Optical coherence tomography for non-destructive testing and imaging applications

Ivan Zorin
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General information

REsearch CEnter for Non-Destructive Testing

RECENDT: located at JKU in Science Park 2

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

SP2, 2. OG
Research topics and groups

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

Common TD-OCT System

Axial Resolution:

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

Lateral Resolution:

\[ \omega_0 \approx \frac{4\lambda_0}{\pi} \cdot \frac{f}{d} \propto \frac{\lambda_0}{NA} \]

Probing depth:

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

\( \lambda_0 \) – center wavelength
\( \Delta \lambda \) – spectral bandwidth
\( n \) – refractive index
OCT in General

Optical Coherence Tomography

- Time Domain OCT
- Fourier Domain OCT
- Spectral Domain OCT
- Swept Source OCT
Fourier domain OCT

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

- **Envelope**
  - Distance of Reference Mirror
  - Intensity

- **A-Scan**
  - Distance of Reference Mirror
  - Intensity

- **B-Scan**
  - A-scan
  - Scanned

- **C-Scan**
  - En-Face
OCT Scans examples

Pearl

Tape Commercial Thorlabs System

Sub2mu system at RECENDT
Polarization sensitive OCT

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

Retardation: \( \delta(z) \sim \text{atan}(A_1(z)/A_2(z)) \)

Optical Axis Orientation:

\[
\Delta \varphi(z) \sim \varphi_1(z) - \varphi_2(z)
\]

\[
\theta(z) = \frac{\pi - \Delta \varphi(z)}{2}
\]
**Micro-crystallites in turbid materials**

Extruded polypropylene with internal defects (micro-crystallites)

- **Cross-sectional** (ac) retardation image (5 x 3 mm)

- **En-face** (ac) retardation image (1 x 1 mm x 200 nm)

Ultra High Resolution OCT System

UHR System at RECENDT

Quality Control in Packaging Industry

Multi-layer foil

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

Wiesauer et al., Optics Express 13, 1015 (2005)
General OCT projects

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

Light source

Beam Splitter

Detection system

Objective

Specimen

Optical Coherence Tomography

Morphological information

Spatially resolved chemical compositions

SRS Spectroscopy

https://www.teachengineering.org/lessons/view/csuf Polymer Lesson01
SRS+OCT

Key parameters:
Covered spectral range: 
1493 - 2018 cm\(^{-1}\)
Spectral resolution \(\approx 4\, \text{cm}\, ^{-1}\)
Lateral resolution \(\approx 10\, \mu\text{m}\)
Acquisition time \(\approx 2.5\, \mu\text{s}\) per single spectrum

Higher depth penetration because of NIR excitation
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

Enhanced Penetration depth has been achieved

Lateral resolution: 35 um
Axial resolution: 50 um

Supercontinuum Source

High power, monochromatic
Non-linear fiber
Broadband supercontinuum

• High power
• High brightness
• Spatial coherence

Enhanced Penetration depth has been achieved

Co-registered spectra
High potential for new types of materials: ceramics, polymers, paints etc.

MIR OCT

Commercial Thorlabs NIR OCT

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 722380
Multimodal mid-IR spectroscopy and optical coherence tomography, WP5

Results: Thermal barrier coating

Spatial information

Spectral information

OCT Reflectivity, (a.u.)

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Diffraction limited Hyperspectral microscopy

Source

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

Dried blood smear on microscopic glass slide

VIS microscopic image

Measured in reflection

Fabry-Pérot Filterspectrometer (FPFS)
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
MIR OCT

Bank card, b-scan

Ceramic sample, b-scan