Polarization-Sensitive Optical Coherence Tomography

Principles and applications outside the biomedical field

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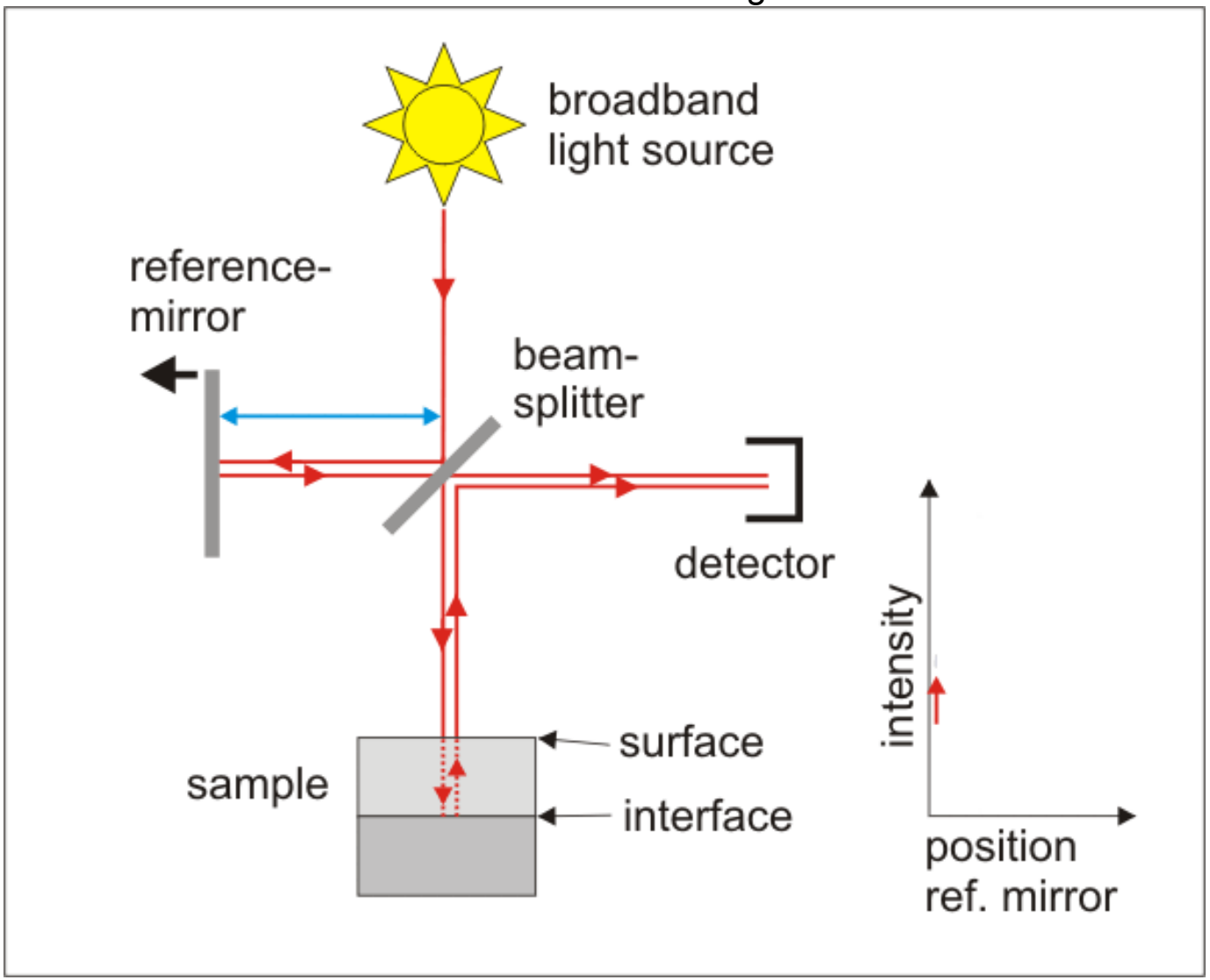
Outline

- Introduction to PS-OCT & Motivation
- History and principles
- OCT for materials imaging: transversal UHR-PS-OCT
- Applications for non-biological material characterisation
- Outlook & Conclusions

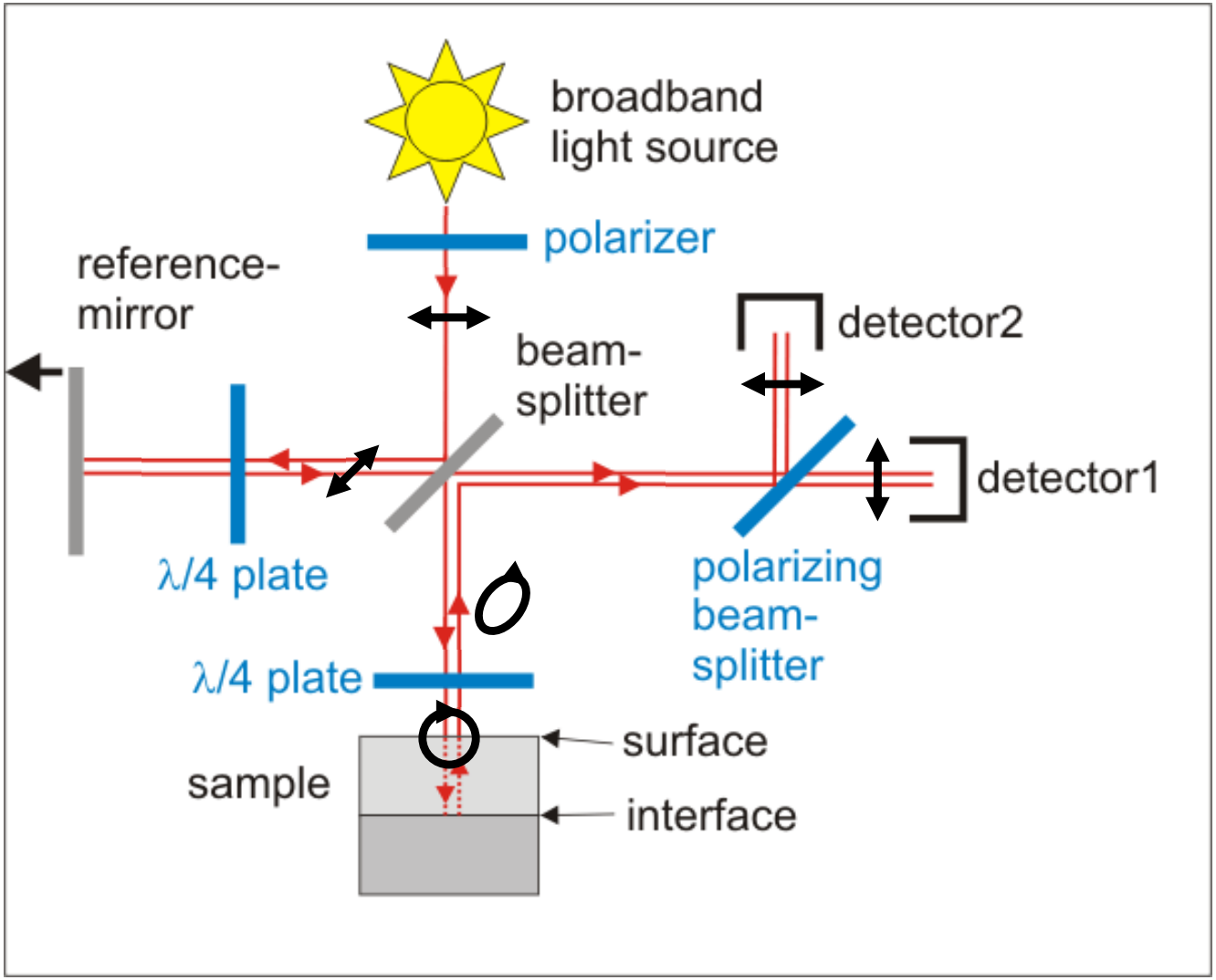
Standard OCT: Intensity-based reflectivity profile

Standard time-domain OCT in Michelson Configuration



Polarization-sensitive low-coherence reflectometry

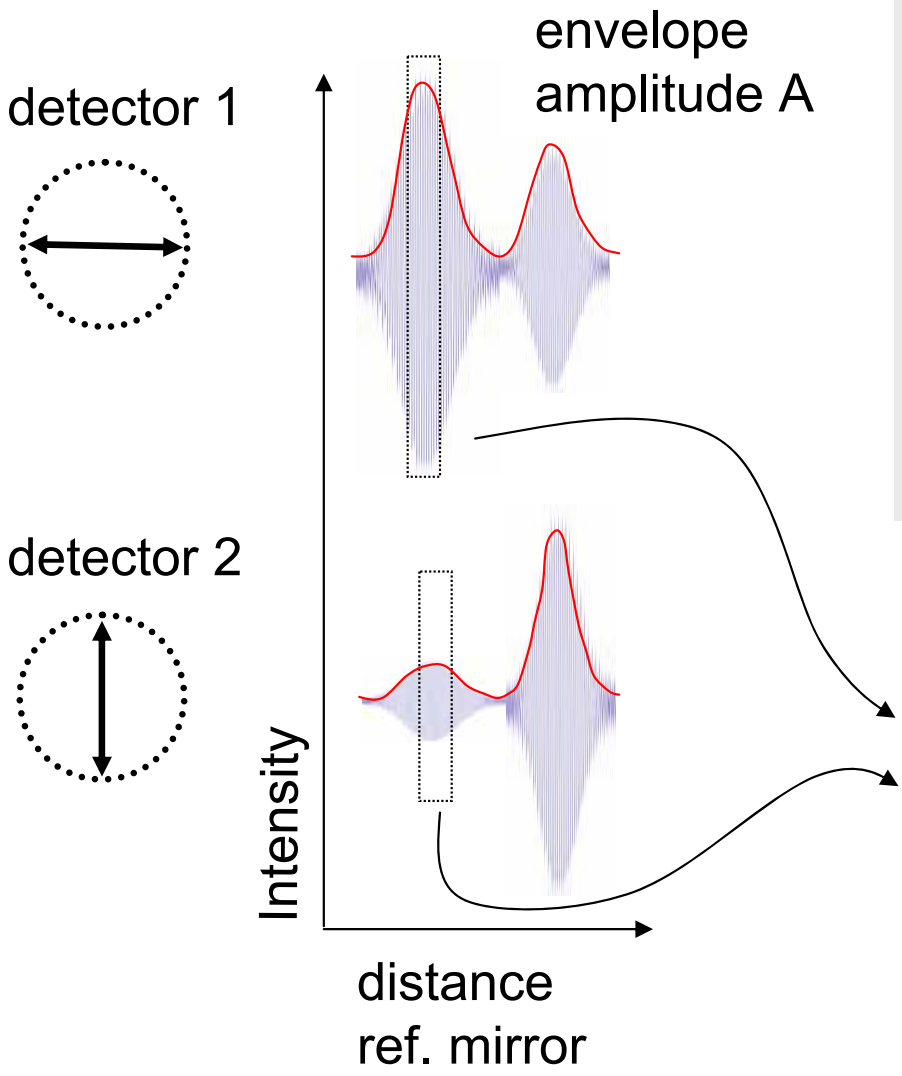
Michelson interferometer



→ M.R. Hee et al., J. Opt. Soc. Am. B 9, 1992.

