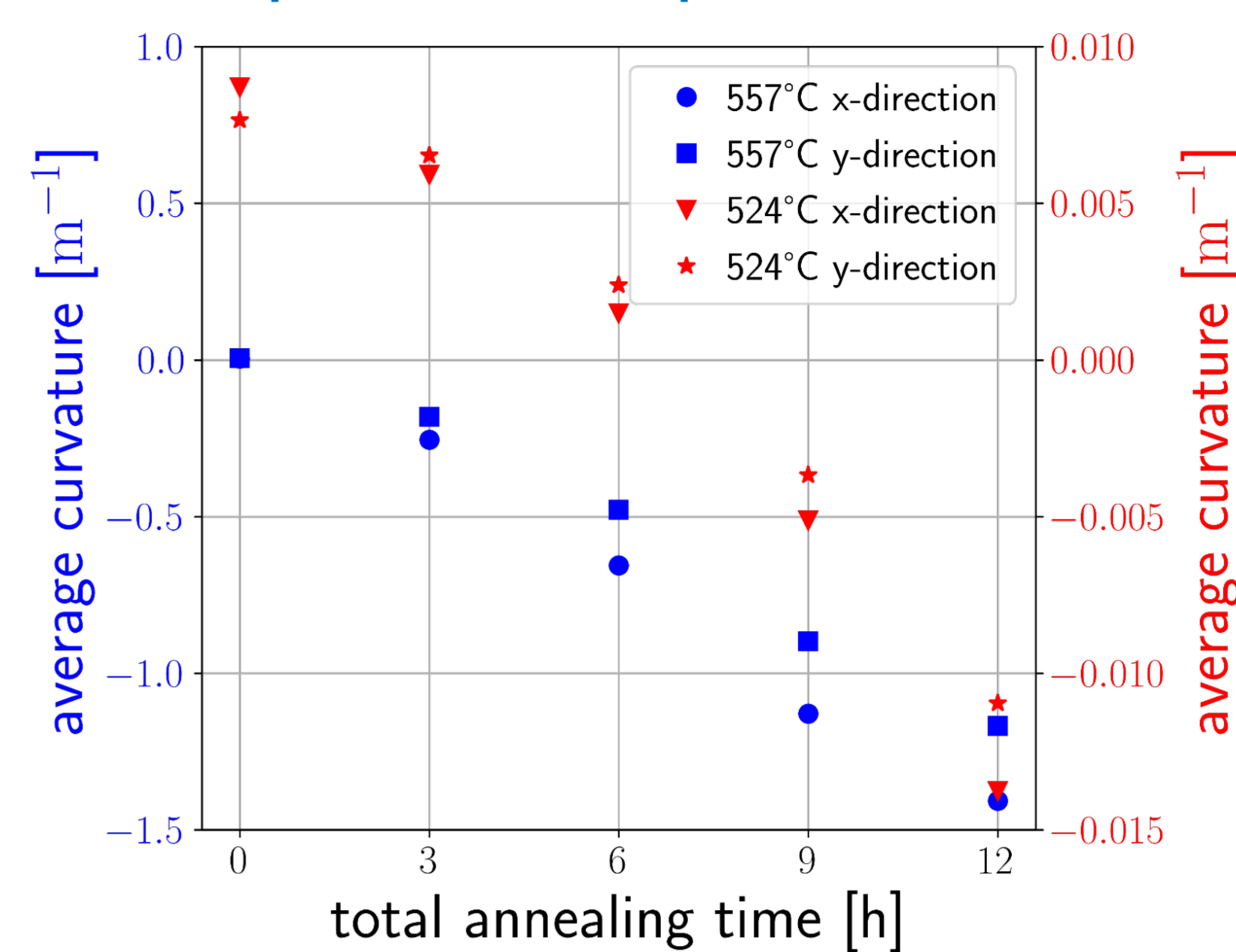


Transmission  $y$  of BK7 and 1130nm  $\text{SiO}_x$  on BK7.  
{ Effect of temperature on the enthalpy of a glass forming melt. [1]}



