Birefringence measurements of residual stresses in indented glasses

A.Errapart[1], H. Aben[1], R. Oldenbourg[2] and C.R. Kurkjian[3],

[1]Tallinn University of Technology, [2]Woods Hole MBL and [3]Univ. of Southern Maine

Purpose and Techniques

- 1. Study stresses resulting from indentation in order to develop a more “robust” glass.
- 2. Use an axially symmetric indenter (cone).
- 3. Employ a fast and convenient ‘new’ device for measurement of stress birefringence (Oldenbourgh et al).
- 4. Develop and employ new algorithms for the calculation of 3D stresses around such indents from the experimentally determined birefringence (Aben et al).
- Use photoelastic measurements and algorithms of integrated photoelasticity to determine 3D residual stresses resulting from the indention of glasses with an axially symmetric indenter (a 138 degree diamond cone).
- In regions where stress gradients are severe, develop modified algorithms.

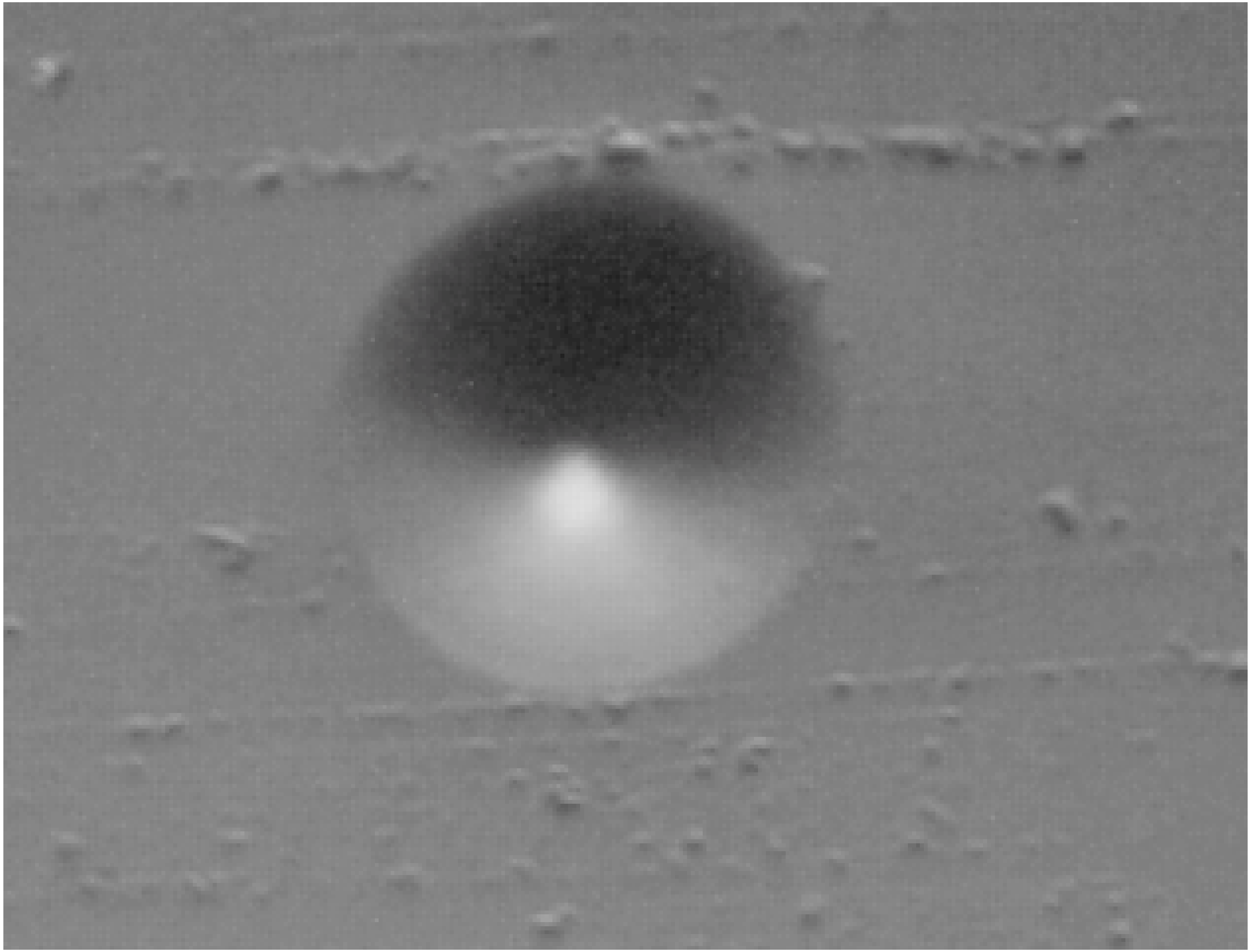
- ***ULTIMATE AIM***

- *By varying the experimental parameters (cone angle, load, loading rate, glass composition, etc.), and by making birefringence measurements in real time, we expect to be able to develop an understanding that will enable us to design glasses with the desired cracking characteristics, i.e., elimination or tailoring of the cracking.*

