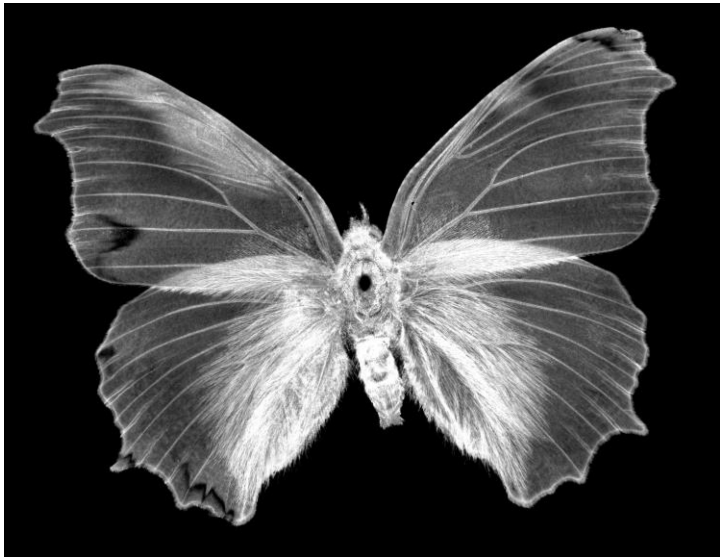
Optical coherence tomography for non-destructive testing and imaging applications



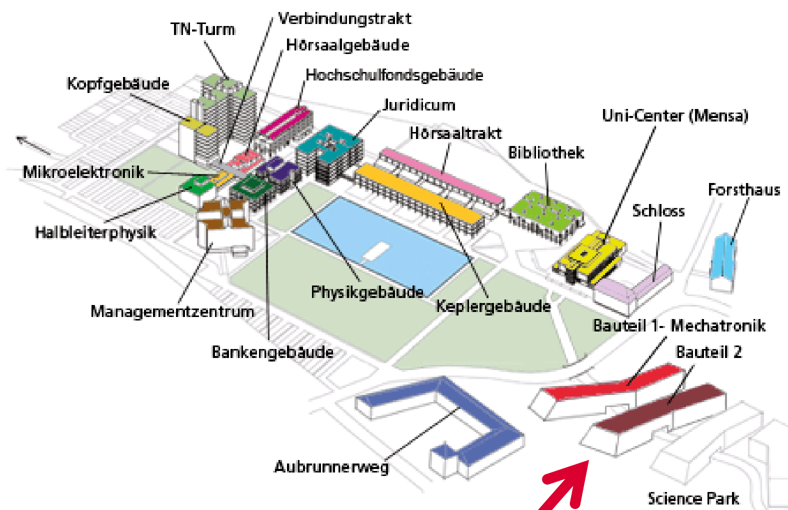
Ivan Zorin

22.01.2019

General information

REsearch **CE**nter for **N**on-**D**estructive **T**esting

RECENDT: located at JKU
in Science Park 2

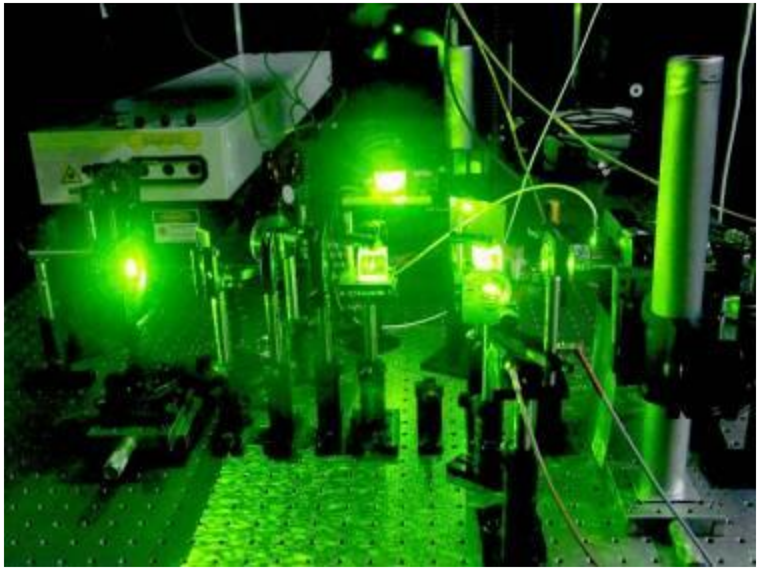


SP2, 2. OG

Altenberger Straße 69, 4040 Linz
Tel.: +43(0)732/2468-4600
e-mail: office@recendt.at
Web: http://www.recendt.at

Research topics and groups

- Laserultrasound
- Photoacoustic
- Infrared-spectroscopy
- Terahertz technology
- Optical coherence tomography



RECENDT RESEARCH CENTER NON DESTRUCTIVE TESTING

Expertise

- **Quality control and quality assurance for batch production and production control**
  contactless control by laser, ultrasound, infrared etc.

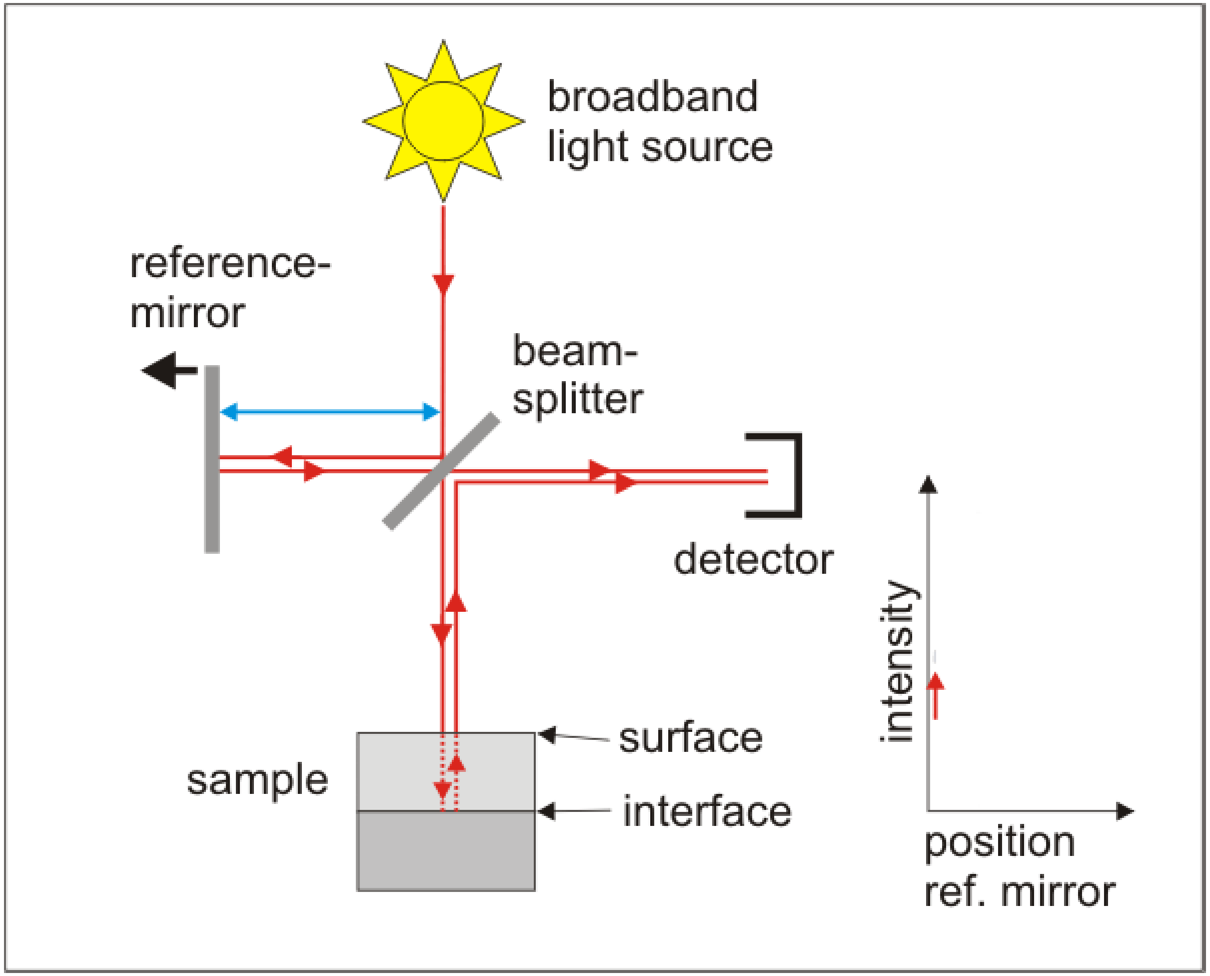
- **Non-destructive testing of materials, contactless analysis and material characterization**
  for carbon fiber, composites, metals, etc.

