RECENDT

Research Center for Non-Destructive Testing

RECENDT GmbH is based in Linz / Upper Austria and is an internationally well recognized Research Center for Non-Destructive Testing and material characterization.

The company is a 2009 – spin-off from the Upper Austrian Research (UAR) where the technological expertise has been built up since the year 2000. Shareholders are still the UAR and the Johannes Kepler University Linz (JKU).

RECENDT has earned the honor of being nominated as a non-university-based Christian Doppler Laboratory (CD-Lab): Until 2016 RECENDT ran one of only two non-university-based CD-labs in Austria. For their scientific work the Researchers have been awarded the special price for research-facilities at the Upper Austrian “Innovationspreis 2010”.

The Austrian Research Company is partner and leader in various national and international projects.

Activities and fields of research:

The activities comprise the whole R&D process chain from application-oriented fundamental research up to the development of novel instrument technologies for industrial application.

Novel technologies that seem promising for a future industrial application are driven forward in fundamental research until the point where **RECENDT** takes the step towards development of prototypes suited for industrial needs.

At the moment the company’s researchers are dealing with the technological fields of optical coherence tomography (**OCT**), infrared- and Raman spectroscopy (**IR**), THz technology (**THz**), laser ultrasound (**LUS**), and photoacoustics (**PA**).

The interdisciplinary, highly qualified team consisting of physicists, chemists, mechatronic and development engineers has state-of-the-art equipment at its disposal in order to effectively apply its competences to contribute to the success of local and international companies. **RECENDT’s** technologies are being applied in almost any industrial branch.

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INFRARED-SPECTROSCOPY

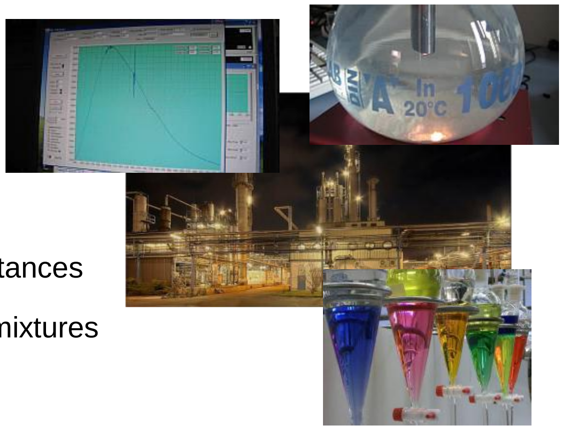
Motivation / Initial Situation:

The steadily increasing competitive pressure in industrial production - due to the global competition on decreasing production costs - requires the introduction of novel technologies in process monitoring and the thus enabled process control to establish a competitive production. Furthermore restrictive environmental regulations and quality assurance requirements demand a monitoring system, which enables continuous recording of sensitive process parameters. For such measurement tasks infrared spectroscopy is the most suitable measurement technique because of high flexibility, selectivity and accuracy.

Principle:

Infrared spectroscopy is based on the excitation of vibrational states of molecules via exposure of substances to infrared radiation. IR spectroscopy is considered as a key technology in the field of molecule-specific sample analysis. By analyzing changes in the spectral composition of the probing light beam, the spectra gathered via these methods provide access to detailed information on the binding characteristics of functional groups within the sample. Therefore this technique is highly important for the identification and characterization of unknown substances as well as the investigation of interactions between different compounds. Thus, this method enables a sophisticated qualitative and quantitative analysis of the chemical composition of a product in solid as well as liquid state.

In order to access measurement positions in an industrial production plant, suitable light guiding and probing components are necessary. The robust optical materials available for near infrared technology enable measurements in liquids and on surfaces. However, due to spectral characteristics in the near infrared region chemometrics (statistical analysis) is an essential mathematical method to retrieve the chemical information.