PS-OCT images

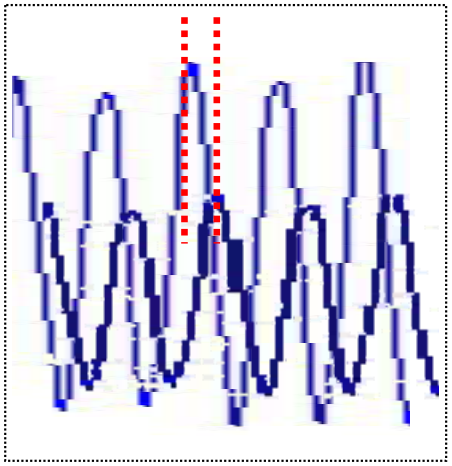
3 Images:



1. **Intensity image:** $\sim (A_1^2 + A_2^2)^{1/2}$

2. **Retardation image:** $\sim \operatorname{atan}(A_1 / A_2)$

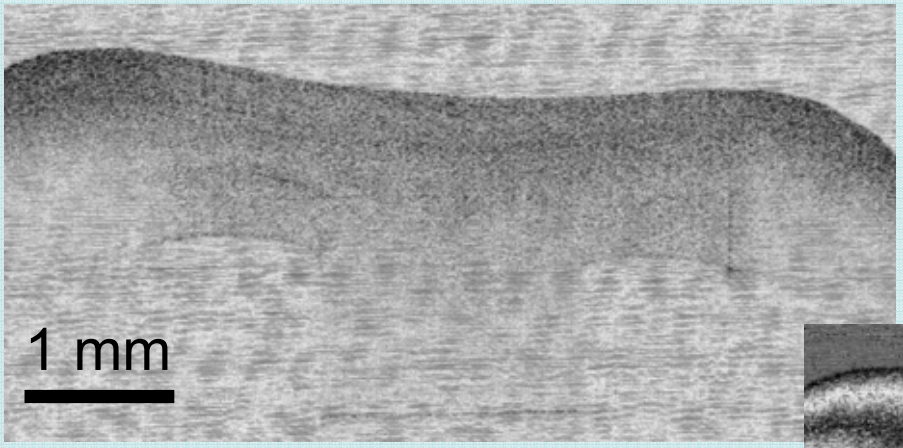
3. **Image of orientation of optical axis:** $\sim \phi$



phaseshift ϕ

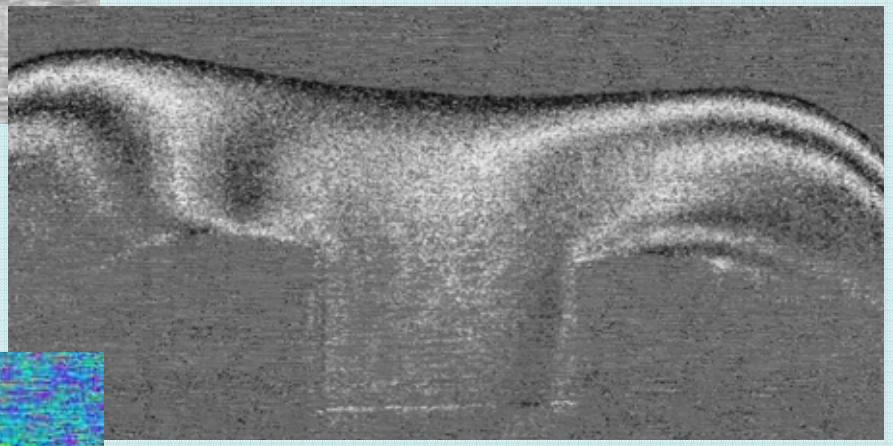
C.K. Hitzenberger et al., Opt. Express 9, 2001