- **Prototype construction for contactless sensors**
  „From the idea to a marketable product": by integration of optics, electronics, µ-processor technology, software (from basic research to a prototype)

- **Technology- and project management / special projects**
  Sensor development for various areas of application and processes (research- and client-specific-projects)

Optical Coherence tomography for non-destructive testing

Common TD-OCT System



Axial Resolution:

$$l_c = \frac{2\ \ln 2}{\pi n} \cdot \frac{{\lambda_0}^2}{\Delta\lambda} \approx$$
$$\approx 0.44 \cdot \frac{{\lambda_0}^2}{\Delta\lambda}$$

Lateral Resolution:

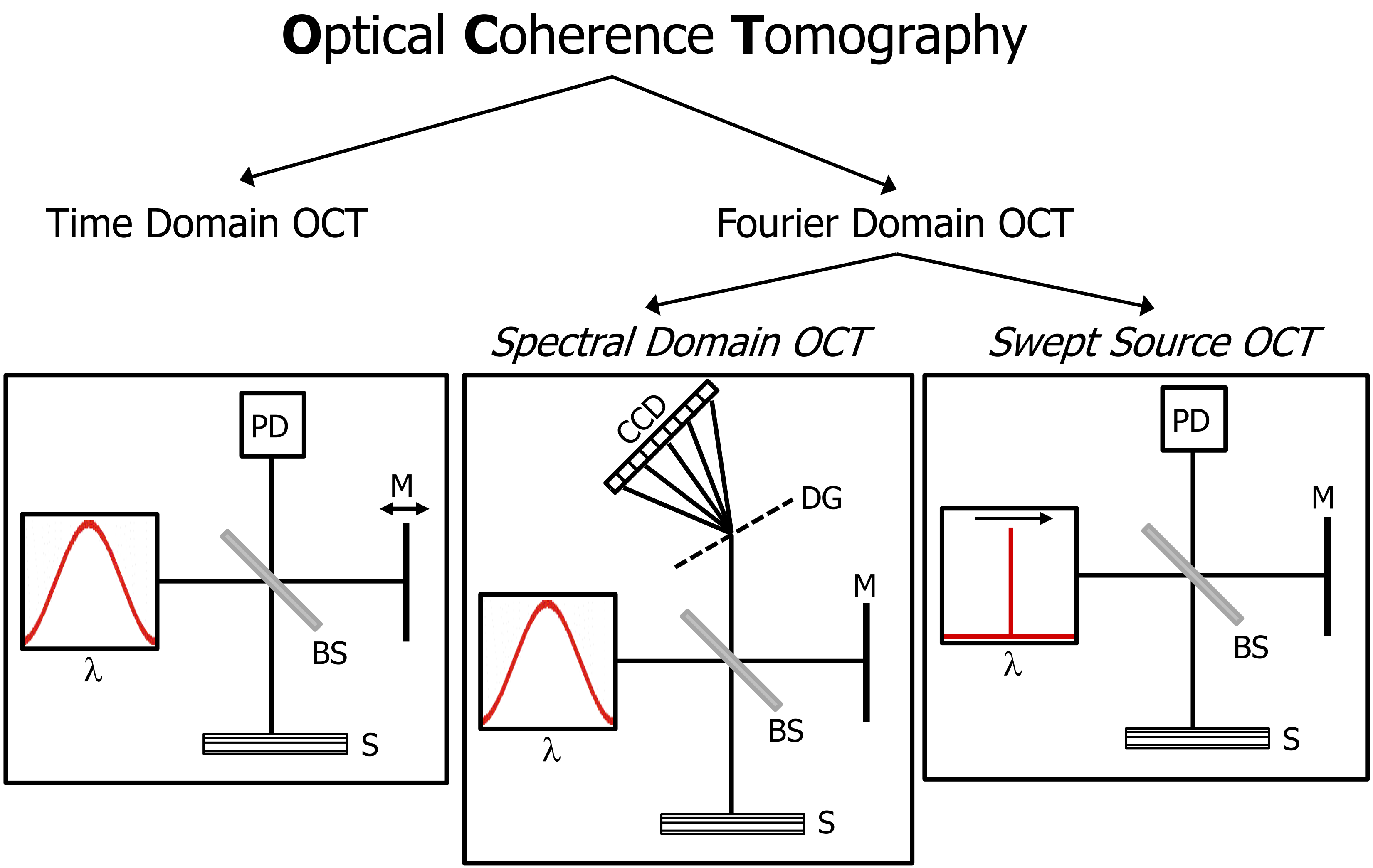
$$\omega_0 \approx \frac{4\lambda_0}{\pi} \cdot \frac{f}{d} \propto \frac{\lambda_0}{\mathrm{NA}}$$

Probing depth:

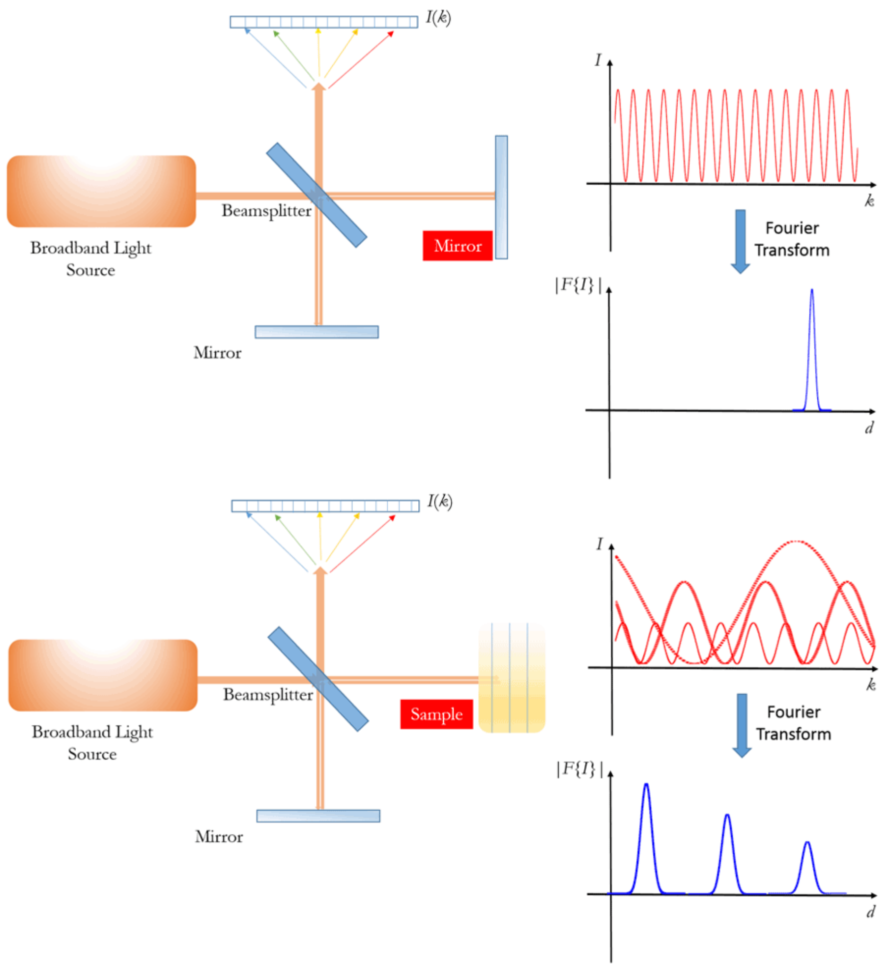
$$b = 2z_r = 2\frac{\pi\omega_0^2}{\lambda_0}$$

λ_0 – center wavelength
$\Delta\lambda$ – spectral bandwidth
n – refractive index

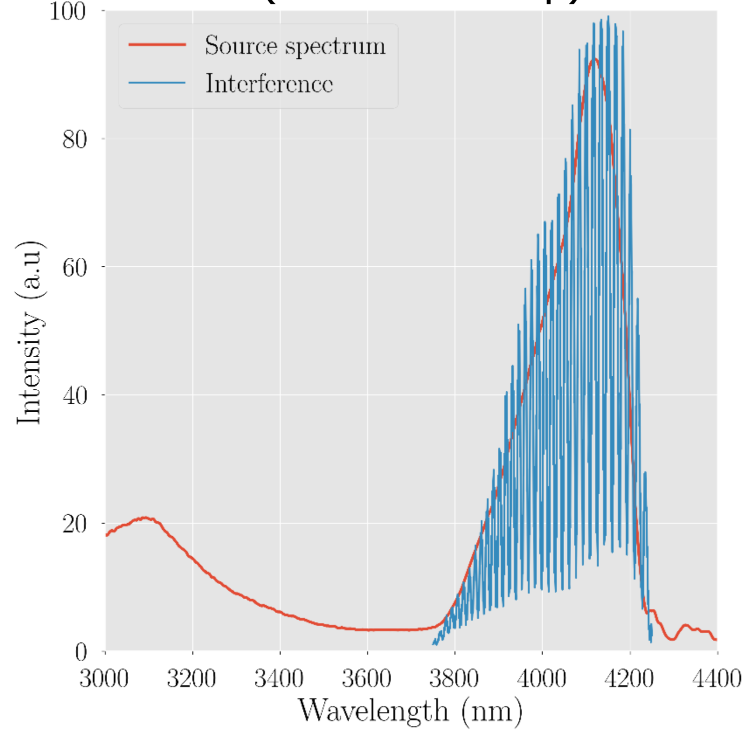
OCT in General



Fourier domain OCT



Reference spectrum and raw signal for the mirror in sample arm (MIR OCT Setup)



