Optical Coherence Tomography OCT

Optische 3D Tomographie

SLN Seminar   2. Dez. 2010

Ch. Meier
www.ti.bfh.ch/OptoLab

Outline

1. Introduction

2. History and technological Basics
   Time Domain TD-OCT, Frequency Domain FD-OCT, Full Field OCT

3. OCT Applications
   Ophthalmology, Cardiology, Dermatology

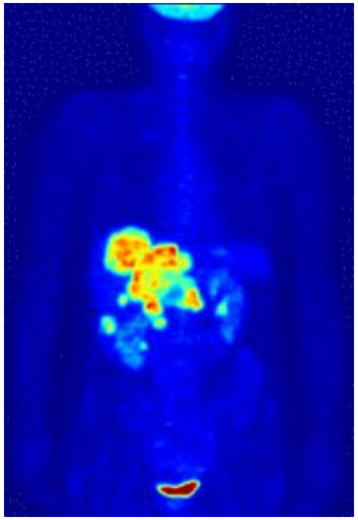
4. Some Projects @ OptoLab, BFH-TI, Biel

5. OCT-Future: Speed, Spectral, Doppler, Phase, Polarization

Tomographic Methods in Medicine

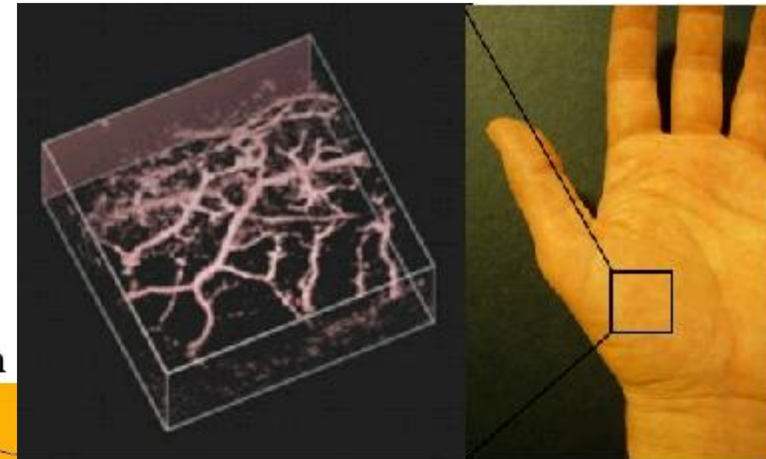
Tomography = 3D image by sections
Greek word tomos = slice, section

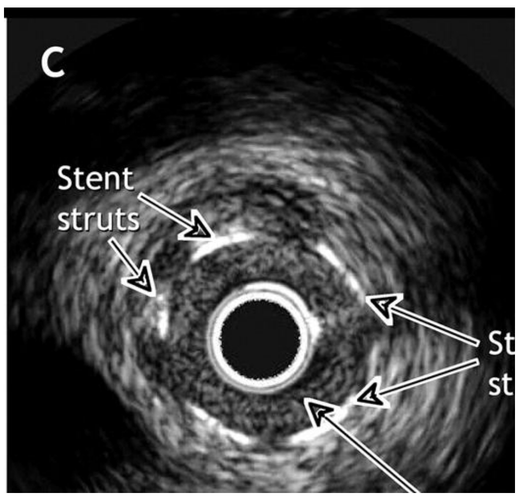
- CT X-ray
- MRI Magnetic Resonance Imaging
- PET Positron Emission Tomography



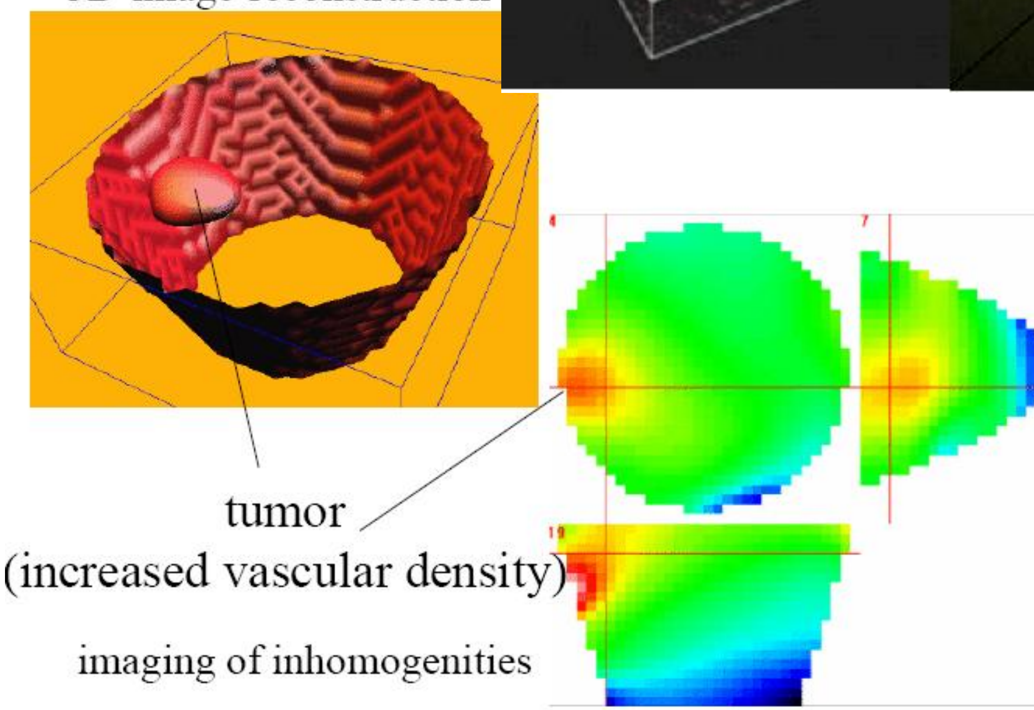
Tomographic Methods in Medicine

- UST Ultra Sound Tomography
- DOT Diffuse Optical Tomography
- PAT Photoacoustic Tomography



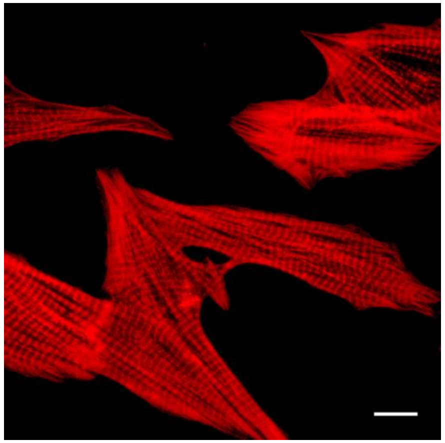


3D-image-reconstruction



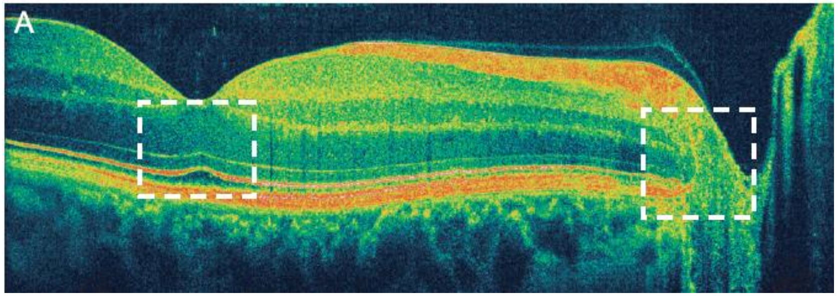
Tomographic Methods in Medicine

- Confocal Microscopy



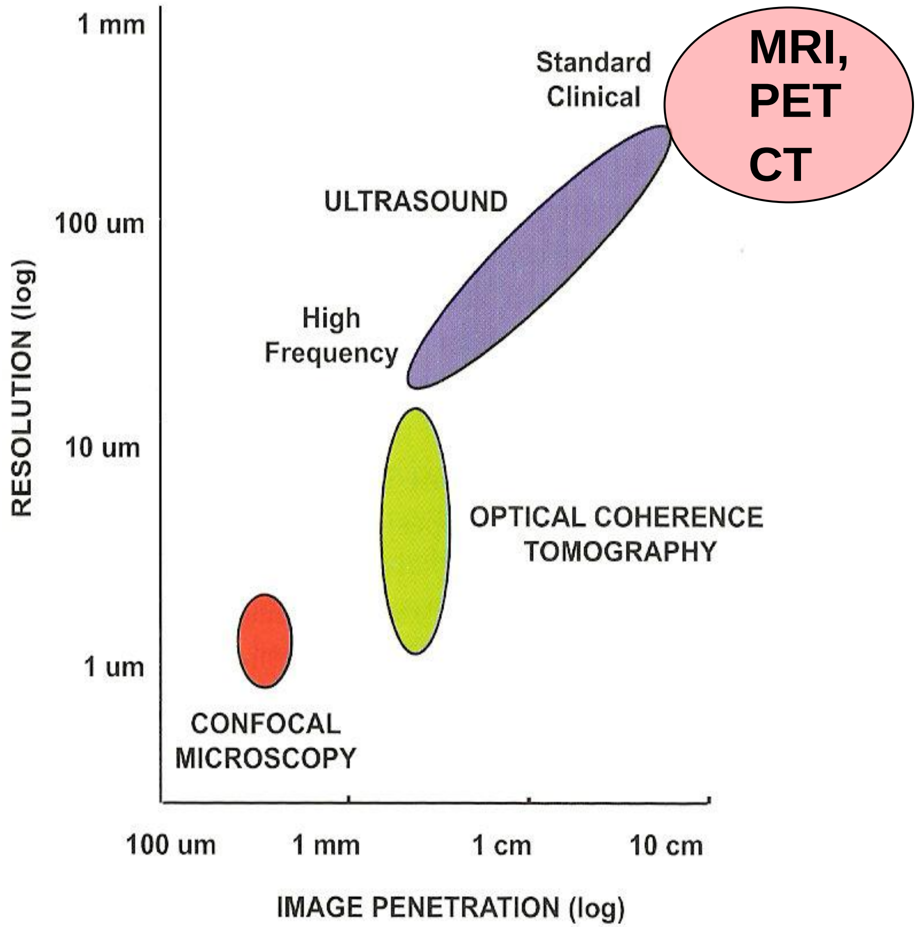
Cardiac myocytes I Bar = 10µm.
Dr. Robert Ross, UCLA Medical School.

- **OCT**
  Optical Coherence Tomography



Drexler W., Fujimoto J. Science Direct 2007

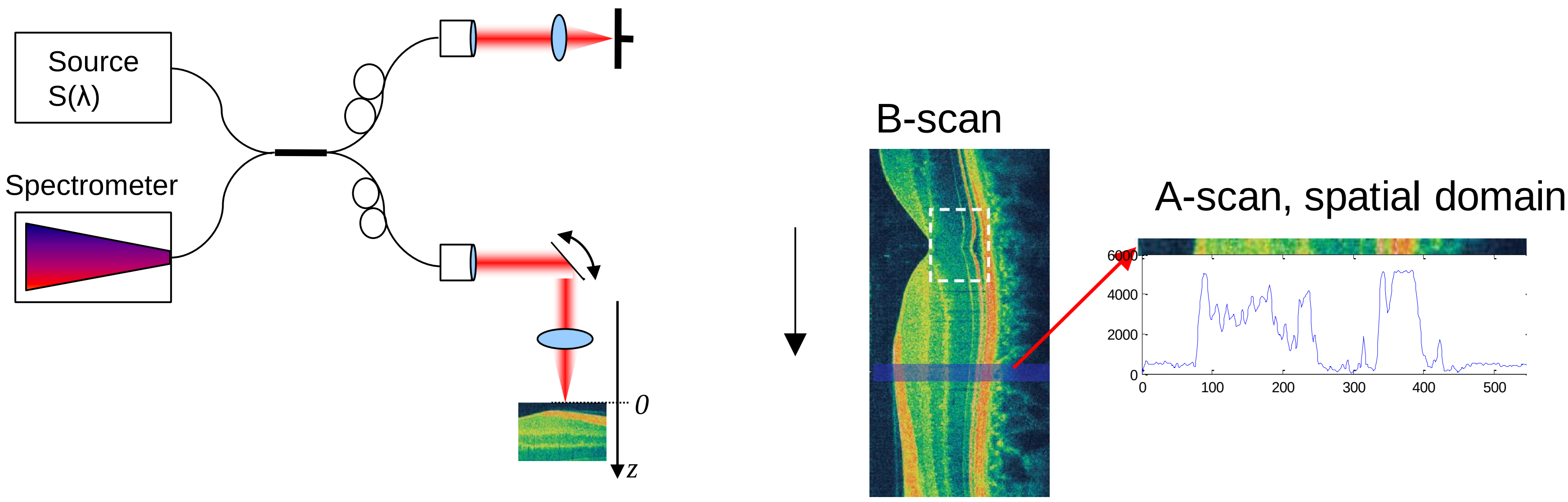
Tomographic Methods in Medicine



Name	Speed	Hazard
CT	-	+++
MRI	-	-
PET	-	+++
UST	++	-
DOT	-	-
PAT	+	-
OCT	+++	-

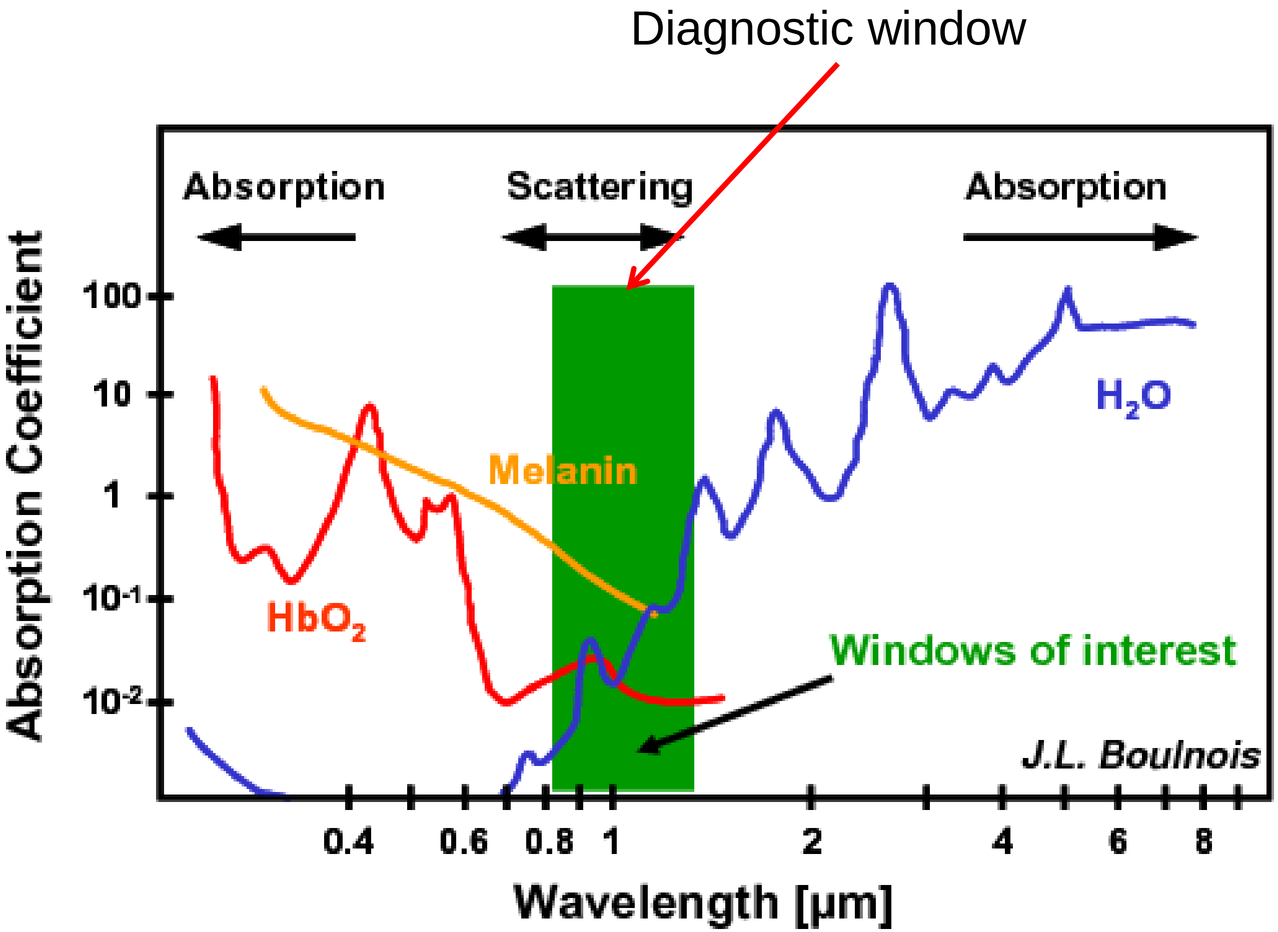
3D Imaging by lateral scanning

- Depth profiles are constructed by measuring the time delay of backscattered or back reflected light by interferometric measurements
- Similar to ultrasonic time of flight measurements
- Cross sectional images are obtained by scanning in x and y direction