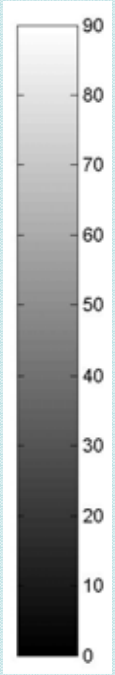
PS-OCT: injection moulded polymer part

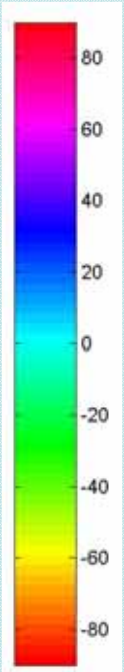


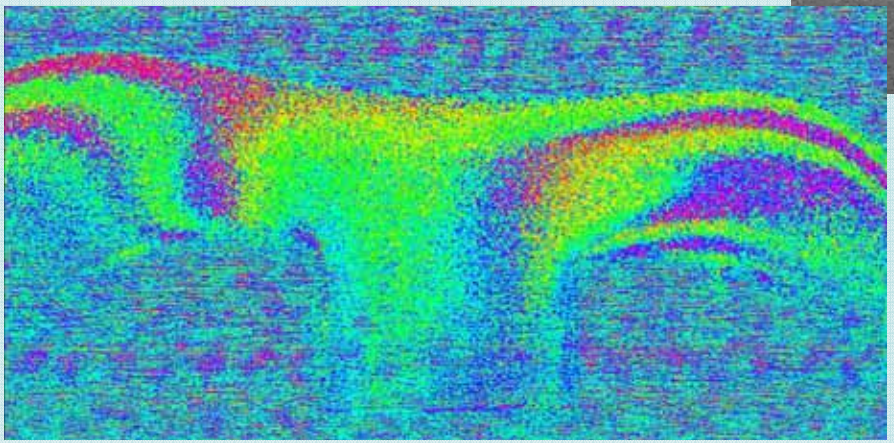
OCT intensity cross-section

PS-OCT
retardation image





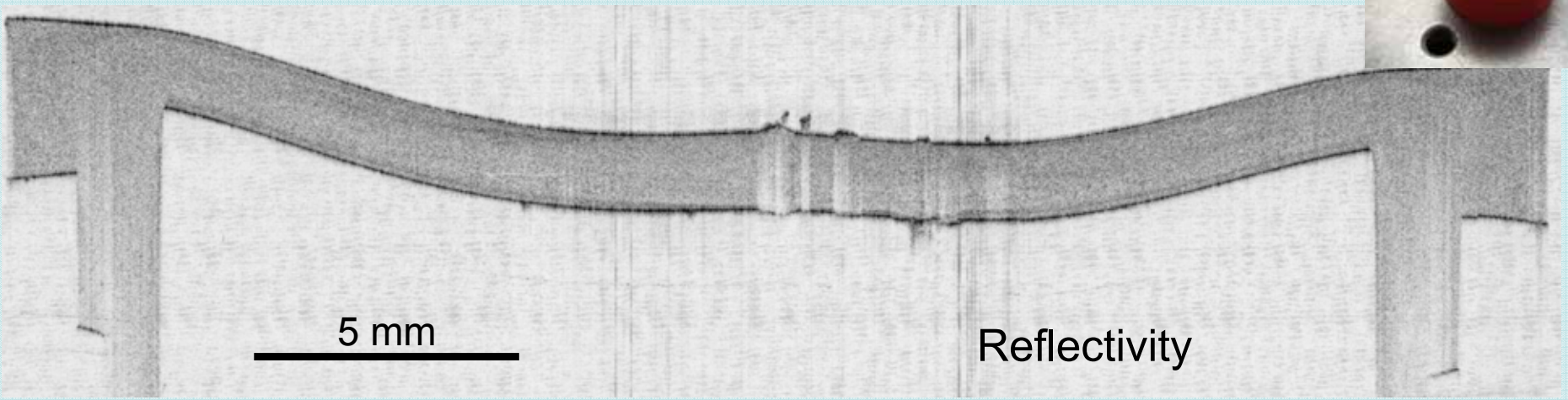


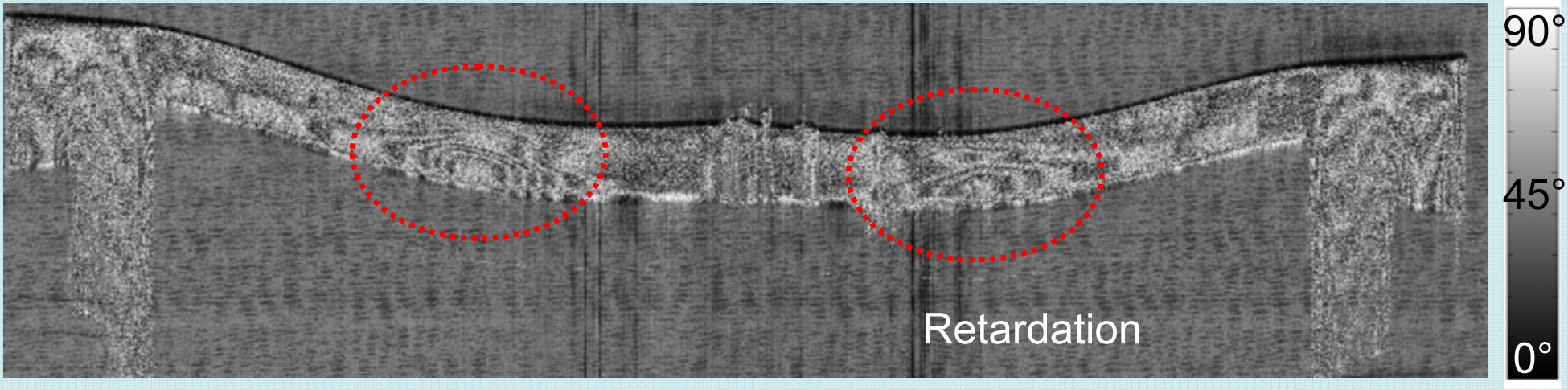


PS-OCT
Optical axis orientation image

Internal stress/flow pattern

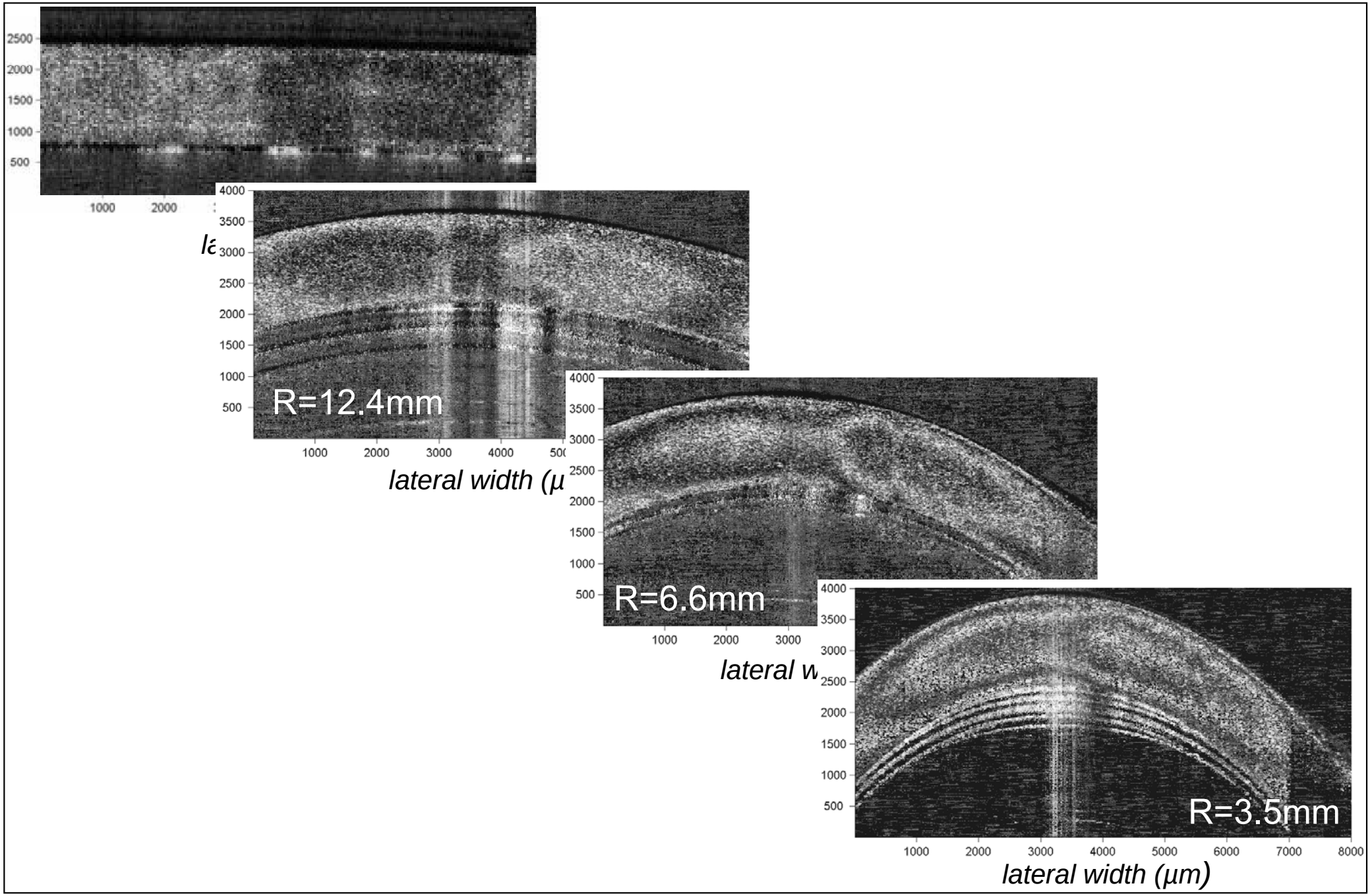
Polymer injection moulded part



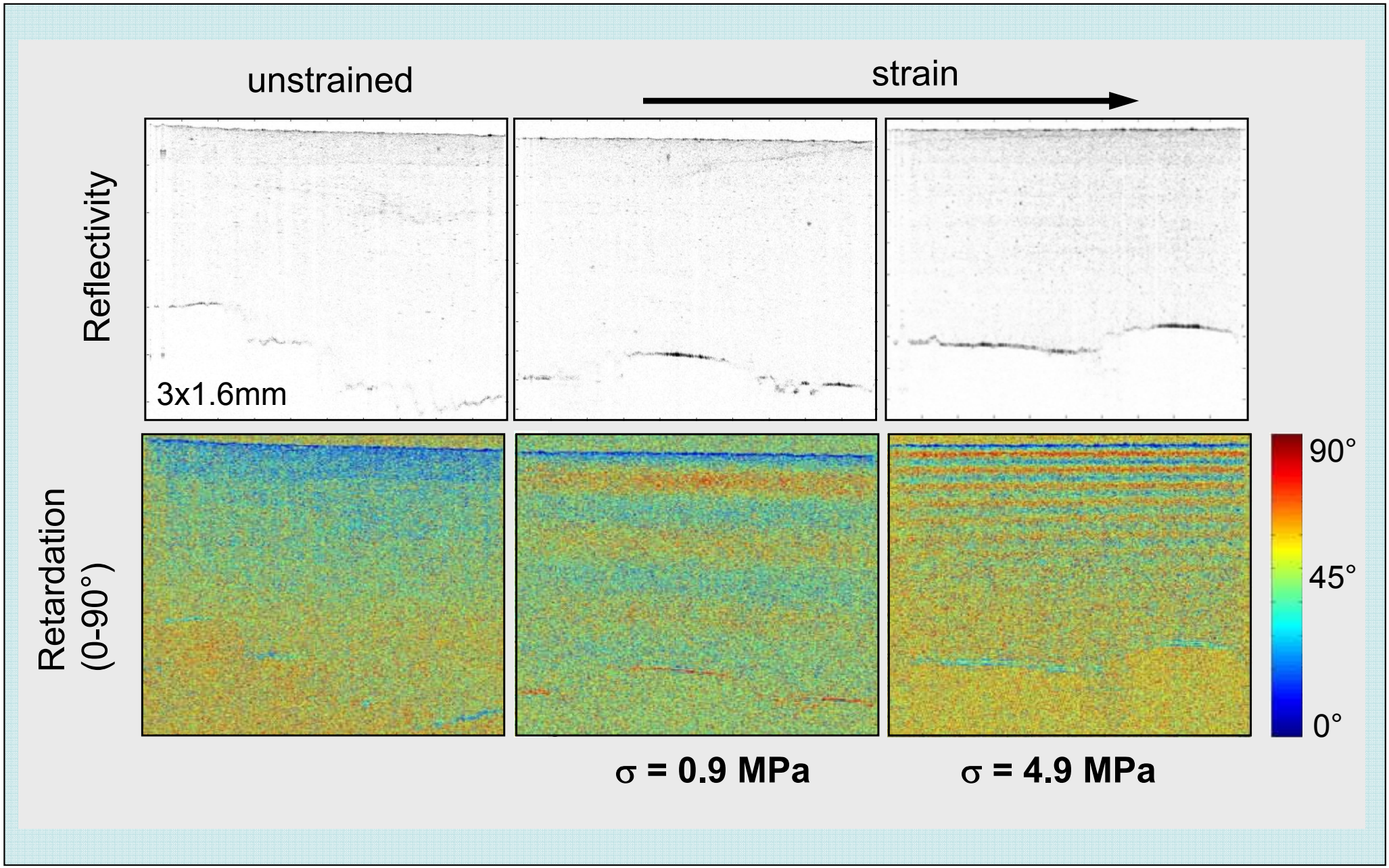


D. Stifter et al., Appl. Phys A 76, 2003

PS-OCT: observation of strain