## Results

### Temperature dependence

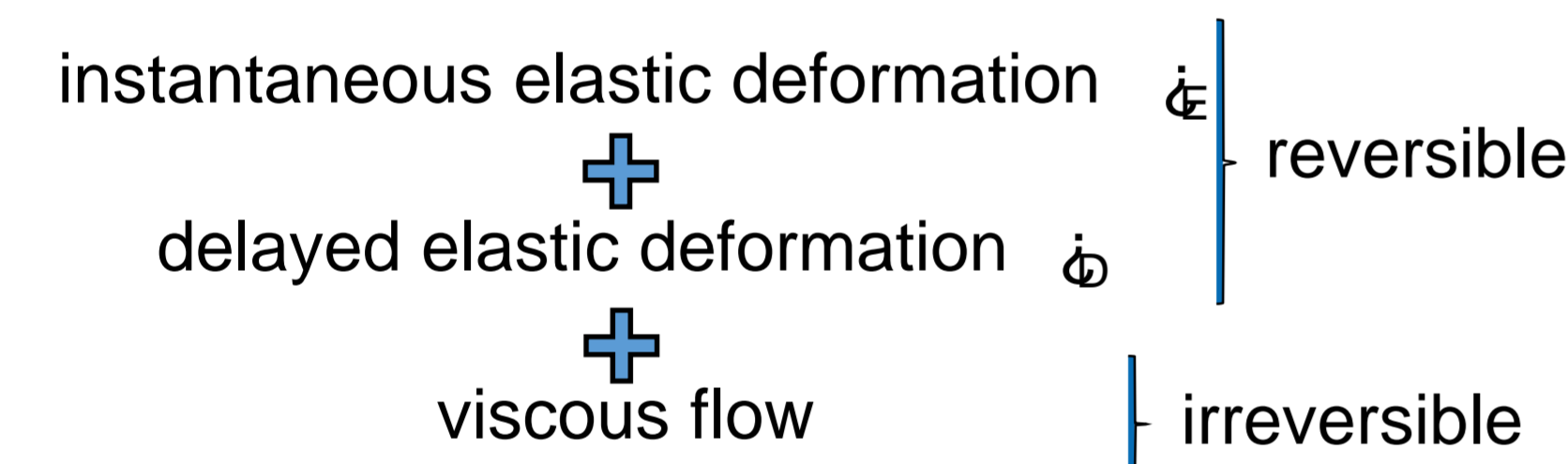


x Mean curvature versus total annealing time of samples heated at 524°C (red) and 557°C (blue) under oxygen atmosphere. The measurement error is estimated at  $6 \cdot 10^{-3} \text{ m}^{-1}$ .

- isotropic deformation due to tensile stress
- curvature evolution is highly affected by the annealing temperature  
→  $\sim 30\text{K}$  or  $10^{1.5} \text{ Pa s}$  causes a difference of two orders of magnitude
- at these temperatures no oxidation of  $\text{SiO}_x$  to  $\text{SiO}_2$  is observed

## Theory

### Viscoelasticity



x Schematic representation of the strain  $\xi(t)$  when a constant stress  $\xi_0$  is applied to a viscoelastic material between  $t_0$  and  $t_1$ . [2]