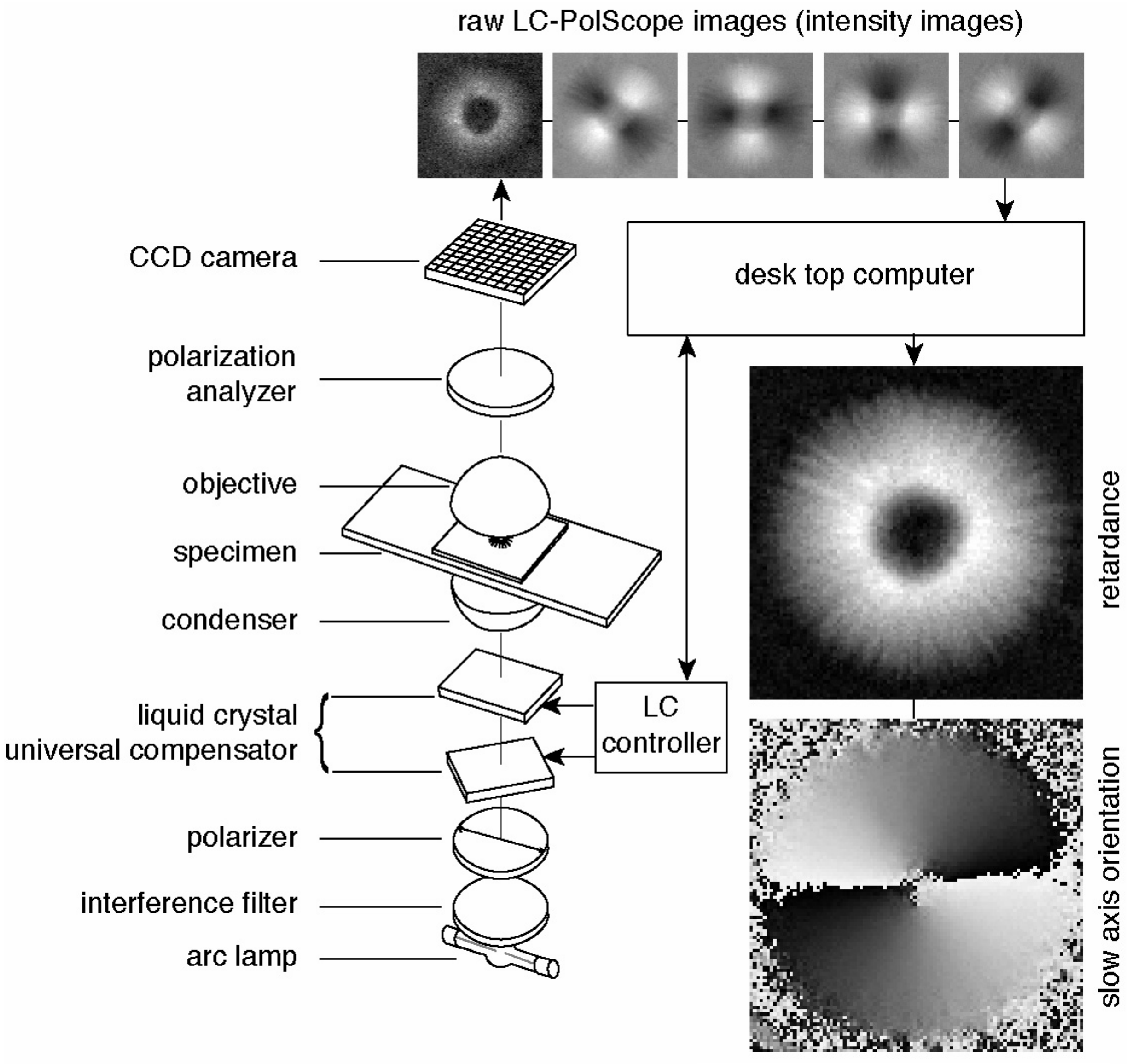
Experimental Procedure

- 1. Indent flat fibers (~ 300 x 400 microns) of soda-lime-silica and silica glass@ 50 grams with an axially symmetric 138 degree diamond cone. Indents are ~ 10 microns in diameter with no cracking.
- 2. View the indentation after removal of the load in a direction perpendicular to the loading direction with sample in index-matching oil. Field of view is ~ 70 X 70 microns (see later slide).
- 3. Develop and apply algorithms to allow calculation of 3D stresses on the basis of birefringence measurement data. Detailed stress calculations have so far only been carried out for silica glass.

Cone indent, 50 grams, d~ 10 microns



Birefringence Imaging with the LC-PolScope

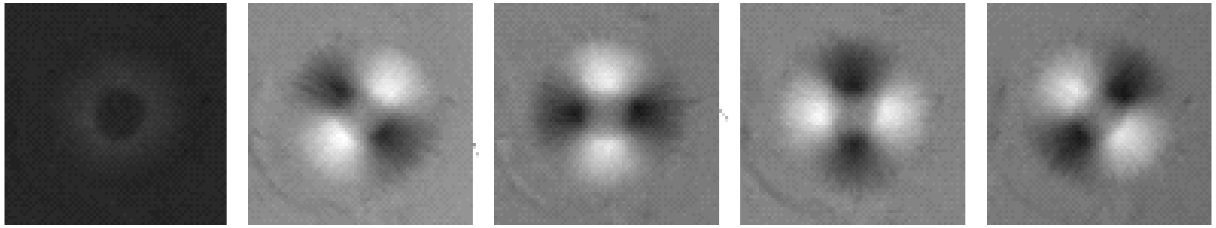


< 1 sec

< 0.5 sec

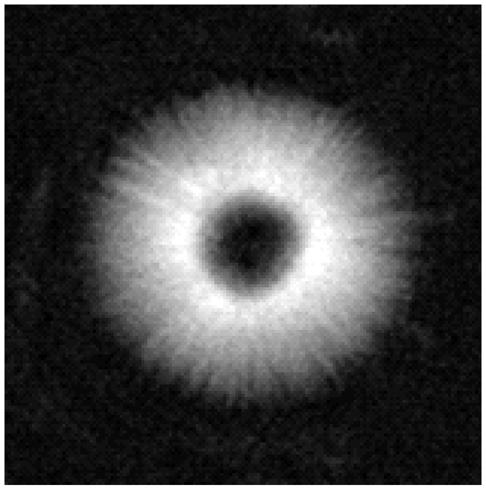
R. Oldenbourg and G. Mei. 1995. New polarized light microscope with precision universal compensator. *J. Microsc.* 180 (Pt 2): 140-7.