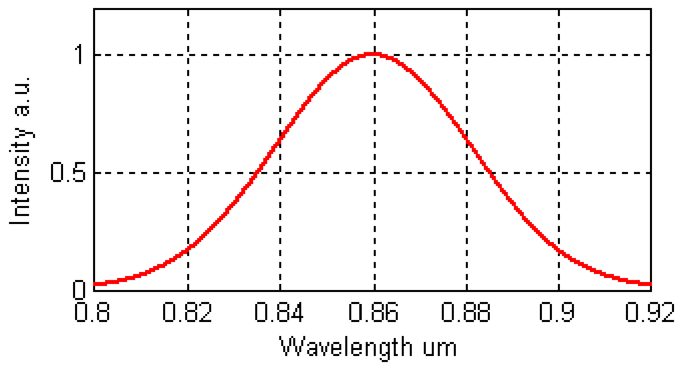
OCT: wavelength range

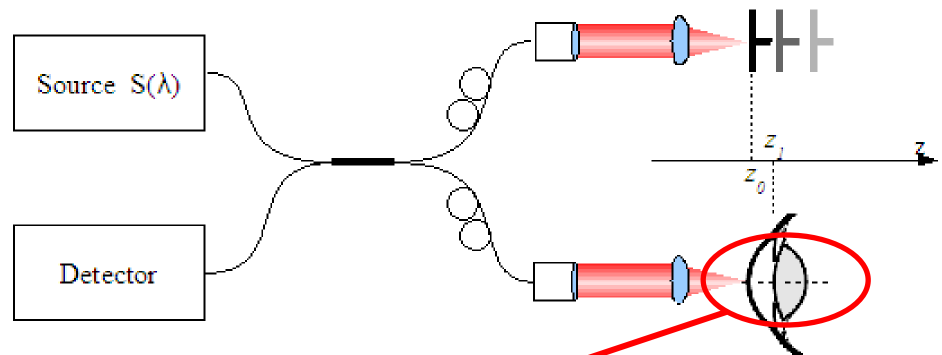
Hemoglobin and water have low absorption in near infrared

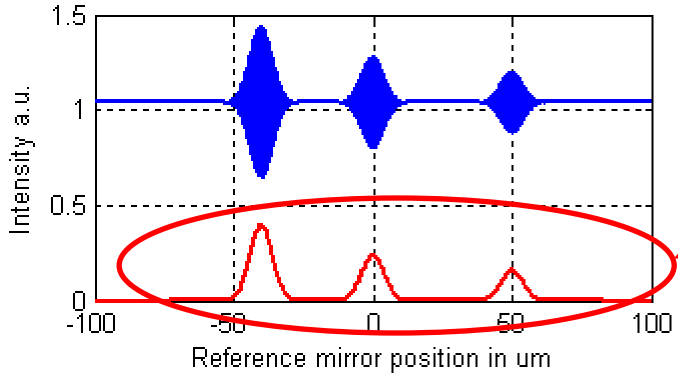


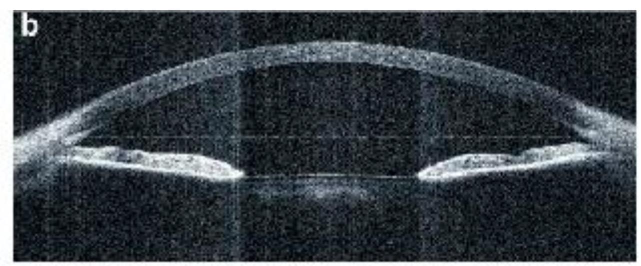
Basic principle: Time Domain OCT

Michelson Interferometer setup with moving reference mirror









From: Sarunic, Optics Letter 2006

The signal envelope represent the reflectivity depth profile

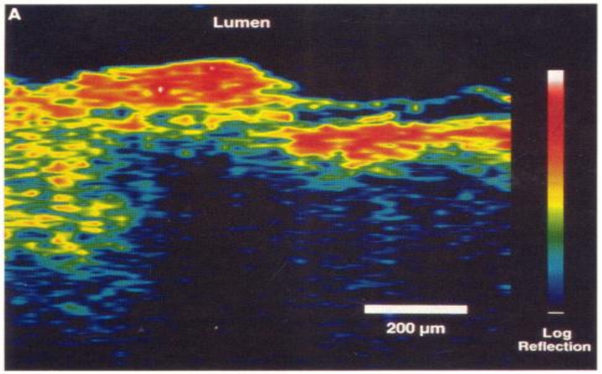
OCT History, the beginnings

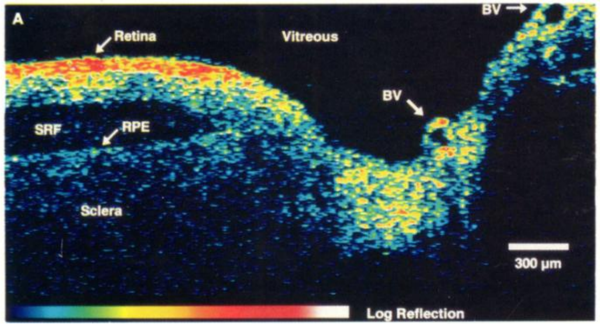
1991 First medical application of Time Domain OCT in vitro (Huang, Fujimoto, Science)

1993 Demonstration of OCT on eye in vivo (Fercher)

1996 First commercial application In Ophthalmology. STRATUS, ZEISS

- Zeiss hold monopole on ophthalmic market thanks to strong patents.
- Glaucoma, AMD, Diabetic Retinopathy.
- 2006 are 6000 Stratus in use.





OCT Market development

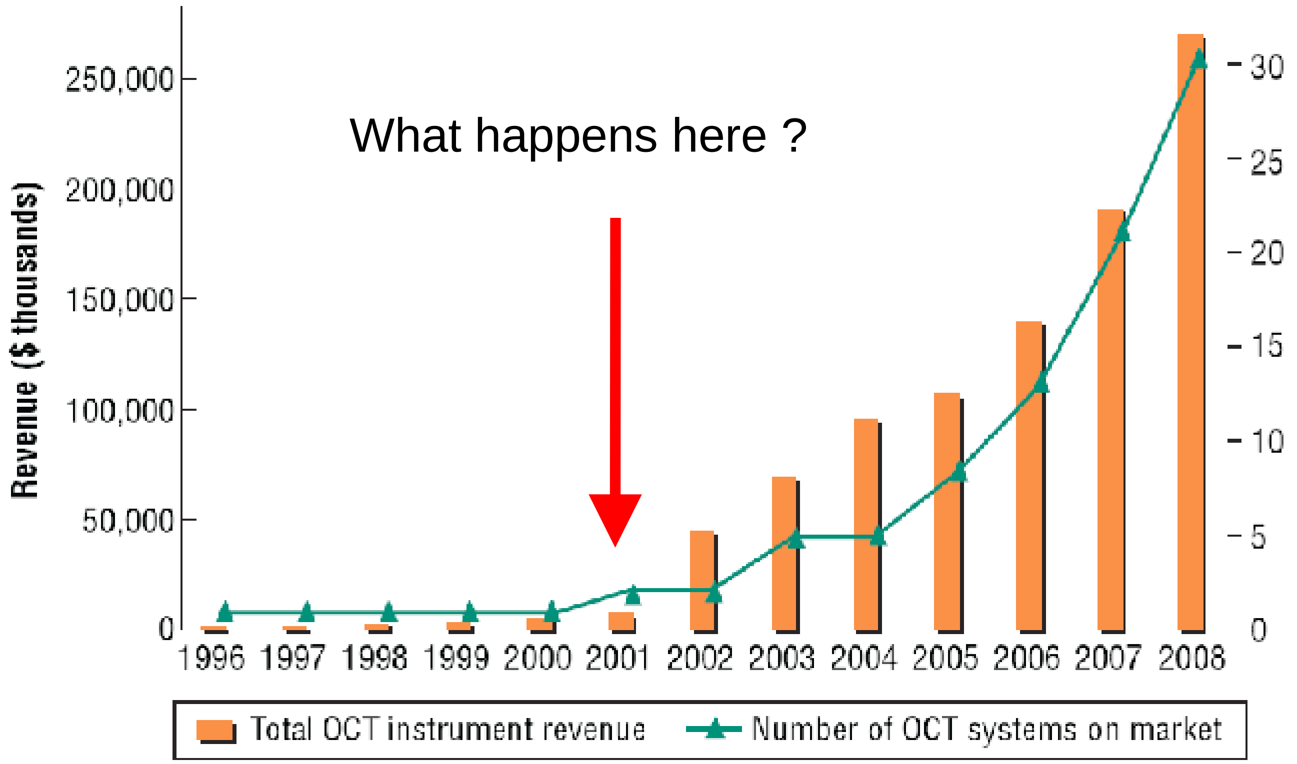


FIGURE 1.3 OCT products and revenue 1996–2008

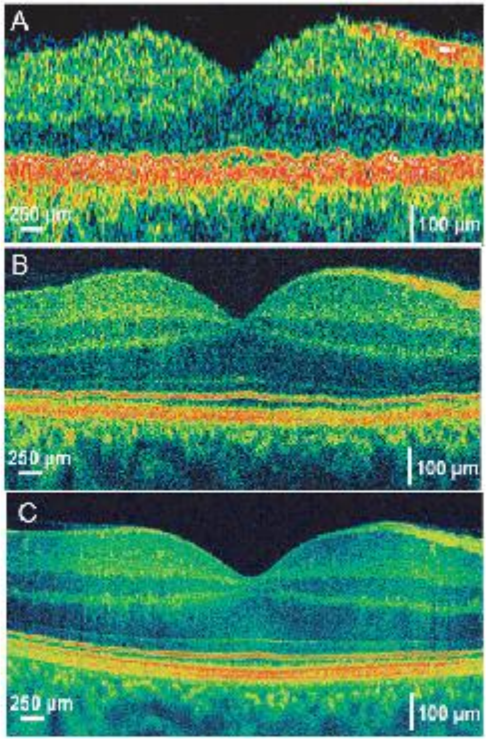
OCT History, second generation

1995 First Publication of a new method: Fourier Domain OCT (Fercher, J. of Optics Communication, 1995)

1998 Application to Dermatology (Häusler, J. of biomedical Optics)

2000 Several papers to Fourier Domain OCT
The new method is faster, has better contrast and image quality

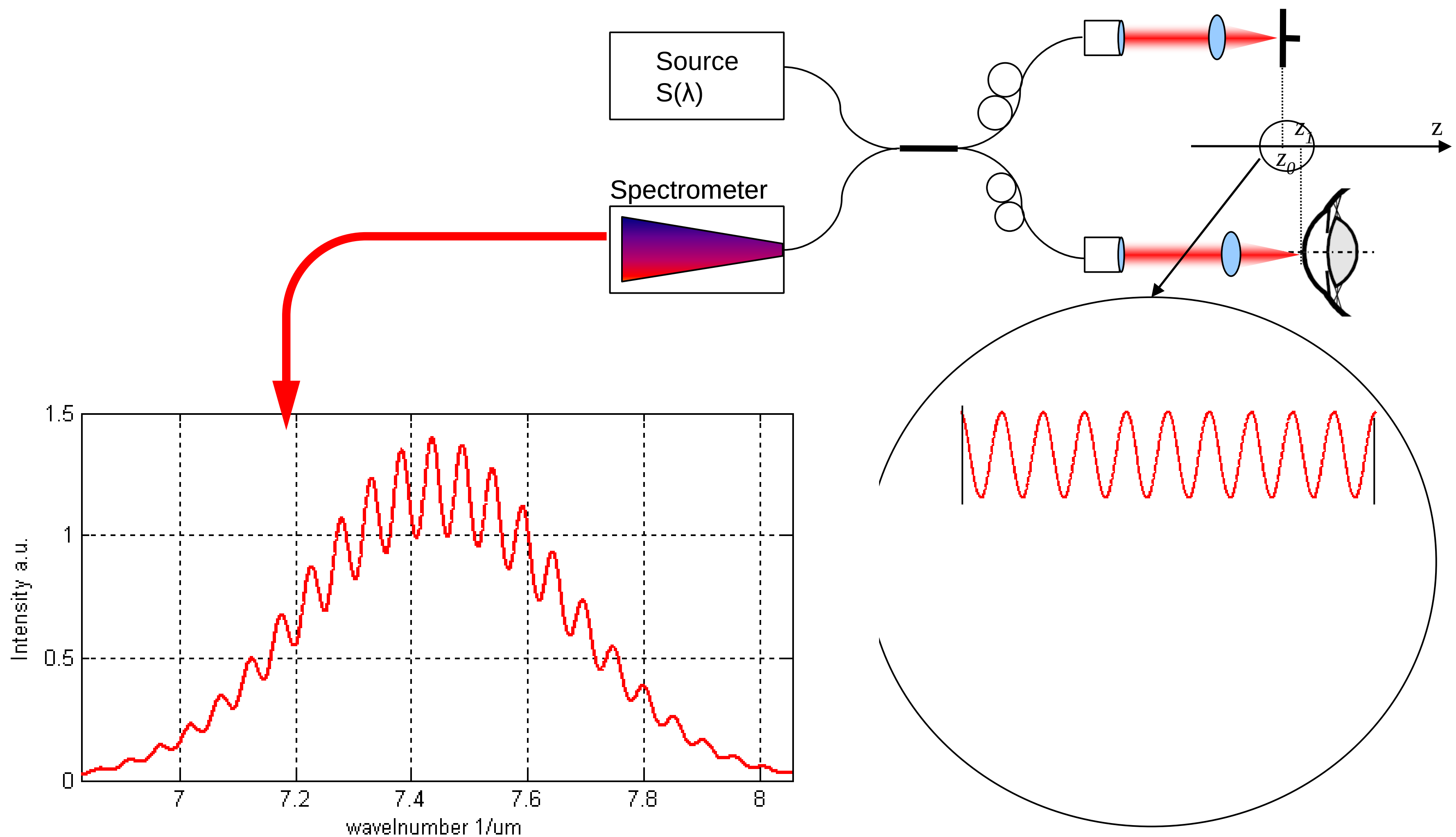
2002 First instrument on market



The ideas to the second generation OCT systems were published before patents were deposed