viscoelastic analogy

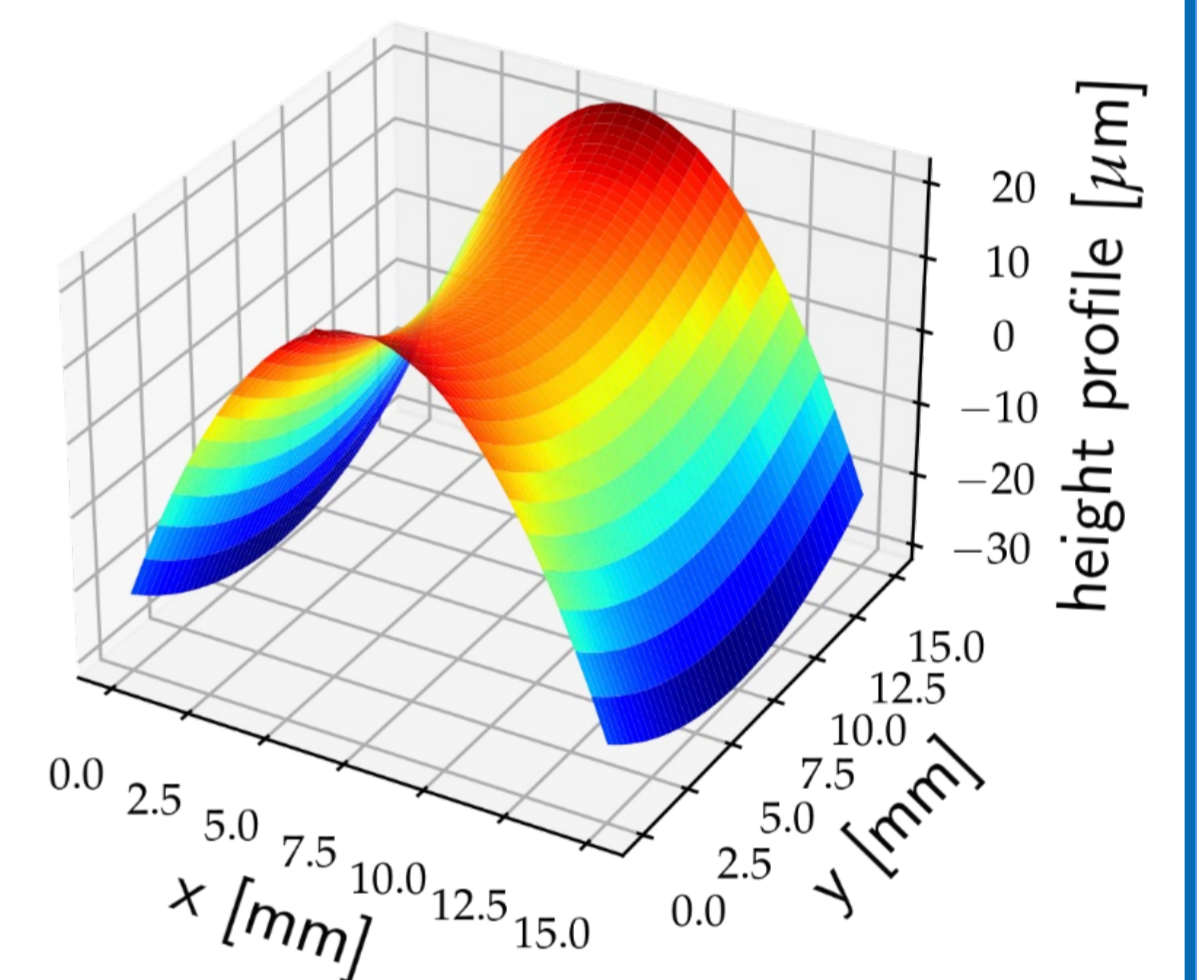