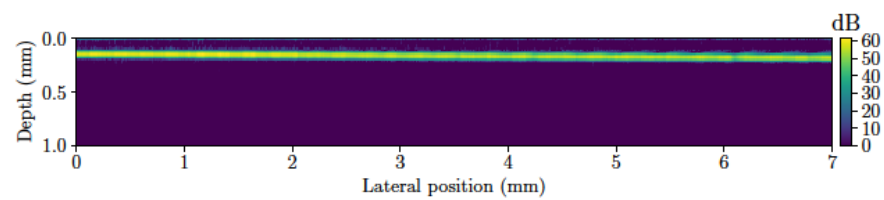
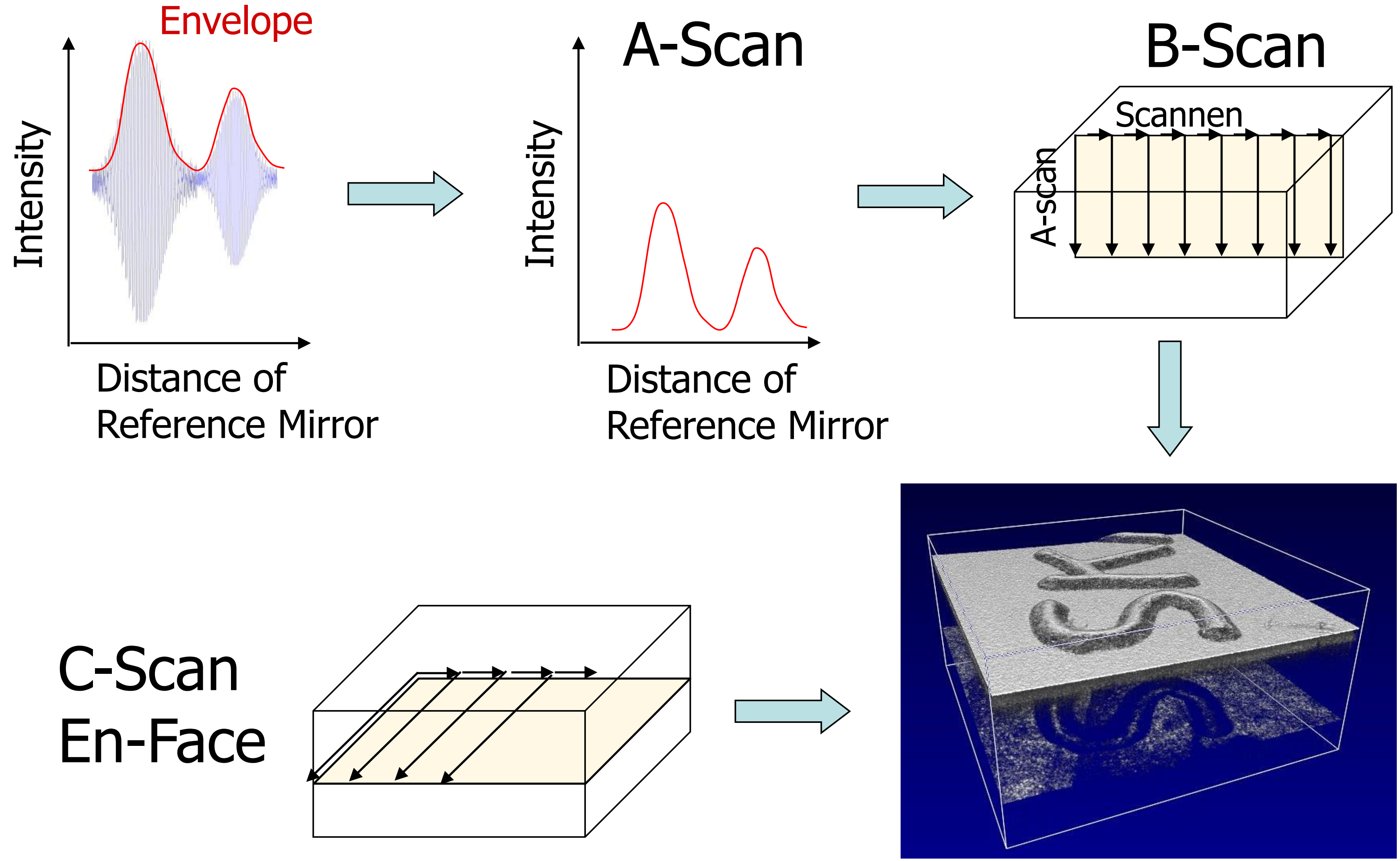


Image formation



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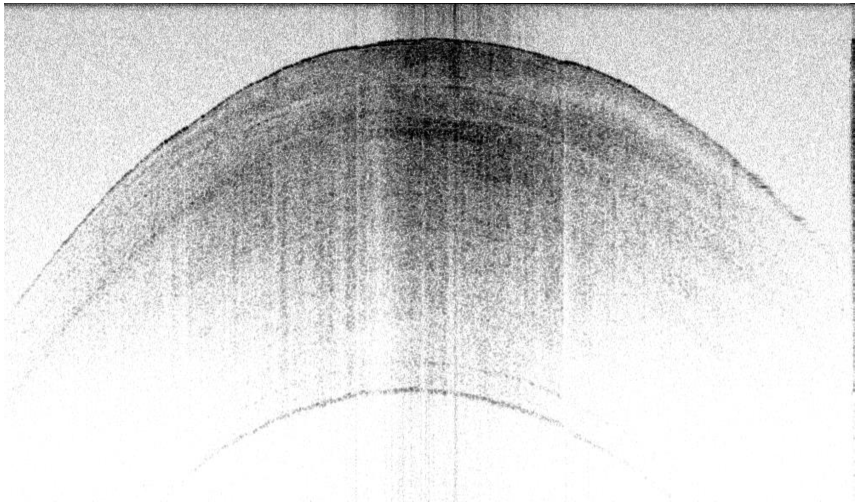
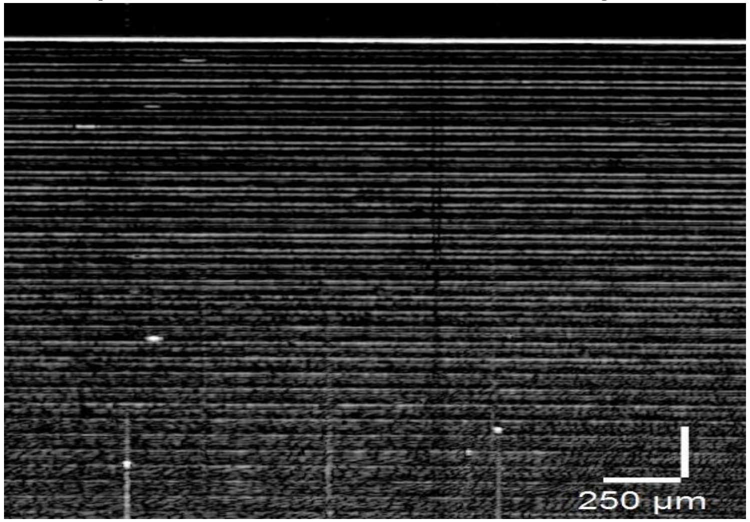
OCT Scans examples

