Berner Fachhochschule
Haute école spécialisée bernoise
Bern University of Applied Sciences

SALON INTERNATIONAL
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PALEXPO GENÈVE

Real Time Process Control with Optical Coherence Tomography

16th of June 2016,

Ch. Meier

Overview

- Short introduction to OCT Systems
- Resolution and NA,
- SD OCT and SS OCT, Scanning and Full Field Systems

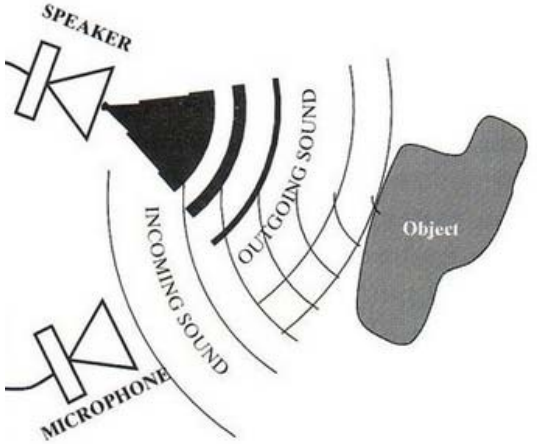
- Examples of Real Time Process Control using OCT

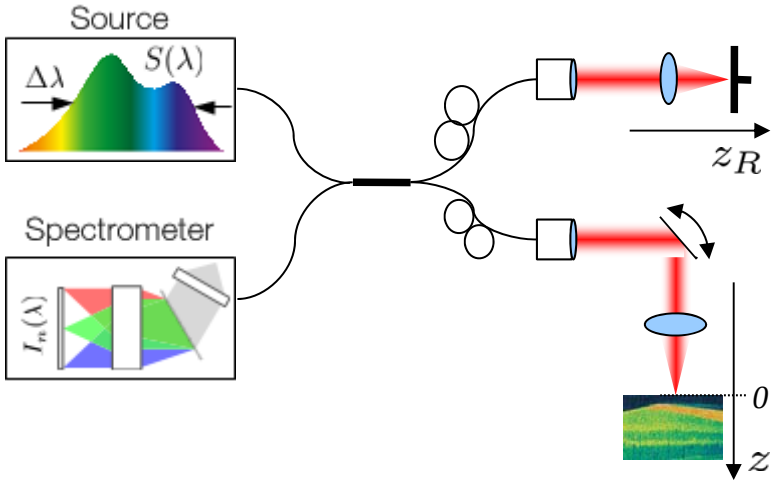
- Braucht mindestens 30 min. Lasik Film ist aus der Präsentation gelöscht

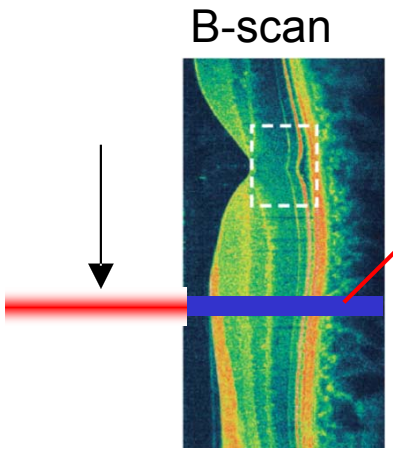
Introduction and Theory

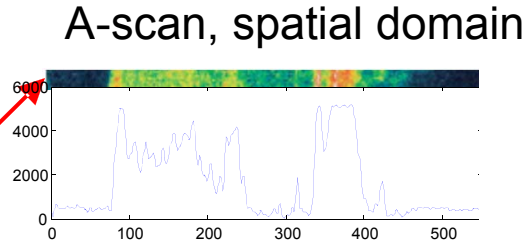
OCT: Basic principle

- Comparable with ultrasonic tomography
- measuring the time delay of back-scattered or back-reflected light
- Too short time delays for direct measurements
- interferometric measurements



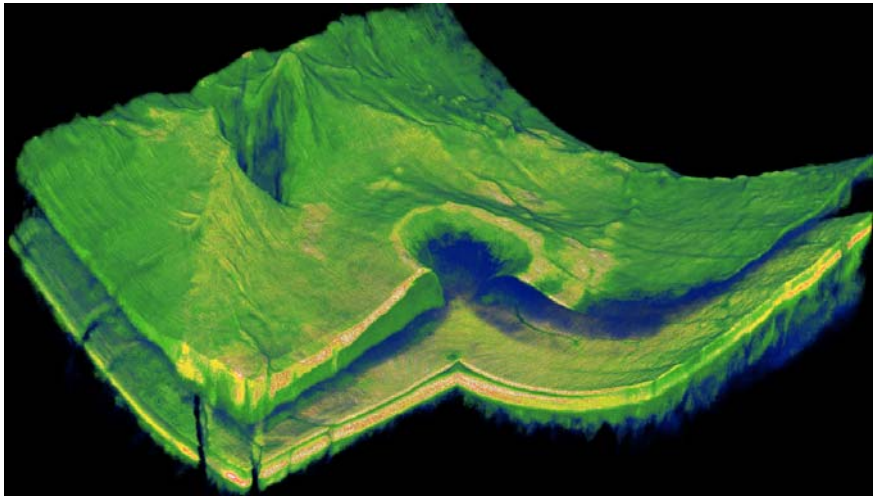


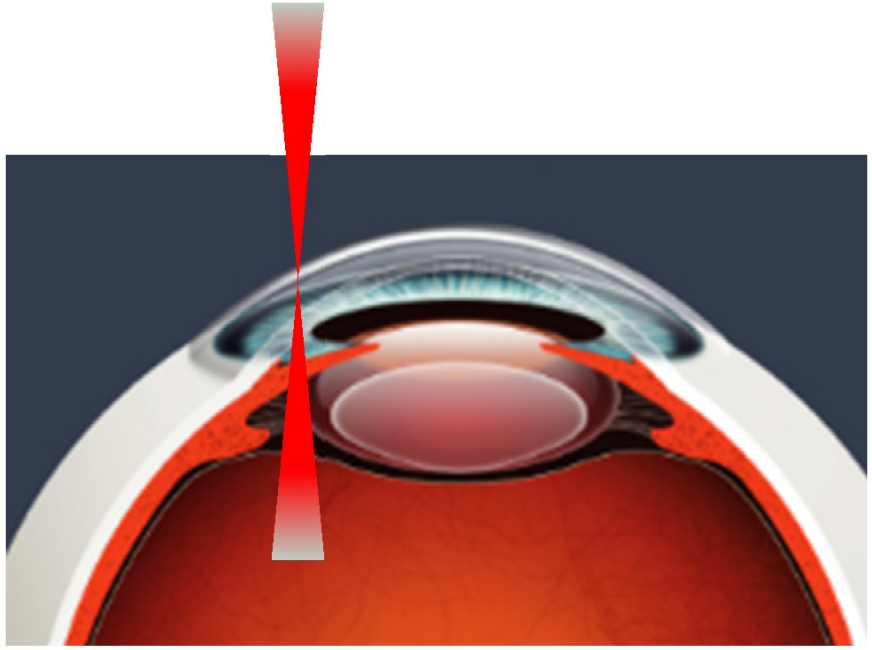




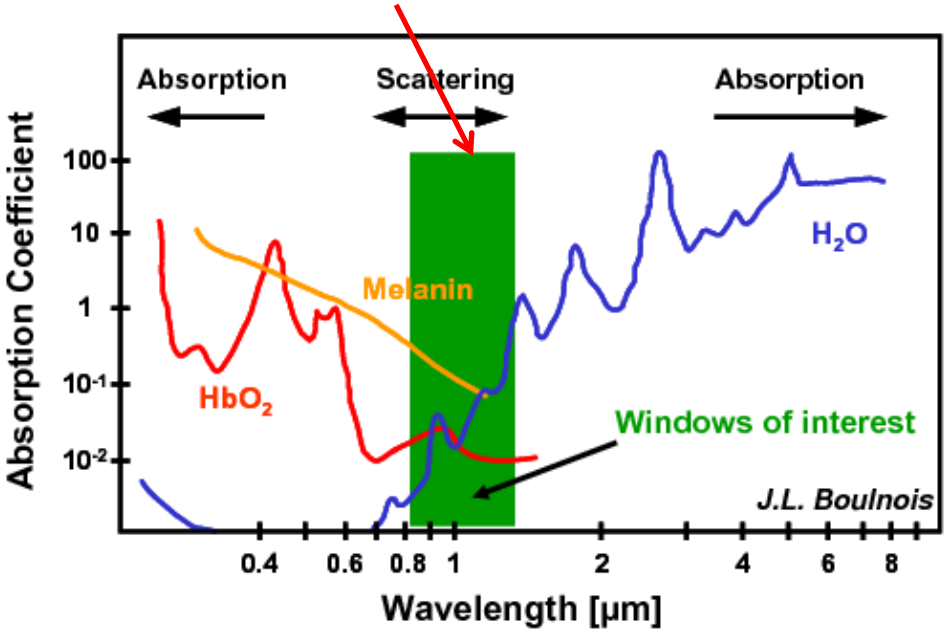
3D Imaging by lateral scanning

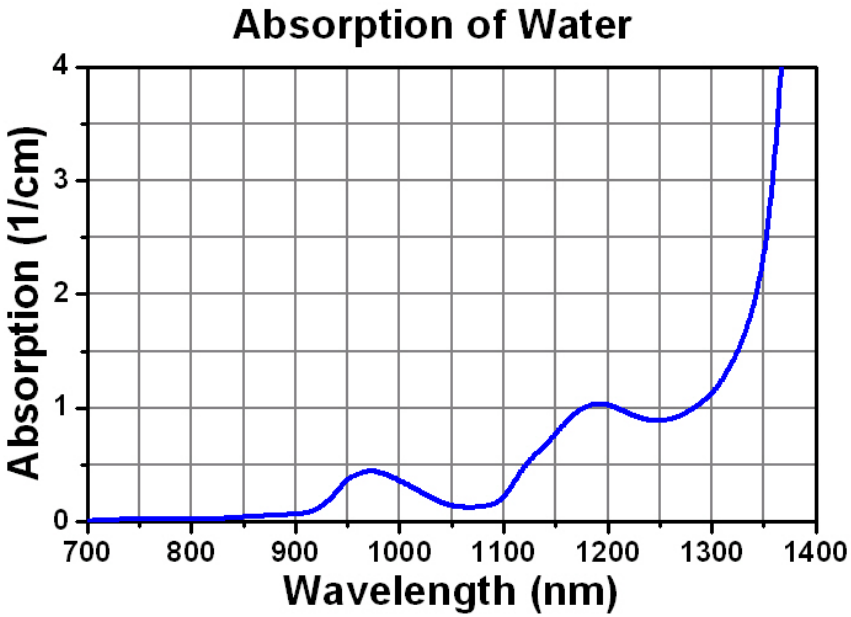
- Cross sectional images obtained by scanning in x and y direction
- A-scan, B-scan, C-scan