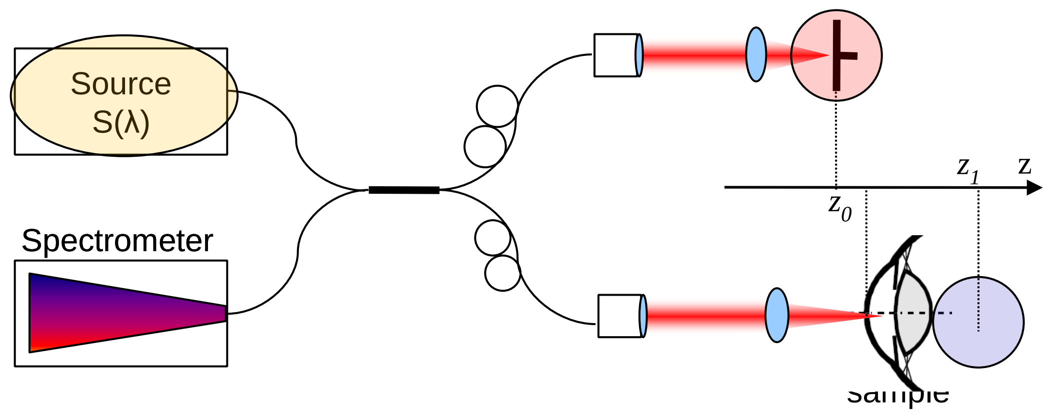
The technique is free !!

FD-OCT, basic principles

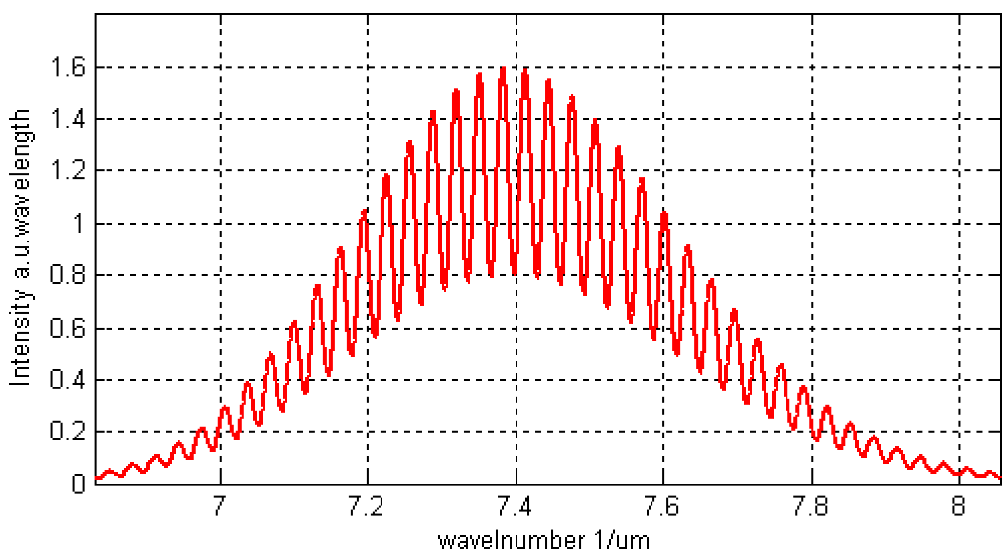


FD-OCT, basic principles

Interferences due to optical path difference



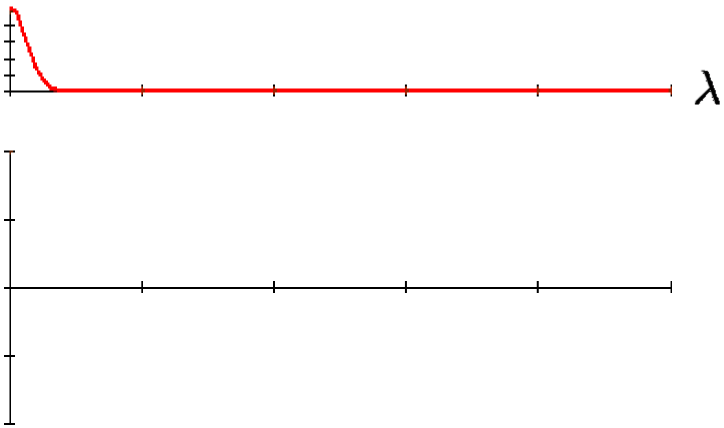
$$FD(k) = S(k)(r_R^2 + r_s^2 + 2r_R r_s cos(2kz))$$

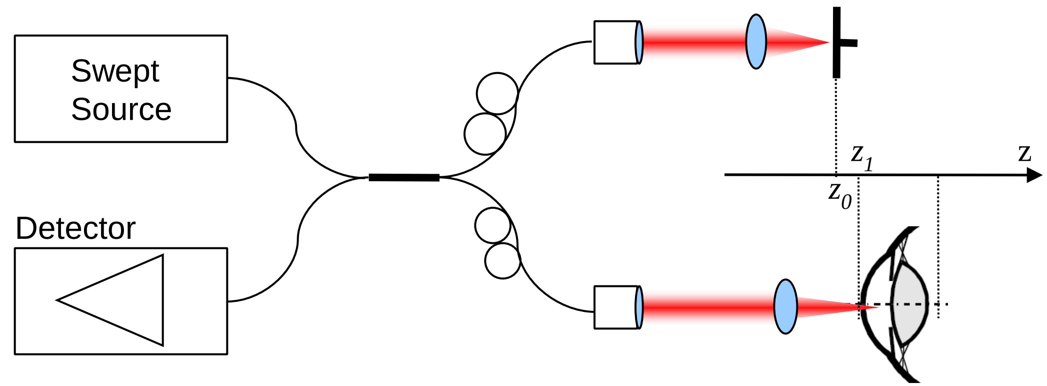


Frequency in k-space is proportional to OPD

Reflectivity profile is obtained by a Fourier transformation

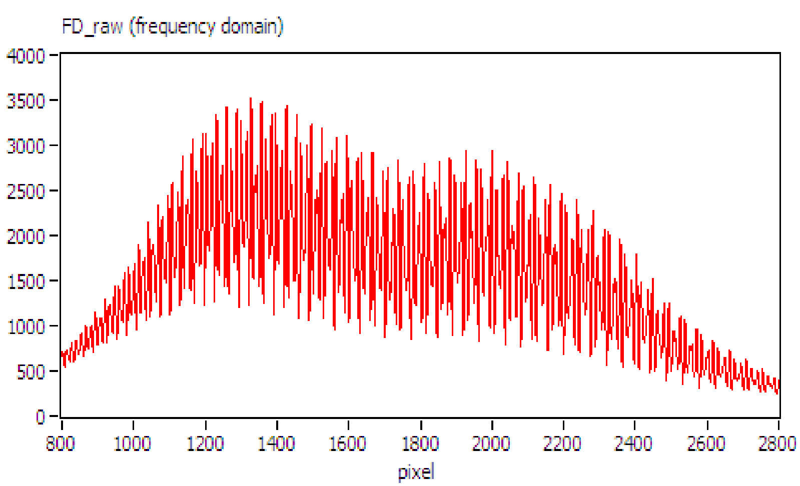
FD-OCT, basic principles, swept source

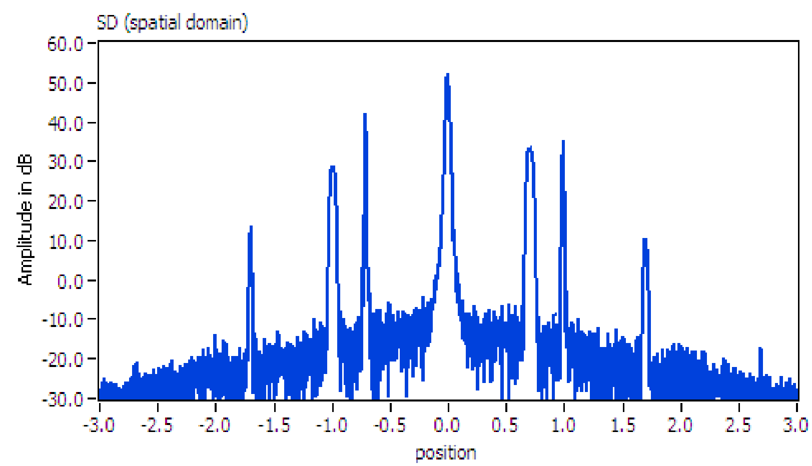




$$FD(k) = S(k)(r_R^2 + r_s^2 + 2r_R r_s cos(2kz))$$

$$SD(z) = \mathcal{F}^{-1}[S(k)] \otimes \mathcal{F}^{-1}[2r_R r_s cos(2kz))]$$

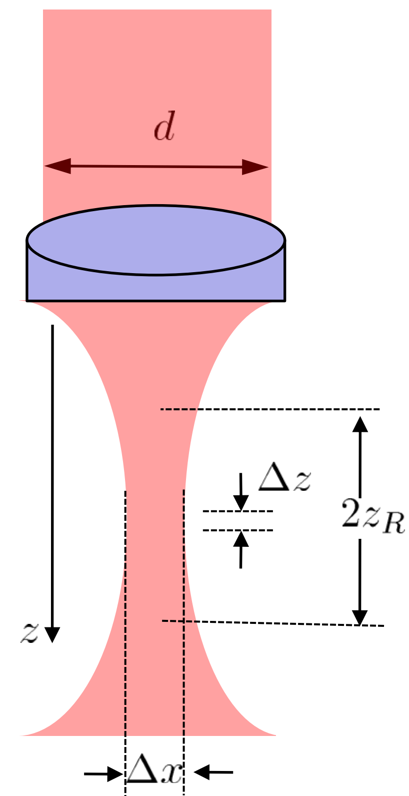




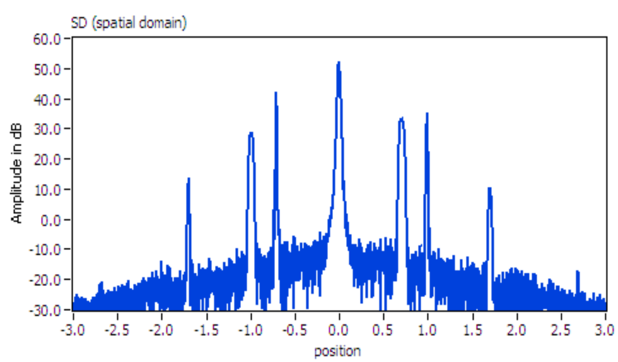
Resolution: OCT and Microscopy

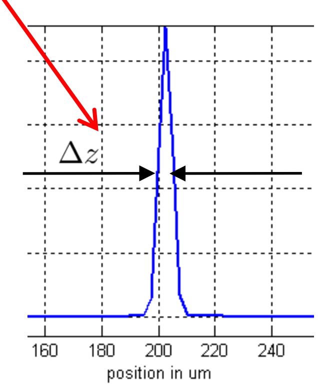
	Lateral resolution	Axial resolution
Confocal Microscope	$\Delta x \sim \frac{1}{N_A}$	$\Delta z \sim \frac{1}{N_A^2}$
OCT	$\Delta x \sim \frac{1}{N_A}$	$\Delta z = \frac{4ln(2)}{\Delta k}$