Calculation of Retardation and Azimuth from measured intensities



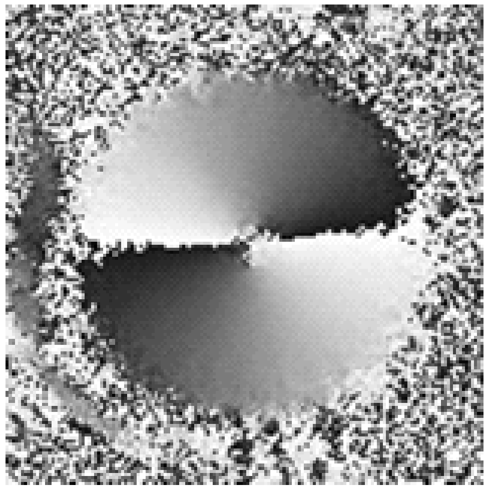
I_1 I_2 I_3 I_4 I_5

$$\sqrt{\frac{(I_4 - I_1)^2 + (I_3 - I_2)^2}{(I_1 + I_2 + I_3 + I_4 - 4I_0)^2}} \qquad \arctan\left(\frac{I_4 - I_1}{I_3 - I_2}\right)$$



retardance

0 5 nm

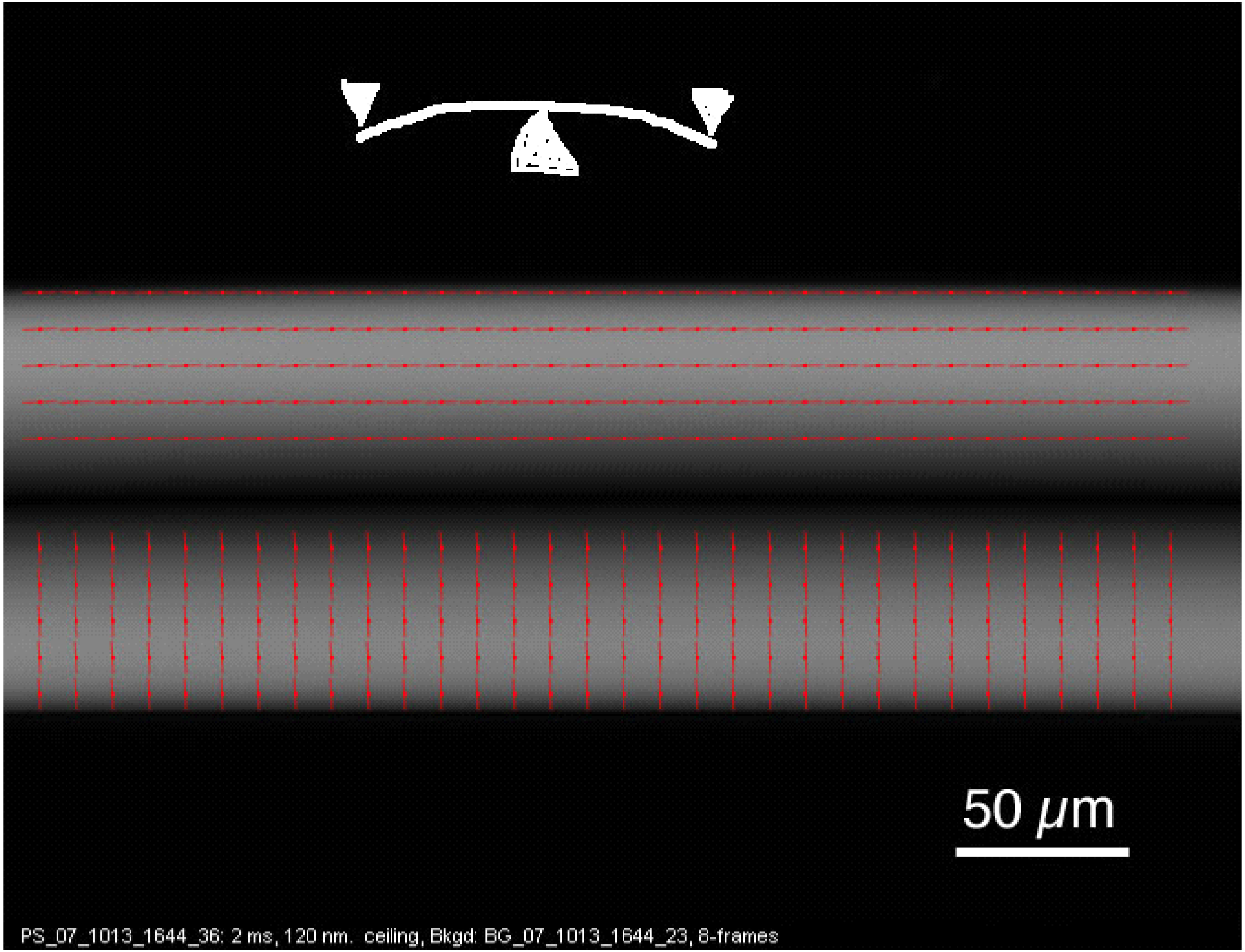