Diagnostic window





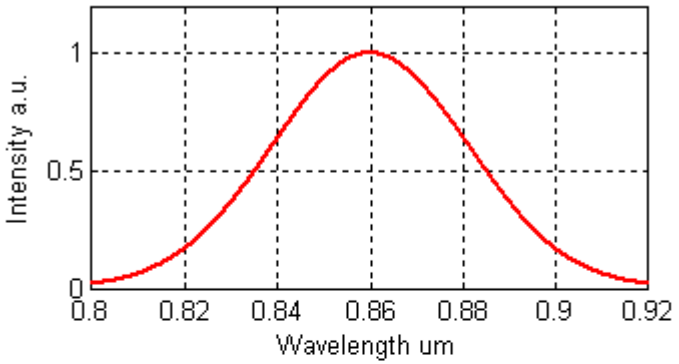
Det.	Silicon	InGaAs	PbS or PbSe
Apll.	Ophthalmic Retina, anterior segment	Cardiovascular, Dermatology, other tissue	NDT, QA

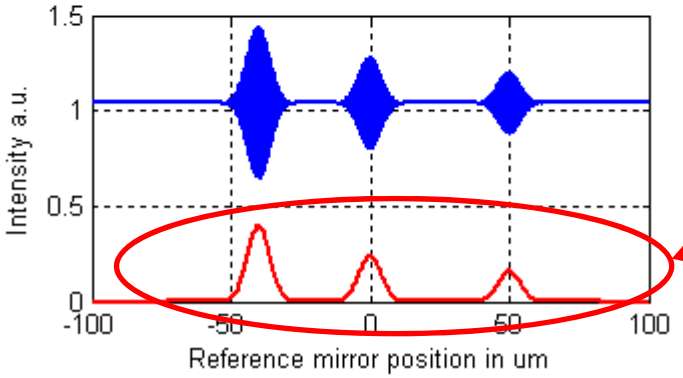
Laser

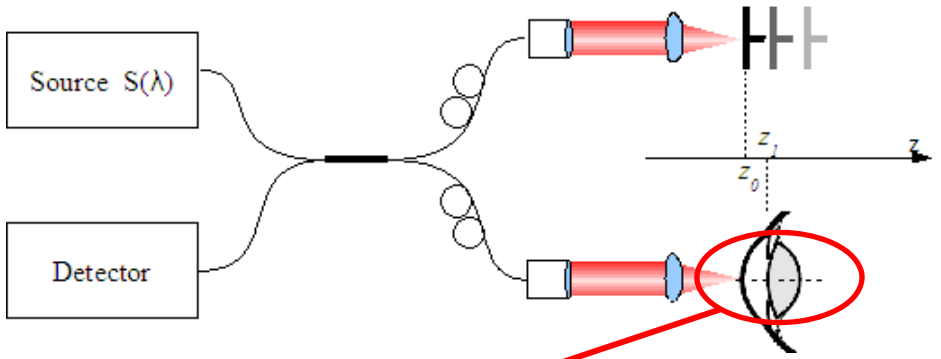
0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 >1.6 $\lambda/\mu m$

Time Domain OCT

Michelson Interferometer setup with moving reference mirror

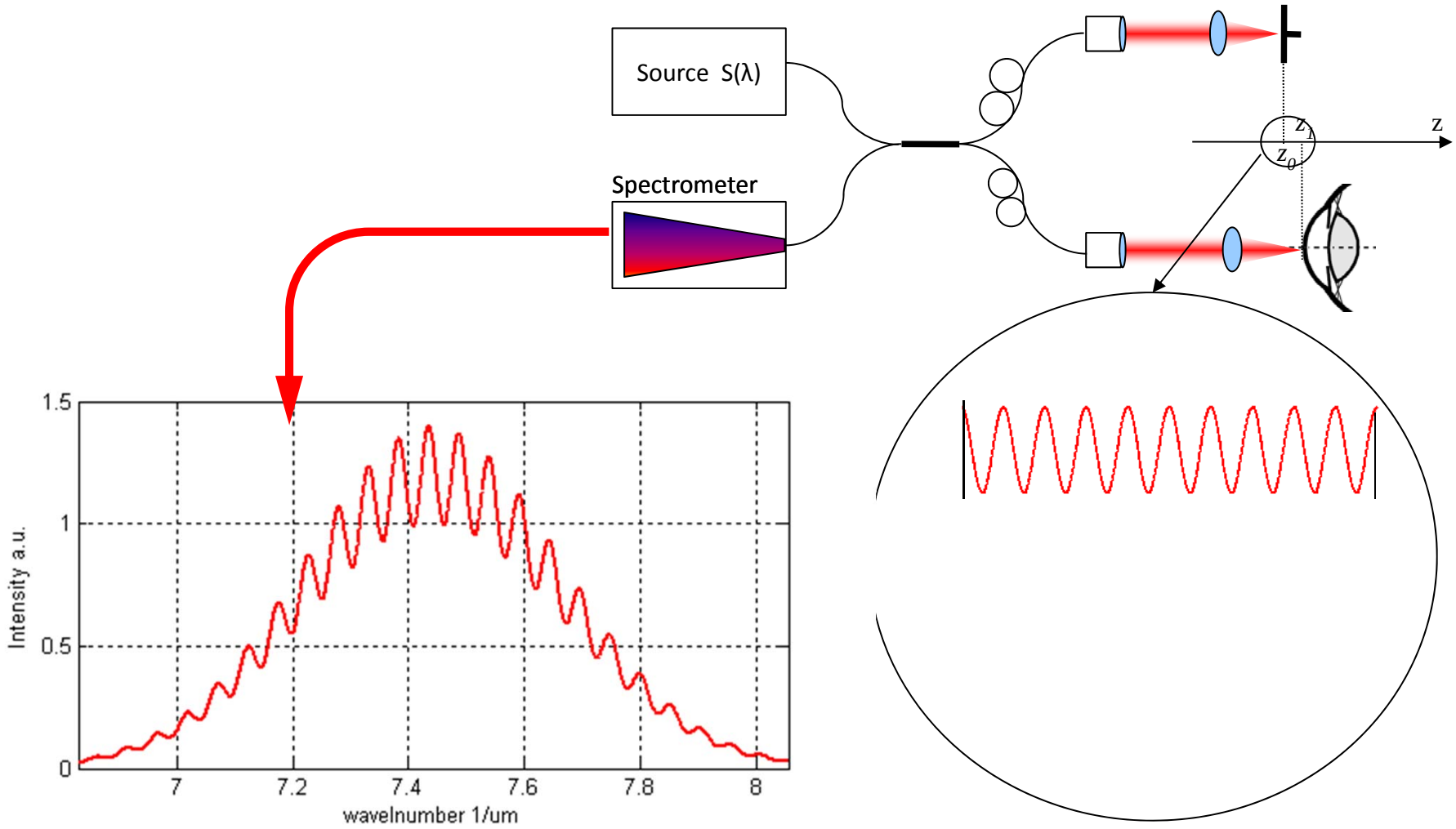






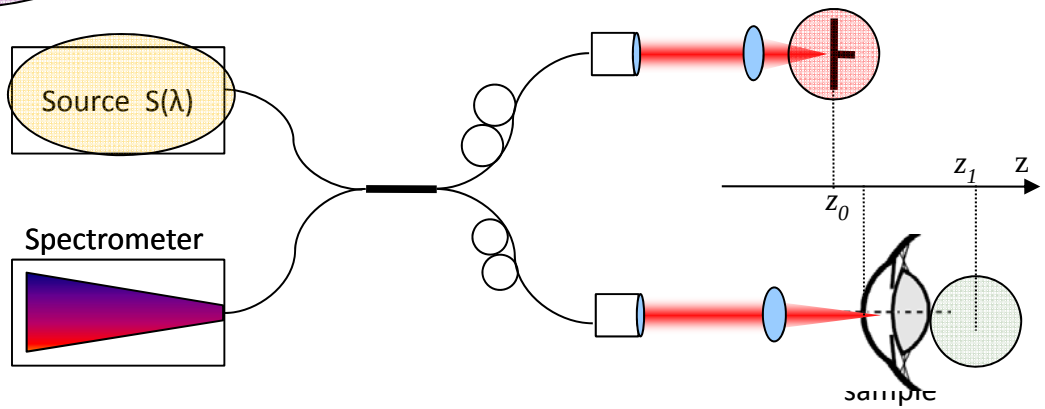
The signal envelope represent
the scattering or reflectivity depth profile