Fields of Application:

- Scientific Field:
  - In situ studies of chemical reactions
  - Investigation of the molecular structure of novel substances
  - In situ determination of the composition of unknown mixtures
- Industrial Field:
  - Qualitative and quantitative process monitoring
  - Quality control of products in numerous industrial areas (e.g. chemical, pharmaceutical, food, plastics, petroleum and paper industry)

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Available Instrumentation:

- Fourier Transform Near Infrared (FT-NIR) process spectrometer (Spin-Off: i-RED)
- Fourier Transform Infrared (FTIR) lab spectrometer (Bruker Vertex 70)
- Probing equipment for non-specific requirements (liquid and solid phase)

Aim / Benefit / Results:

The implementation of spectroscopic process-control in an industrial plant (=inline) enables a continuous monitoring of a vast variety of process parameters. This creates the possibility for a direct closed loop control of important parameters such as chemical concentration or layer thickness in realtime applications in the production process. This leads to

- more precisely defined process conditions
- less raw material- and energy consumption
- reduced amount of unwanted by-products
- decreased loss through waste

Inline process control offers a huge potential of reducing production cost and environmental pollution.

Industrial Partners:

In recent years a number of applied research projects have been conducted with Austrian and international industrial partners. Within the research project PAC - Process Analytical Chemistry (see map) we are currently working together with a number of prominent industrial partners on innovative process analytical solutions.

Further project partners:

- Danisco Sweeteners GmbH
- Tann Papier GmbH
- DSM Fine Chemicals Austria Nfg GmbH & Co KG
- Voestalpine Stahl GmbH

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POLARISATION-SENSITIVE
INFRARED – SPECTROSCOPY

Motivation / Initial Situation:

A rather young field of RECENDT's research – offering great opportunities for industry – is dealing with the characterisation of anisotropic materials and surfaces (e.g. stretched plastics, directed coatings).

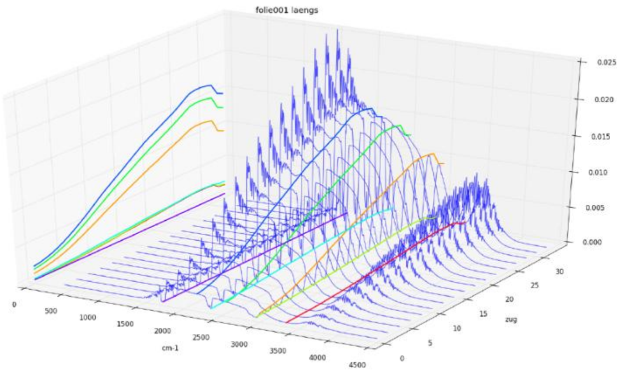
In various technical areas exact knowledge regarding directional dependencies of materials' properties is essential for optimisation of further processing and process control. Making use of a new method, developed at RECENDT, those properties can be measured very precisely.

Principle:

The technology makes use of Fourier transform infrared spectroscopy to measure the chemical properties of the sample, and combines that with the evaluation of the polarization properties of the IR light used. Thus the birefringence effects are measured and the orientation of the molecules can be determined.
By an active polarisation modulation the sensitivity as well as the accuracy and stability of the method can be increased.

Fields of Application:

- currently laboratory measurements on different samples for further optimisation of the technology
- Industrial systems are being prepared, implementation with interested company partners will follow



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Industrial optical coherence tomography system

(IND-OCT)

- **Contactless and non destructive** imaging of subsurface structures in translucent materials.
- **Penetration depth** is material dependent (up to several millimetres)
- **Compact and small** (computer mouse sized probe head)
- Works with **harmless** infrared light
- **Fast**: delivers several cross-section images per second
- **Ultra high resolution**: depth resolution of **1µm** possible, determination of layer thickness with sub-µm accuracy.
- **Low costs** (comparable with the costs for a „normal" microscope)
- High potential for **cost reduction** in product development and **quality control**