orientation

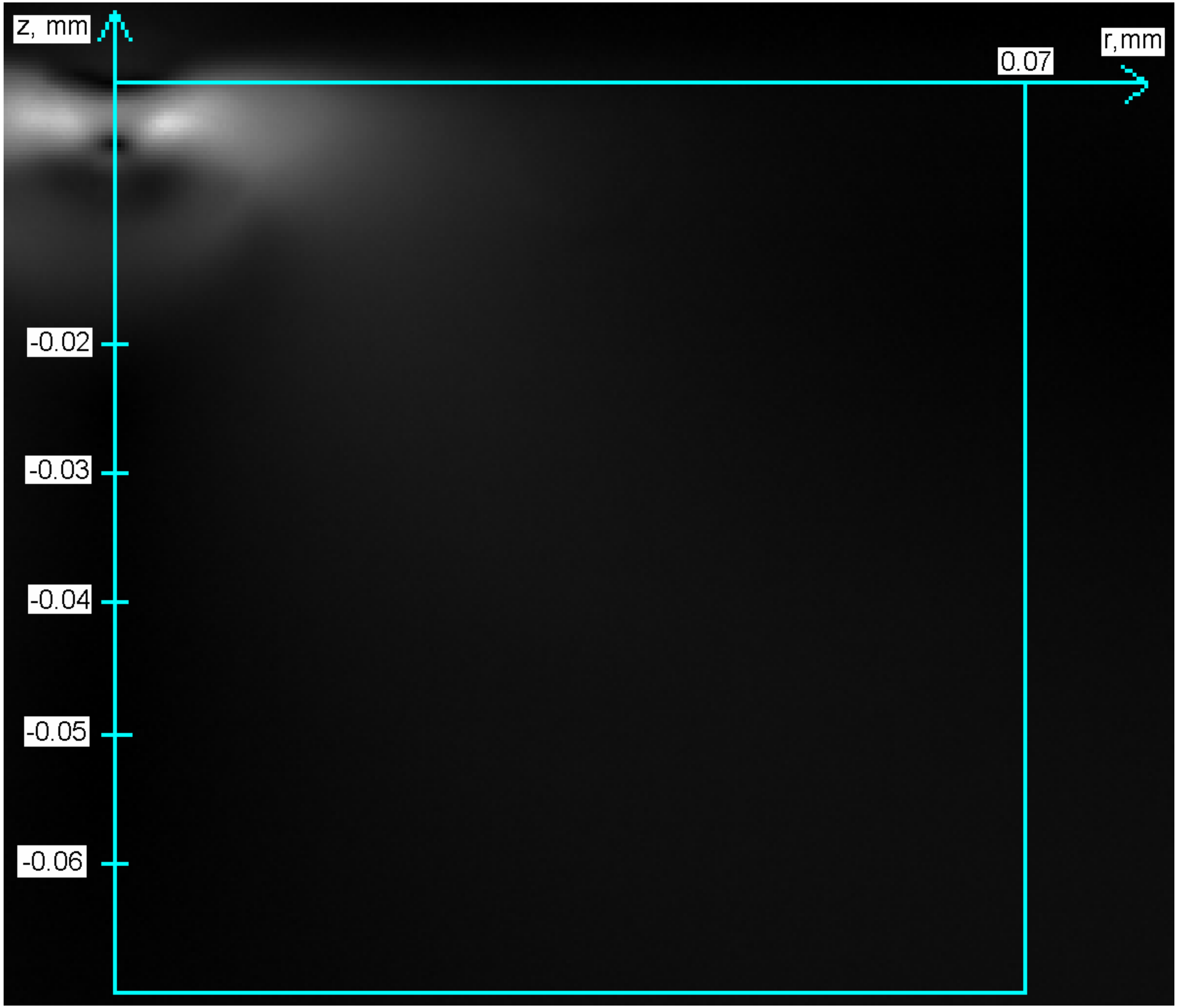
0° 90° 180°

Shribak, M. and R. Oldenbourg. 2003. Techniques for fast and sensitive measurements of two-dimensional birefringence distributions. Appl. Opt. 42:3009-17.

Slow-axis direction in a bent fiber



Measurement scheme (indent in upper left hand corner)