PS-OCT: strain/stress – birefringence



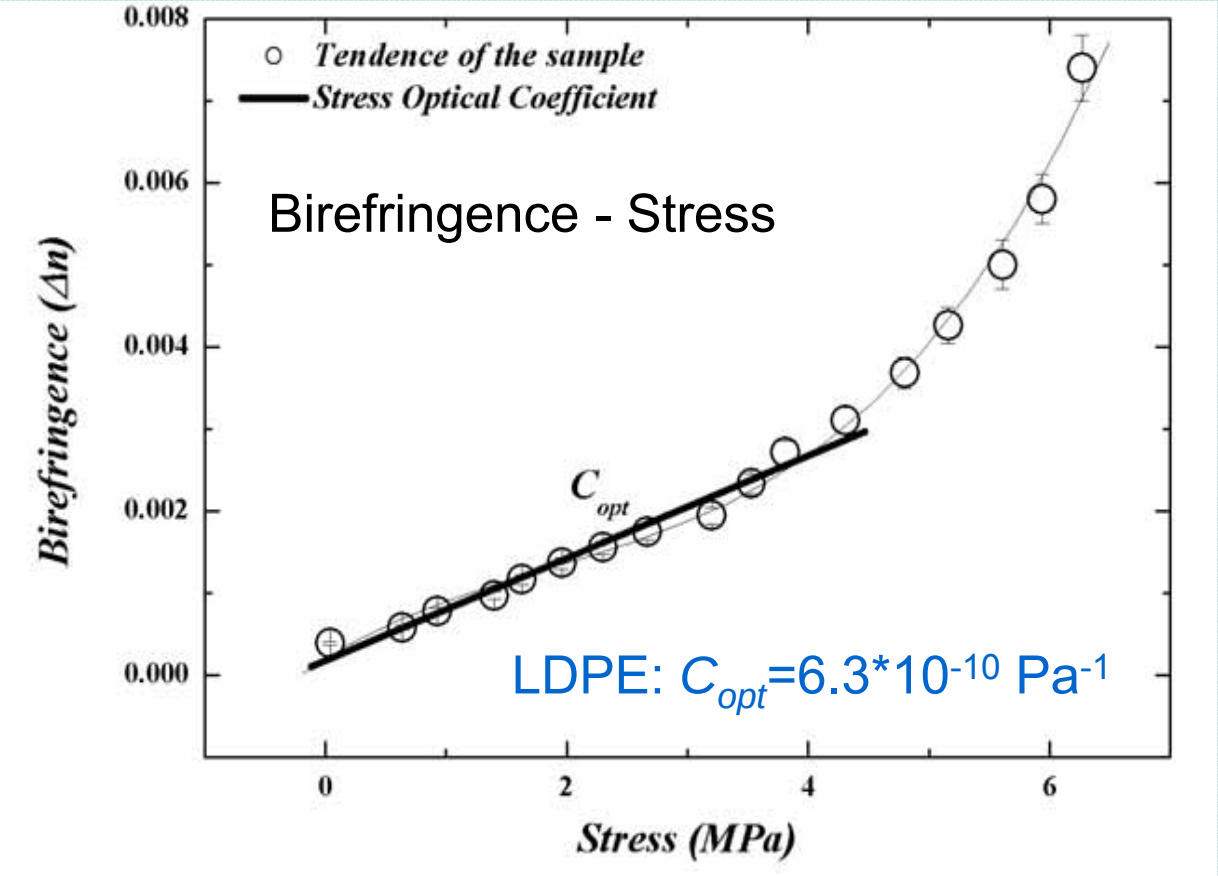
PS-OCT: stress – birefringence calibration

Birefringence Δn:

$$\Delta n = \frac{\lambda}{360} \frac{\mathrm{d}(retardation)}{\mathrm{d}(depth)}$$

Stress optical coefficient C_{opt}:

$$C_{opt} = \frac{\Delta n}{\sigma}$$



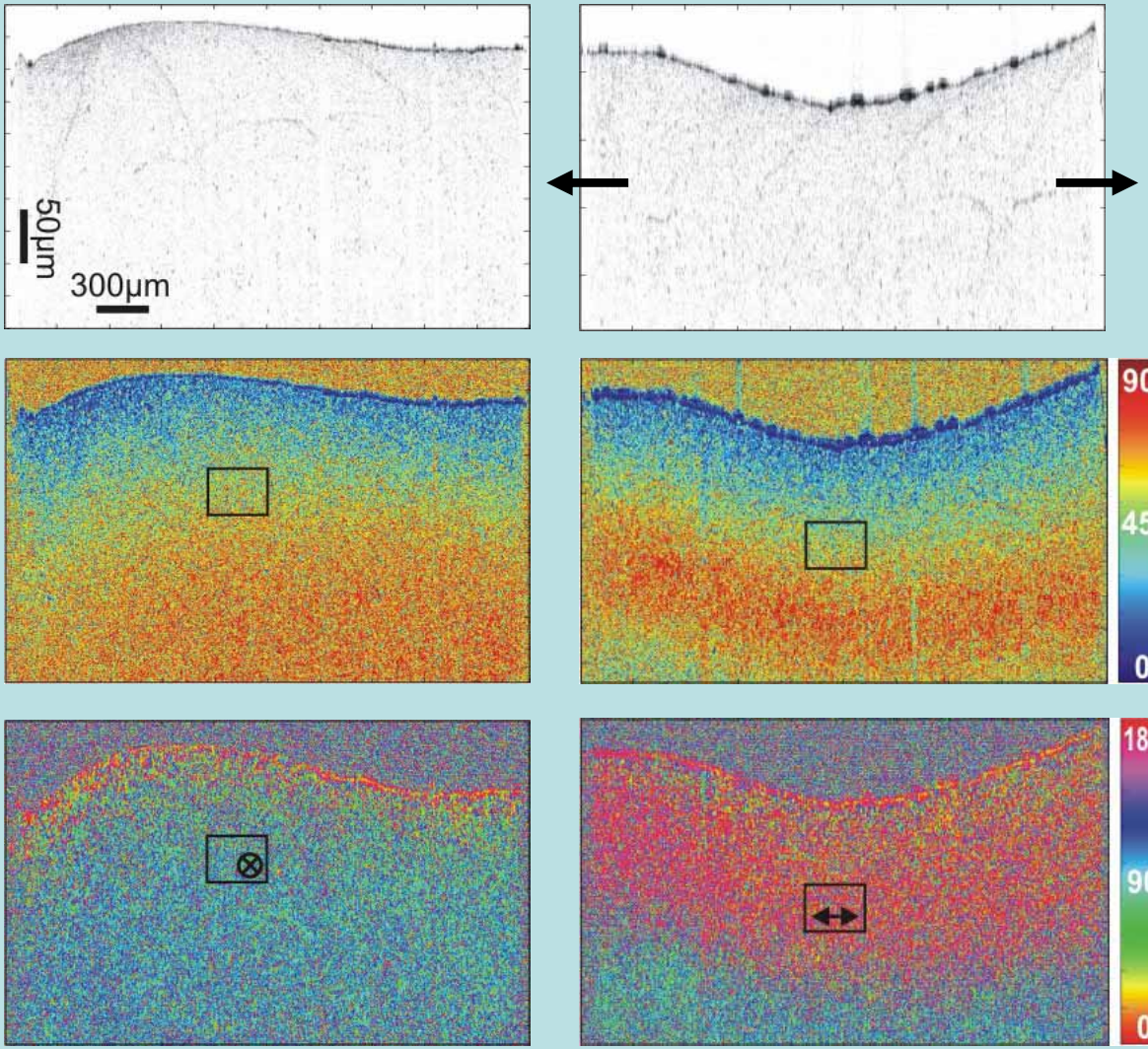
→ K. Wiesauer et al., Acta Materialia 53, 2005

PS-OCT – orientation of optical axis

Elastomer sample

Unstrained

Stretched



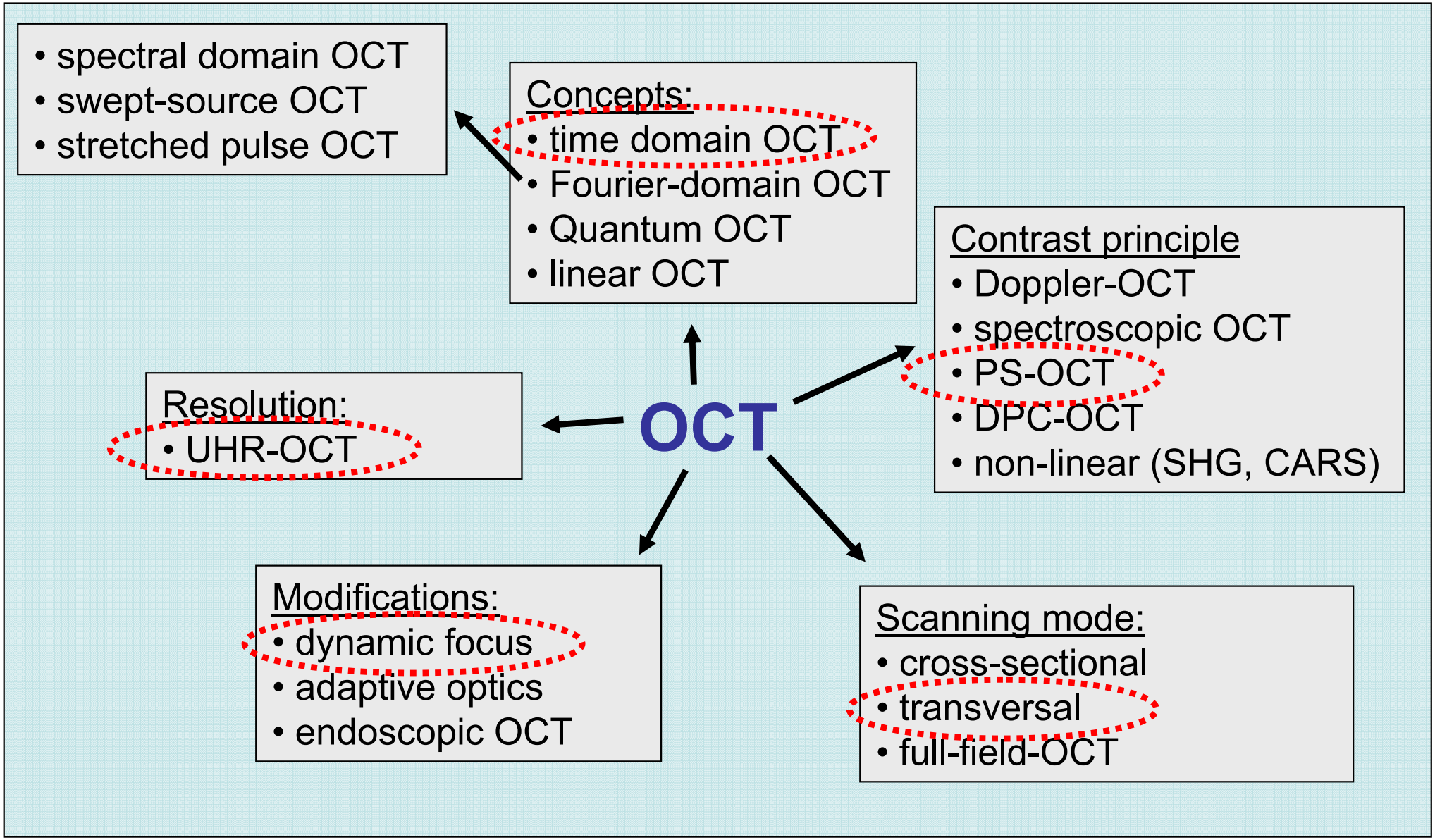
- Reflectivity
- Retardation
- Orientation of optical axis