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

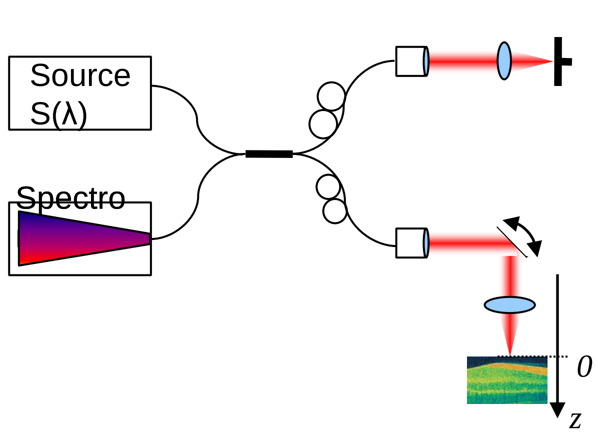


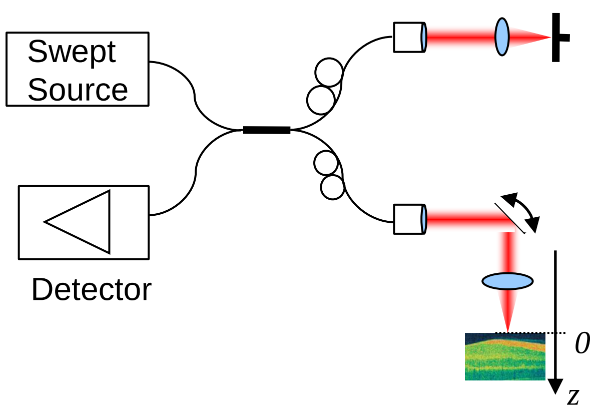
Coherence gate



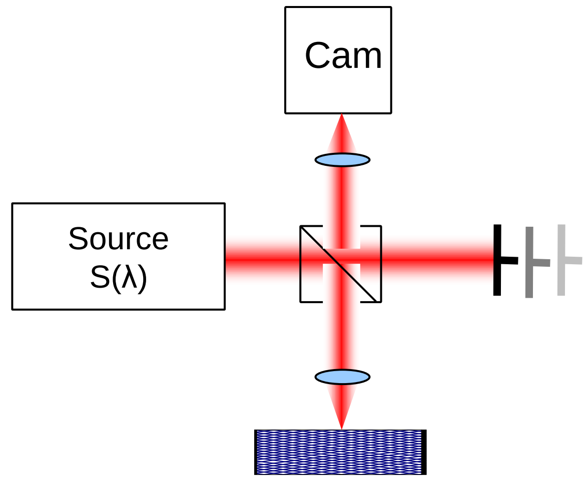


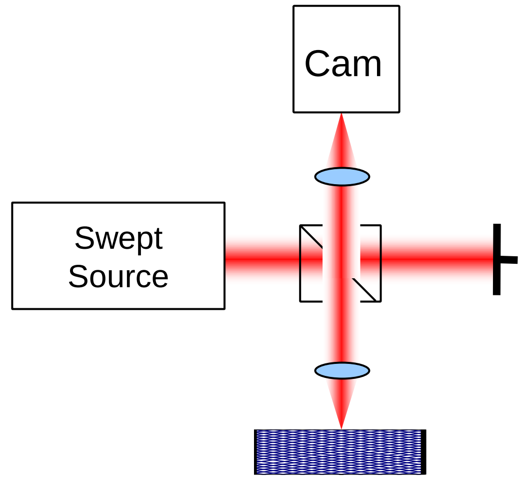
Scanning FD OCT



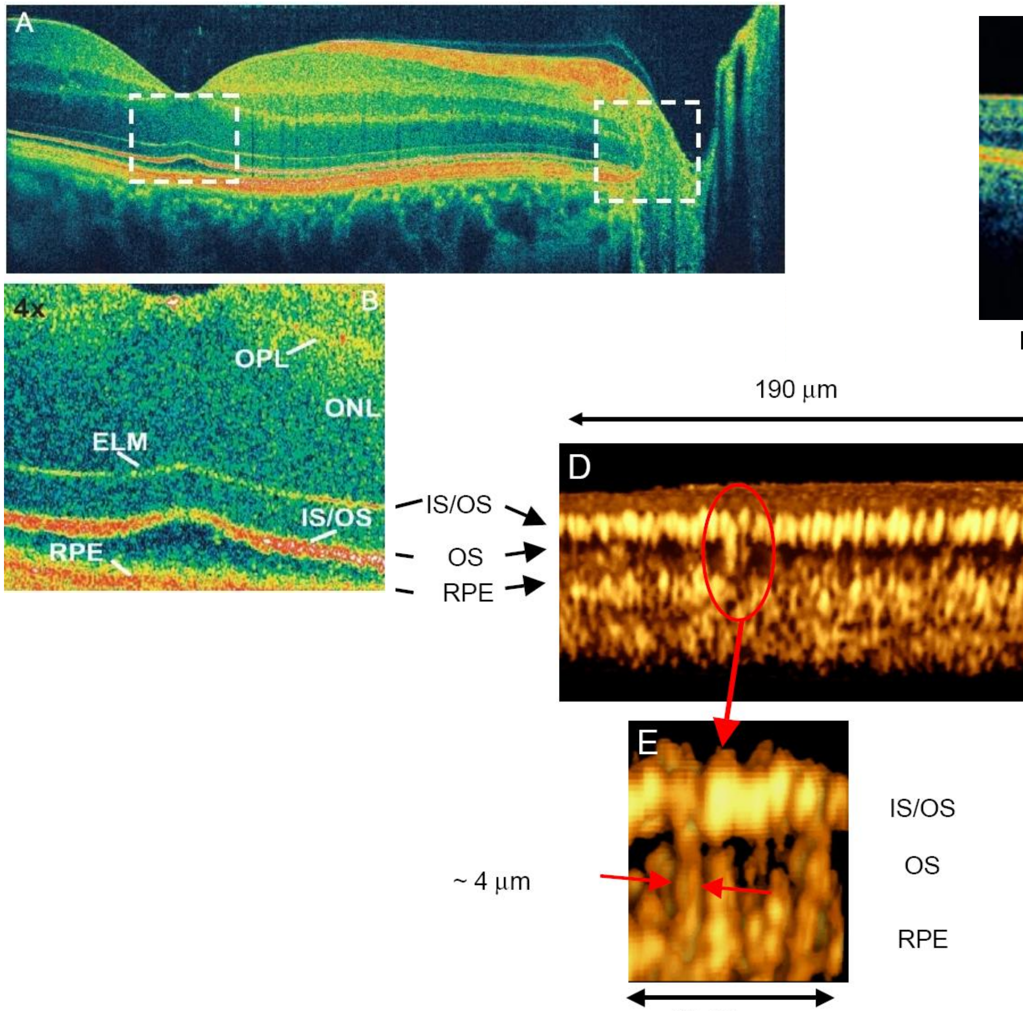


Full Field OCT

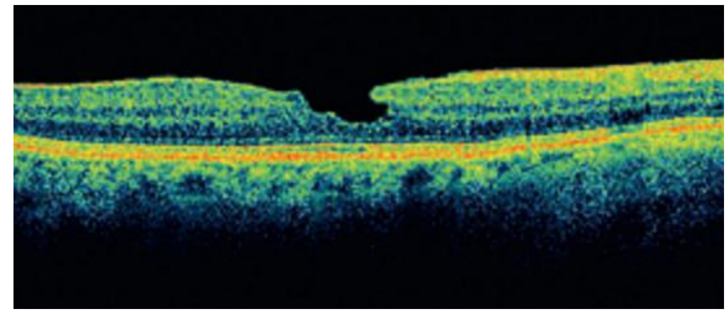




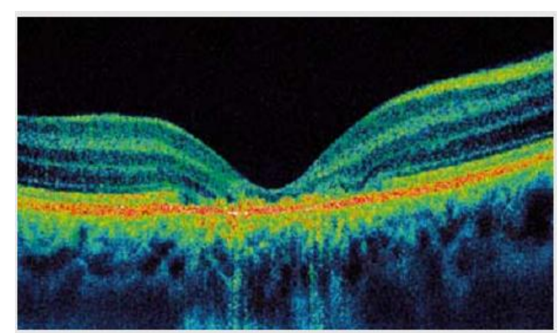
State of the art, retina imaging



From: Drexler W., Fujimoto J. Science Direct 2007

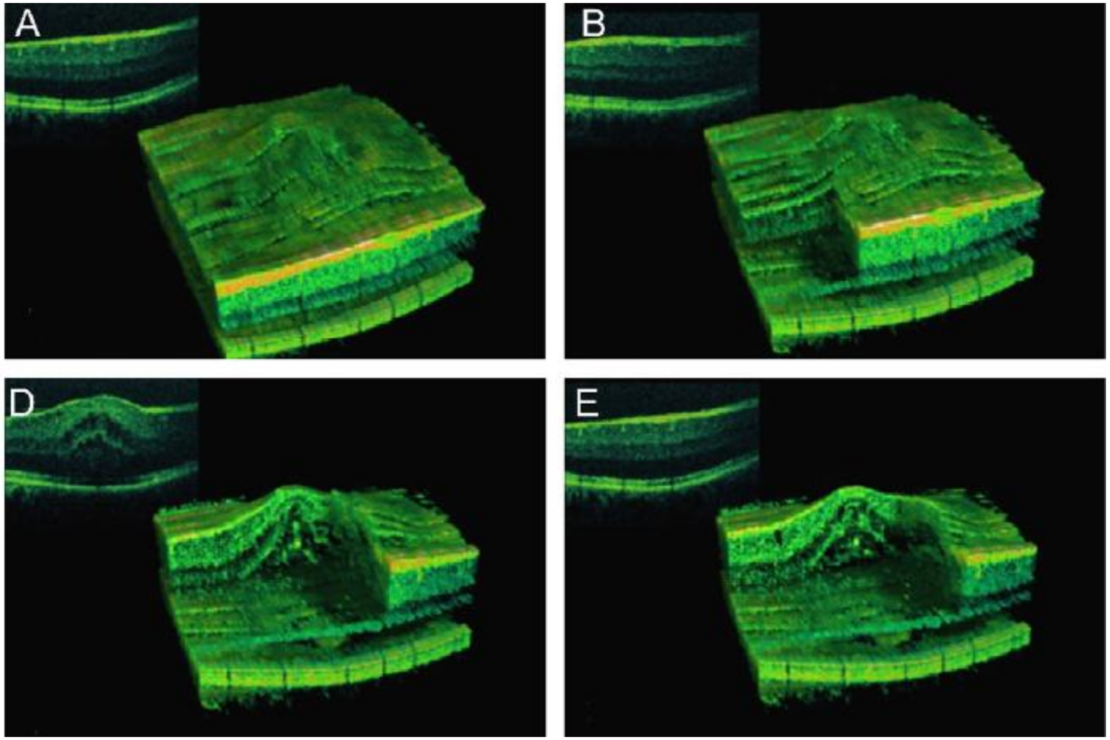


From Zeiss cyrrus



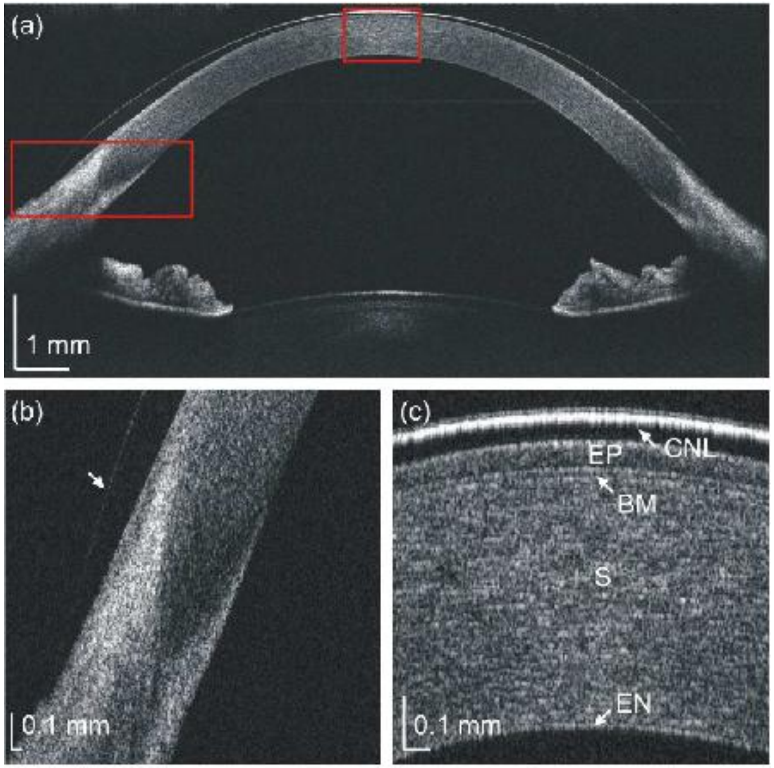
From OptoPol, soct_HR

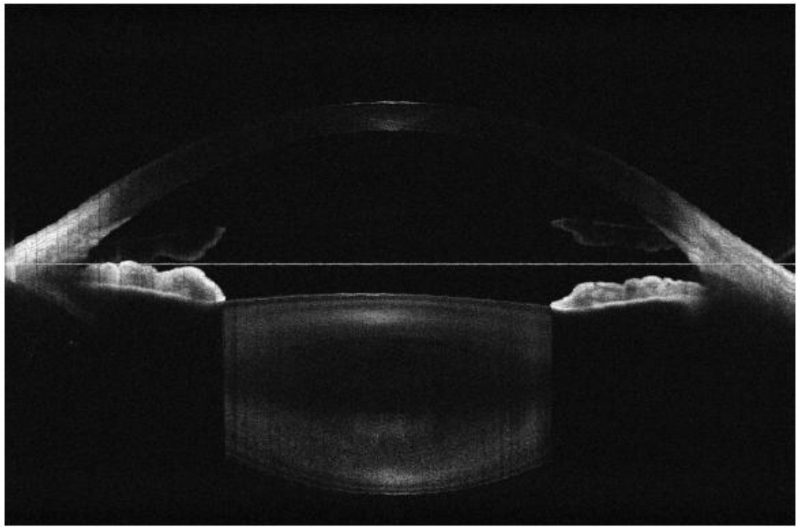
State of the art, retina imaging



From: Drexler W., Fujimoto J. Science Direct 2007

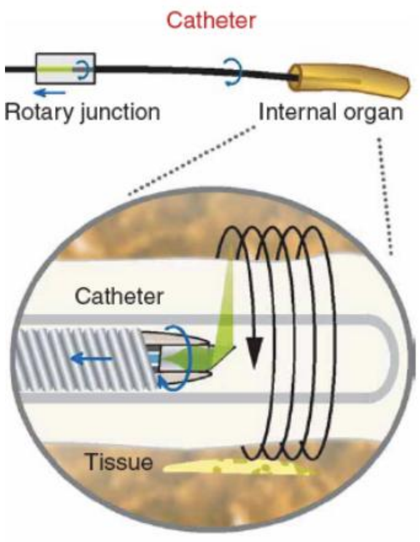
Anterior segment of the eye



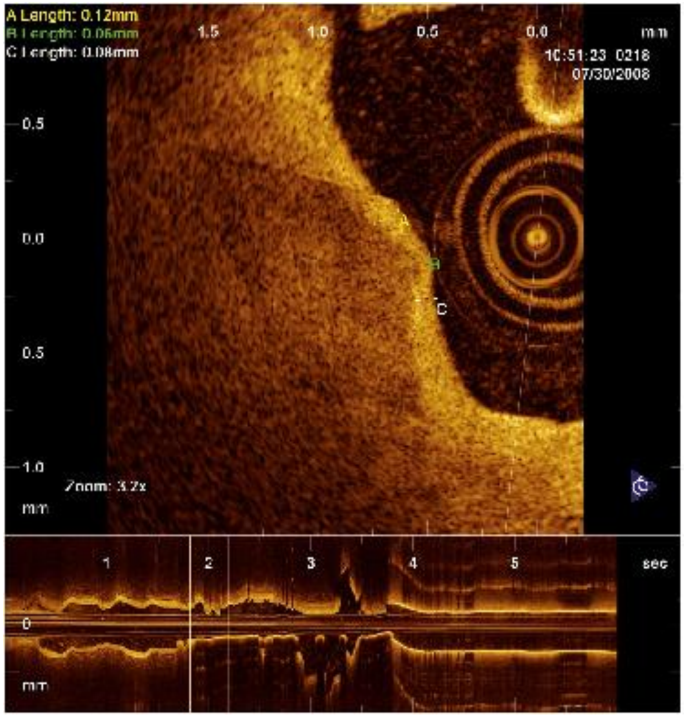


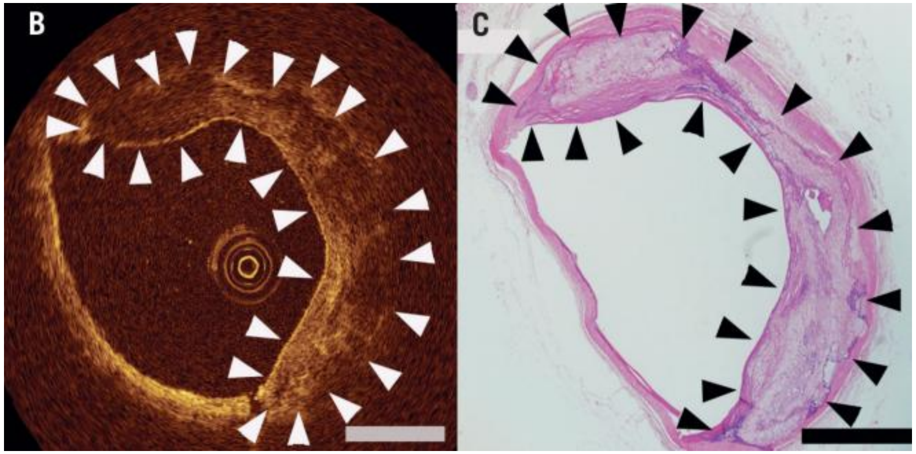
From: Grulkowski., Optic Express, march 2009