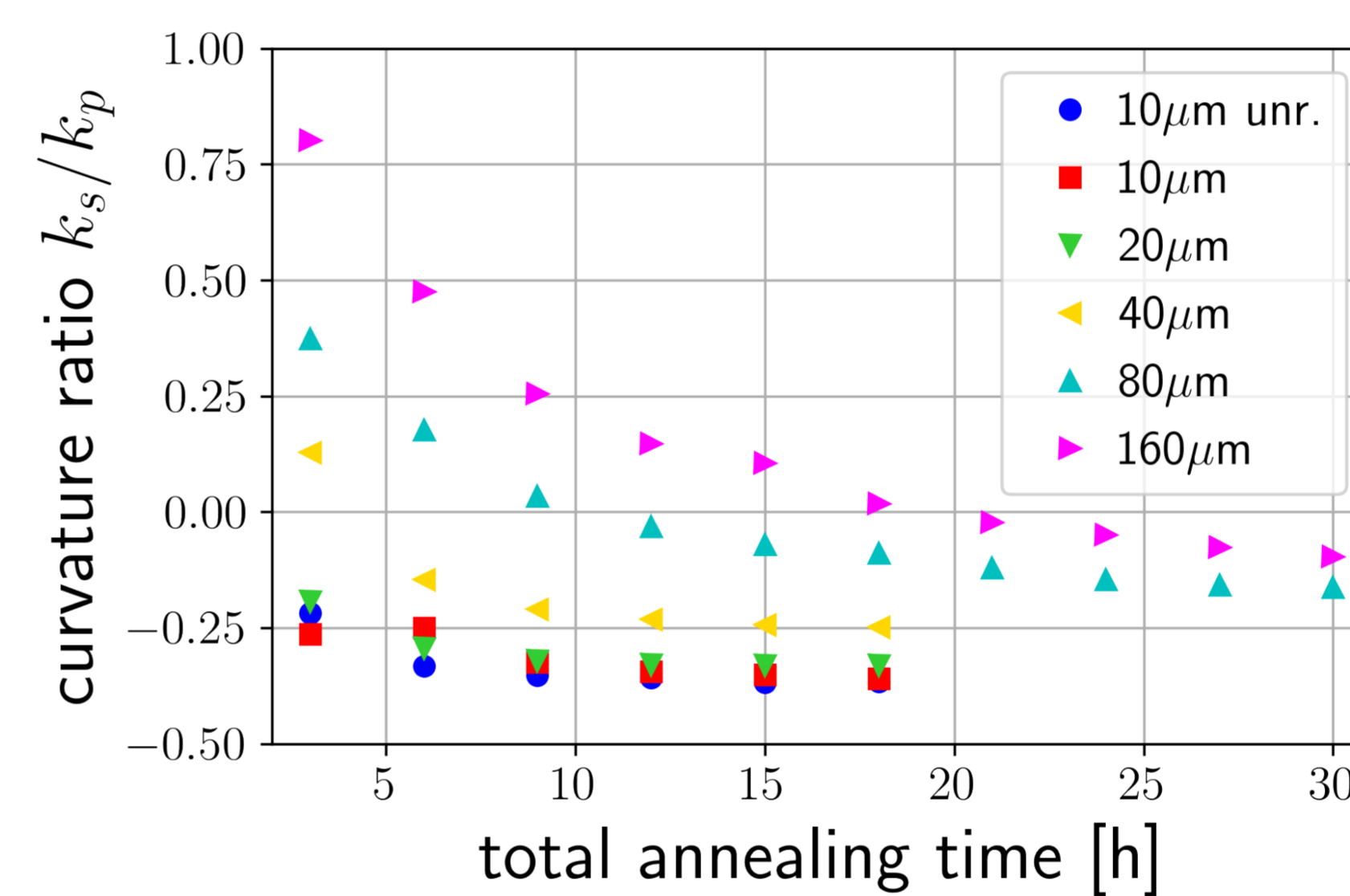
### Stoney-Equation: [3]