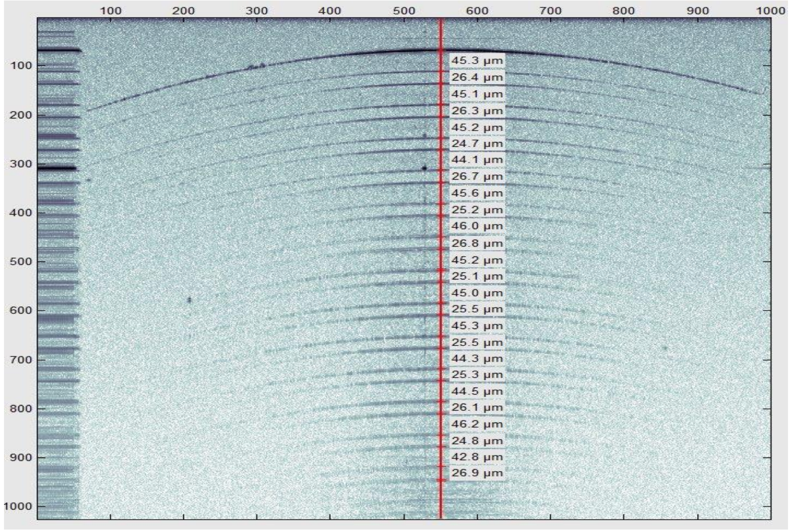
Pearl



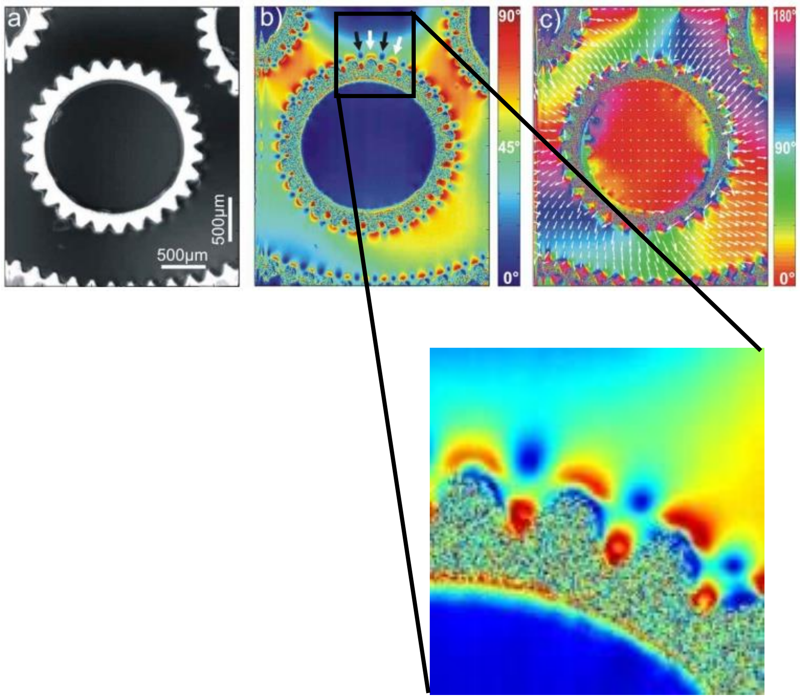
Tape Commercial Thorlabs System

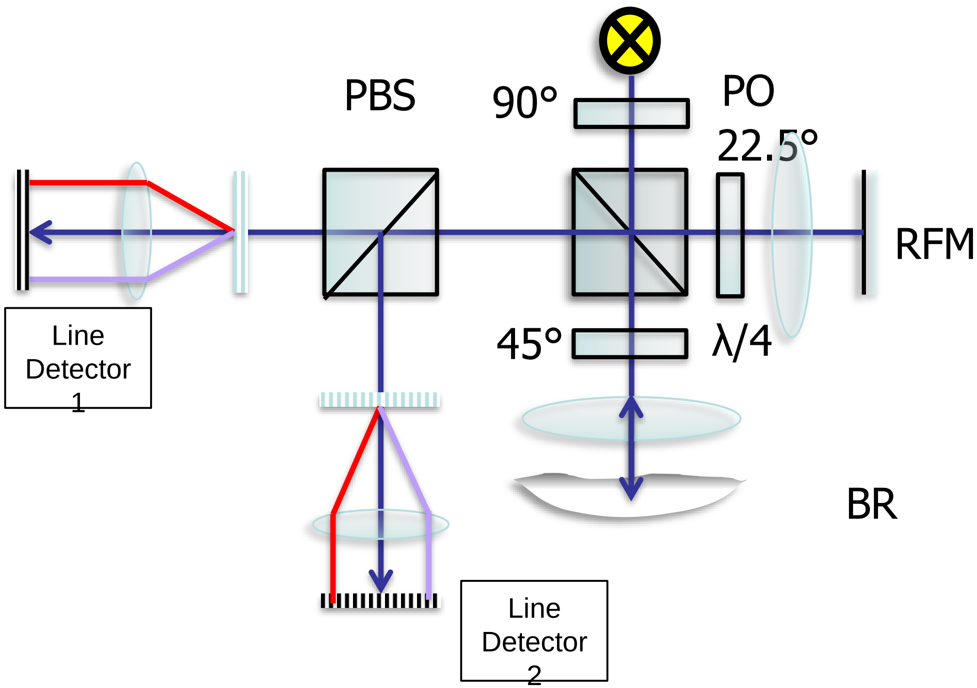


Sub2mu system at RECENDT



Polarization sensitive OCT





Optical Axis Orientation:

Reflectivity: $R(z) \sim A_1{}^2(z) + A_2{}^2(z)$

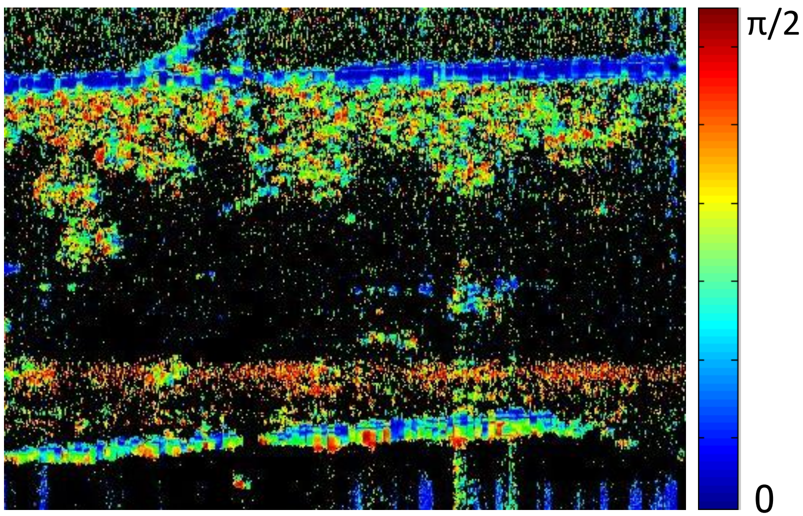
$\Delta\varphi\,(z) \sim \varphi_{1\,(z)} - \varphi_{2(z)}$

Retardation: $\delta(z) \sim \operatorname{atan}(A_1(z) \,/\, A_2(z))$

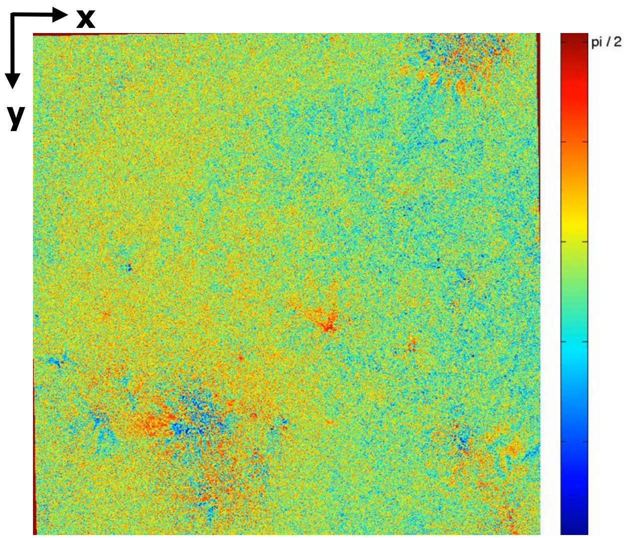
$$\theta(z) = \frac{\pi - \Delta\varphi(z)}{2}$$

- Micro-crystallites in turbid materials

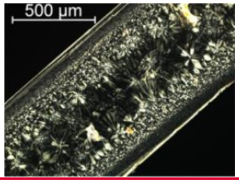
Extruded polypropylene with internal defects (micro-crystallites)



PS – raster scanning OCT:
Cross-sectional (ac) retardation image (5 x 3 mm)