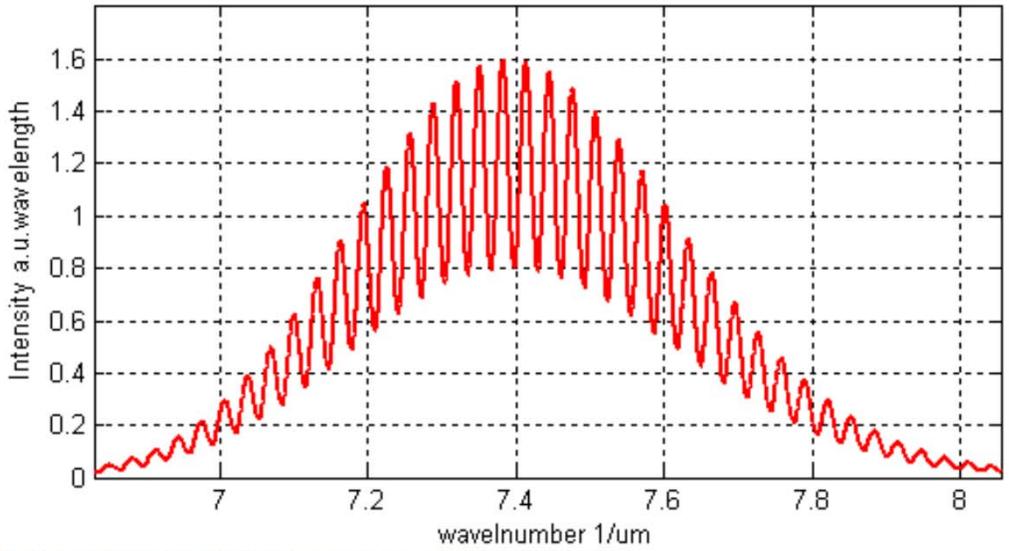
FD OCT, Spectrometer based



FD OCT, Spectrometer based

$$FD(k) = S(k)\left(r_R^2 + r_s^2 + 2r_R r_s cos(2kz)\right)$$



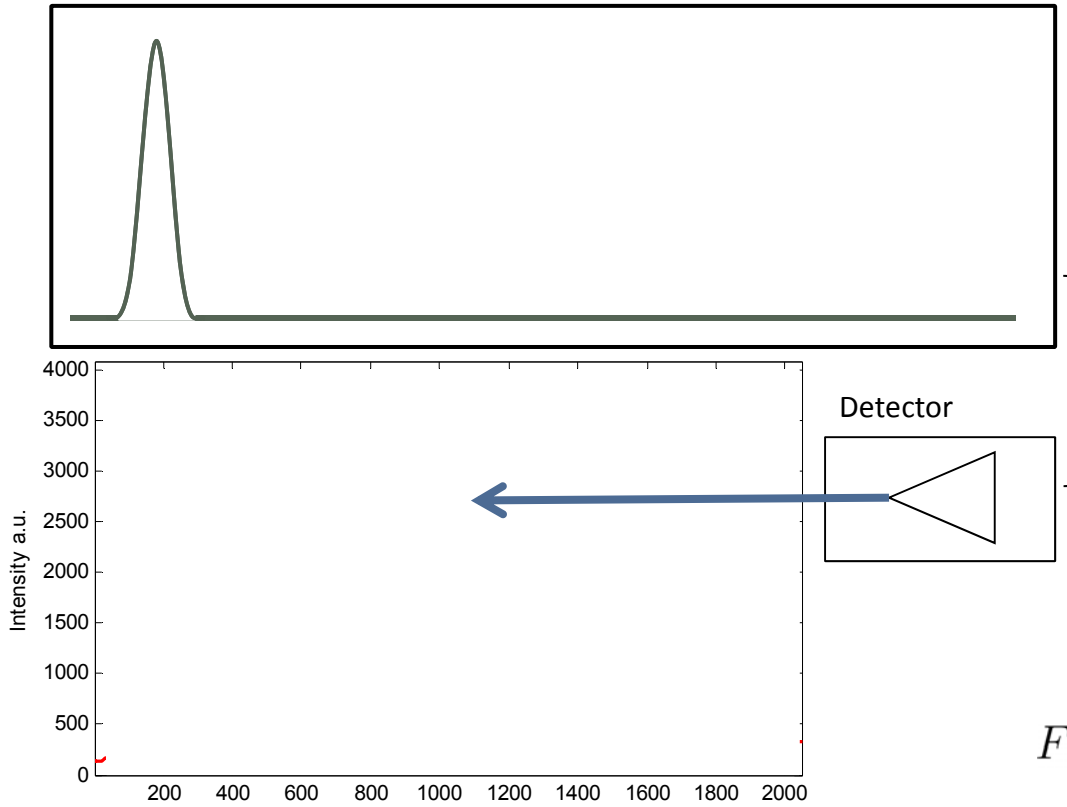


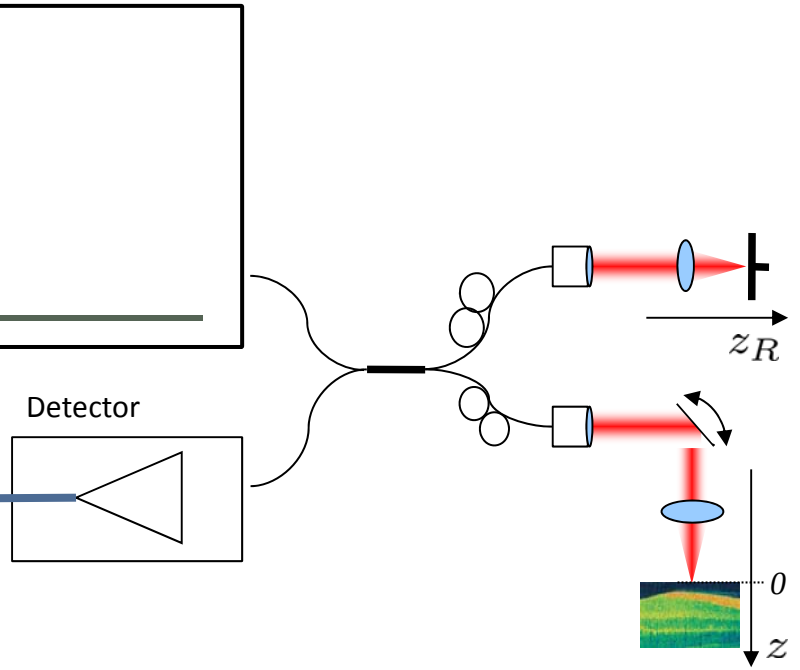
Interferences due to optical path difference

Frequency in k-space is proportional to OPD

Scattering or reflectivity depth profile is obtained by a Fourier transformation

Swept Source OCT



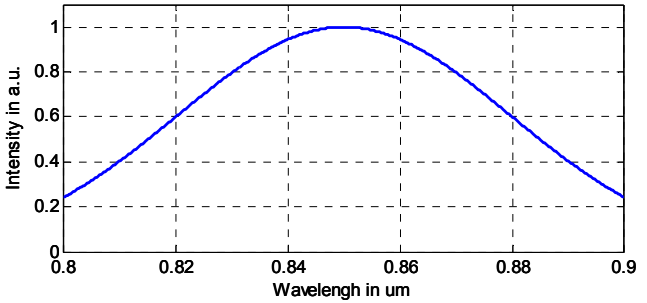


$$FD(k) = S(k)(DC + 2r_R r_s cos(2kz))$$

Axial Resolution

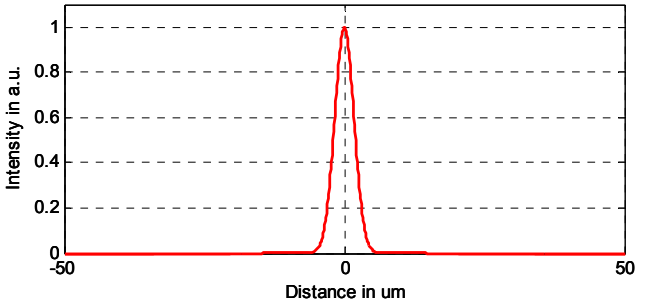
- General signal in Frequency Domain

$$FD(k) = S(k)\left(DC + 2r_R \sum_i r_{s_i} cos(2kz_i)\right)$$



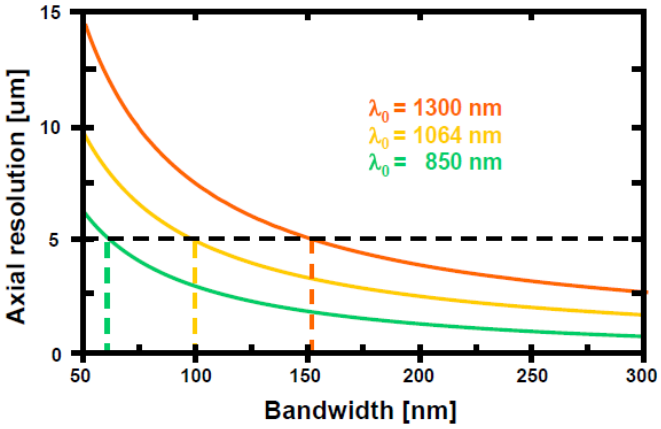
- General signal in Frequency Domain

$$SD(z) = \mathcal{F}^{-1}[S(k)] \otimes \mathcal{F}^{-1}[2r_R \sum_i r_{s_i} cos(2kz_i)]$$



- Gaussian source spectrum -> Gaussian PSF
- PSF = axial resolution = Coherence Length

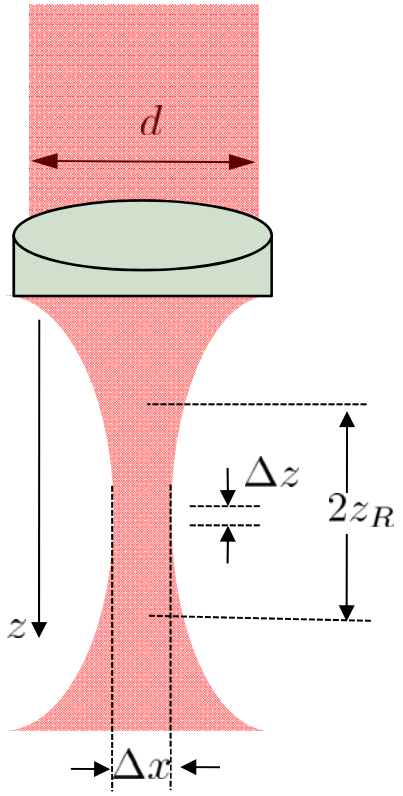
$$\Delta z = \frac{2\ln(2)}{\pi}\frac{\lambda_c^2}{\Delta\lambda} = \frac{4\ln(2)}{\Delta k} \qquad \Delta k = \frac{1}{2\pi}\frac{\Delta\lambda}{\lambda_c^2}$$



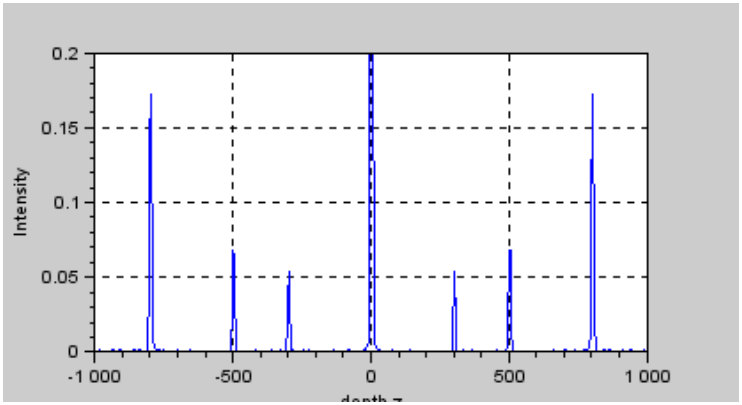
Resolution

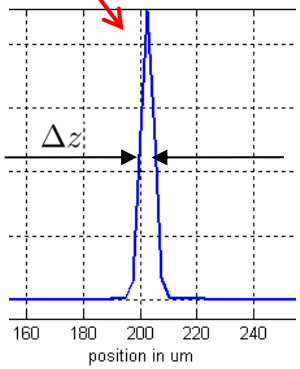
	Lateral resolution	Axial resolution
Confocal Microscope	$\Delta x \sim \frac{1}{N_A}$	$\Delta z \sim \frac{1}{N_A^2}$
OCT	$\Delta x \sim \frac{1}{N_A}$	$\Delta z = \frac{4ln(2)}{\Delta k}$