- elastic curvature phenomena for closed coated substrates with layer thickness  $h_f \ll h_s$  substrate thickness

### Wikström -Equation: [4]

- describes elastic curvature phenomena for line patterned coated substrates

### Samples with line pattern



x Curvature ratio against total annealing time of samples with different line width heated at 557°C under  $\text{N}_2$ -atmosphere.

x Surface topography (40 $\mu\text{m}$  line width) after 18h of annealing at 557°C in a  $\text{N}_2$ -atmosphere. (structured lines along the x-axis; visible lines along y-axis result from the measurement method)

- precise ablation of the  $\text{SiO}_x$  layer possible
- perpendicular to the lines:
  - small line widths:  $k > 0$  (uncoated side)  $\Rightarrow$  concave deformation
  - large line widths (80 $\mu\text{m}$ , 160 $\mu\text{m}$ ): initially convex deformation ( $k < 0$ ), which then changes to concave deformation ( $k > 0$ )
- parallel to the lines: convex deformation due to tensile stress, analogous to the closed layer
- curvature ratio decreases asymptotically with time : greater line width  $\Rightarrow$  lower curvature ratio

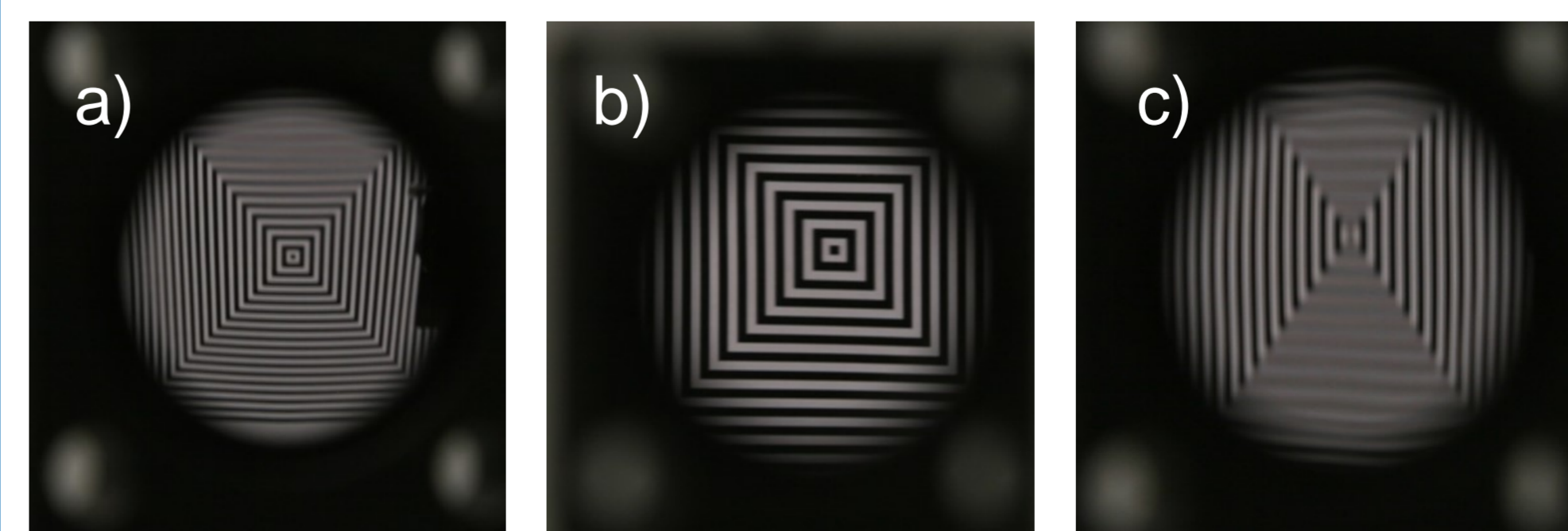
## Methods

### Structuring of the samples [5]

{ Ablated line pattern.  
(line width:  $\sim 20\mu\text{m}$ ;  
over whole sample)  
laser parameters:  
308nm, 1Hz, 2 pulses  
per stripe,  
 $F > 450 \text{ mJ/cm}^2$

x Optical setup for rear side ablation (beam first passes through substrate and then through thin film) of lines from  $\text{SiO}_x$  on BK7.

### Demonstrators



{ Reflection of a pattern of concentric squares on aluminum-coated surfaces of: a) flat, b) convex (closed layer), c) concave-convex (line-structured) sample. The deformations in b), c) were caused by viscous flow due to heat treatment.

## Conclusions and Outlook

The viscoelastic deformation of Schott-BK7 substrates with a  $\text{SiO}_x$  coating has an enormous sensitivity to temperature. With closed layers, annealing resulted in an isotropic deformation of the sample, which further increased with time. It is possible to structure the samples with a XeCl laser using rear side ablation. Thus, anisotropic deformations can be induced, e.g. by structuring with lines.

Our results contribute to the understanding of the viscous deformation of substrates and can also be used for the development of processes for the production of optics, especially individualized free-form optics. But for this, further knowledge is needed about the influence of gravity during annealing and about the influence of the structure on deformation.

## References

- [1] Shelby, James E. Introduction to glass science and technology. Royal Society of Chemistry, 2005.
- [2] Scherer, George W. "Relaxation in glass and composites." (1986)
- [3] Stoney, George Gerald. "The tension of metallic films deposited by electrolysis." Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character 82.553 (1909): 172-175.
- [4] Wikström, Adam, Peter Gudmundson, and Subra Suresh. "Thermoelastic analysis of periodic thin lines deposited on a substrate." Journal of the Mechanics and Physics of Solids 47.5 (1999): 1113-1130.
- [5] Ihlemann, J., J. Meinertz, and G. Danev. "Excimer laser ablation of thick  $\text{SiO}_x$ -films: etch rate measurements and simulation of the ablation threshold." Applied Physics Letters 101.9 (2012): 091901.