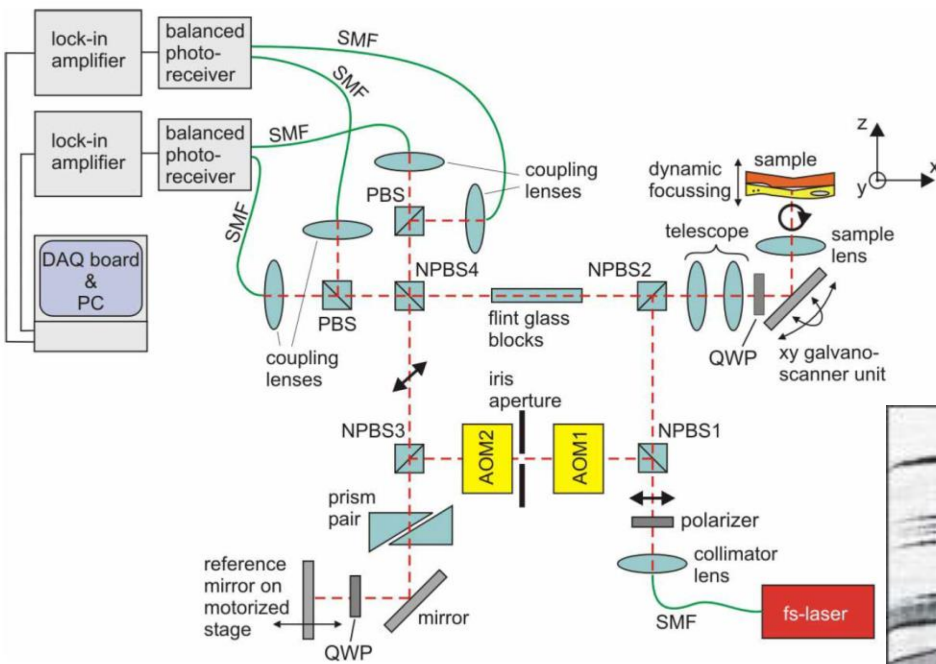
PS-Full Field-OCT:
En-face (ac) retardation image (1 x 1 mm x 200 nm)



➢ P. Hierzenberger et al.; Macro Molecules 47, (2014).

Ultra High Resolution OCT System

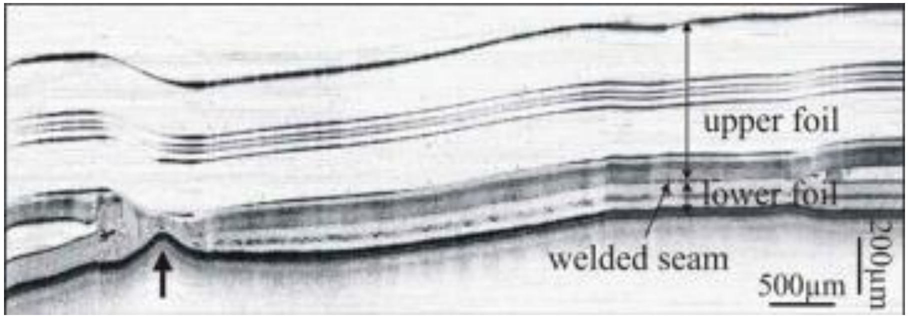
UHR System at RECENDT



Femtosecond laser/SuperK 800 nm, resolution<2 um, balanced detection, PSOCT

Quality Control in Packaging Industry

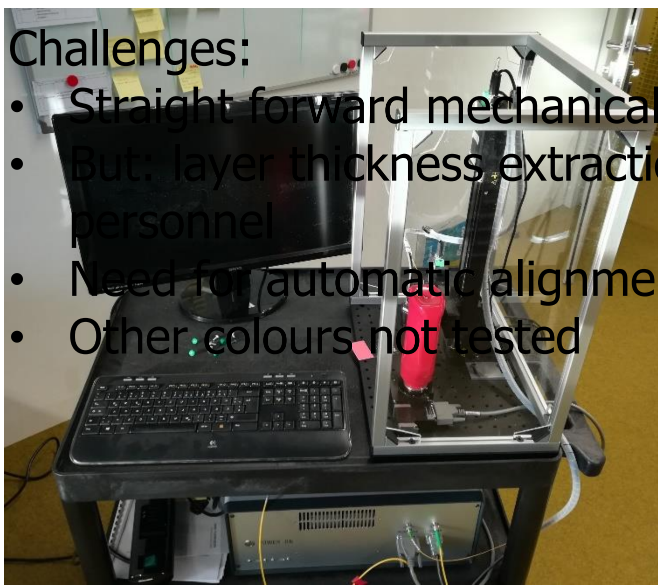
Multi-layer foil



Wiesauer et al., Optics Express **13**, 1015 (2005)

Semi-automated thickness measurement of wall-layer-thickness

- Plastic bottle, three layer structure: PP / EVOH / PP
- At-line setup for easy measurement at 16 points
- New bottle geometries possible
- Colours: transparent and red



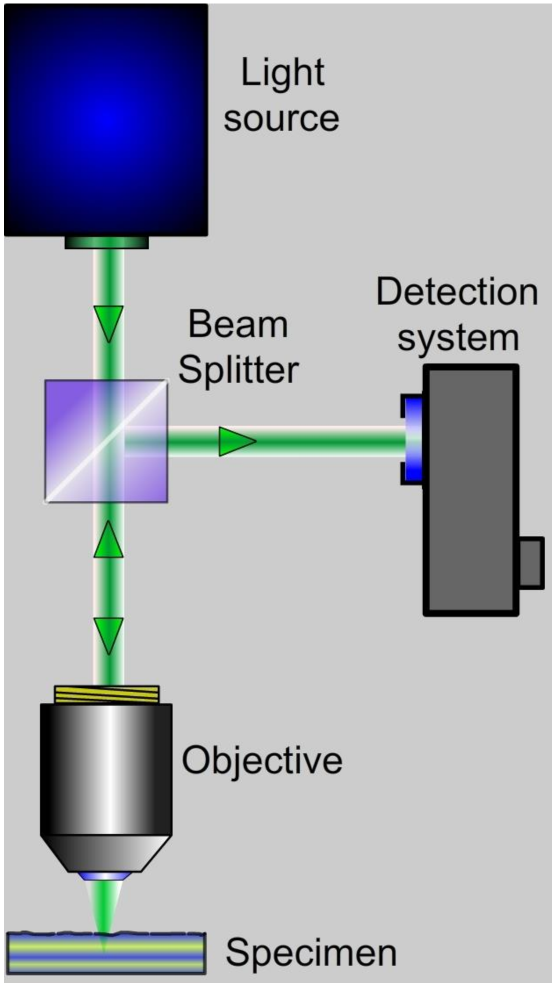
Challenges:

- Straight forward mechanical setup and control
- But: layer thickness extraction without trained personnel
- Need for automatic alignment
- Other colours not tested