$$N_A = \frac{d}{2f}$$



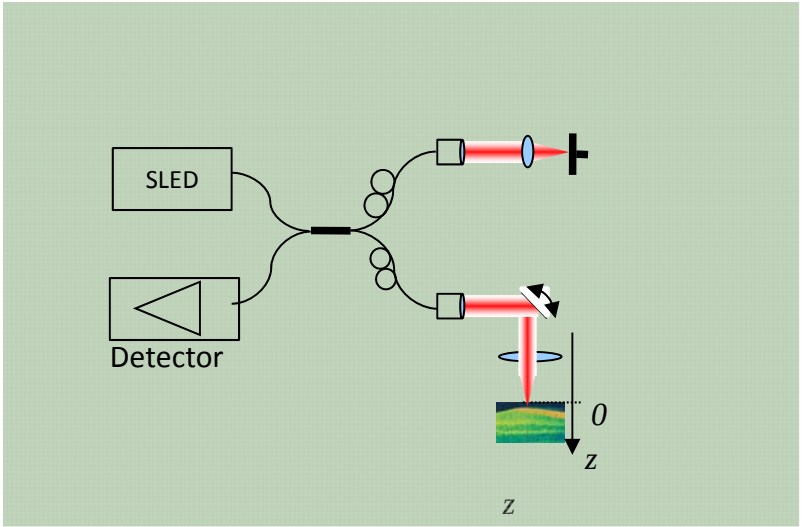
Coherence gate



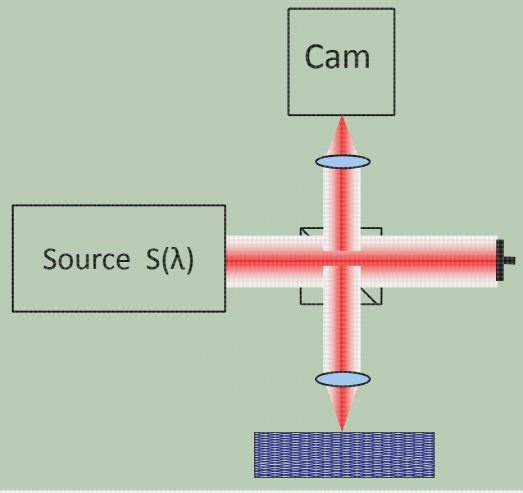


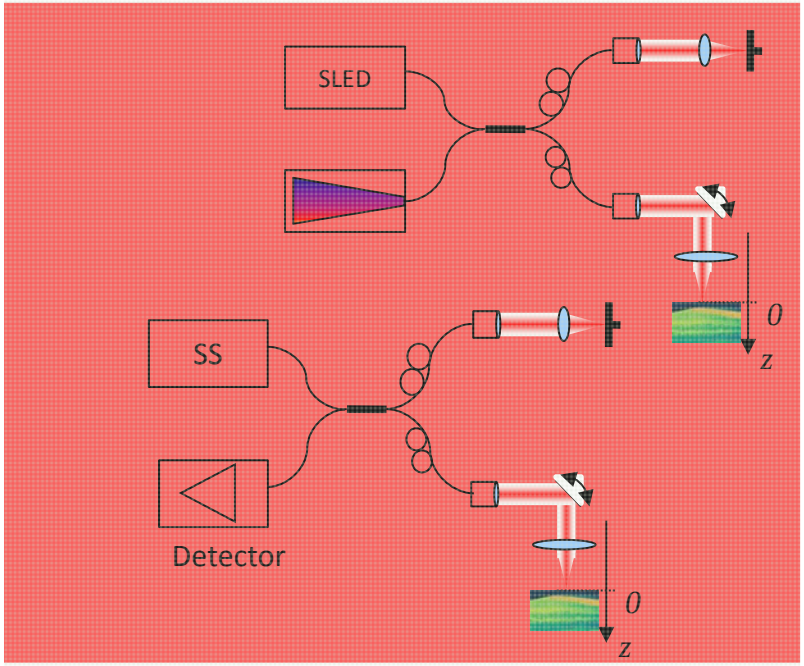
Scanning OCT

Full Field OCT

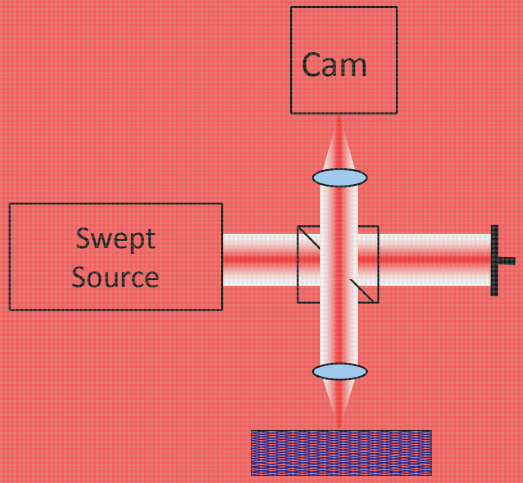


TD OCT

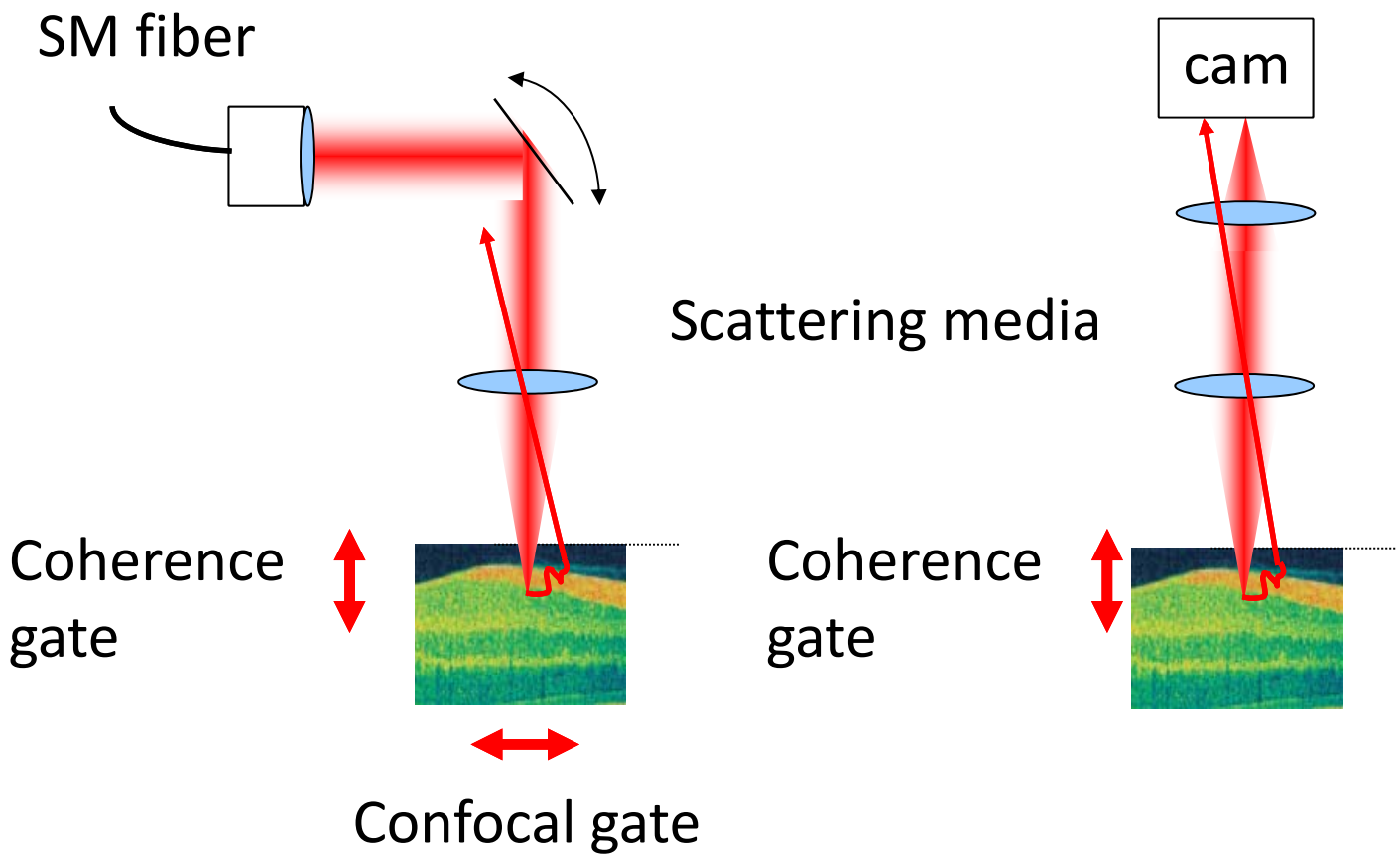




FD OCT



Scanning versus Full Field OCT



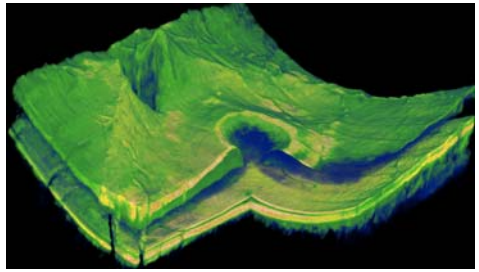
Acquisition Time

- A-scan rate

Camera	Line rate /kHz	Swept Source	Rate /kHz
AVIIVA	100	Santec	50 - 100
Basler	140	Axsun, Insight, Thorlabs	100- 200
Fraunhofer, AIT	600	OCTLight	850
		OptoRes	1500

- 512 lines/frame, 512 frames

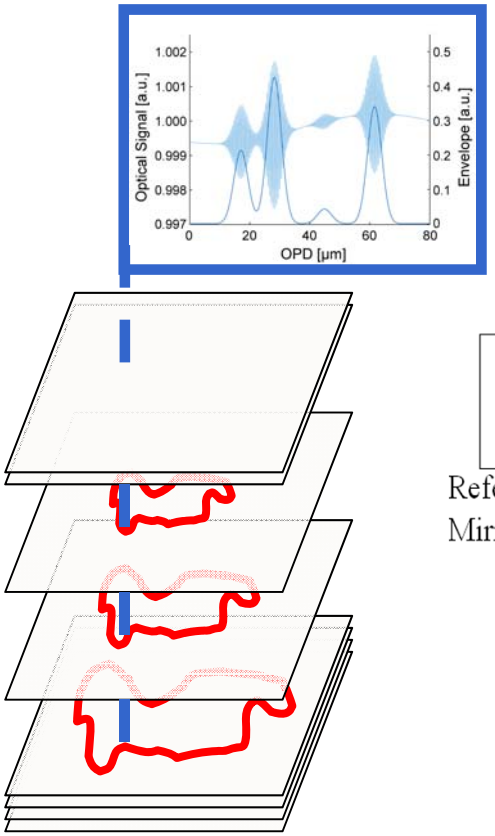
A_Scan rate/kHz	B-scan rate/ Hz	C-scan rate/ Hz
100	195	0.38
200	390	0.76
850	1660	3.24

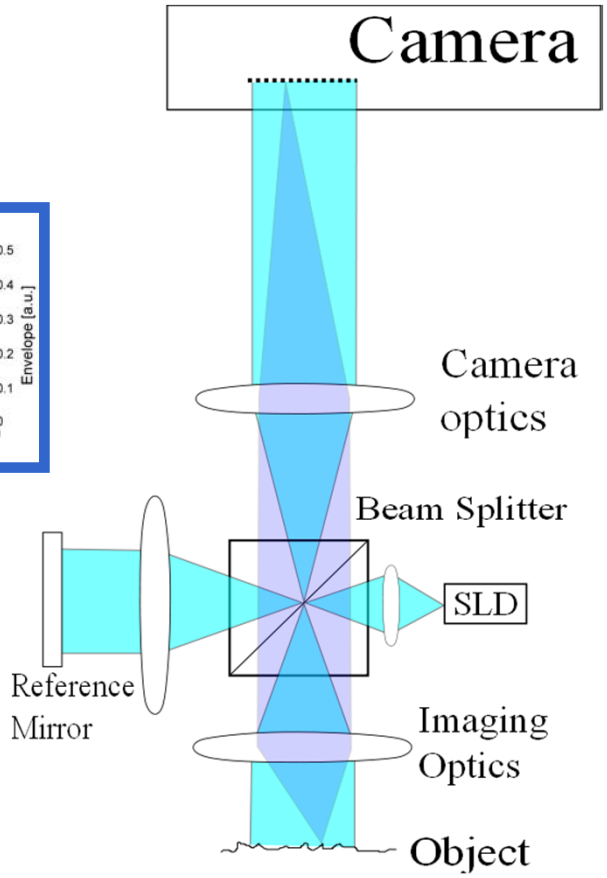


Examples of Real Time Process Control

Full Field OCT

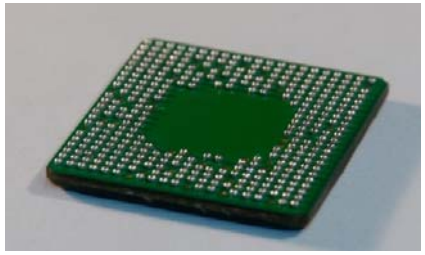
- Phase-Sensitive Parallel Optical Coherence Tomography
- Number of pixels: 300 x 300
- Smart pixels (demodulation)
- Frame rate up to 10^6/s
- C-scan rate 3-6 Hz (1mm depth)