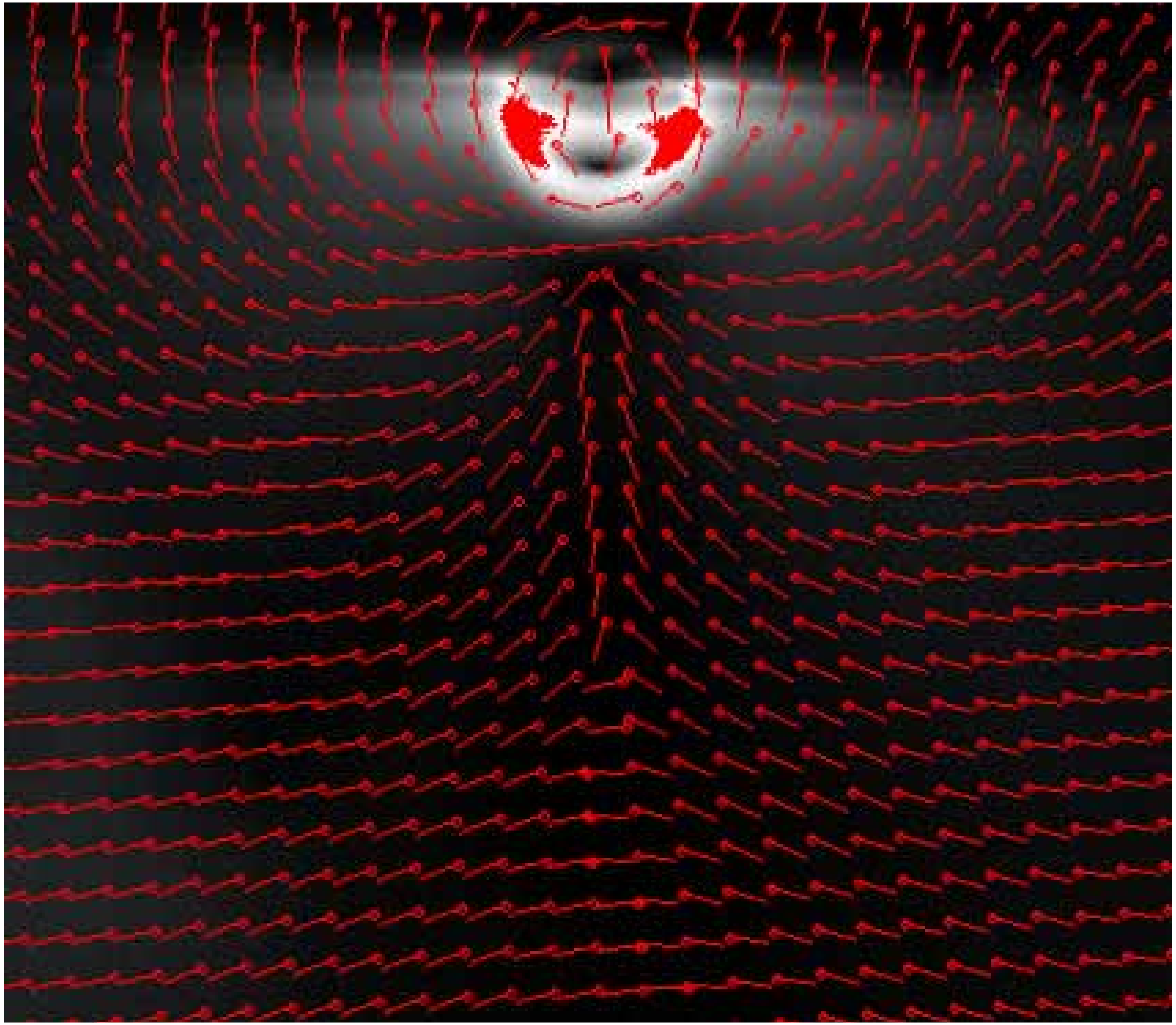


Retardation and Azimuth

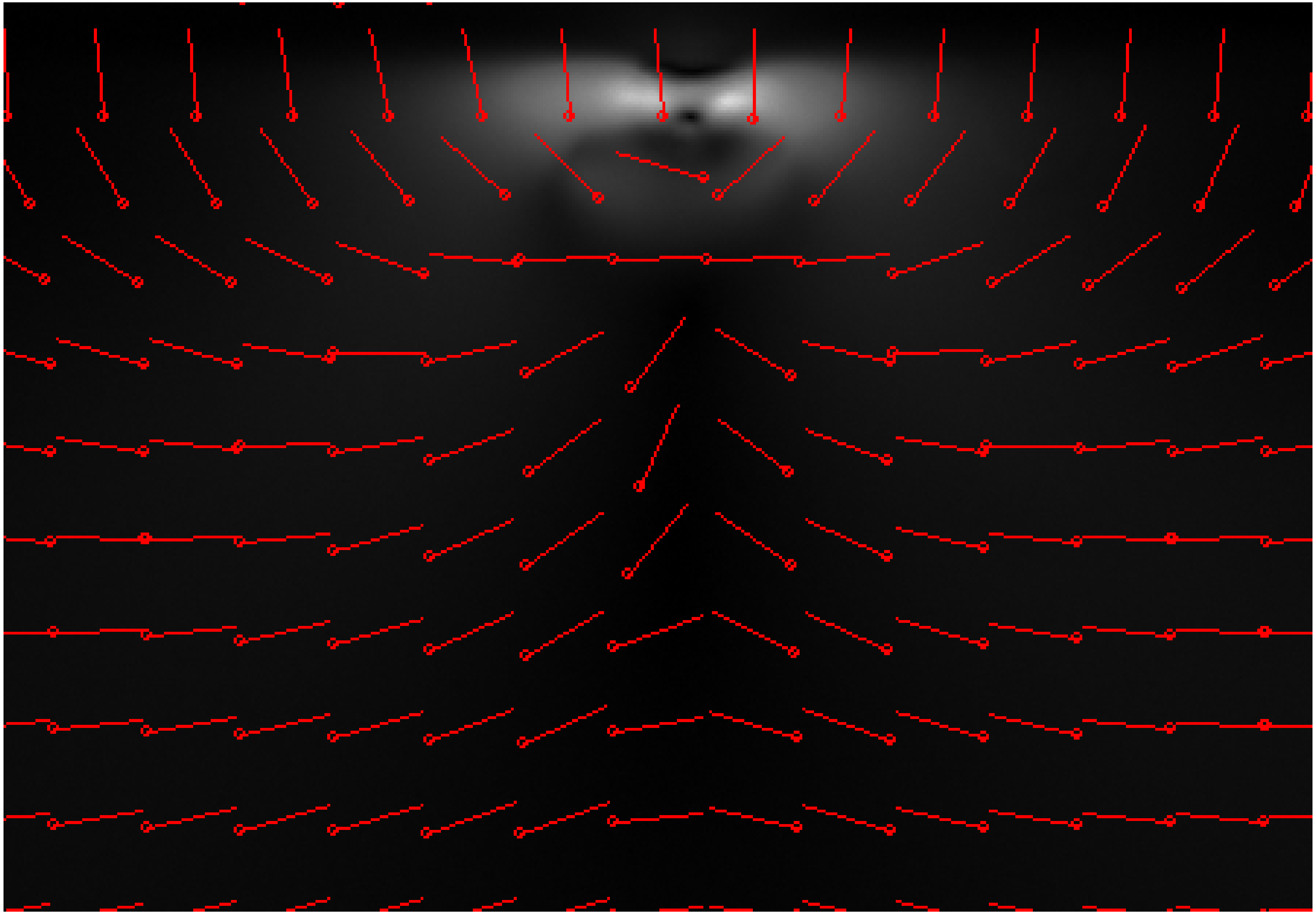
- The next two figures show actual images taken with the CRI instrument* employed here. The ‘color’ indicates the retardation and the arrows show the ‘slow-axis’ direction. In both the SLS and silica images, very high and rapidly changing retardation is observed near the indenter tip position. Even without calculation, it can be seen that the two glasses show very different behavior. Stresses in the soda lime glass are substantially higher than in silica.