Research projects

MORSPEC Main Idea

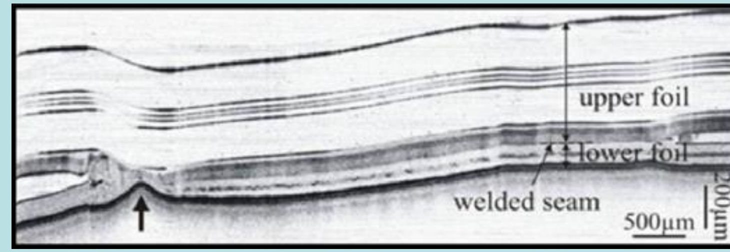
Optical Techniques



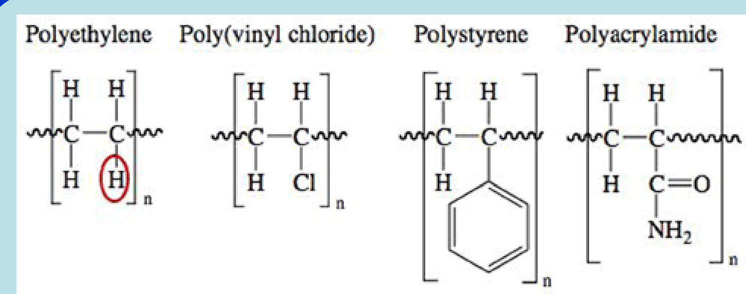
Optical Coherence Tomography

SRS Spectroscopy

Morphological information

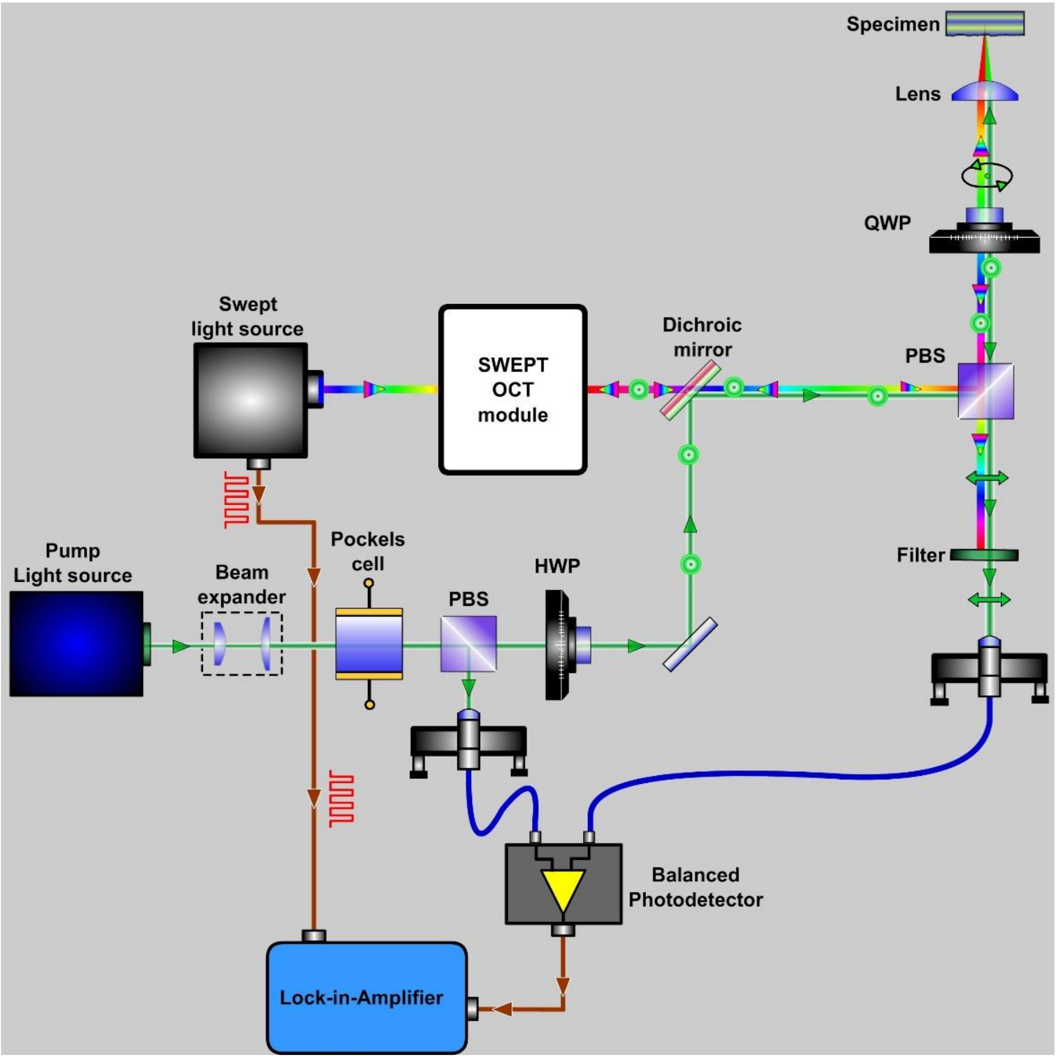


Spatially resolved chemical compositions



https://www.teachengineering.org/lessons/view/csu_polymer_lesson01

SRS+OCT



Key parameters:

Covered spectral range:

1493 - 2018 cm^{-1}

Spectral resolution $\approx 4\ cm^{-1}$

Lateral resolution $\approx 10\ \mu m$

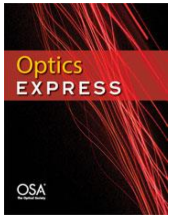
Acquisition time $\approx 2.5\ \mu s$ per single spectrum

Higher depth penetration because of NIR excitation

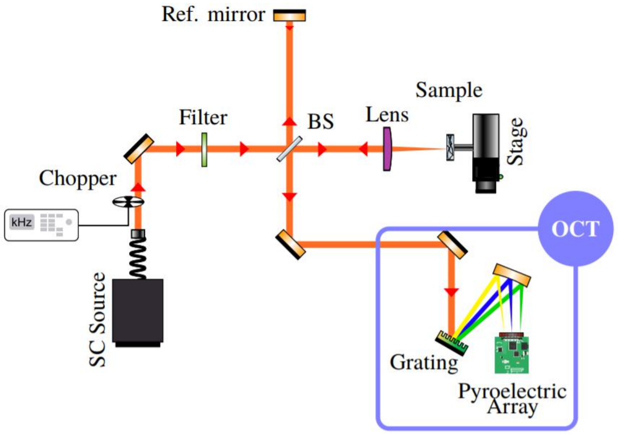
MID IR OCT

Mid-infrared Fourier-domain optical coherence tomography with a pyroelectric linear array

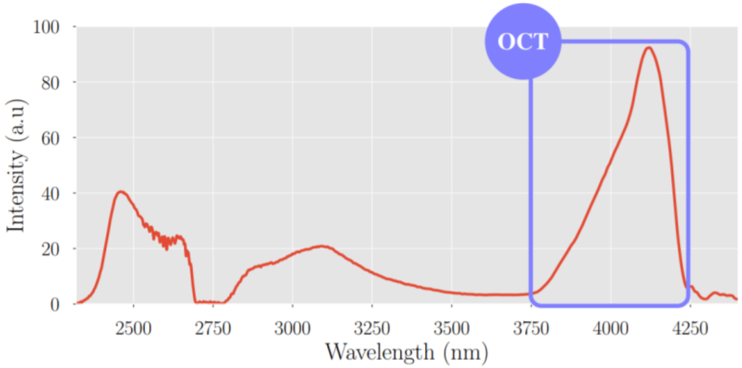
Ivan Zorin, Rong Su, Andrii Prylepa, Jakob Kilgus, Markus Brandstetter, and Bettina Heise



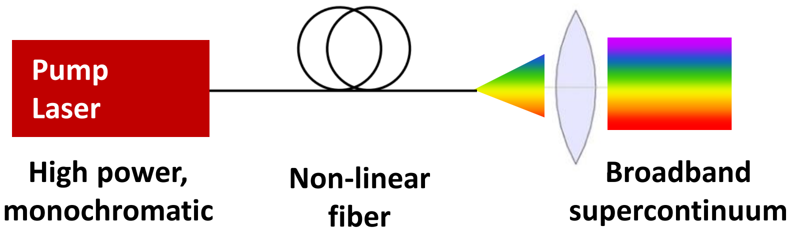
Optical scheme and spectral range



Lateral resolution: 35 um
Axial resolution: 50 um

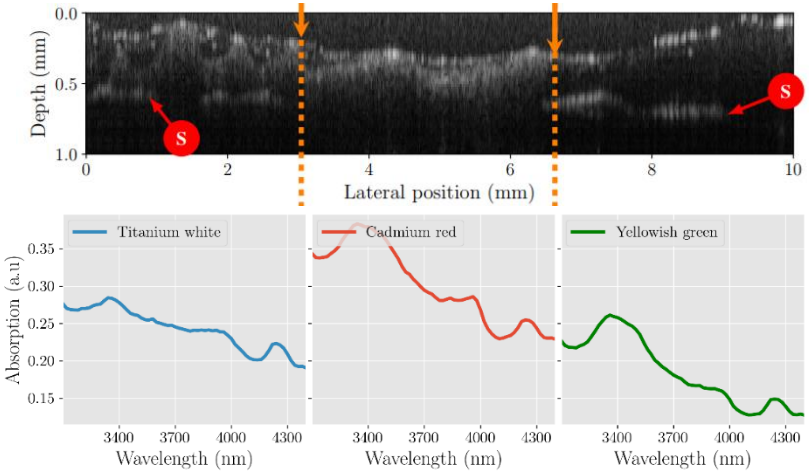


Supercontinuum Source



- High power
- High brightness
- Spatial coherence

Enhanced Penetration depth has been achieved



Co-registered specta

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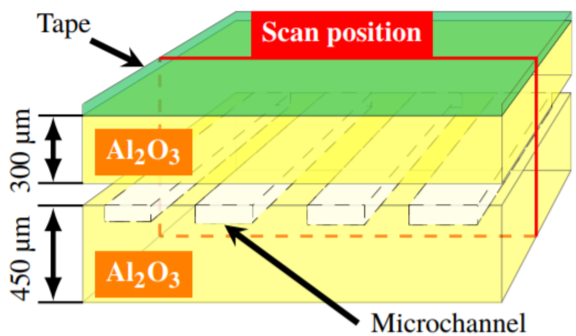
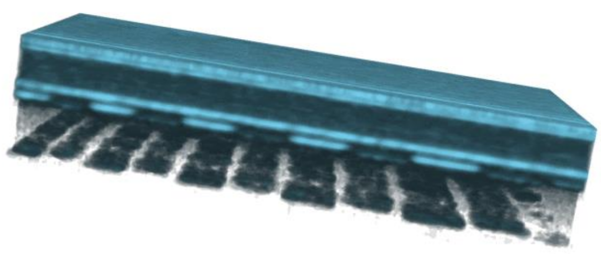
MID IR OCT

High potential for new types of materials: ceramics, polymers, paints etc.