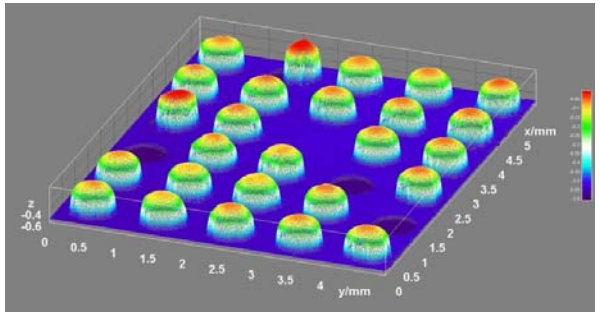


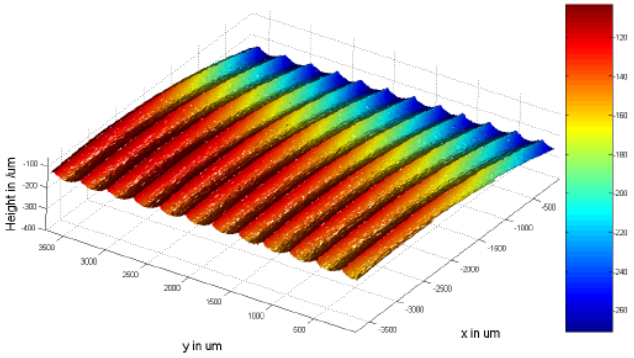
Topographic measuremenents

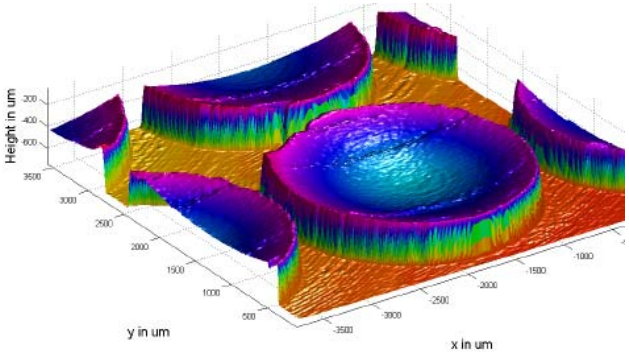
- Solder Bumps



3D





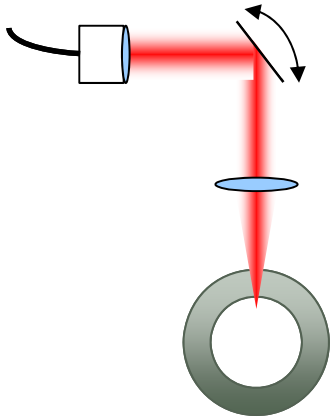


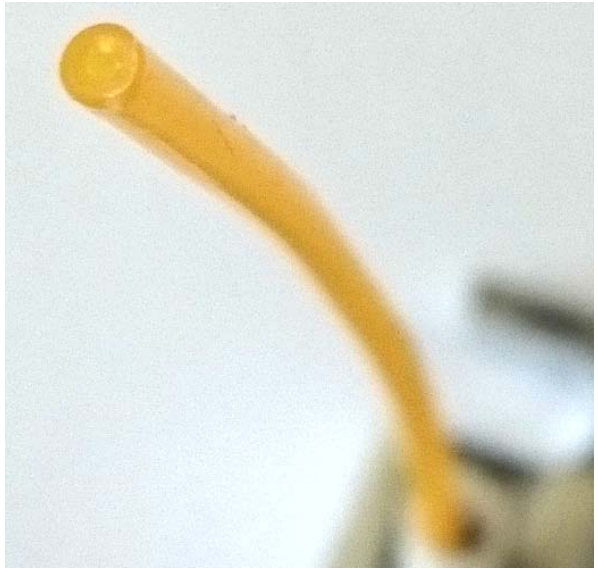
Layer thickness measurement

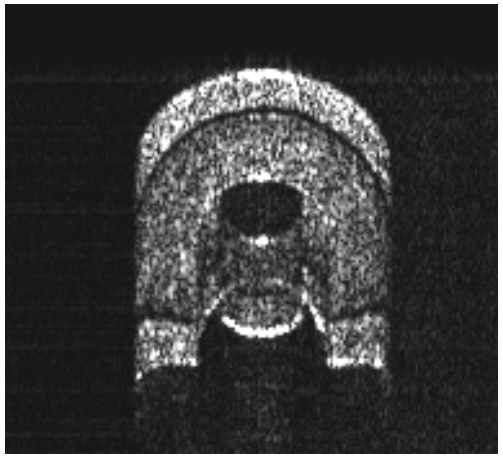
Zumbach
SWISS PRIME MEASURING SINCE 1957