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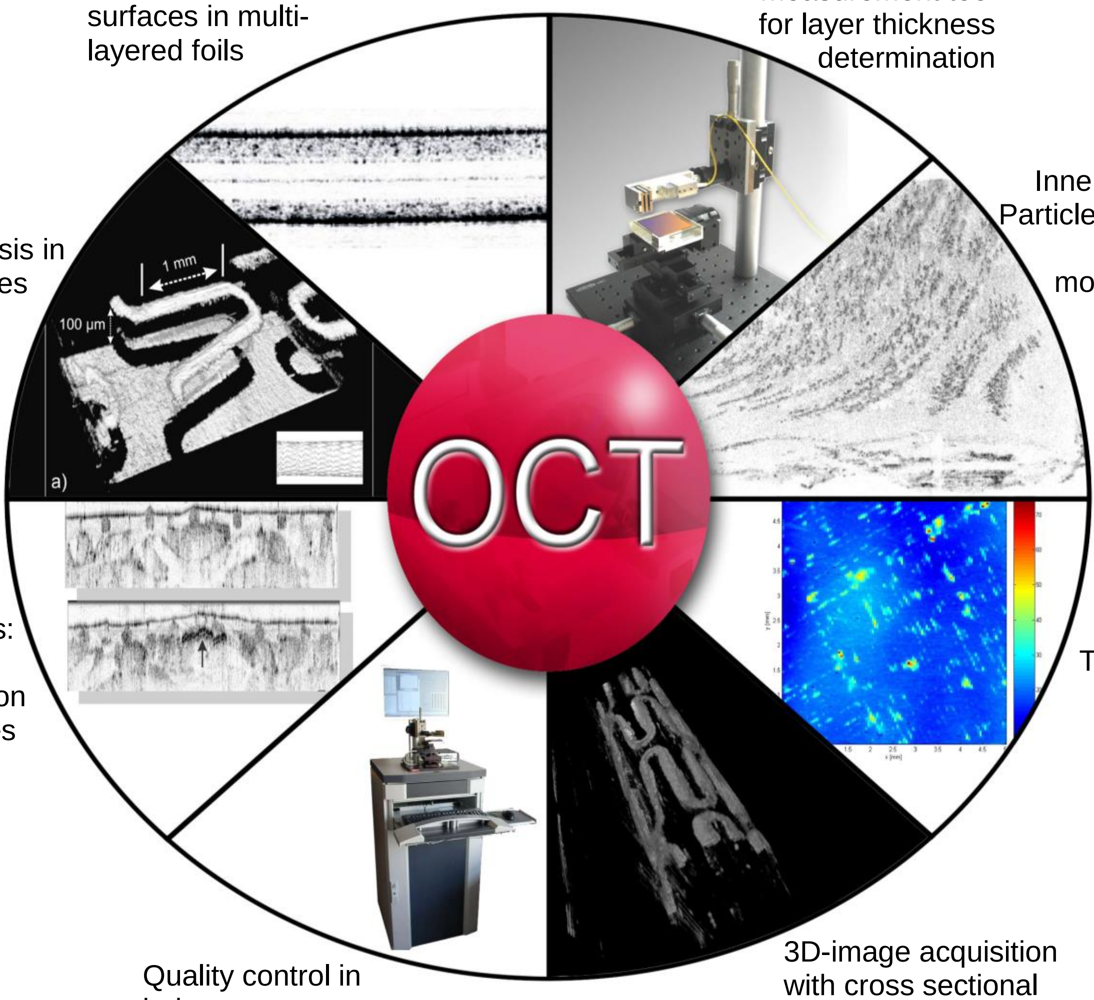
Fields of application:

OCT is well suited for semi-transparent materials, as e.g.

- plastics (injection moulding parts, multi-layered foils,…)
- composite materials (carbon fibre composites,…)
- metals (surface morphology, coatings)
- glasses, ceramics
- semiconductors



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Non destructive cross sectional analysis with optical coherence tomography (OCT)

Motivation:

Non destructive measurement and imaging techniques, which can resolve the inner structure of materials play an important role in industrial research and quality control, e.g. for composite materials, plastics, etc. Common measurement approaches like ultrasound techniques only provide a depth resolution of around 100 µm and have the disadvantage that the sample has to be in direct contact with the probing apparatus (e.g. via water or contact gels).