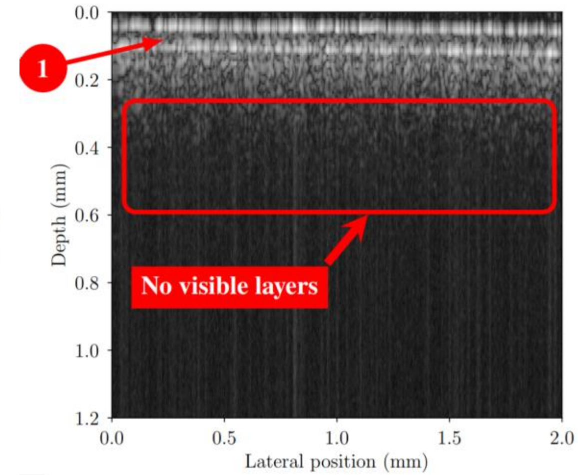
Multi-layer ceramic sample



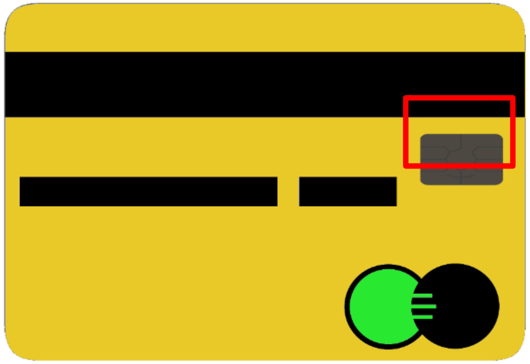
MIR OCT



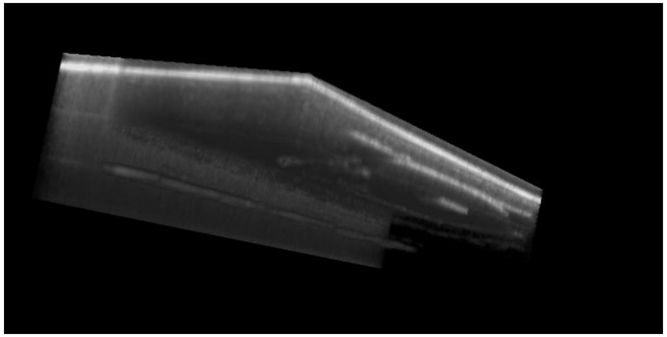
Commercial Thorlabs NIR OCT



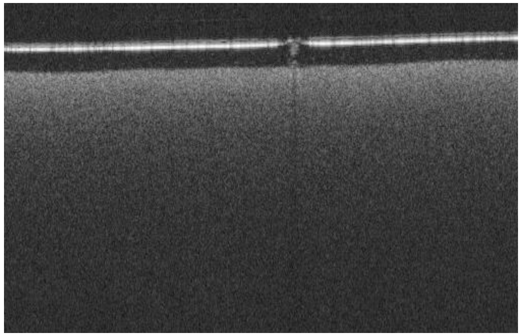
Polymers



MIR OCT



Commercial Thorlabs NIR OCT



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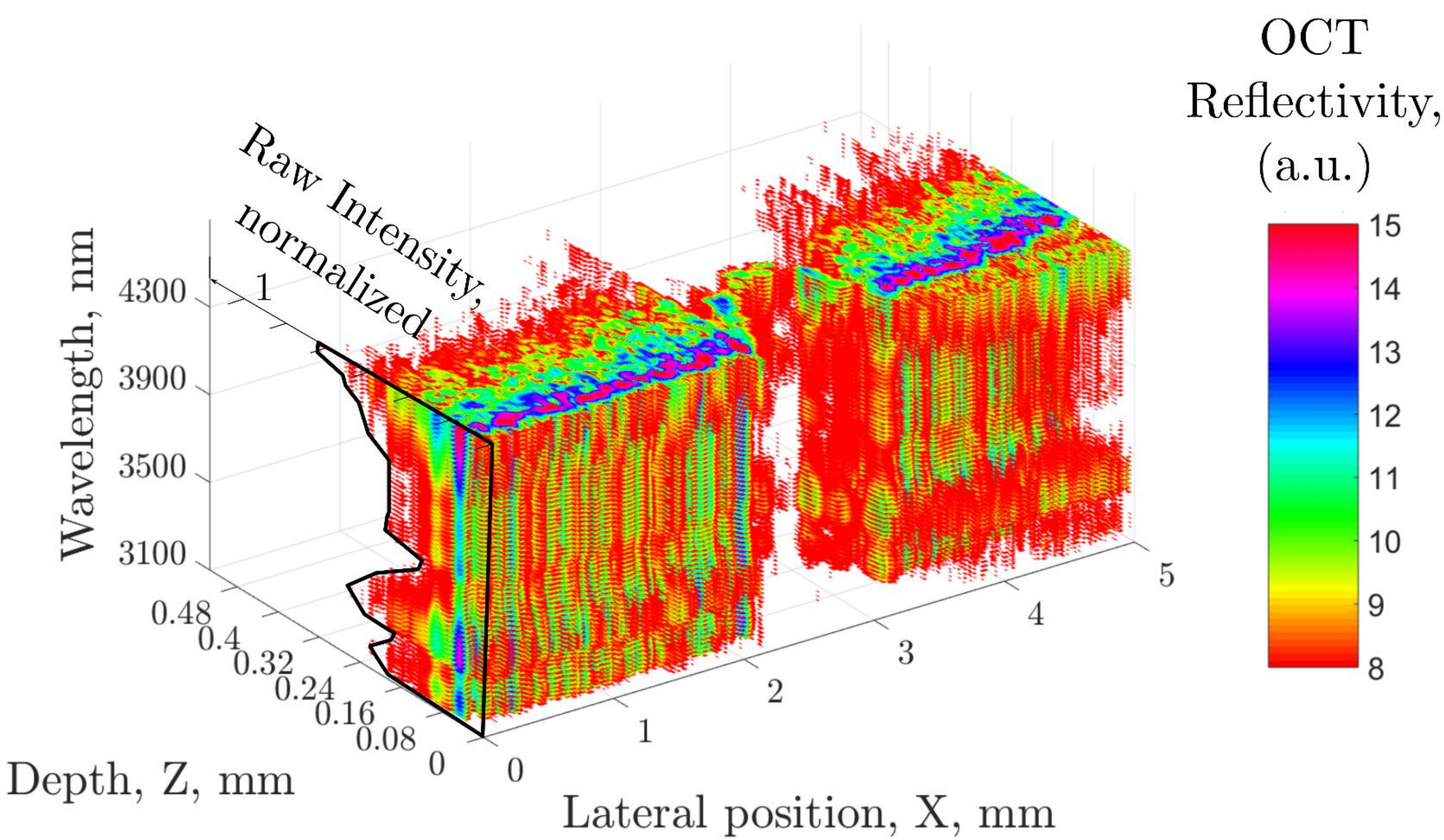
Multimodal mid-IR spectroscopy and optical coherence tomography, WP5

Results: **Thermal barrier coating**

Spatial information **Spectral information**



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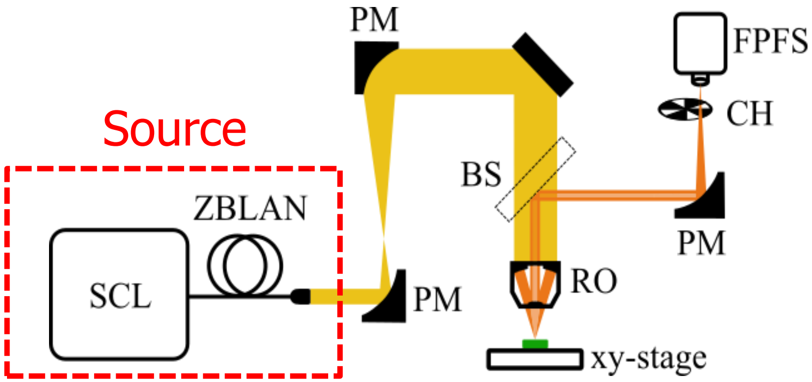
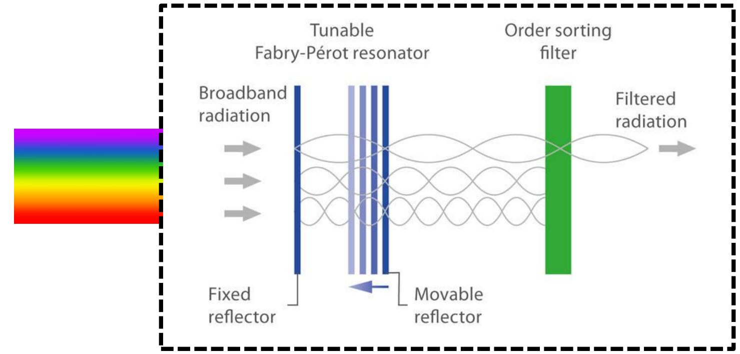
Diffraction limited Hyperspectral microscopy