Layer thickness measurement

Zumbach
SWISS PRIME MEASURING SINCE 1957

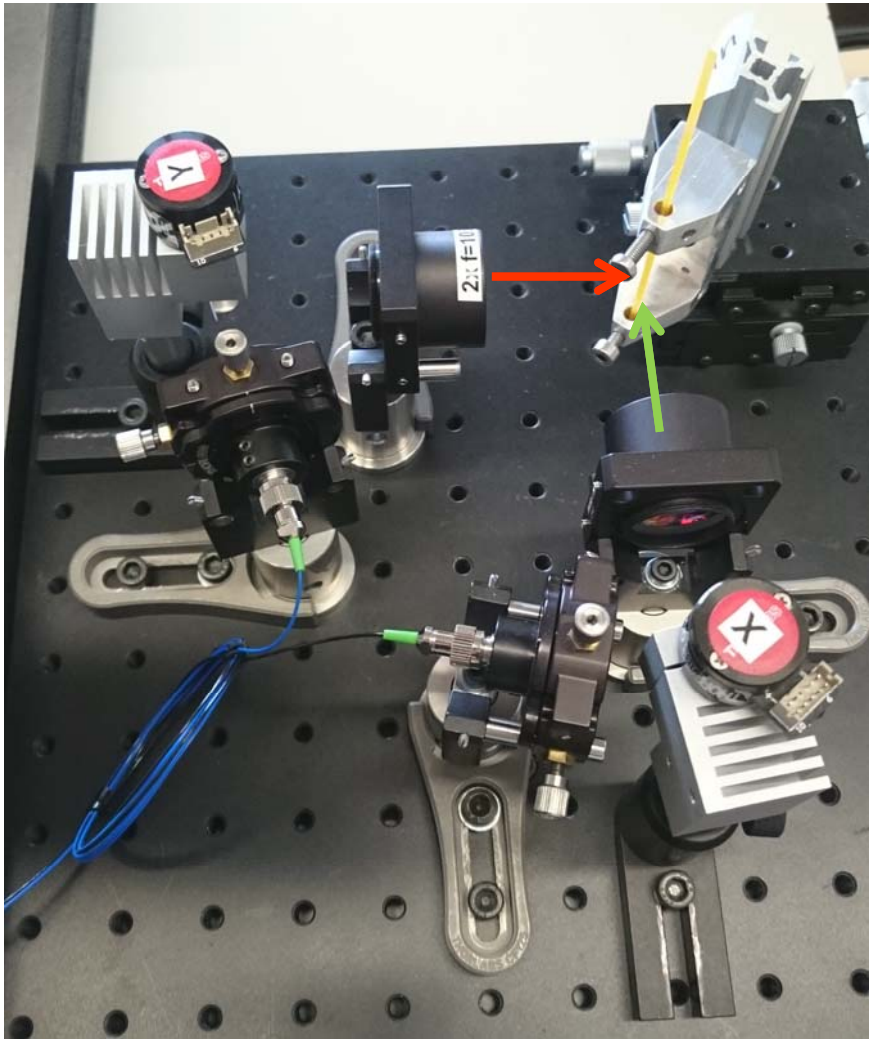


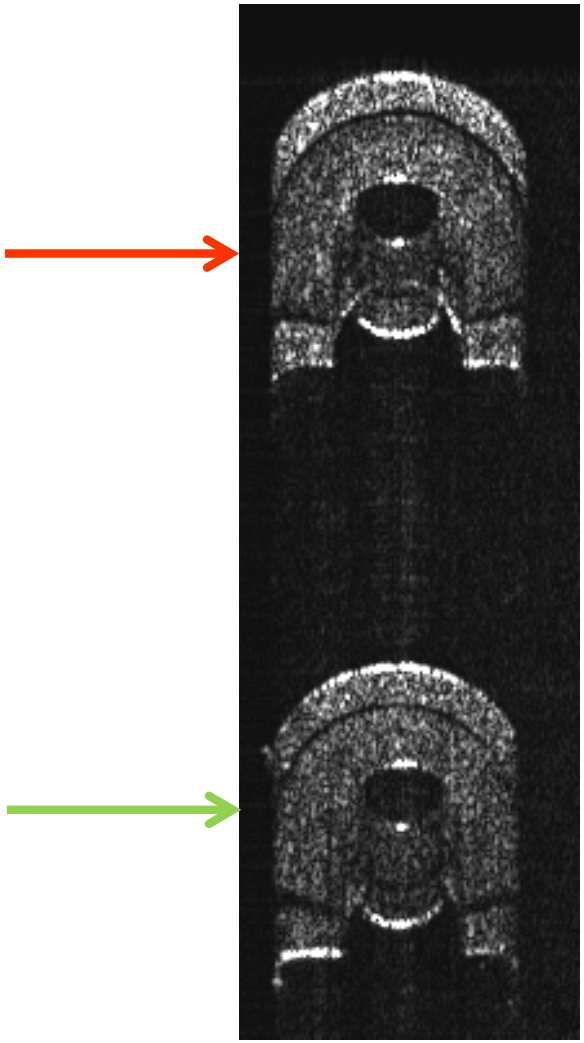




Schichtdickenmessung in Schläuchen

Zumbach
SWISS PRIME MEASURING SINCE 1957

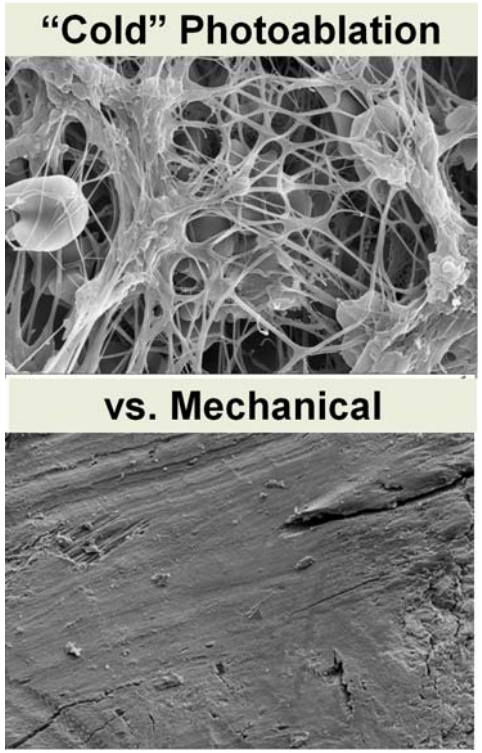


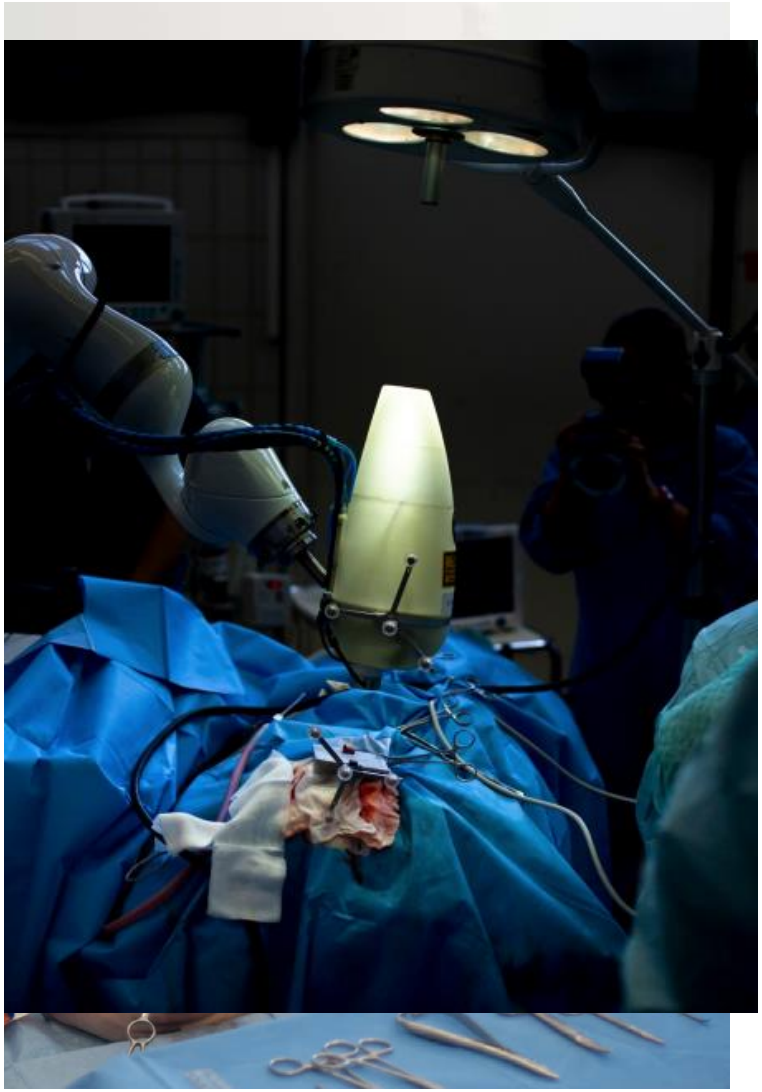


Optimized Laser Head for Contact-Free Osteotomy with real time Depth Control

AOT
Advanced Osteotomy Tools

- Robot for bone cutting
- Clean cuts, better healing



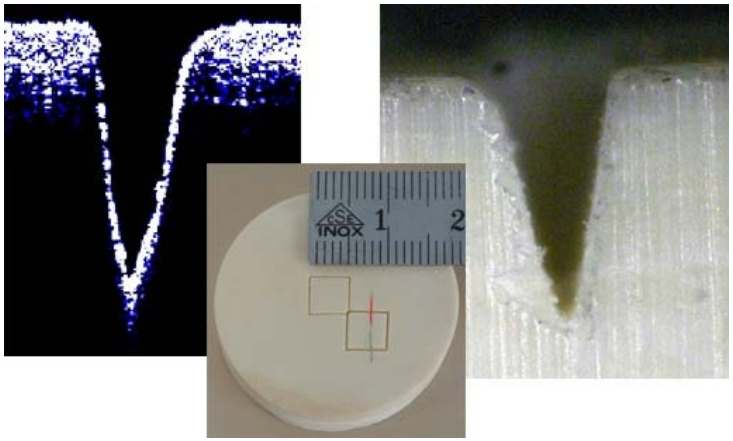


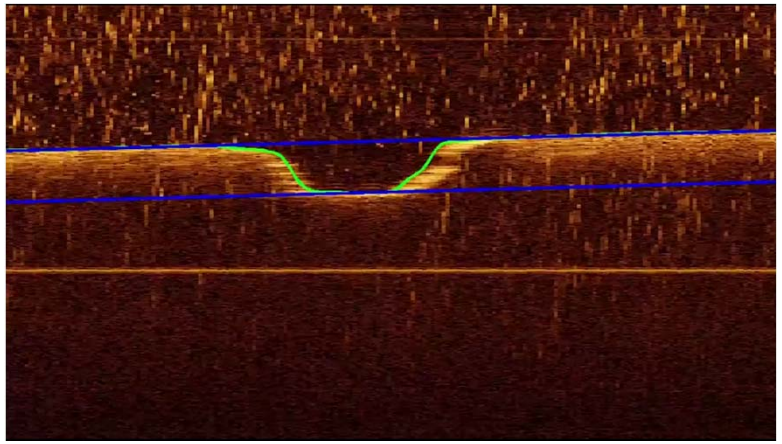
Measurement of cutting depth

AOT

Advanced Osteotomy Tools

- After each laser-shot one B-scan for depth measurement





Ultra-high Resolution OCT Monitoring for Dosimetry Control during Selective Retina Laser Treatment

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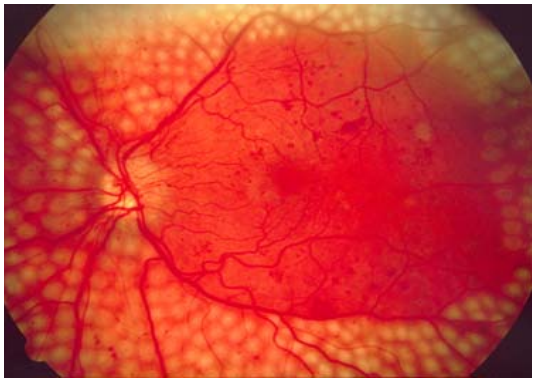
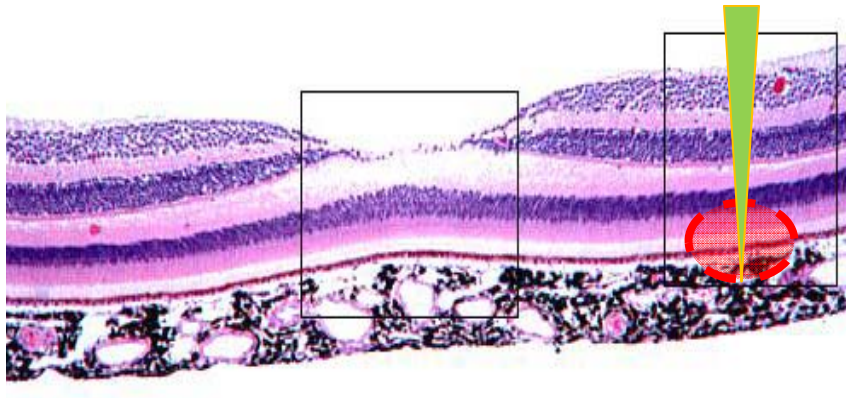


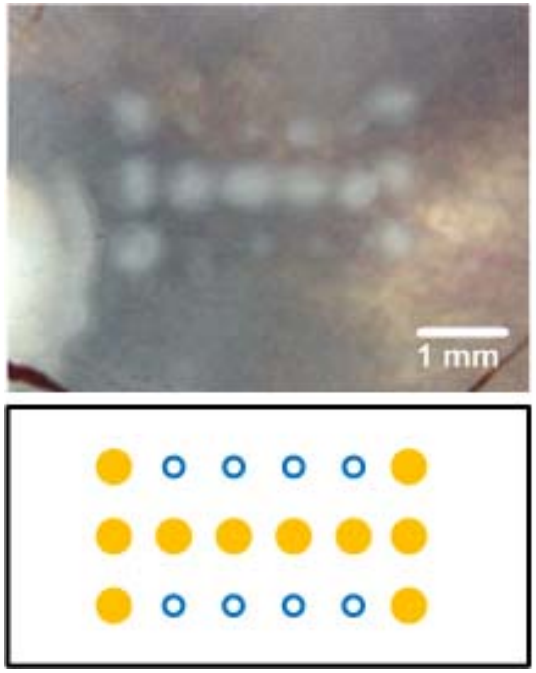
- Coagulation of RPE, photoreceptor cells, choroid
- Introduced tissue damage is irreversible
- Excessive tissue damage for RPE-linked pathologies[1]

[1] Brinkmann R, and Birngruber R, Medizinische Physik 2007; 17:6-22

Selective Retina Therapy (SRT)

- Sub-threshold laser treatment
- Tissue damage remains limited to the retinal pigment epithelium (RPE)
- Introduced retinal lesions remain ophthalmoscopically barely visible or invisible
- Dynamic changes in tissue detected by time-resolved OCT provide real-time feedback for laser dosimetry

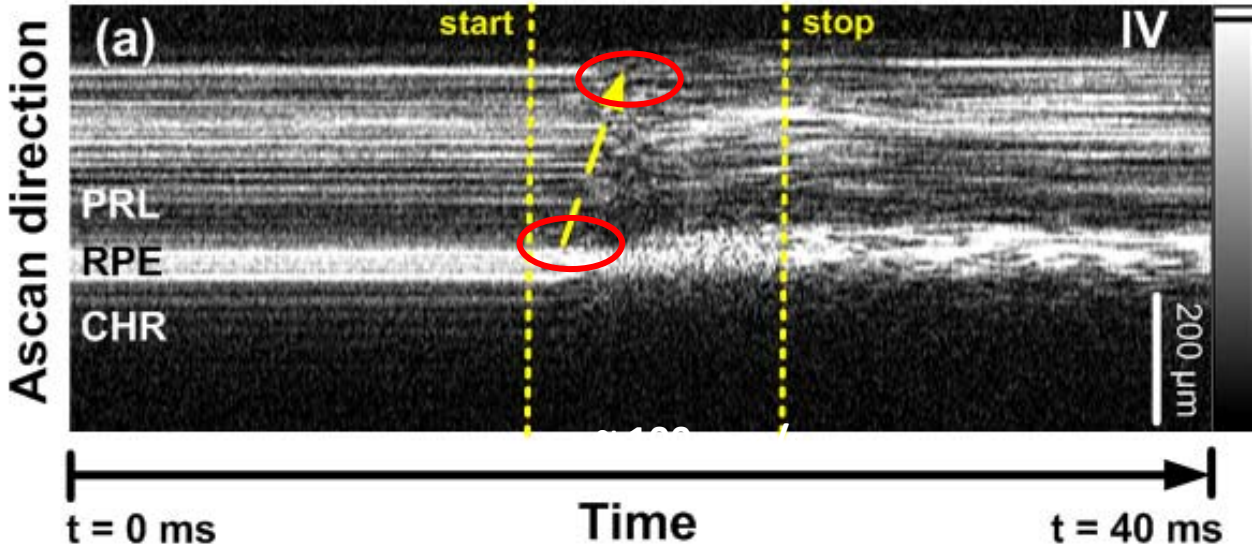




Retina: en-face view. Treatment sites (white) at different power levels and treatment plan