Endoscopic OCT and cardiology



From LightLab





Kume, **Assessment of corocary calcification by OCT**, PCR online 2010

Optical Biopsy

Tissue investigation without extraction

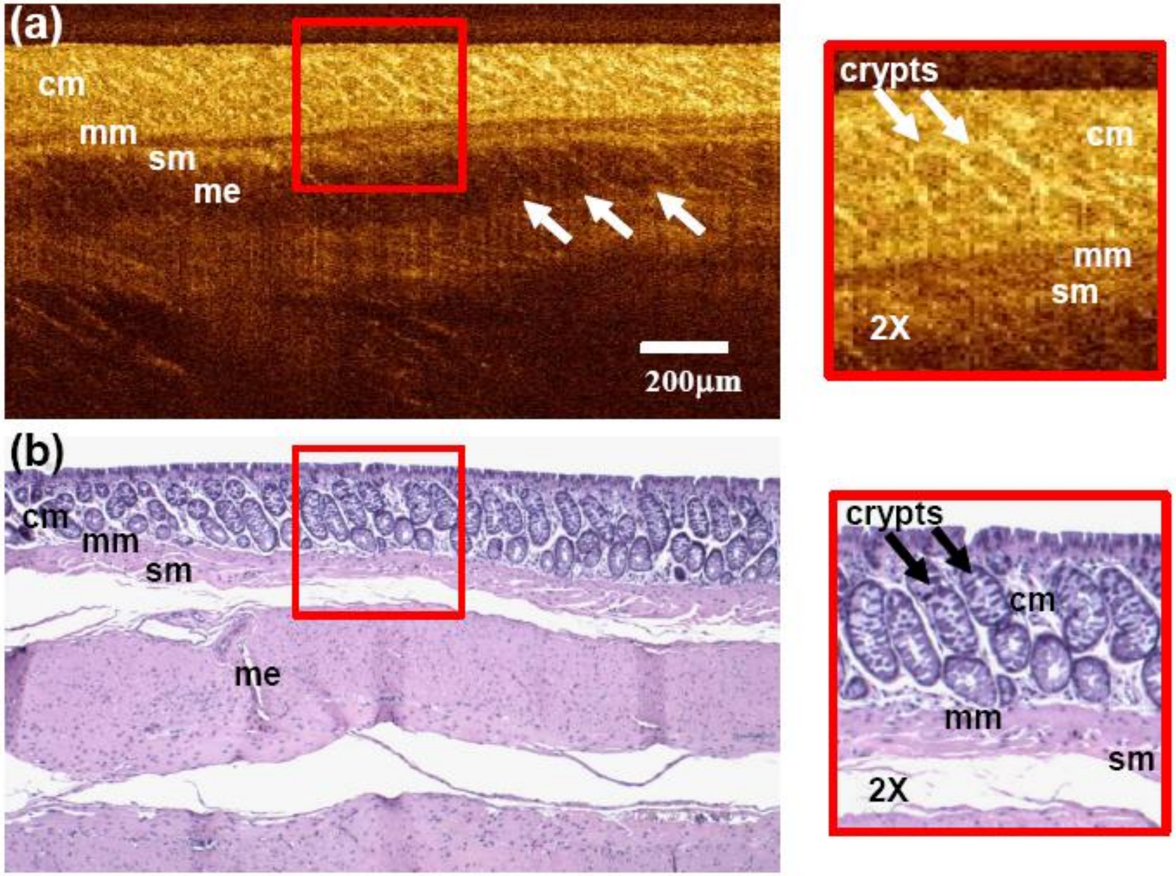


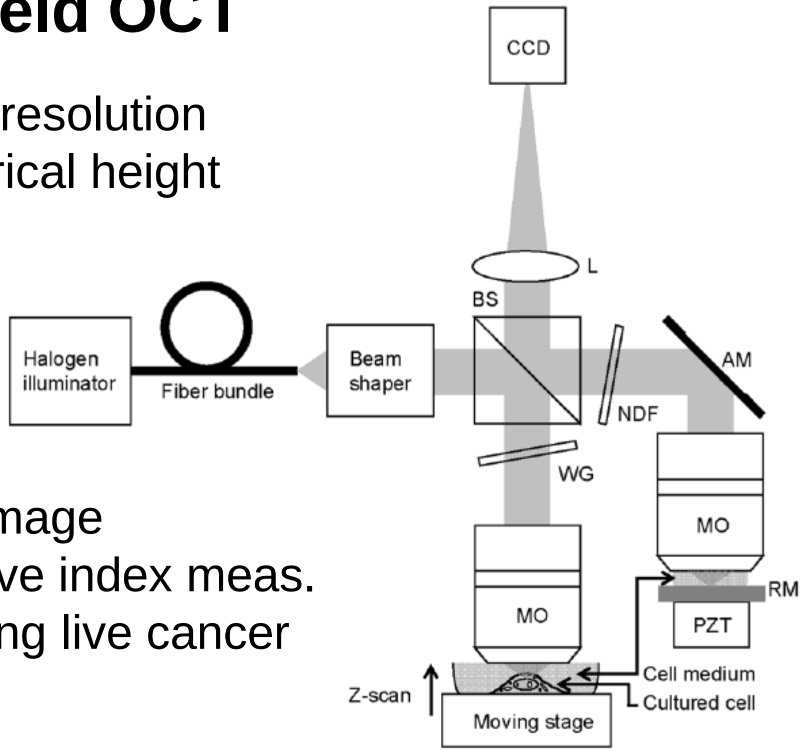
Fig. 7. (a) *In* vivo endoscopic OCT image of rabbit colon with (b) corresponding histology. Delineation of upper colonic mucosa (cm), muscular mucosa (mm), submucosa (sm), and muscularis externa (me) is possible. Enlarged images show the capability to visualize crypt structure. Tissue separations seen in the lower part of the histology images are due to a histology processing artifact.

Herz,… Fujimoto, OpticsExpress 2004

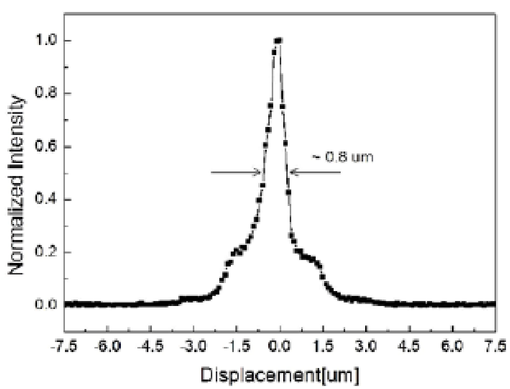
Full Field OCT

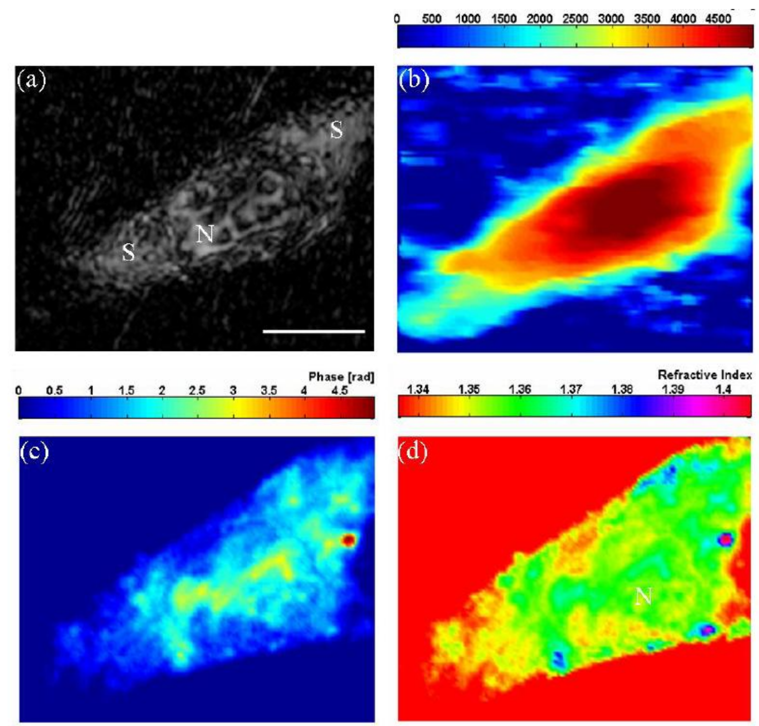
- sub um resolution
- geometrical height

Choi, **Full-field optical coherence microscopy …**, *Opt. Express* (2010),

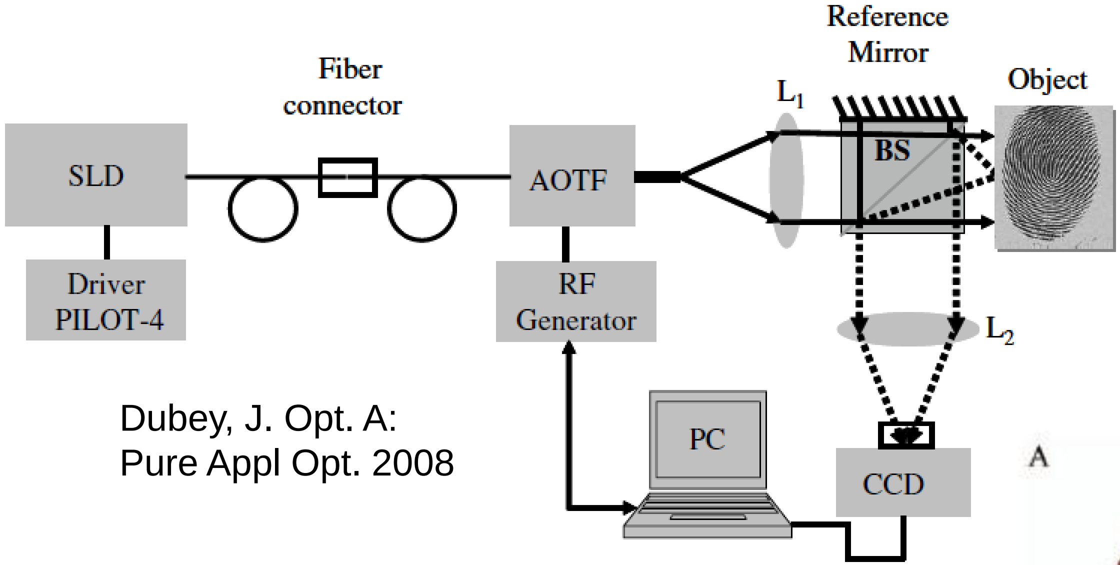


- phase image
- Refractive index meas.
- Identifying live cancer cells



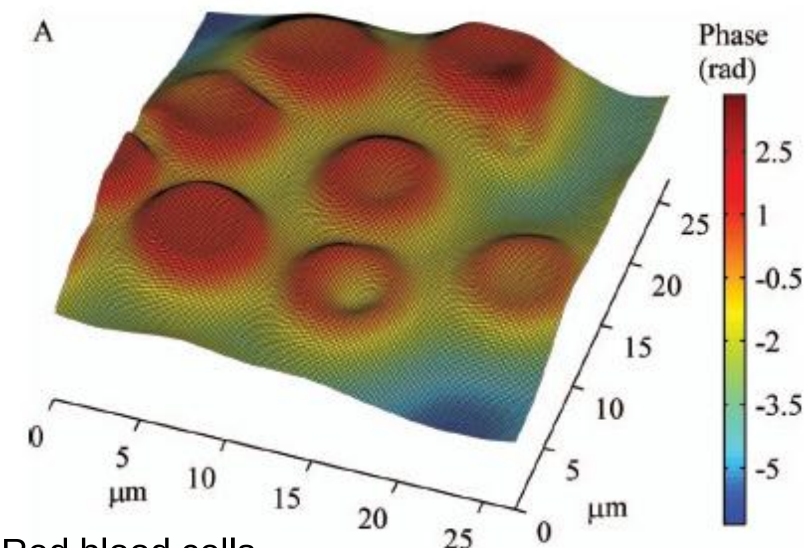


Full Field Swept Source OCT



Dubey, J. Opt. A:
Pure Appl Opt. 2008

- No real swept source available in Si- camera range (300 – 1000 nm)
- fast NIR cams are very expensive

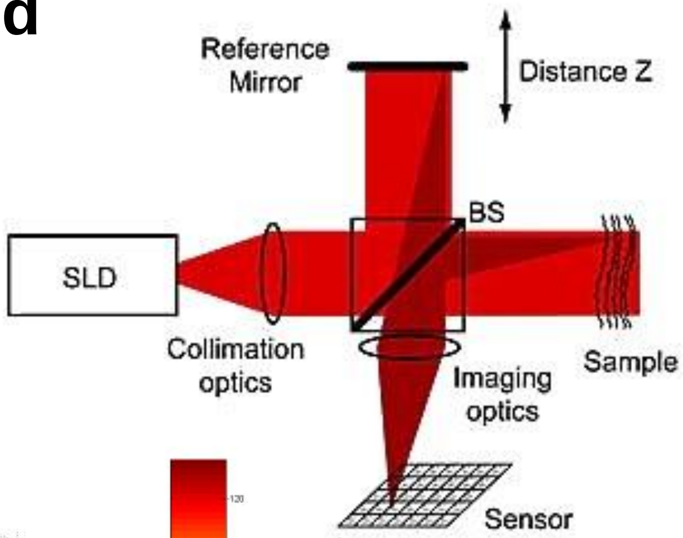


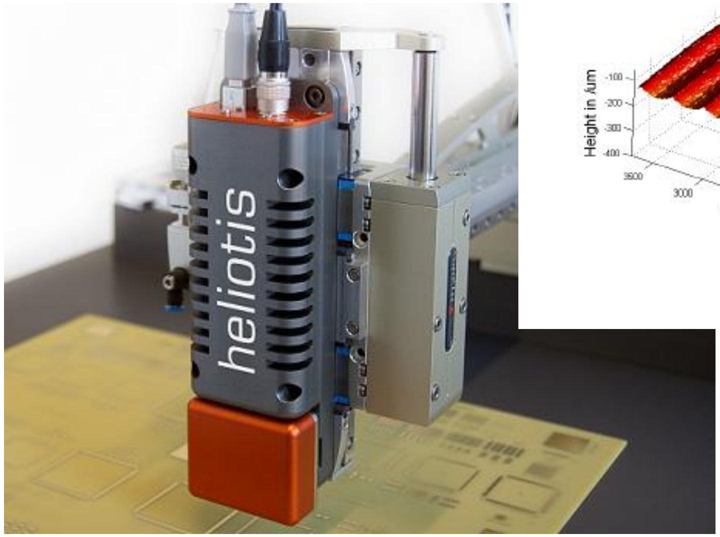
Red blood cells
Sarunic, **Full Field Swept Source Phase Microscopy** , Optics Letters 2006