Working principle:

Optical coherence tomography (OCT) gives the possibility to acquire cross sectional images of the sample under investigation in a contactless and non destructive manner. The depth resolution with this technique generally lies in the range of 3-4 µm and can be improved towards resolutions of as low as 1 µm. The physical phenomenon behind OCT is the interferometric superposition of a reference light wave with light back-reflected from different layers within the sample. The intensity and the travelling times of the back-reflected light waves contain depth resolved information and through the use of mathematical algorithms it is possible to reconstruct cross sectional images of the sample.

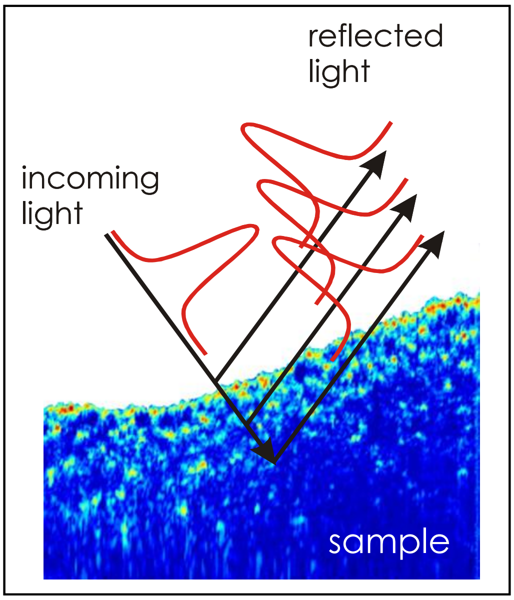

Figure 1:
Detection scheme of OCT. Depth resolved information is acquired via the different reflected infrared light waves.

Aim / Gain / Result:

OCT has already been used extensively in biomedical applications like e.g. ophthalmology, and at RECENDT (formerly UAR) this non destructive technique has been used since 2002 for material sciences and quality control in industry.

Fields of application of optical coherence tomography OCT:

- Non destructive testing of materials
- Analysis tool in process development (e.g. injection moulding processes, extrusion of multi-layered foils)
- Industrial inspection and quality control in the production process (e.g. layer thickness measurements in multi-layered foils).