Time-resolved OCT data

- Effects originate in RPE / Bruch's membrane complex and expand to inner retina
- Signals linked to thermal expansion, thermal vibration and changes in tissue scattering
- Axial tissue movement in the range of few µm/s up to few m/s detectable



Clinical SRT Studies: OCT Visibility

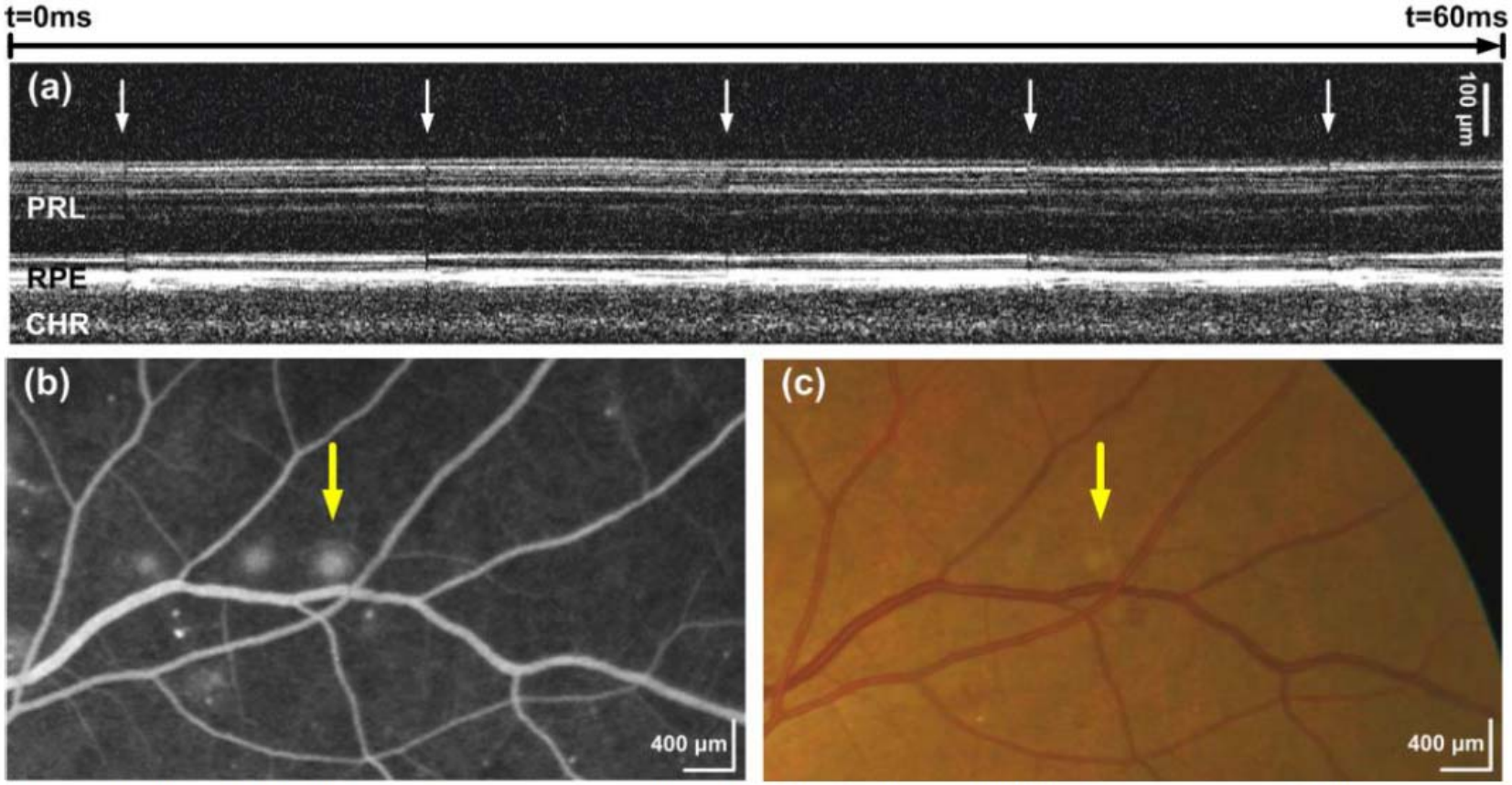


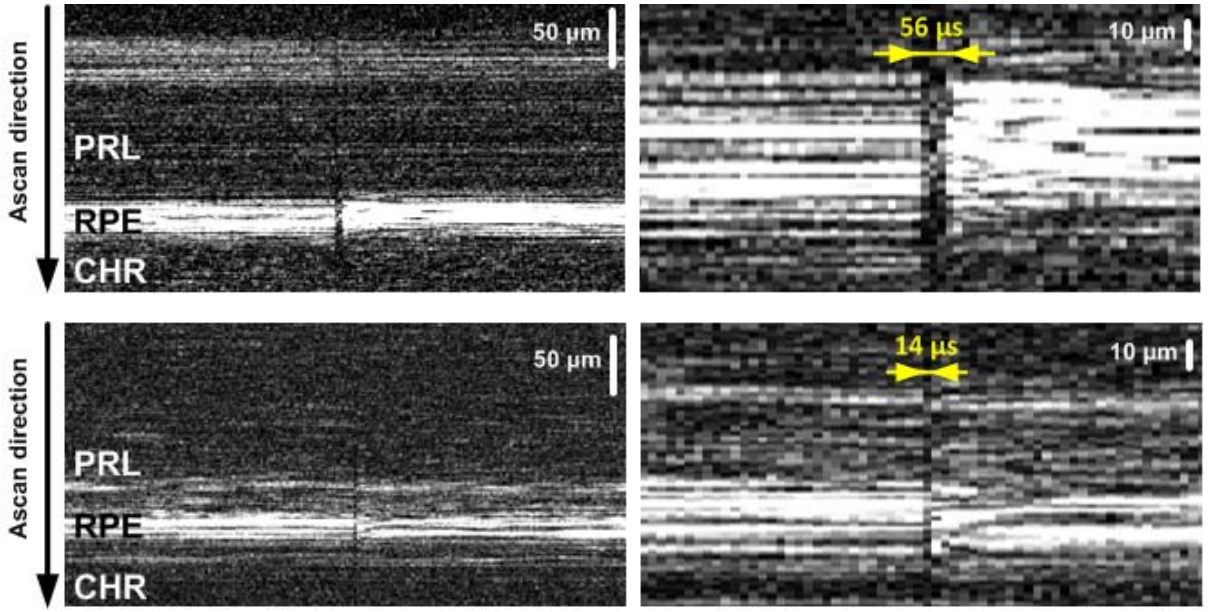
Fig. 3. The OCT M-mode scan (a) depicts SRT-induced RPE damage in OCT imaging (fringe washout), the corresponding fluorescein angiography (b) and fundus photography (c). The treatment was done on an ex-vivo porcine eye.

Damage mechanisms

- Thermal vibration
  shockwaves introduced by abrupt heating

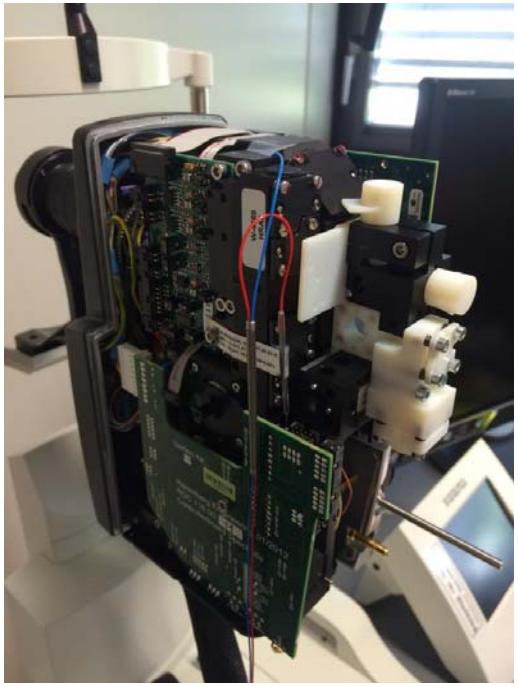
- Thermal expansion
  long term changes after the pulse, typical relaxation times of tens of ms

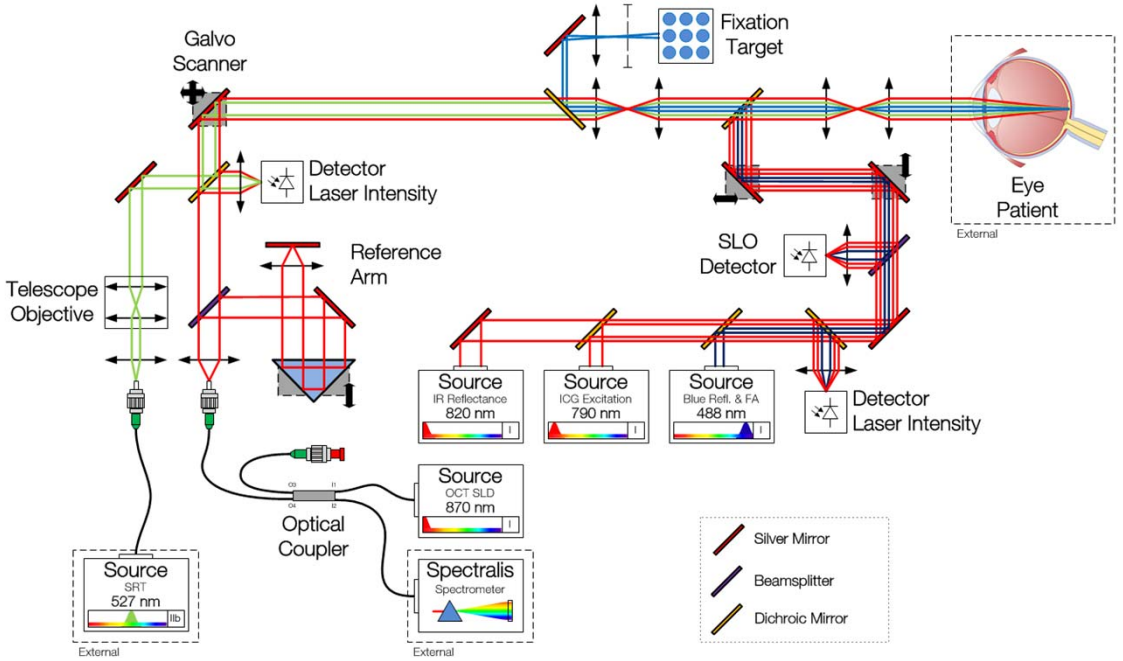
- Rapid dynamic changes
  Rearrangement of scatterers due to microbubble creation