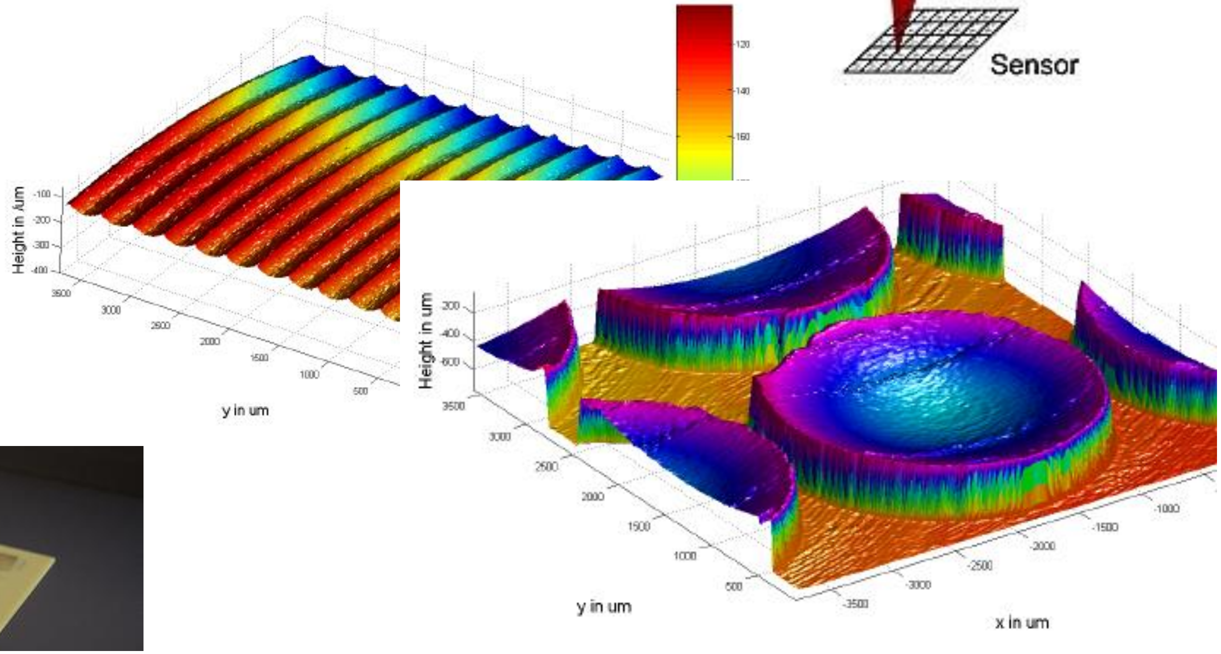
Full Field OCT, made in Switzerland

Phase–Sensitive Parallel
Optical Coherence Tomography

Number of pixels 144 x 90
Vertical resolution 200nm
Lateral resolution 2 um



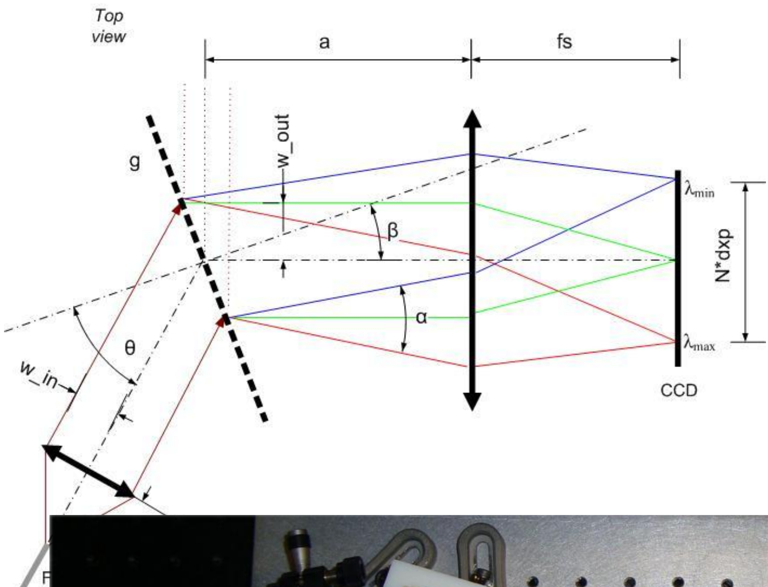


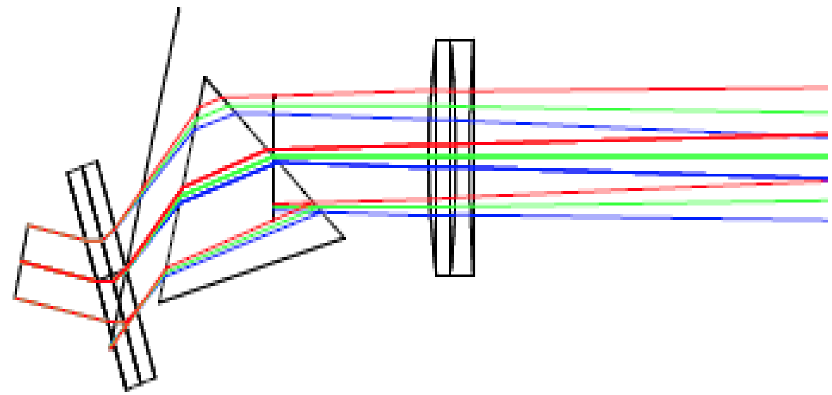


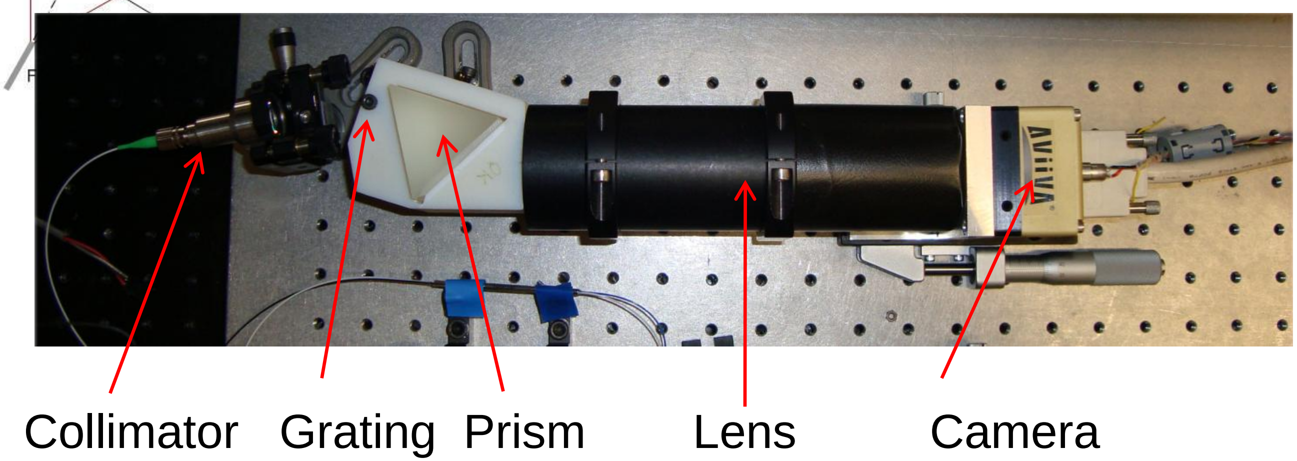
Some Projects @ OptoLab

Linear k-Spectrometer for OCT

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

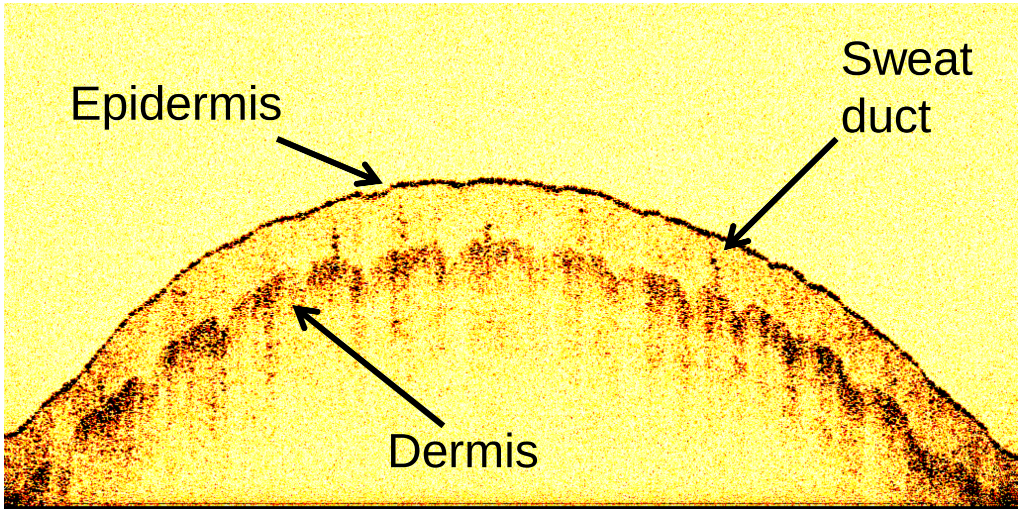




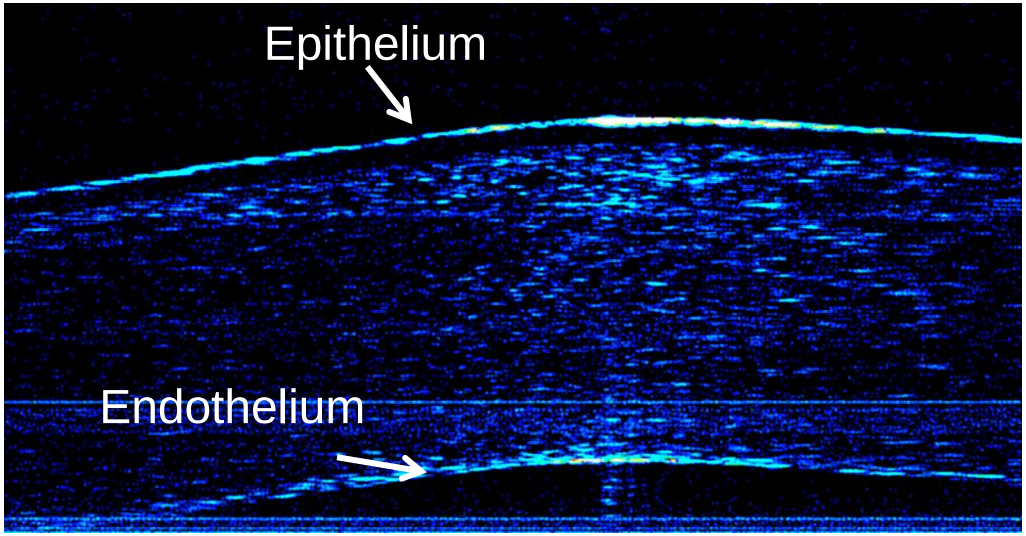


- Sensitivity: 93 dB @ 40 µs integration time
- Camera speed: 28’700 A-scans/s
- Measuring range: 6 mm

Linear K-Spectrometer for OCT



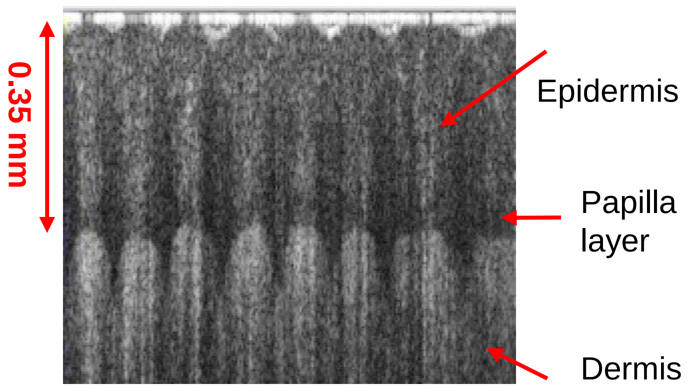
- Human finger @ 835 nm
- 3 x 10 mm
- 1024 x 1024 pixels
- Integration time: 0.111 ms



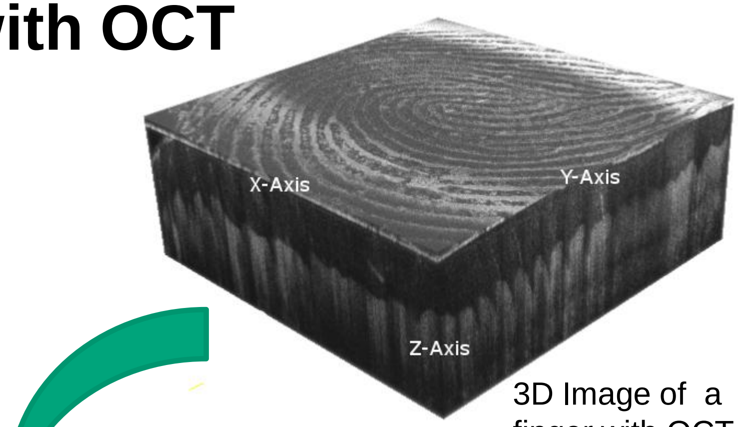
- Pig cornea @ 830 nm
- 1 x 3 mm
- 1024 x 1024 pixels
- Integration time: 0.250 ms

Internal Fingerprint Identification with OCT

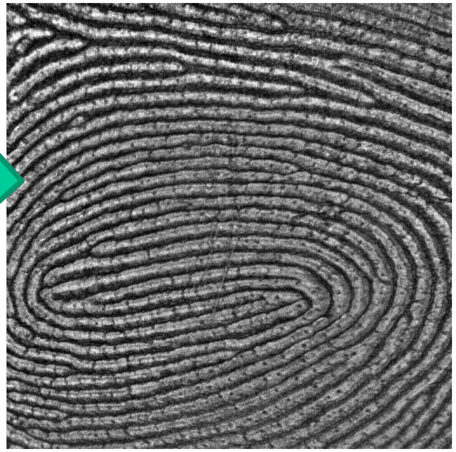
- Secure and reliable identification
- Use of the internal structures of the finger (region around the papilla layer)
- Compatible with algorithm for fingerprint identification



B-scan of finger,
BFH OptoLab, 2009

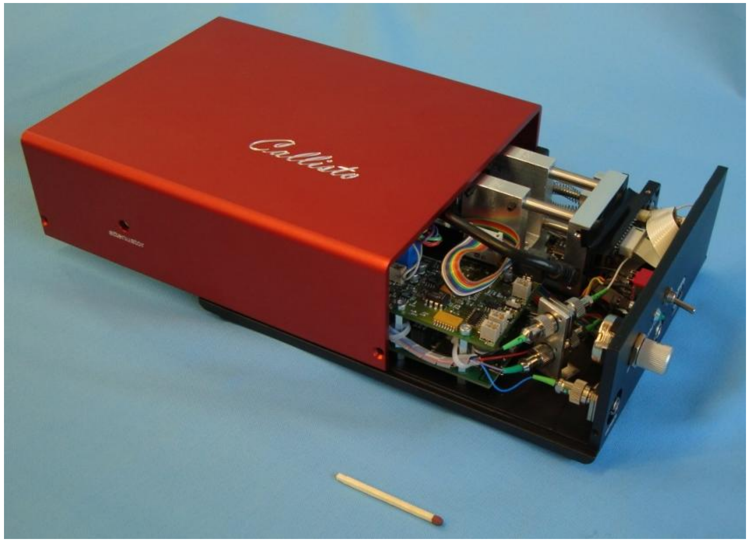


3D Image of a finger with OCT



A.Bossen, R. Lehmann, C. Meier, **"Internal fingerprint identification with optical coherence tomography"**, Photonics Technology Letters, IEEE, vol.22, no.7, pp.507-509, April1, 2010.