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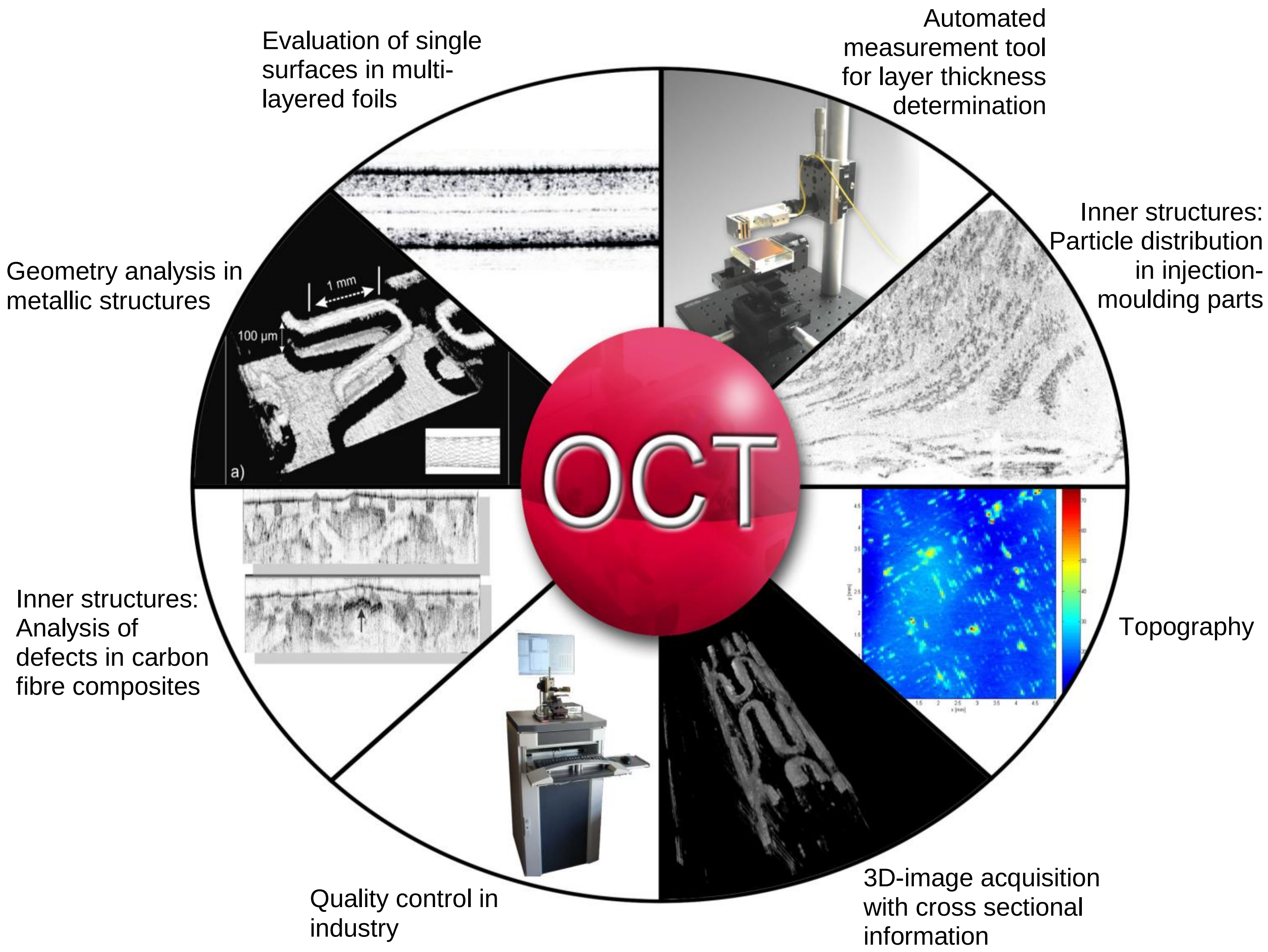
Fields of application:

OCT is well suited for materials, as e.g.

- plastics (injection moulding parts, multi-layered foils,…)
- composite materials (carbon fibre composites,…)
- metals (surface morphology, coatings)
- glasses, ceramics
- semiconductors



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LASER-ULTRASOUND

Laser-ultrasound is a method to generate and detect ultrasonic signals contactless.

Motivation:

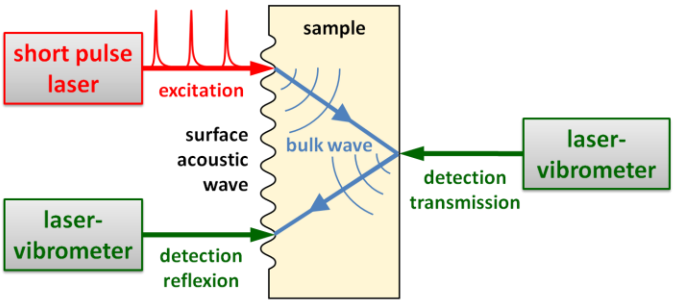
Conventional ultrasonic measuring devices like piezotransducers have the disadvantage that the sample must be in direct contact with the sample. In manual testing this is done by applying a coupling agent or in automatic tests by a water jet (squirter systems) or a water bath.

On very hot samples (e.g. hot steel during manufacturing) or on samples where a coupling agent is not allowed by the test method, laser ultrasound enables a non-contact, rapid test method.