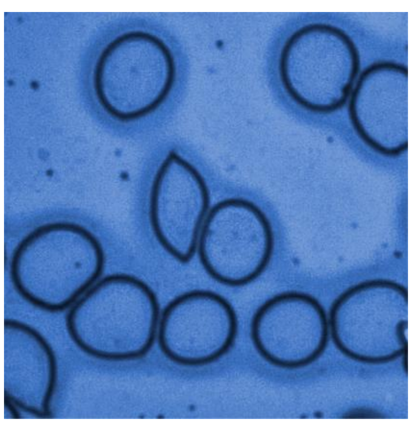
SCL ... Supercontinuum Laser
FPFS ... Fabry-Pérot Filterspectrometer
PM ... Parabolic Mirror
BS ... Beamsplitter
CH ... Chopper
RO ... Reflective Objective

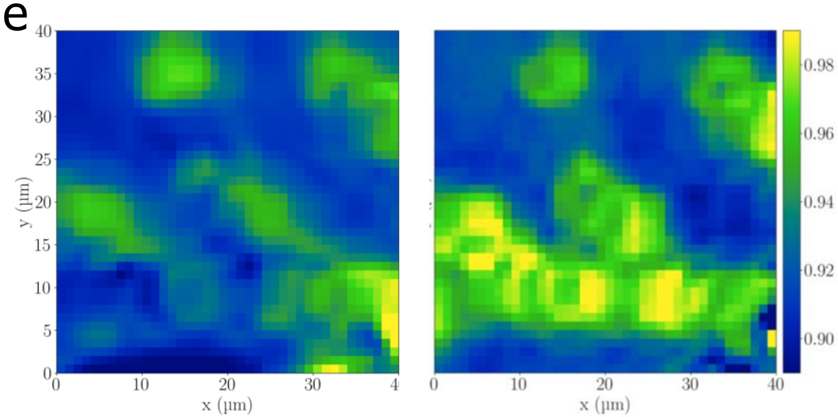
Fabry-Pérot Filterspectrometer (FPFS)

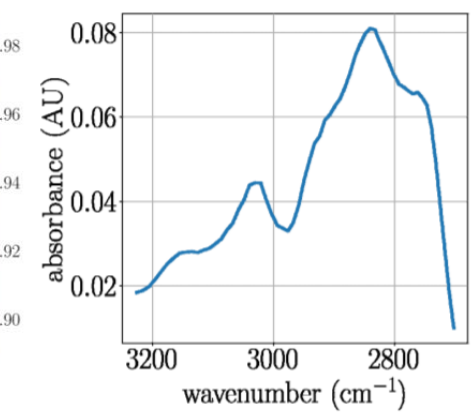


Dried blood smear on microscopic glass slide

VIS microscopic image







Measured in reflection

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Thank you!

- **RECENDT GmbH**
  - **Ivan Zorin:**
    ivan.zorin@recendt.at
  - **Head of OCT:**
    Dipl.-Phys. Dr. **Bettina Heise**
    Bettina.Heise@recendt.at
    +43 / 732 / 2468-4666
  - www.recendt.at
  - A – 4040 Linz, Altenberger Straße 69, Science Park 2

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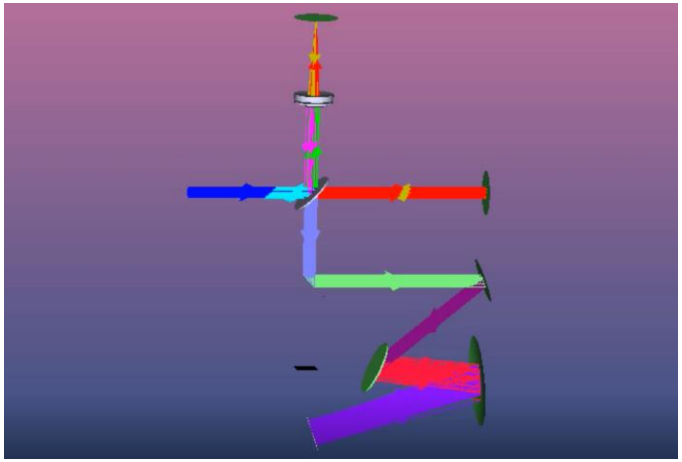
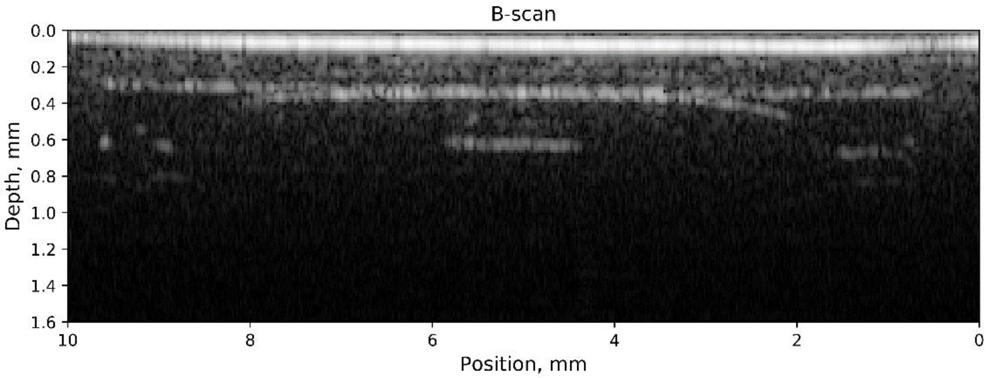
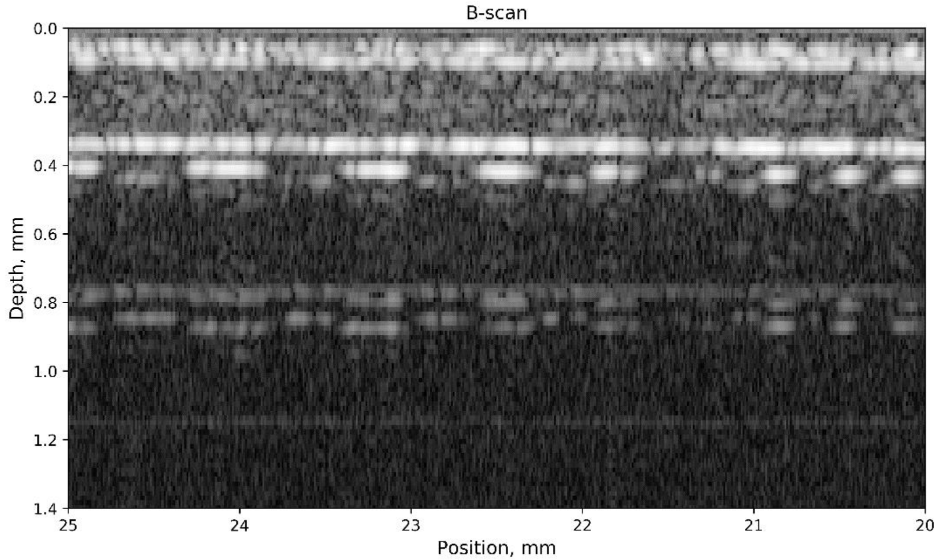
MIR OCT

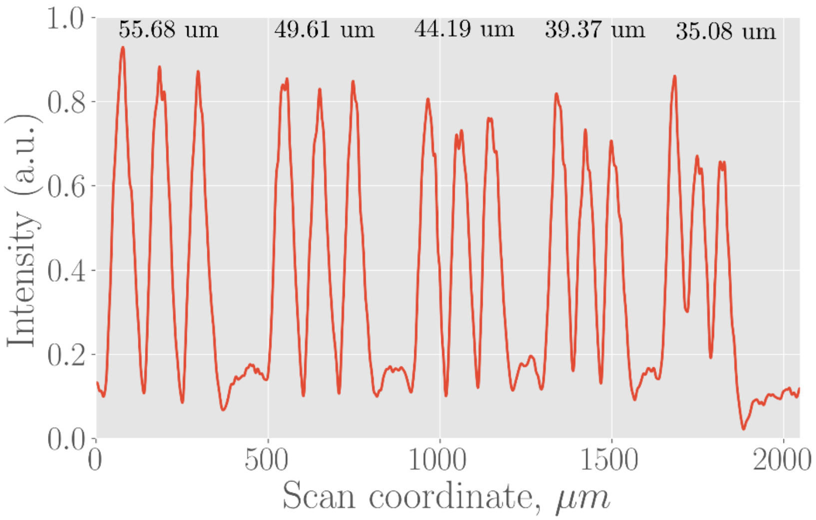




Bank card, b-scan



Ceramic sample, b-scan



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