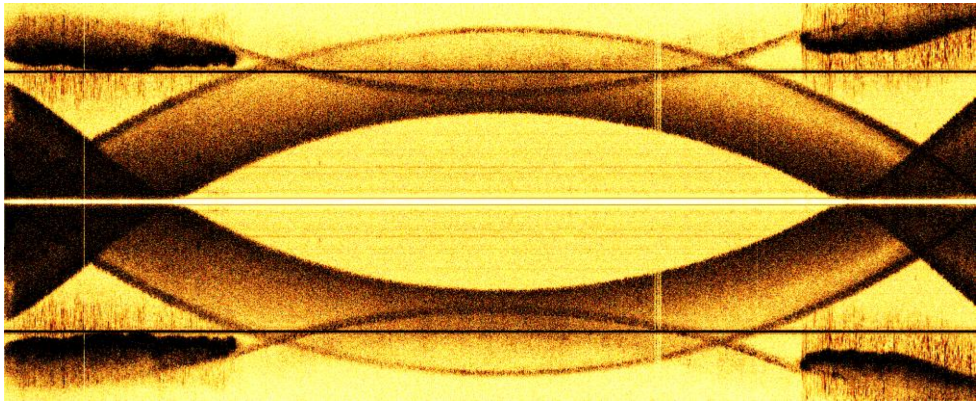
OCT Callisto



OCT Box Callisto

Includes: - Source
- Spectrometer
- Reference arm
- Interferomter

Dimensions:	200 x 150 x 70
Axial Scan Resolution:	6.5 µm
Measurement range	6.6 mm

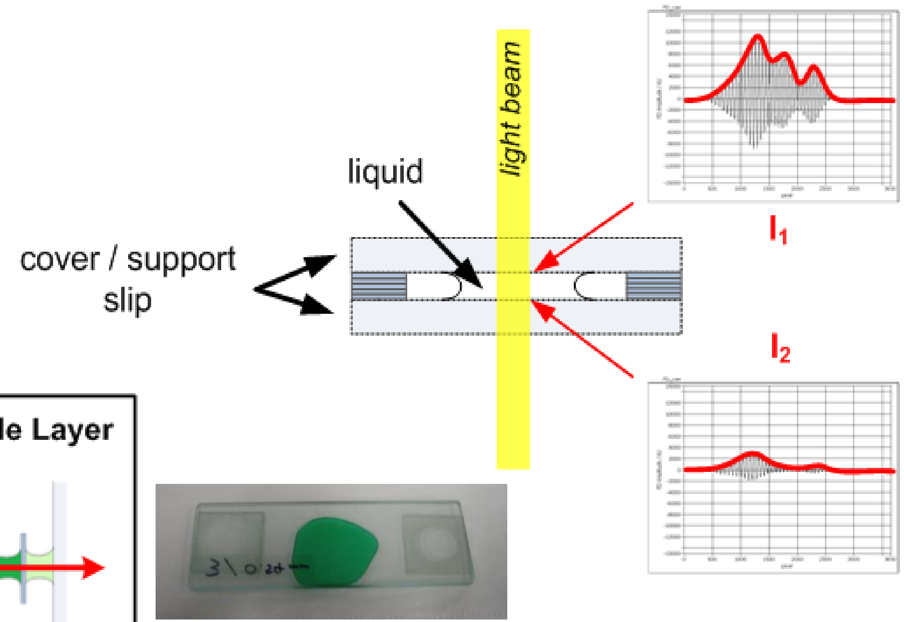


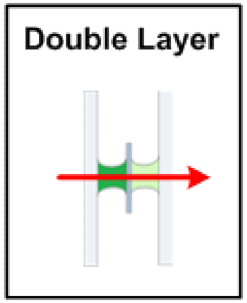
Spectroscopic OCT

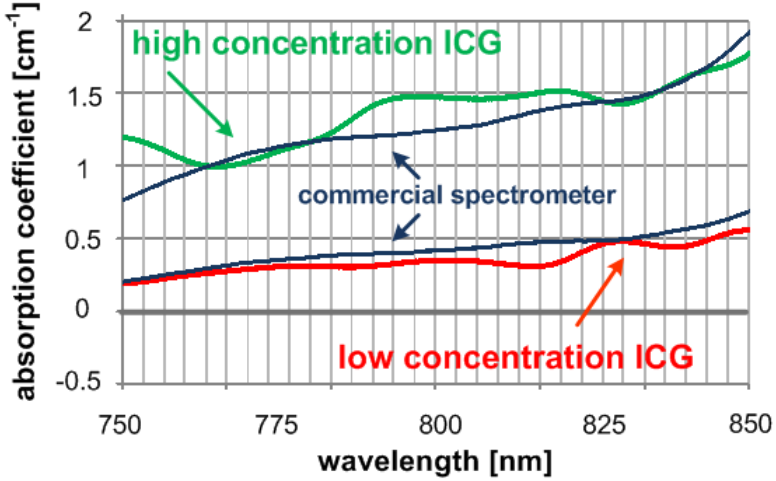
- System developed to analyze spatial resolved spectral absorption of substances using OCT

- Possible ability to determine physiological parameters (e.g. in blood) non-invasively

- Distinguishable levels of ICG (*indocyanine green, near-infrared absorber*) in micromolar (µM) concentrations



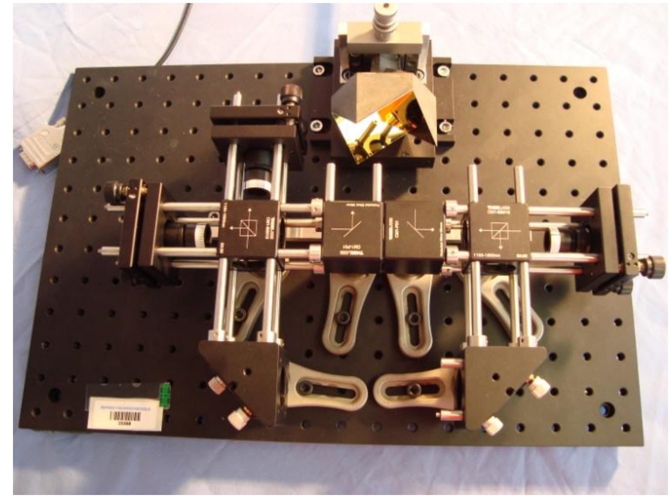




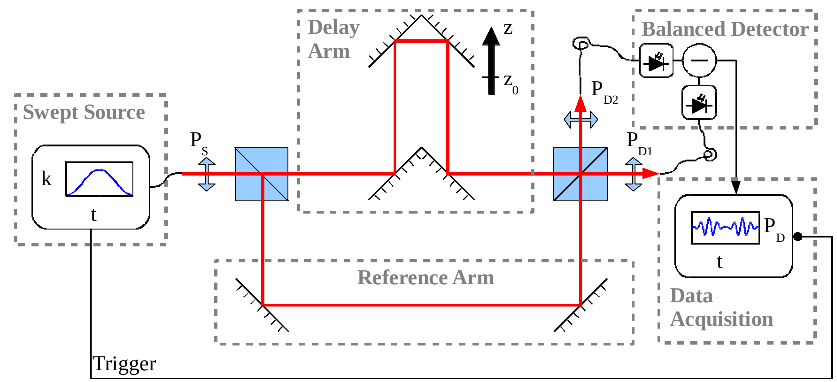
P. Steiner, Ch. Meier, V.M. Koch, **„Influence and compensation of autocorrelation terms in depth resolved spectroscopic Fourier-Domain optical coherence tomography"**, Applied Optics 2010

Coherence Length Measurement

- System development to measure the instantaneous coherence length.
- Crucial performance indicator for swept laser sources
- Setup is based on a Mach-Zehnder interferometer with variable delay length
- Application in the development process of rapidly swept laser sources
- Measurements at sweeping rates up to 120 kHz possible



a) Real world measurement device (MZI)



b) Schematic measurement device

Outlook

- **Speed**
  Example: 1024 x 1024 x 1024 = 1Gvoxel
  with 20kHz A-scan rate acquisition time = 52 s too long !

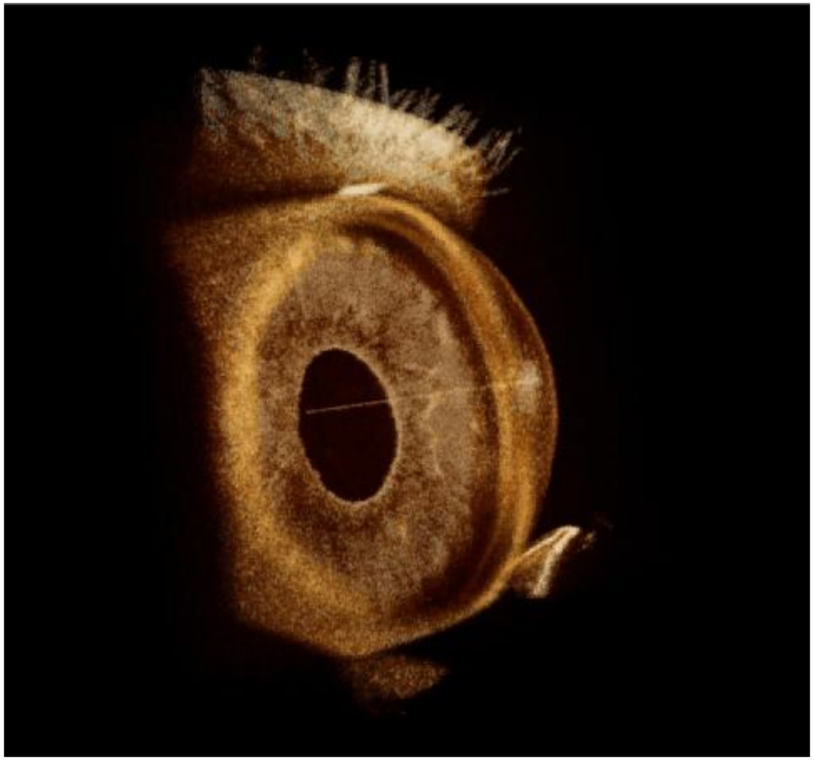
- **Data Processing**
  De-noising, segmentation, 3D representation
  Data reduction -> compressive sampling

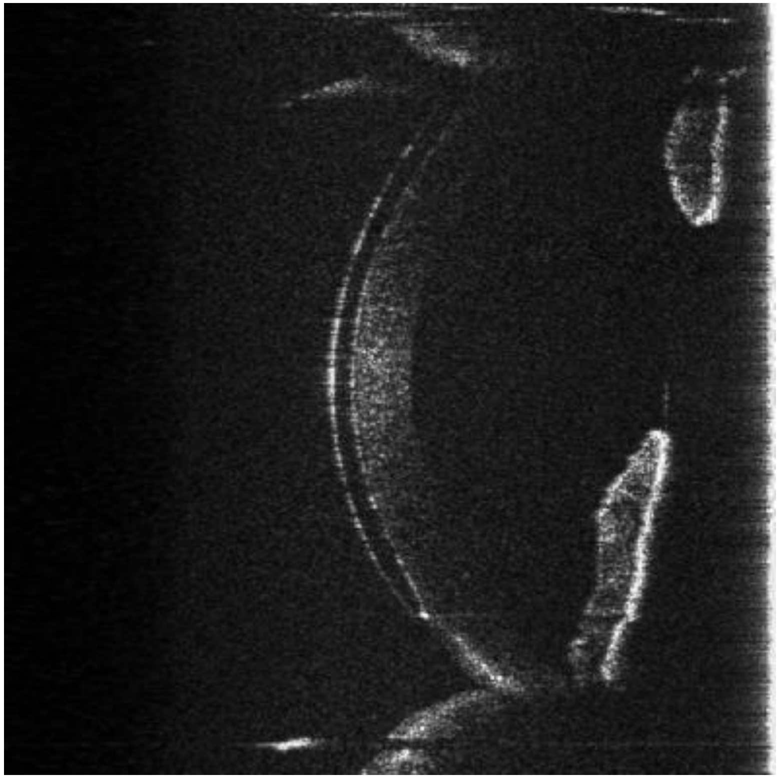
- **Sources**
  Stable broad band laser sources @ affordable cost,
  Miniaturized high speed swept source

- **Functional OCT**
  Polarization, Spectroscopic, Phase, Doppler,
  Combination with Fluorescence Microscopy, or Raman Spectroscopy

Speed

• 3D images in vivo: speed minimize motion artifacts





Gora, M.;…Wojtkowski, M. OpticExpress, Aug. 2009, (up to 200kHz A scan rate)

Ultra High Speed OCT

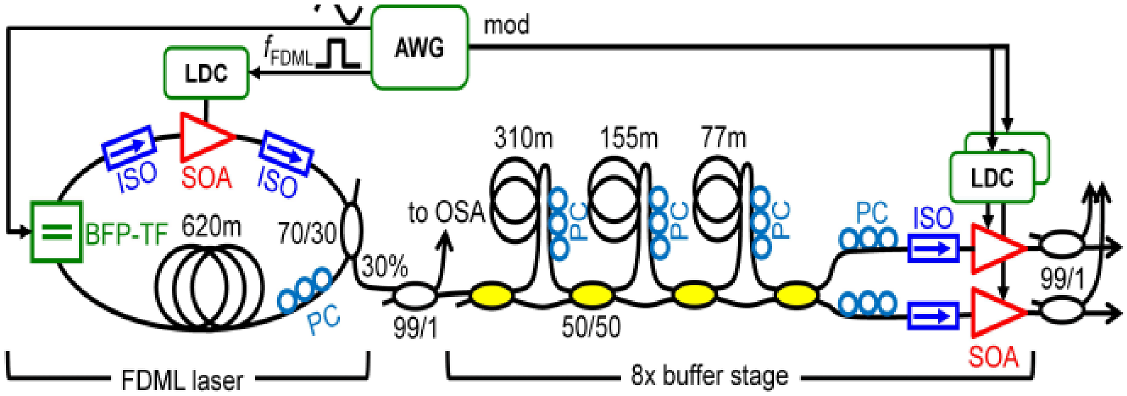
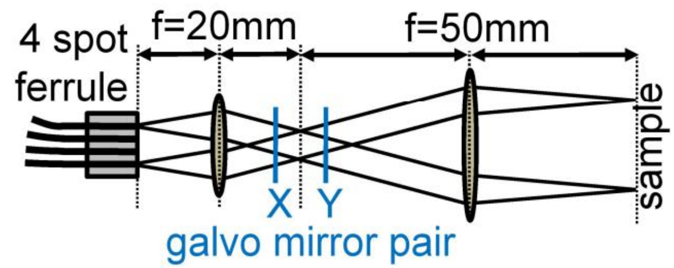


Fig. 3. FDML laser "*B8*" with bulk Fabry-Perot tunable filter (BFP-TF), followed by an 8x buffer stage with 2 booster SOAs. The laser "*B16*" differs merely by adding another buffer stage element with 39m fiber delay.