- Structural imaging
- Birefringence – strain, anisotropies
- Orientation of strain fields

Advanced OCT techniques for material testing

Useful add-ons and extensions

OCT Concepts and Extensions

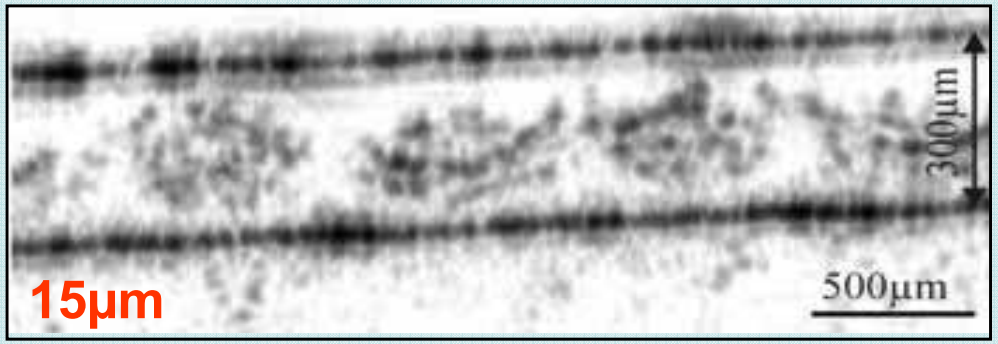


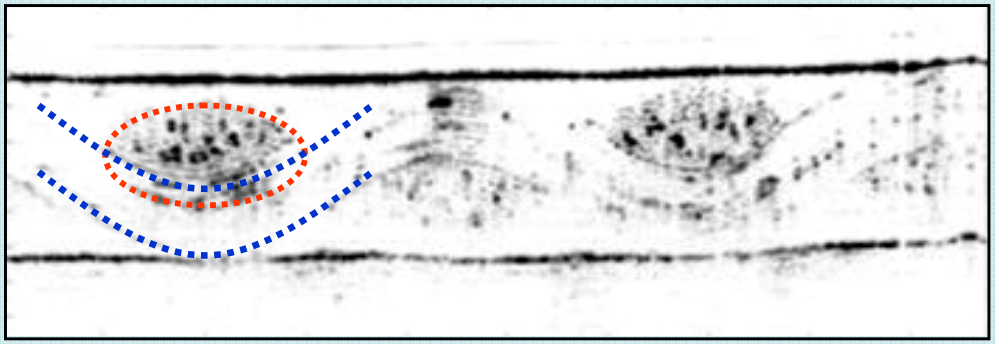
UHR-imaging

SLD

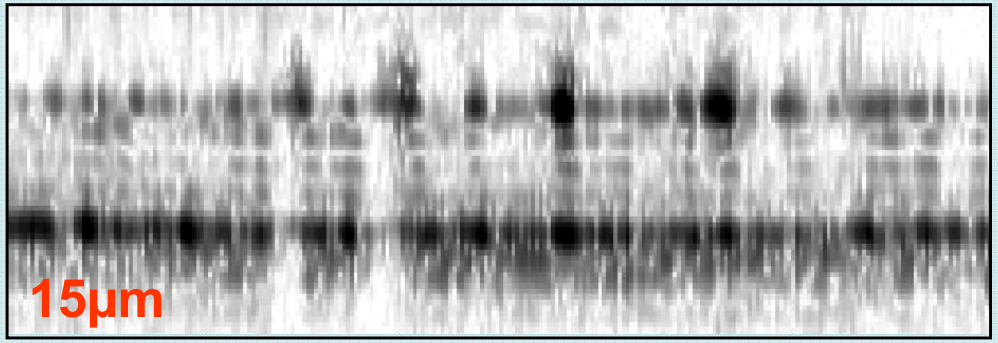
fs - laser: < 2µm

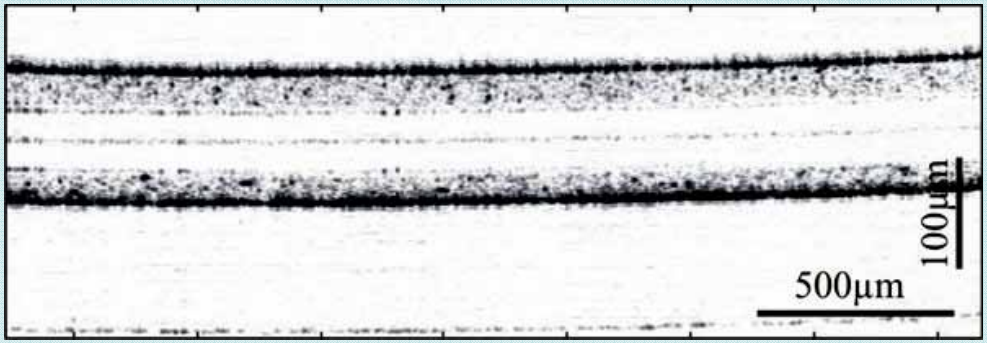
- Epoxy-glass fibre sheet:



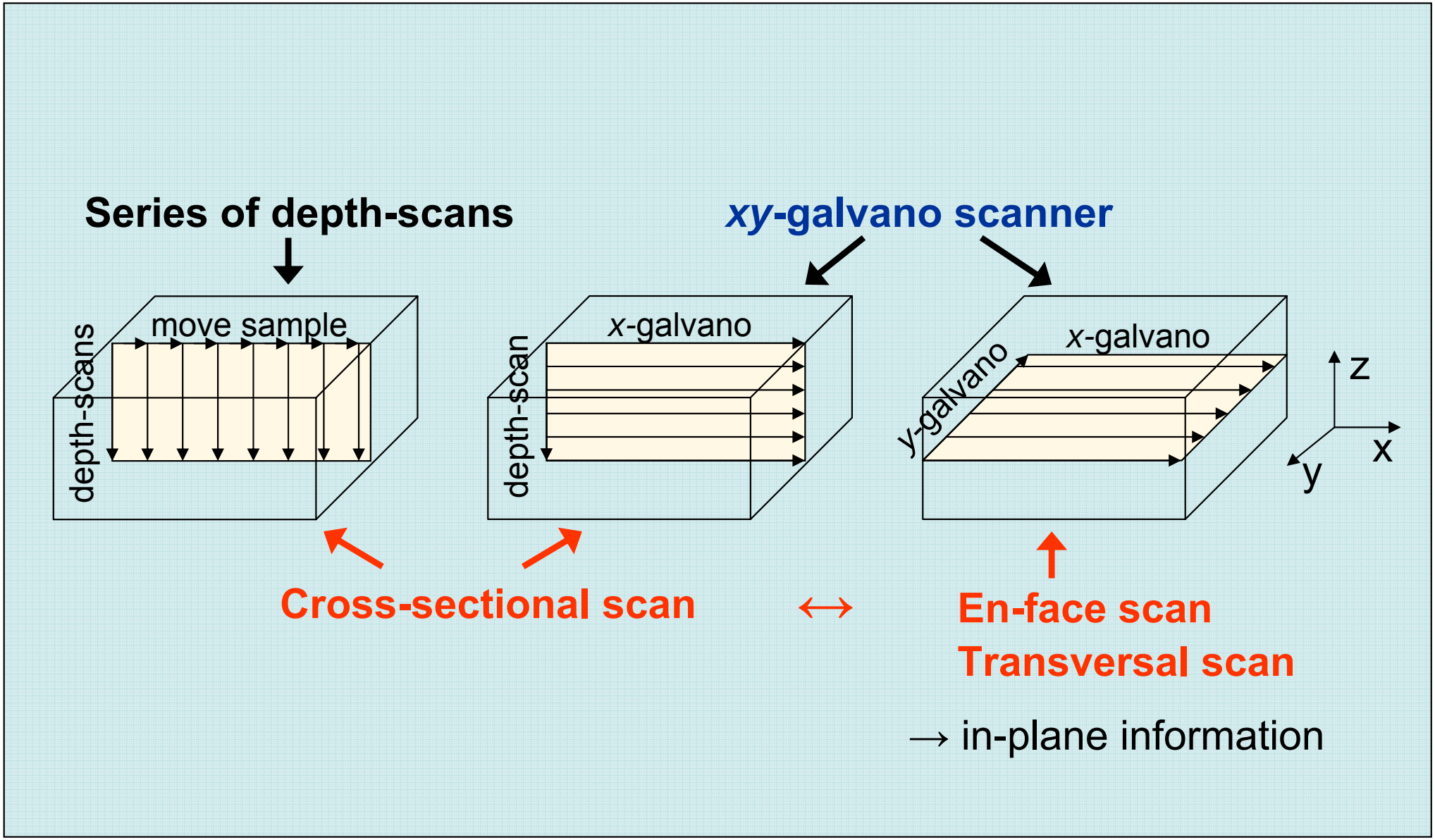


- Multi-layer foil:





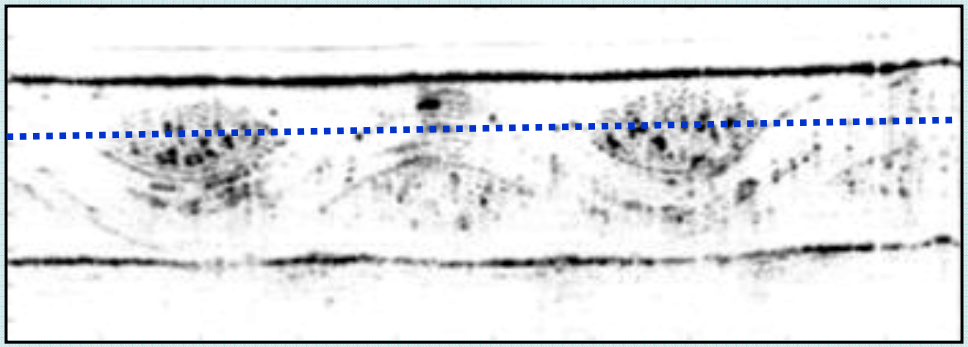
Transversal scanning

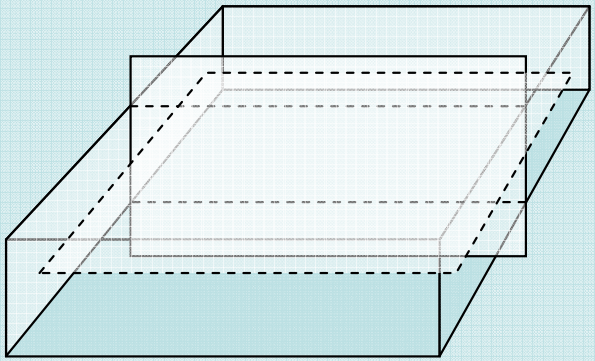


Transversal imaging

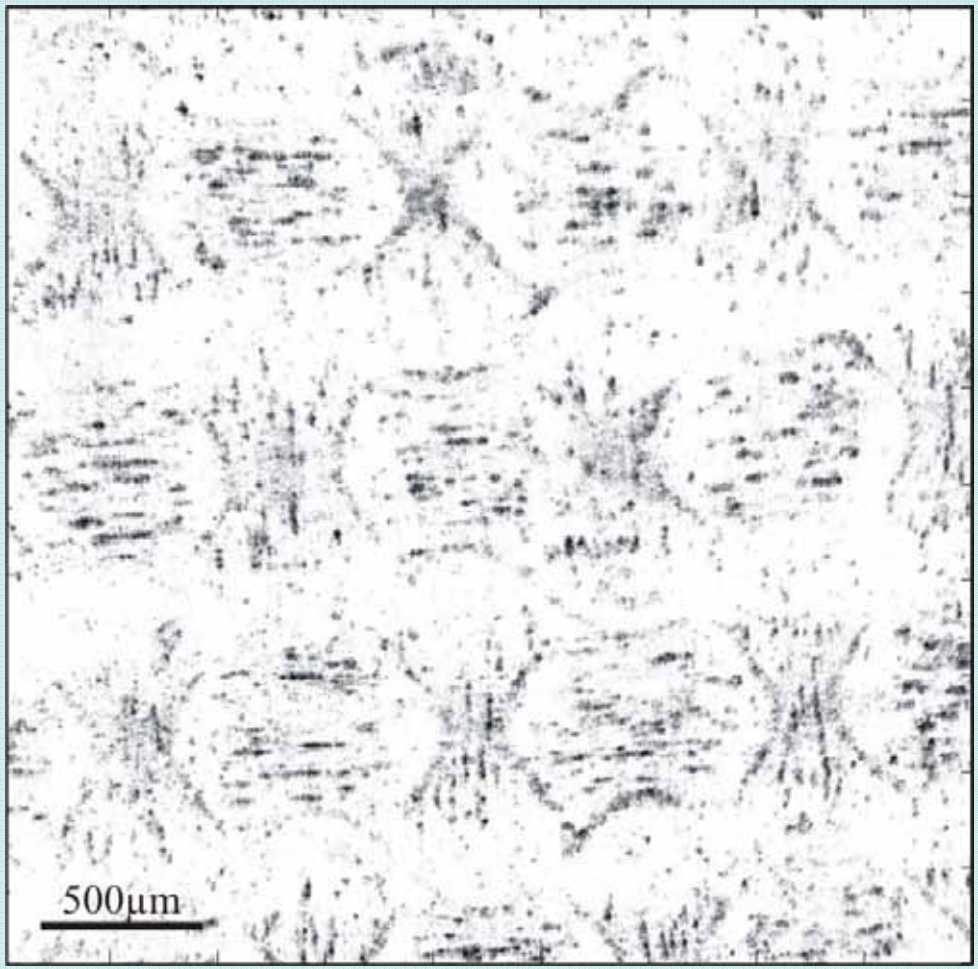
Epoxy-glass fibre sheet

Cross-sectional scan





3x3mm² en-face scan



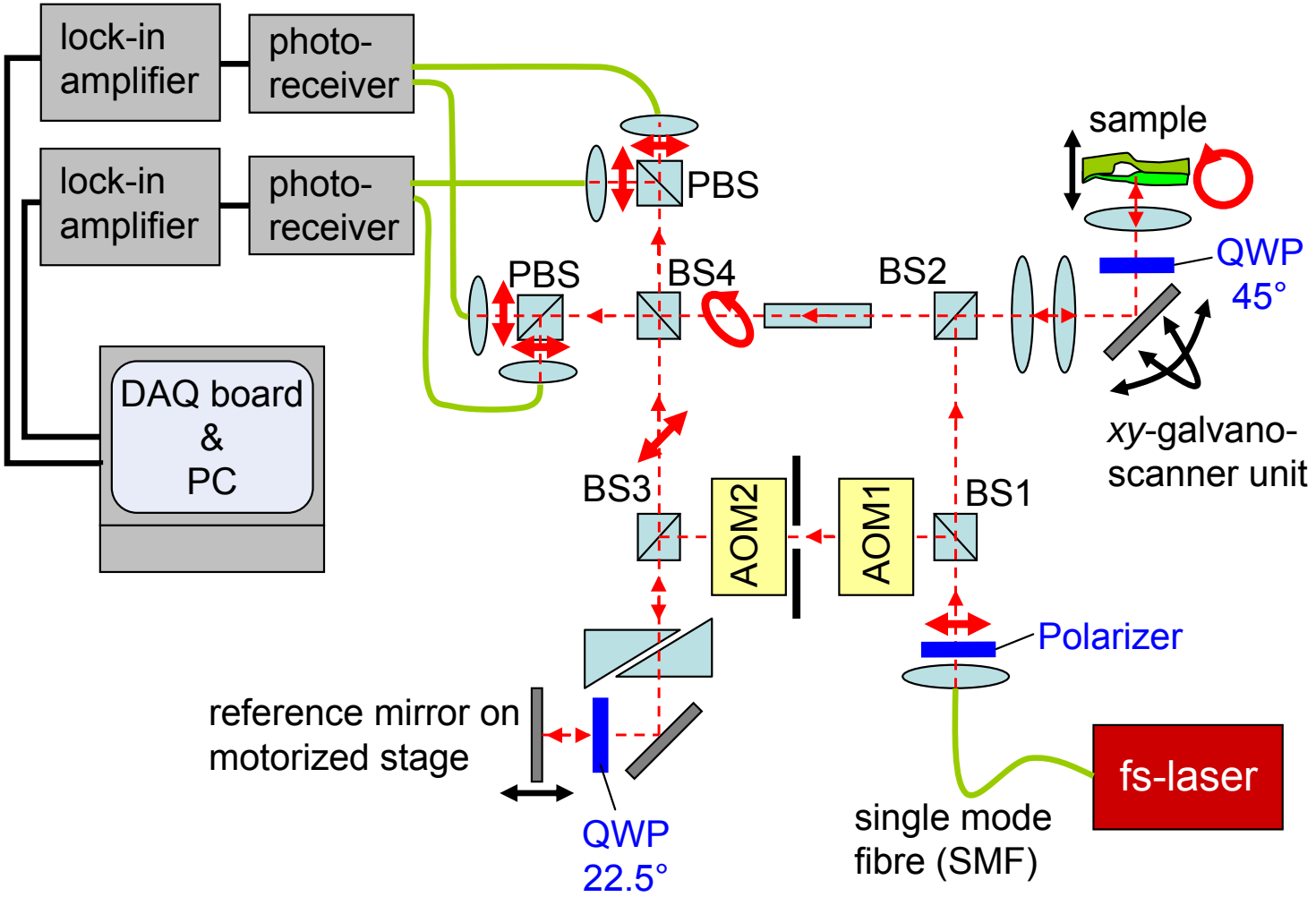
In-plane information **without** evaluation of whole 3D dataset

Combination of 3 add-ons in one setup:

UHR
+
Transversal scanning incl. dynamic focus
+
PS-imaging

Experimental setup: transversal UHR-PS-OCT

Mach-Zehnder interferometer



Extension to **PS-OCT**:

- Polarizer
- Quarter-wave plates
- Polarizing beam-splitters

Transversal UHR-PS-OCT

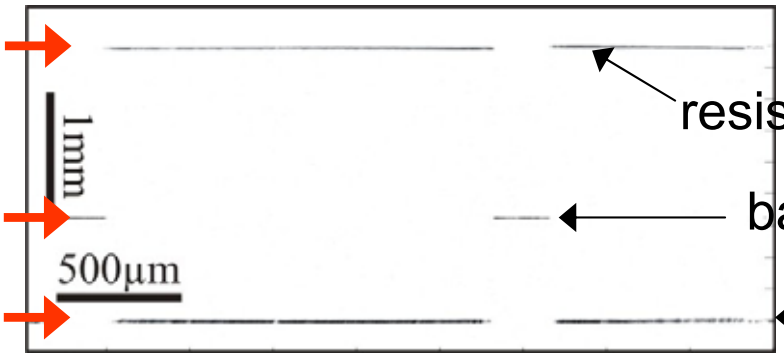
Applications…

…of transversal UHR-PS-OCT

Surfaces and interfaces

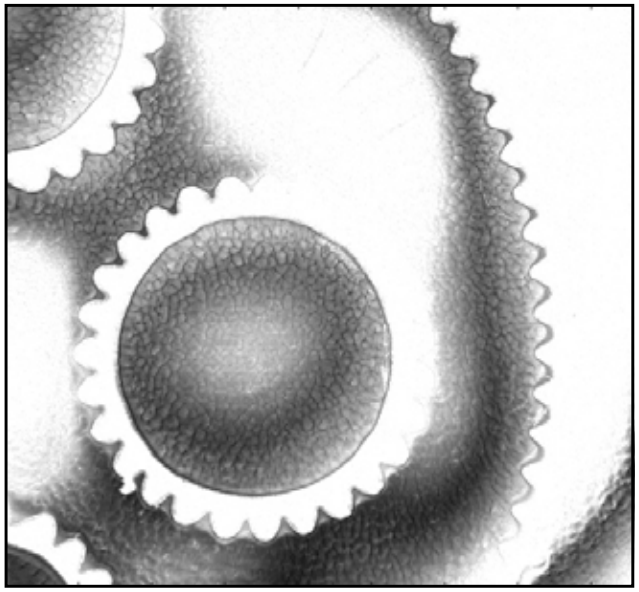
Photoresist moulds for miniature gear-wheels*

cross-sectional scan

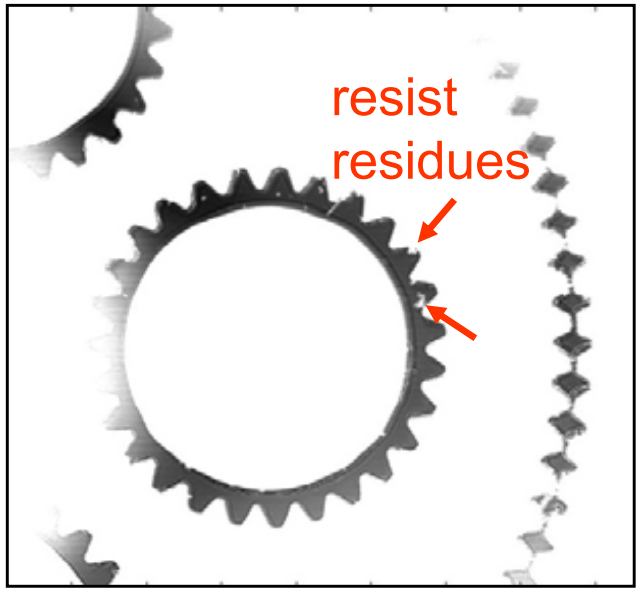


*Design of the wheel structures by Micromotion GmbH

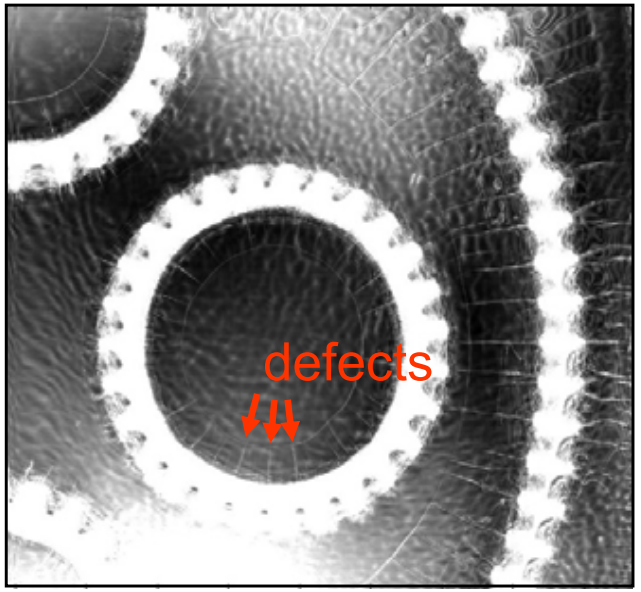
en-face scans (~3x3mm^2)



resist surface

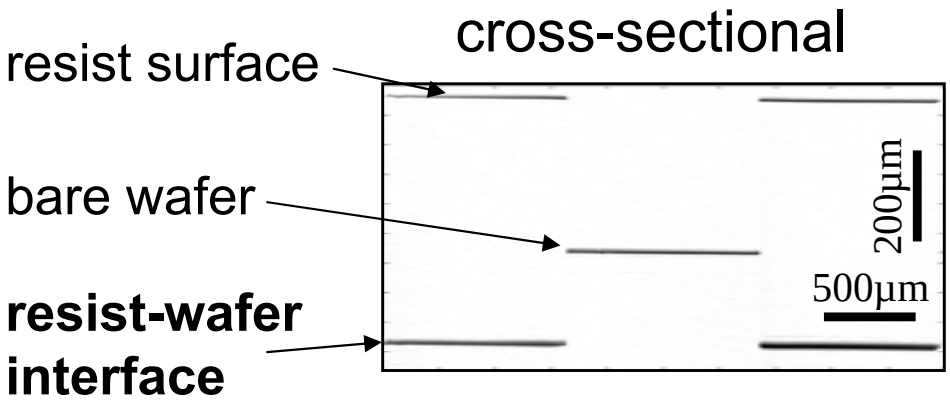


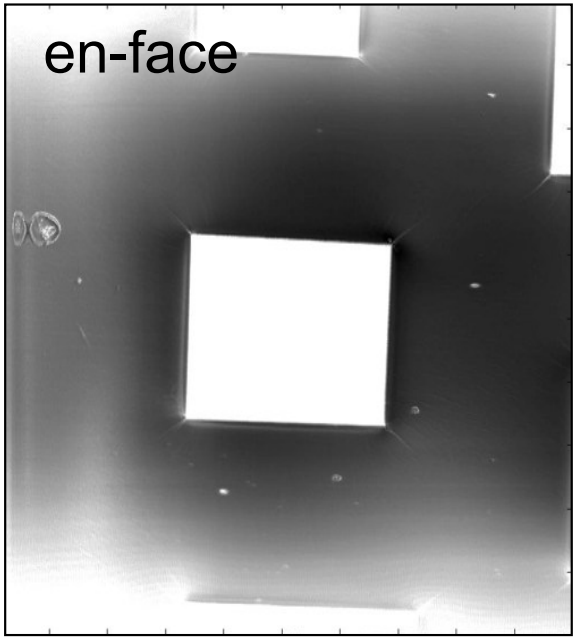
bare wafer



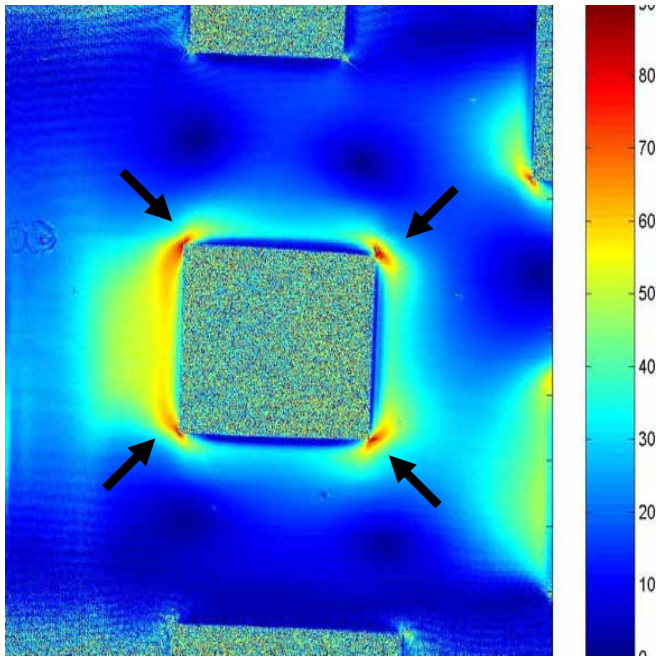
resist-wafer interface

PS-OCT: Strain distribution in photoresist moulds

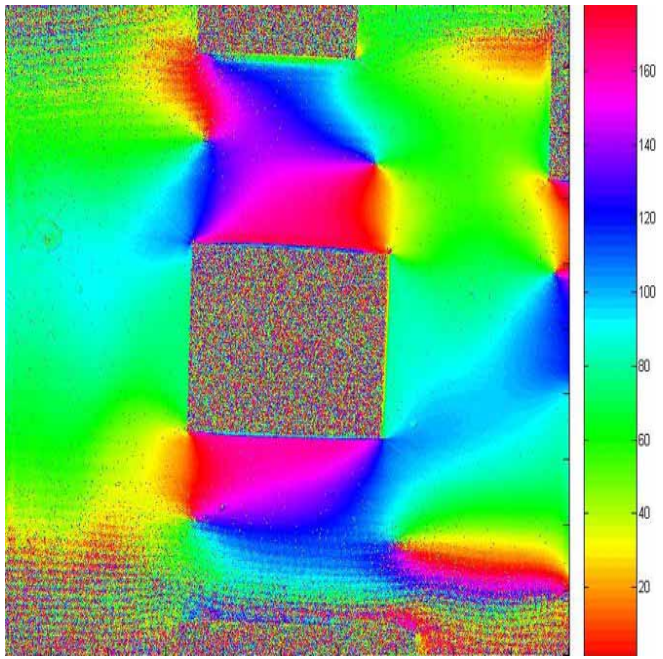


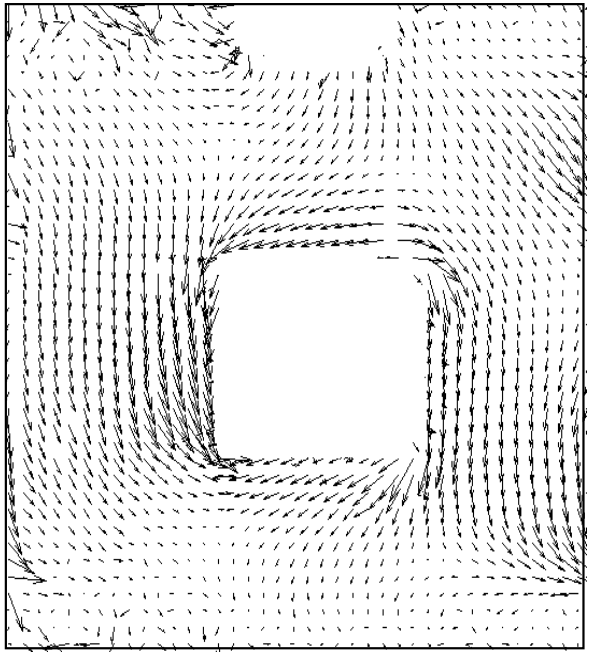


retardation (0-90°)