P. Steiner. PhD Thesis 2015

Real Time Optical Coherence Tomography Laser Dosimetry control during Selective Retina Therapy





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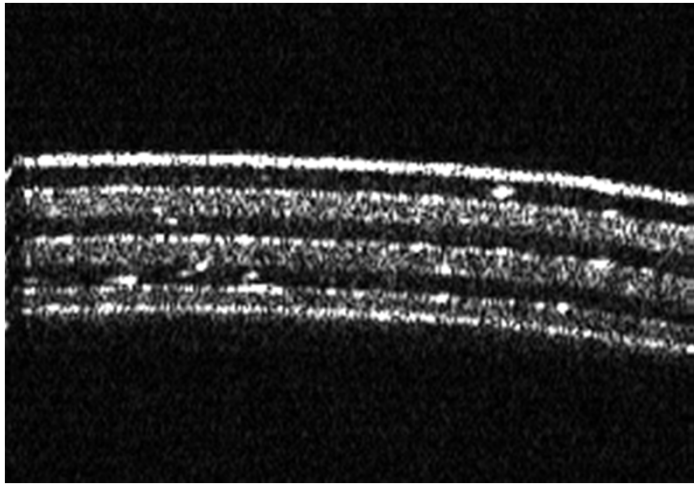
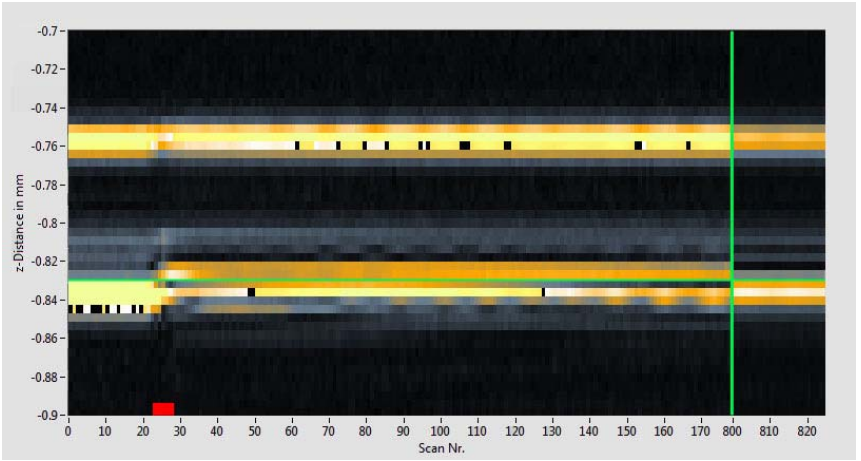
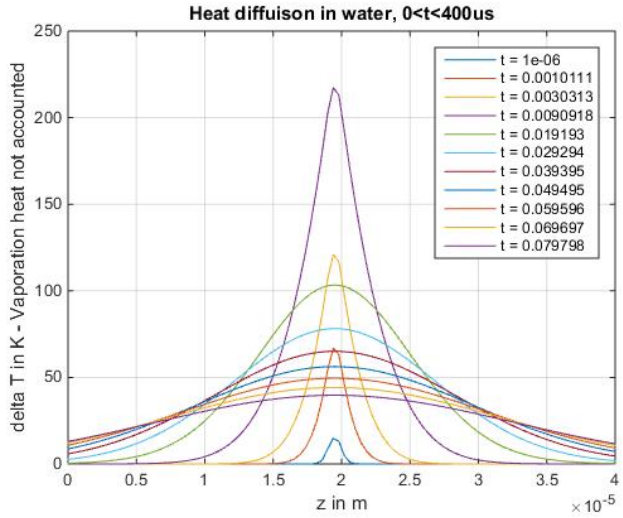
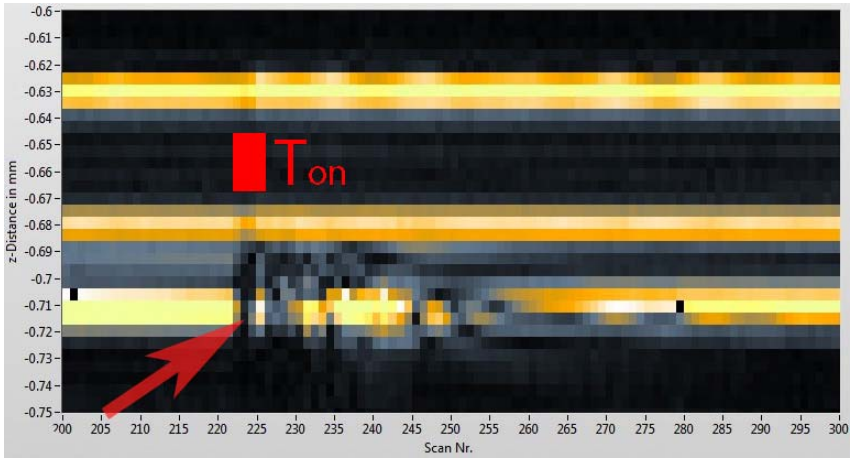
ARTORG CENTER
BIOMEDICAL ENGINEERING RESEARCH

Investigation with technical samples





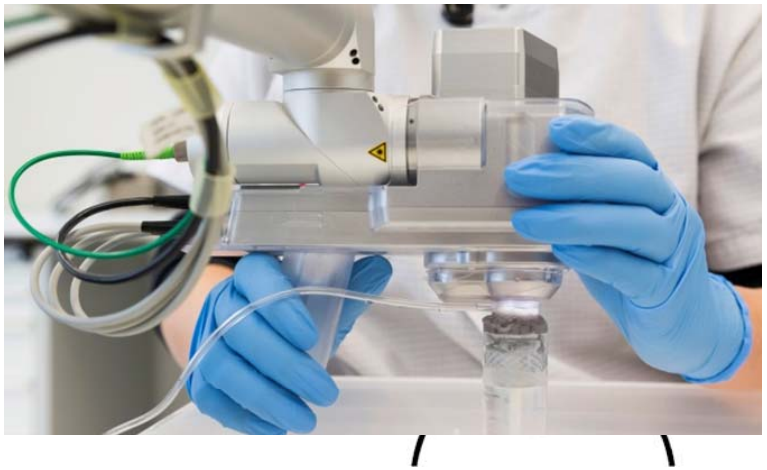




P. Morgenthaler Master Thesis 2016

Seeing Surgical Laser

- Surgical laser equipped with measurement and visualization system
- Enables planning and controlling the surgery
- Product launch 2014



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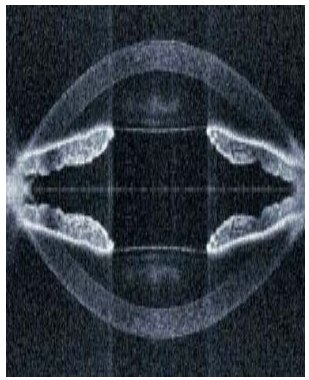
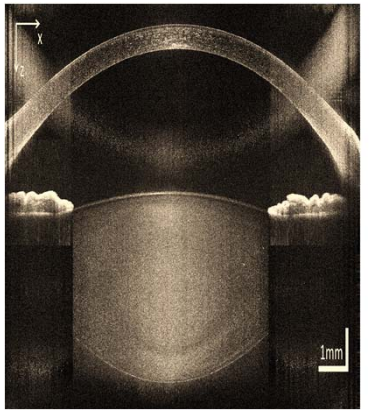
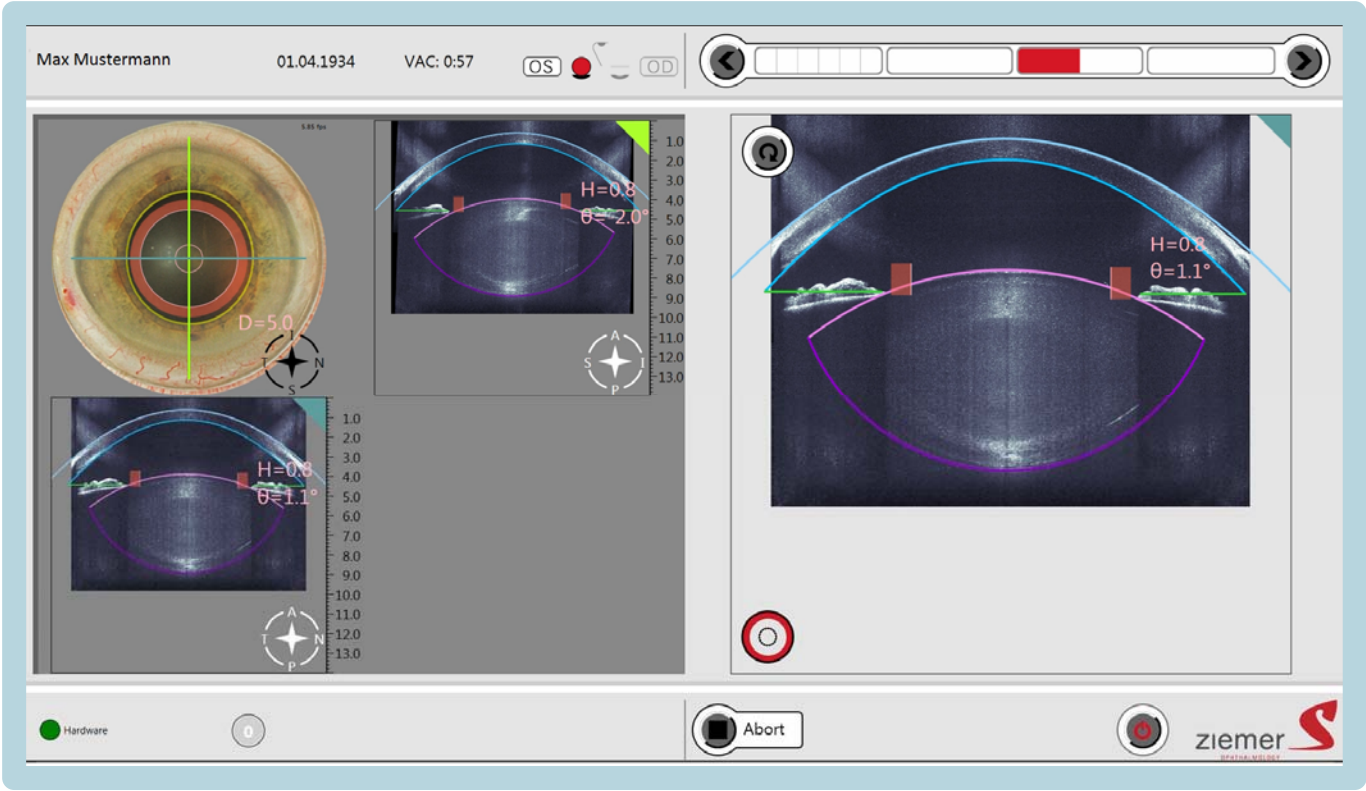
Challenge: Data Processing

- Algorithms to extend the imaging range
- Surgery planning by touch screen







HuCE-optoLab

Thank you for your attention