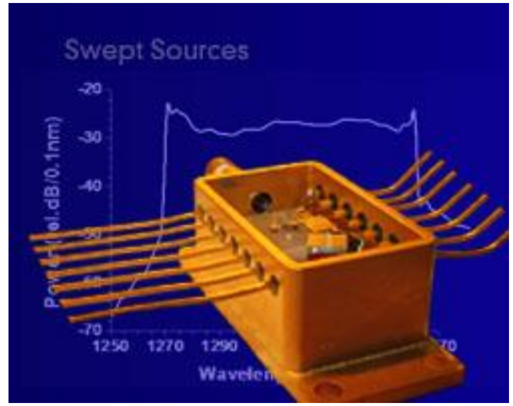


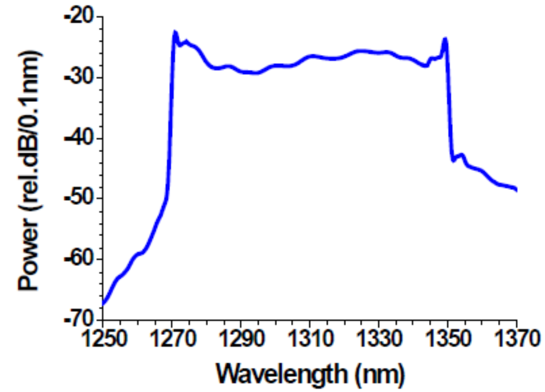
- 325 kHz FDML frequency
- 2.6 MHz effective sweep rate after 8x buffer
- More than 10 MHz depth scan rate with 960 samples per depth scan
- **4.5 GVoxel/ s**

Wieser, W.; Biedermann, B. R.; Klein, T.; Eigenwillig, C. M. & Huber, R. (2010), 'Multi-Megahertz OCT: High quality 3D imaging at 20 million A-scans and 4.5 GVoxels per second', *Opt. Express*

Miniaturized Swept sources

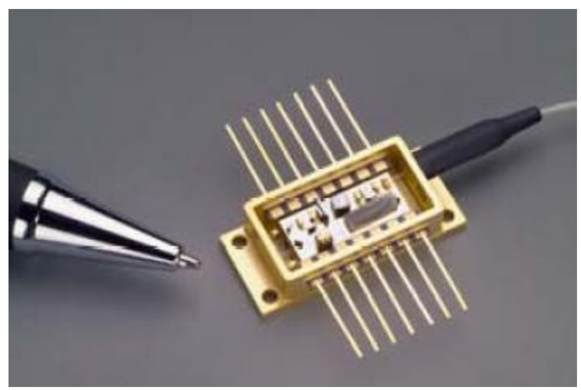
EXALOS
50 kHz sweep rate

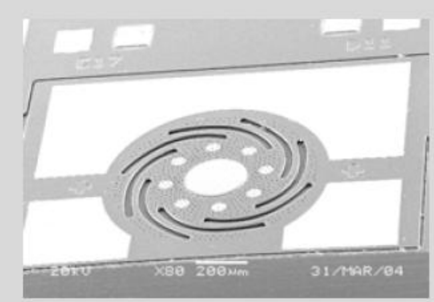




AXSUN

Parameter	***Value***
Wavelength Range	1250 – 1360 nm
Output Power	20 mW
Sweep Rate	50 kHz
Coherence Length	12 mm

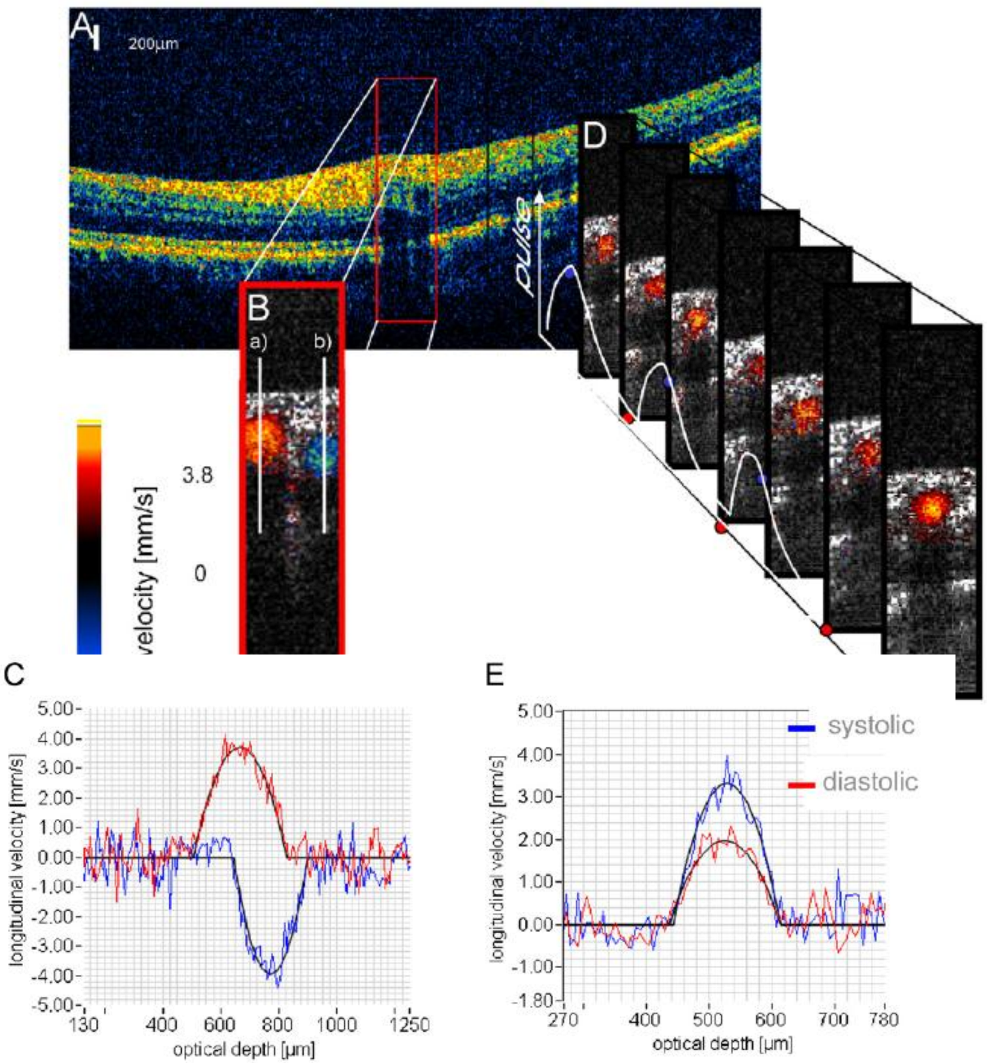


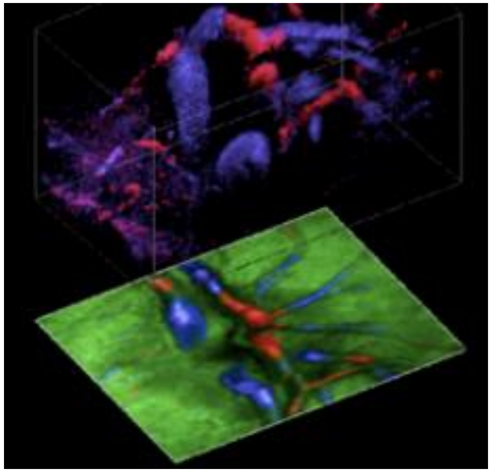


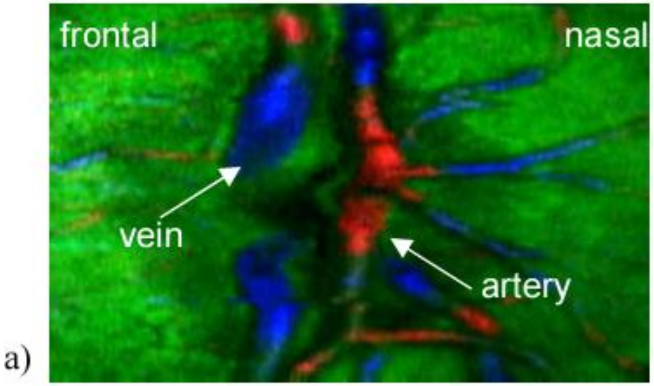
Axsun MEMs Tunable Filter

Sweeping due to tunable Fabry-Perrot filter

Functional OCT, Doppler





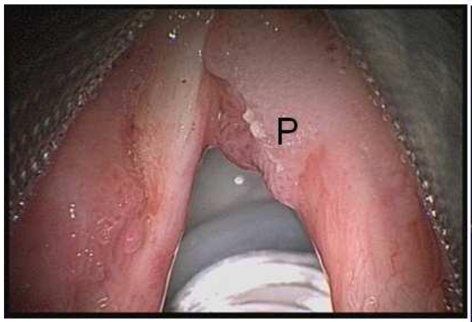


Bachmann,…Leitgeb. OpticExpress,. 2007

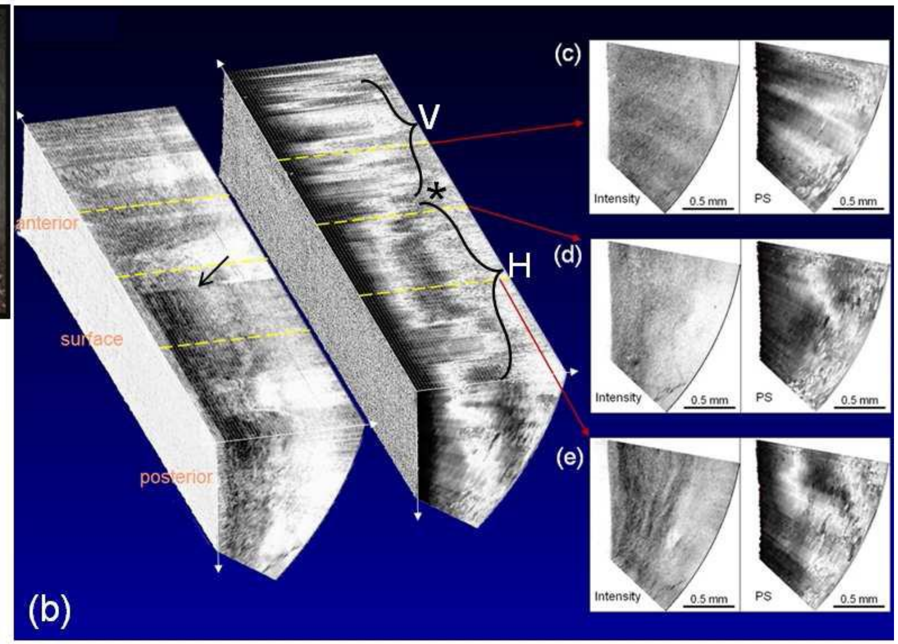
Leitgeb in Optical Cherence Tomography, Springer 2008

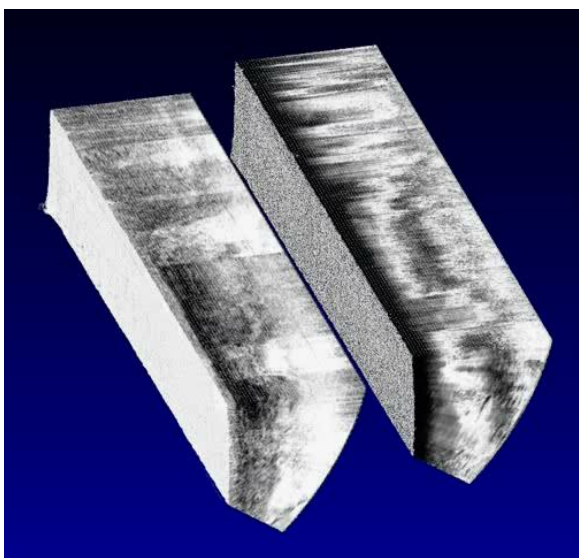
3D Polarization sensitive OCT

- Images sub-surface vocal fold tissue non-invasively
- Useful information in guiding surgeons during phonomicrosurgery



(a)

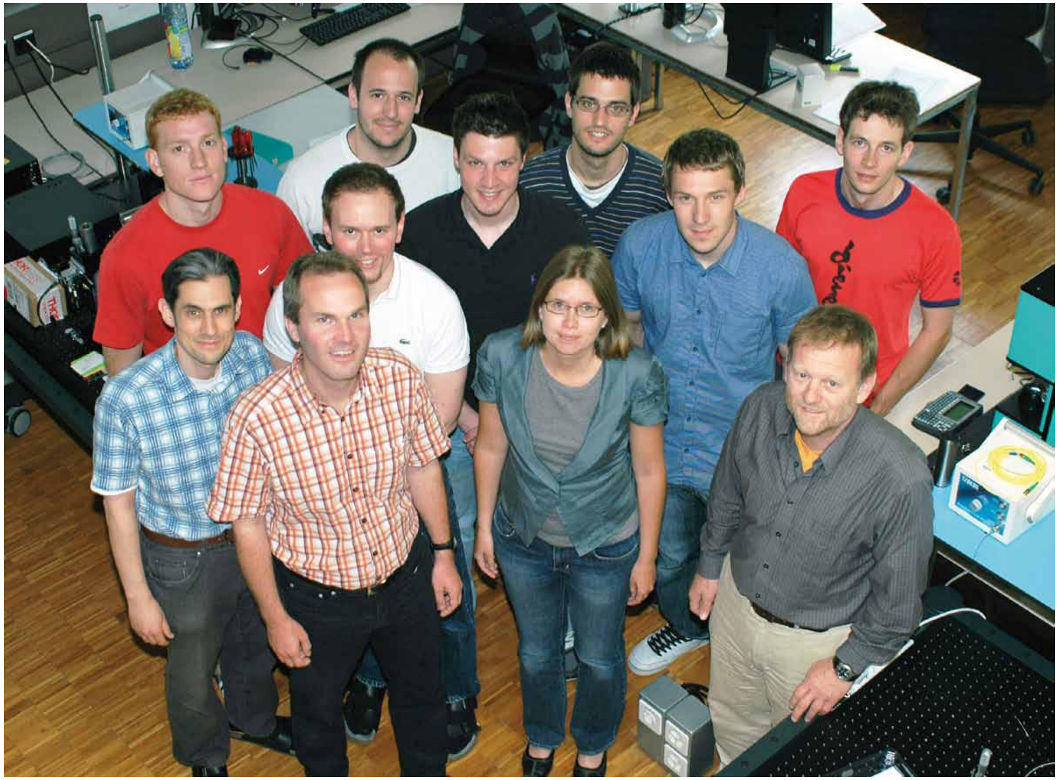




K.H. Kim, **In vivo 3D human vocal fold imaging…**
OpticsExpress 2010

OptoLab
BFH TI Biel

www.ti.bfh.ch/OptoLab



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Thank you for your attention