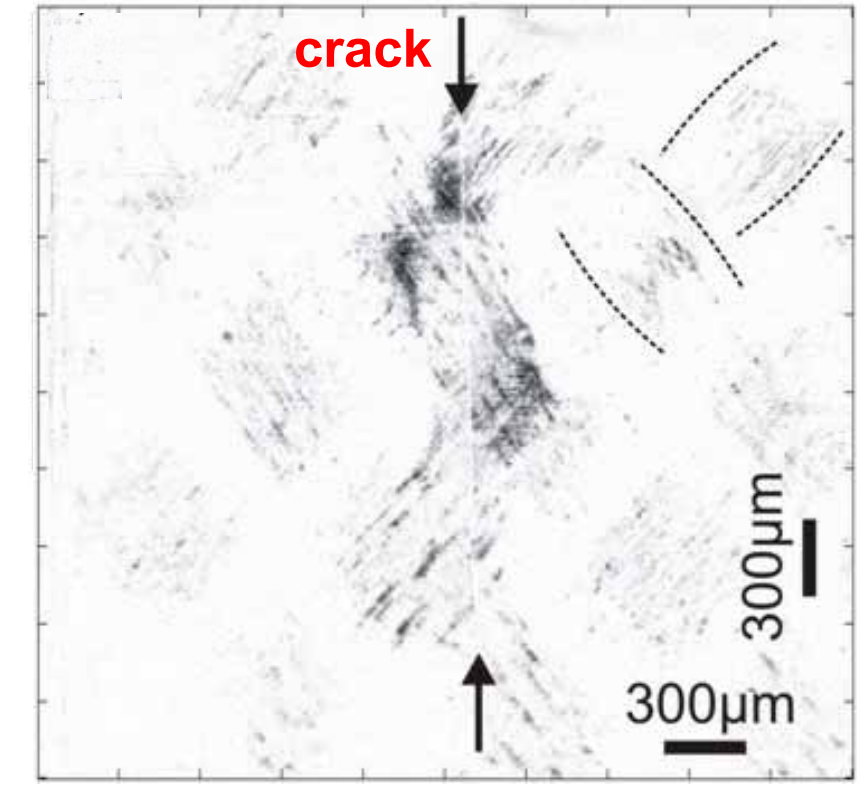
orientation fast opt. axis (0-180°)

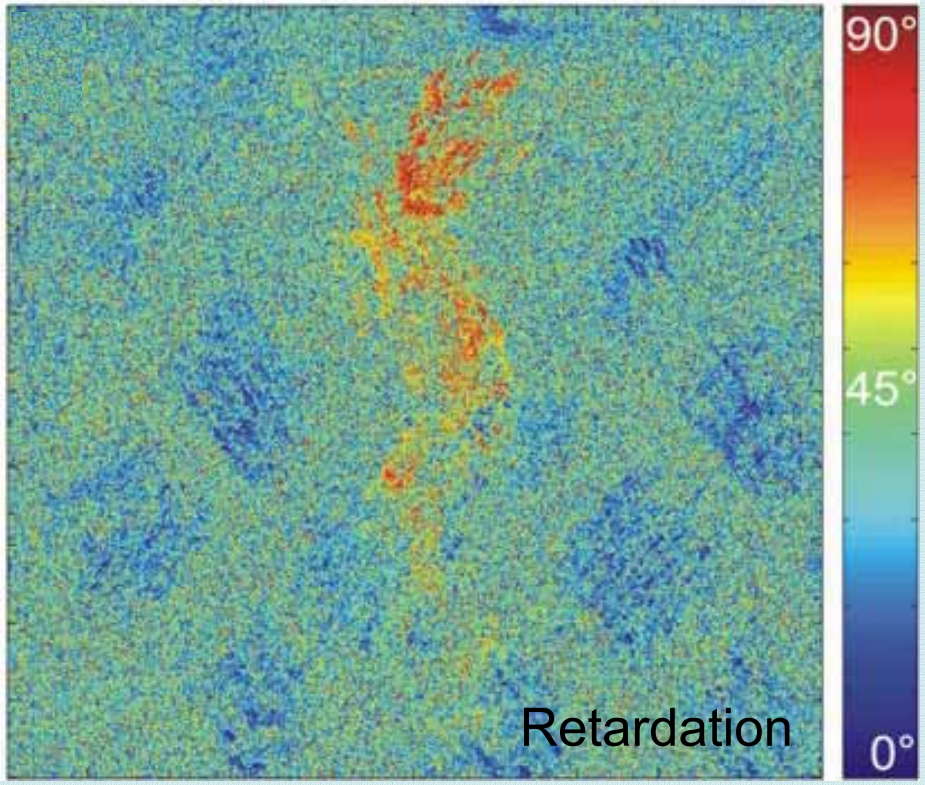




Cracks in glass-fibre composites

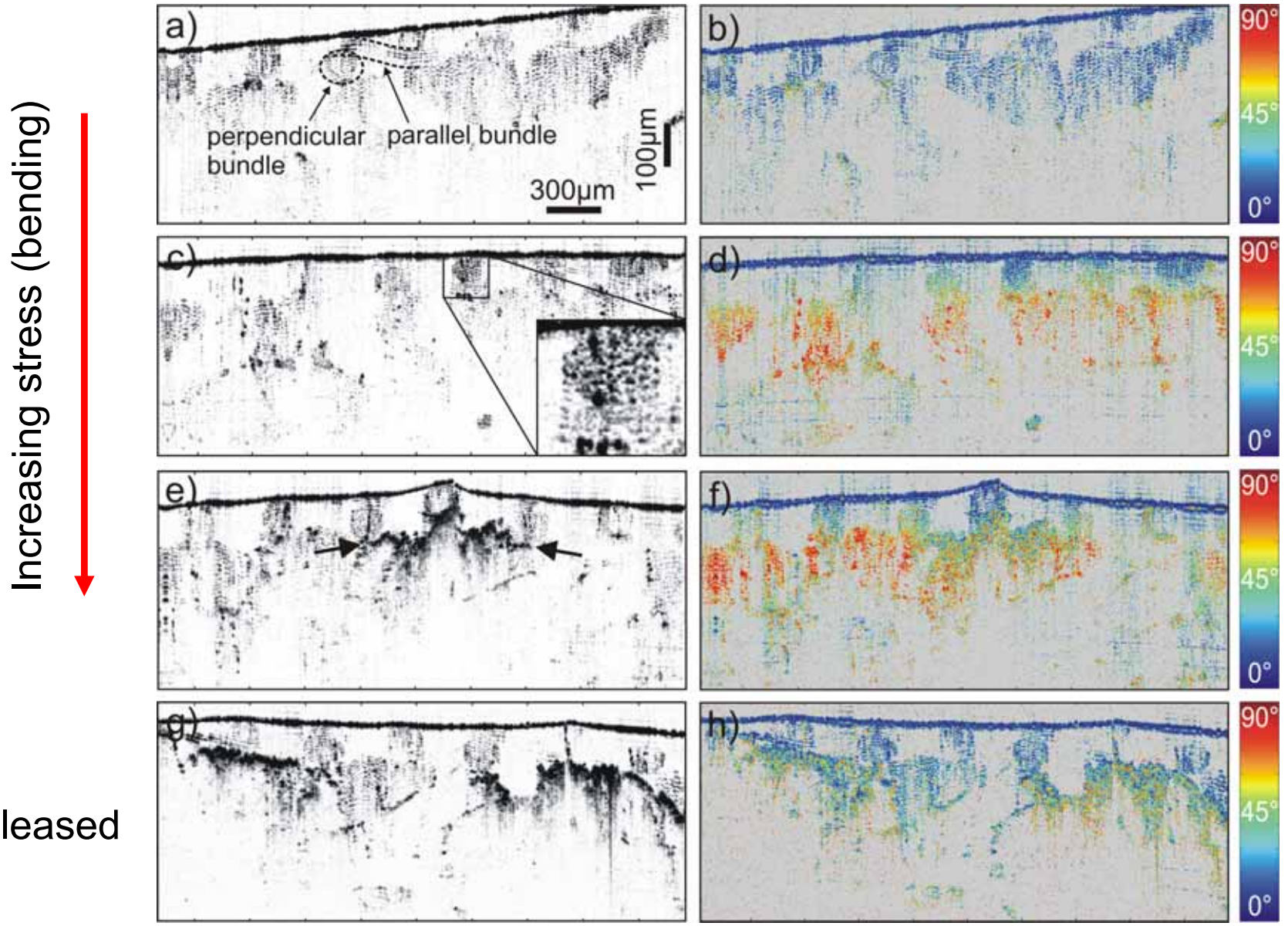
Glass-fibre composite (GFC) material:
→ **crack-formation** due to loading tests





Increased birefingence in fibre bundles near crack

Damage formation in fiber composites



→ K. Wiesauer et al., Composites Science & Technology 67, 2007.

Advanced PS-OCT: Conclusions

PS-OCT: a powerful new method also for non-biomedical applications

PS imaging for
- PS – additional contrast
- Strain-mapping at defined optical depths

Combination with:

UHR for
- Features with µm size

Transversal / en-face scanning for
- additional in-plane information
- selective investigations of interfaces

Application to different types of materials and samples
(e.g. resist layers, GFC materials, bulk polymers...)

Outlook: Potential applications…

…for art diagnostics

PS-OCT: Potential applications for art diagnostics

- Anisotropy
  - Preferential orientation (e.g. fibre orientation)
- Strain / stress
  - Glaze layers
  - Lacquer layers (antique furniture)
  - Varnish (?)
  - Glass and precious stone objects
  - Ceramic objects
  - …

Thank you for your attention !

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UAR:

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