- ***cri-inc.com**

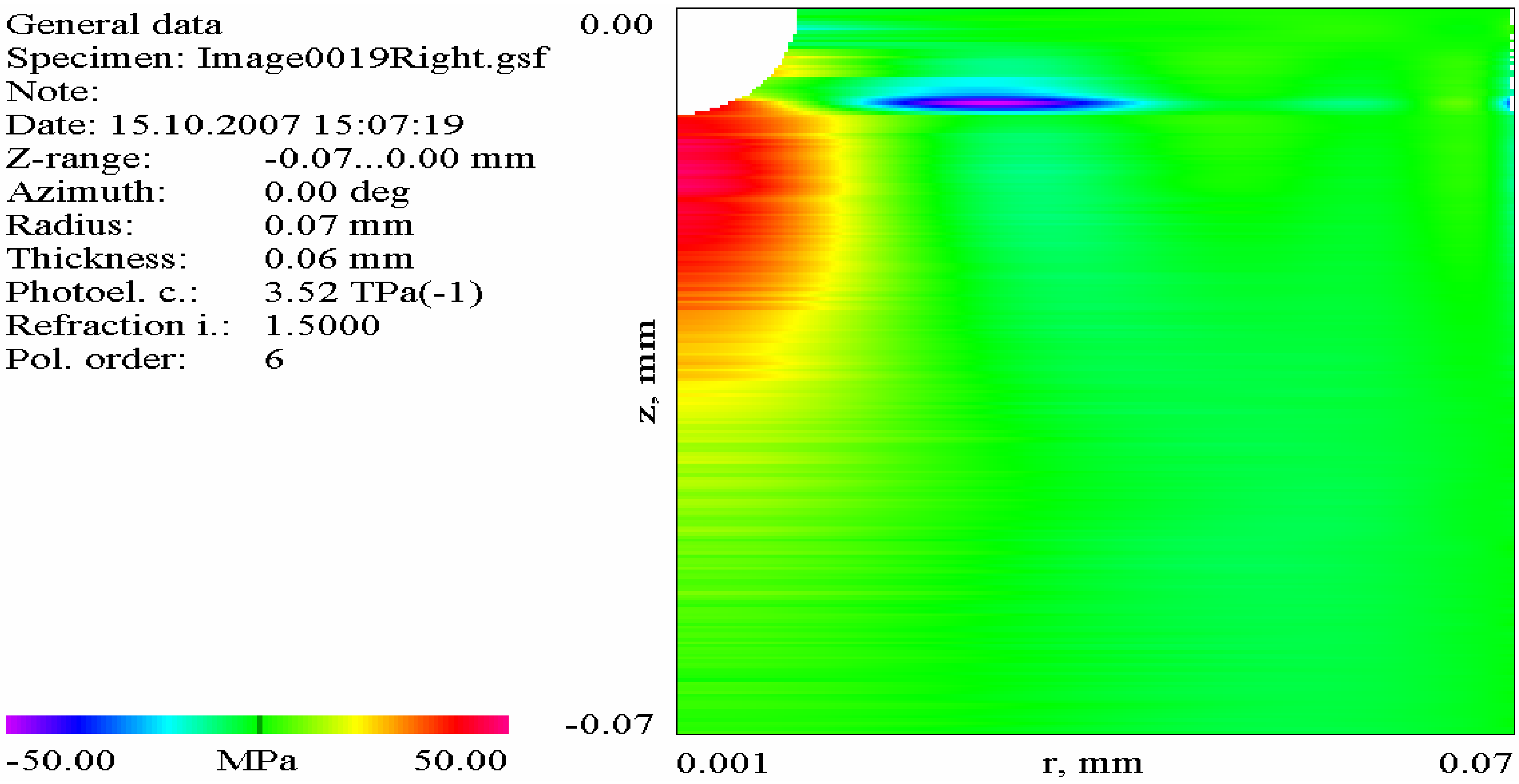
Soda-lime-silica glass



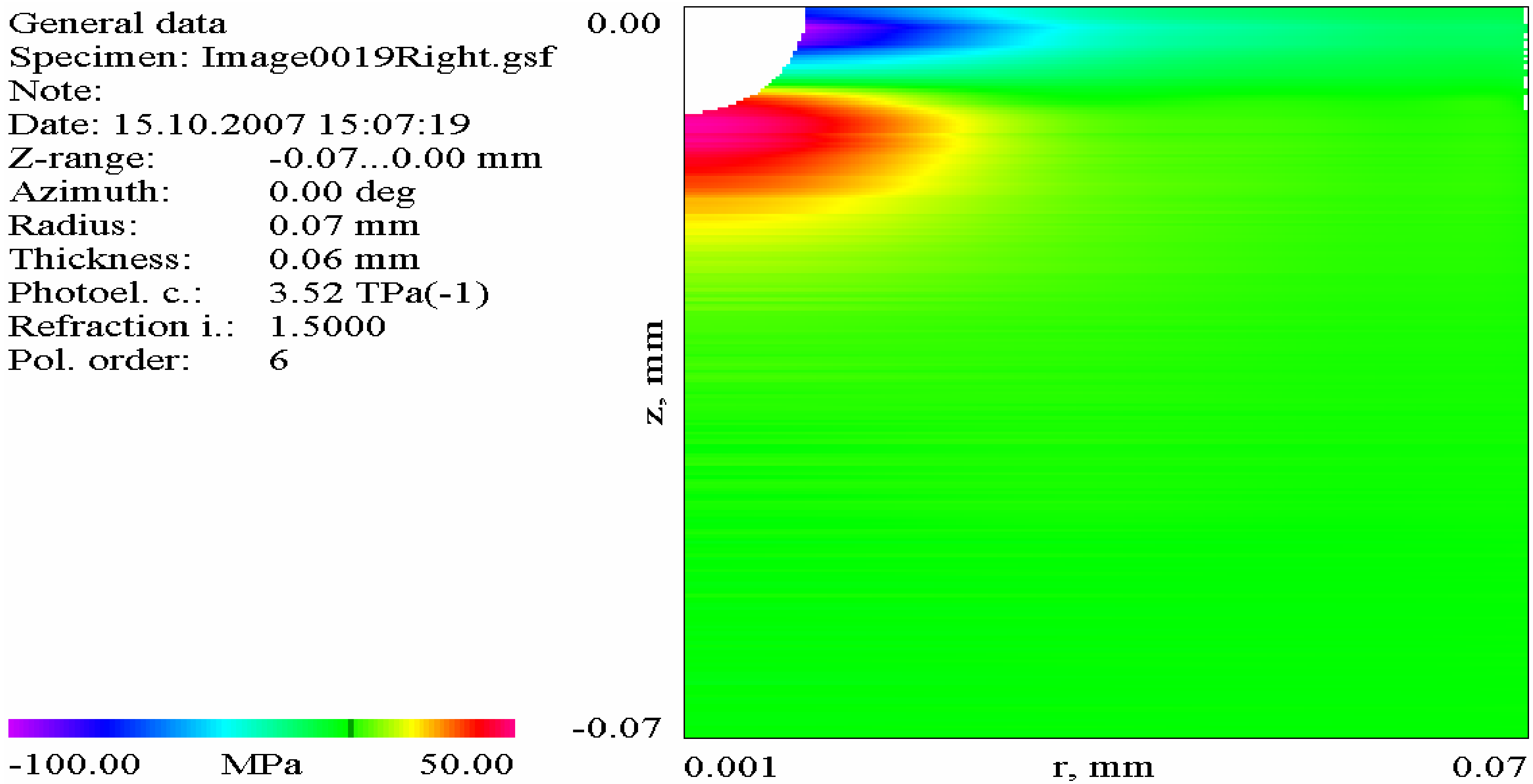
Silica glass



Axial stress in silica glass



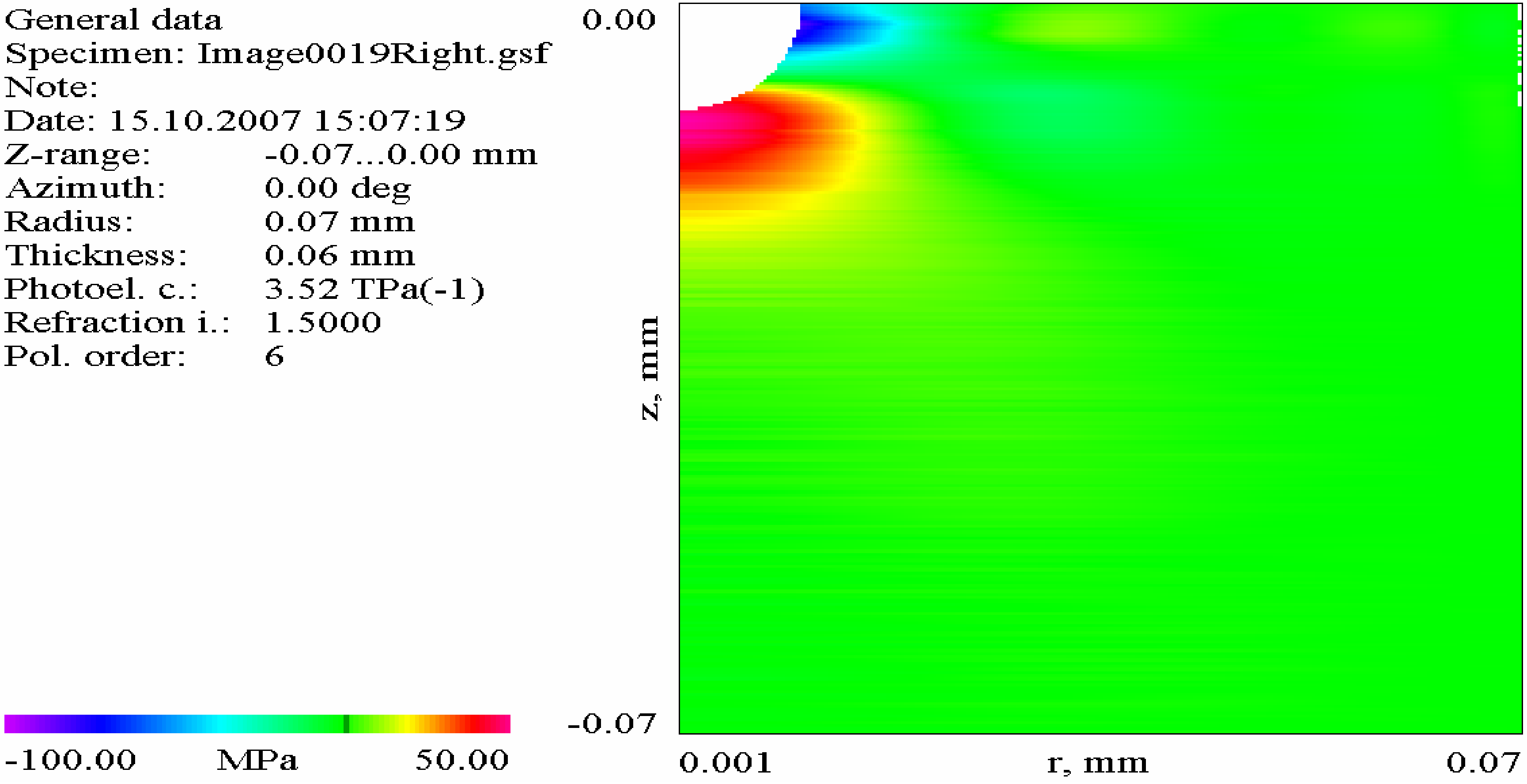
Circumferential stress in silica glass



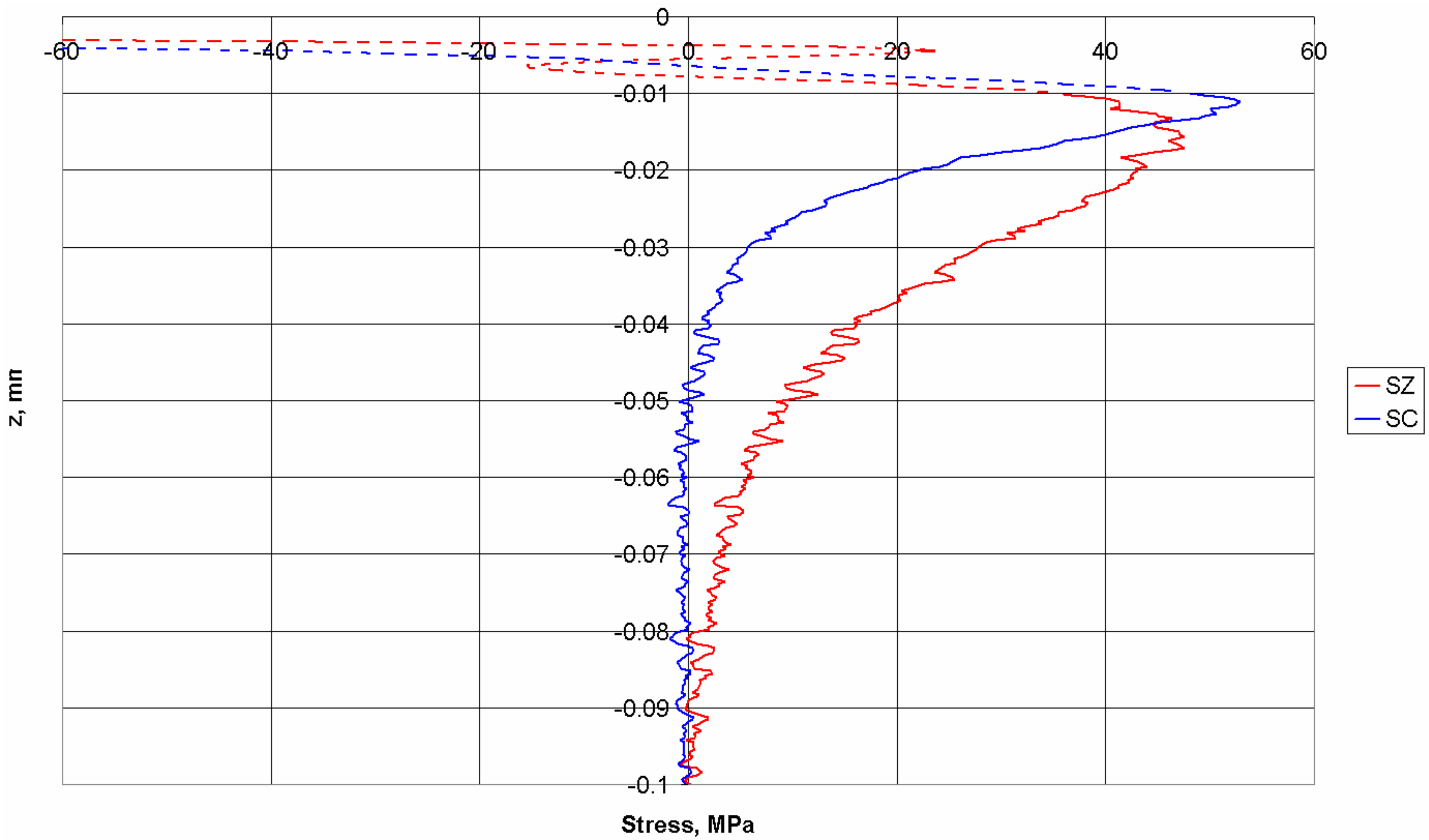
radial stress in silica glass

General data
Specimen: Image0019Right.gsf
Note:
Date: 15.10.2007 15:07:19

Z-range:	-0.07...0.00 mm
Azimuth:	0.00 deg
Radius:	0.07 mm
Thickness:	0.06 mm
Photoel. c.:	3.52 TPa(-1)
Refraction i.:	1.5000
Pol. order:	6



Stress distribution along the z –axis in silica glass



CONCLUSIONS

- *1. Photoelastic measurement technology and algorithms have been developed that allow calculation of 3D stresses around an axially symmetric indent.*
- *2. It has been found that these first algorithms are not appropriate when the stress gradient is very high. New algorithms are being developed to address this.*
- *3. While detailed calculations have only been made for silica glass, the images of retardation and azimuth show quite different behavior for silica and soda-lime-silica glasses.*
- *4. At some distance below the indenter, substantial tensile stresses (~ 50 MPa) are found in agreement with the theory of Yoffe, with compressive stresses at or near the surface and at some distance from the indent.*
- *5. Calculations will be redone using newer algorithms for both the soda-lime and silica glasses.*
- *6. Comparisons will be made with other theoretical calculations as well as with other experiments using indentation probes.*