A further advantage which results from the optical excitation and detection is an increased resolution. The broad spectrum of ultrasound (ultrasonic frequencies) ranges up to 1 GHz. Thus, it is - depending on the acoustic properties of the sample - possible to achieve resolutions smaller than 10 microns.

Method:

The ultrasonic wave is generated by thermo-elastic expansion or ablation of the surface by a short laser pulse. Further the sample itself is the ultrasonic generator and thus determines the direction of propagation of the sound waves. The detection of the ultrasonic wave is done also contactless with a laser vibrometer.



Advantages:

- High bandwidth, therefore high depth resolution (<10 microns, depending on the elastic properties of sample).
- No couplant required - interesting for high temperature samples (like steel tubes during manufacturing) and for ultrasound testing on samples where a coupling agent is prohibited.
- Direction of the ultrasonic waves is not determined by the angle of the incident excitation laser. The sample itself is the ultrasound generator and thus determines the direction of ultrasonic waves.
- Very fine structures (coatings up to the nanometer range) can be measured with surface waves (e.g. Rayleigh or Lamb waves).

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Purpose:

- Ultrasound measurements on samples where a coupling agent is prohibited due to high temperature or where contacting is not possible because of geometrically inaccessible samples / test points.
- High-resolution measurement: thickness measurement and high-resolution scan of the sample for the detection of voids, delamination.
- Determination of elastic properties.
- Determination of the anisotropy of elastic properties of different materials, like rolled steel, aluminium, paper or fiber-reinforced composites.
- Determination of the hardening depth of case hardened steel samples.

Equipment:

- Laser Ultrasound detectors: BossaNova Technologies Tempo, Tecnar TWM, laboratory setups with different types of interferometers like confocal Fabry-Perot Interferometer, Mach-Zehnder interferometer with photorefractive crystal
- Ultrasound generation: Brilliant B Nd:YAG 750mJ ns-Laser, Ekspla Nd:YAG 80mJ ps-Laser, Edinburgh Instruments CO_2 150mJ/50ns-Laser
- Data acquisition: oscilloscopes up to 20GS/sec (Tektronix, Lecroy, Rhode & Schwarz), and PC-based systems (Gage 14 bit digitizer)

Partners:

- Institute of Materials Science and Technology – Vienna University of Technology
- Institute of Experimental Physics - University of Graz

Established users:

- Tecnar and National Research Council, Canada: Failure detection (cracks, delaminations) in composite materials (CFRP, GFRP), measuring the wall thickness of hot steel tubes during manufacturing
- Lockheed Martin, USA: Testing of carbon fiber parts of fighter aircraft
- Lawrence Berkeley National Laboratory (LBNL), Institute of Paper Science & Technology (IPST): Paper stiffness and anisotropy

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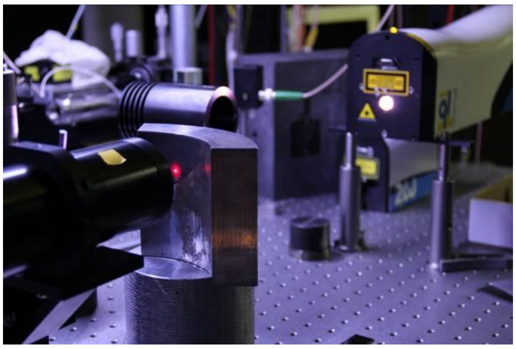
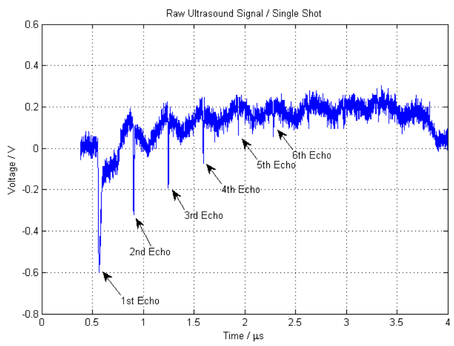


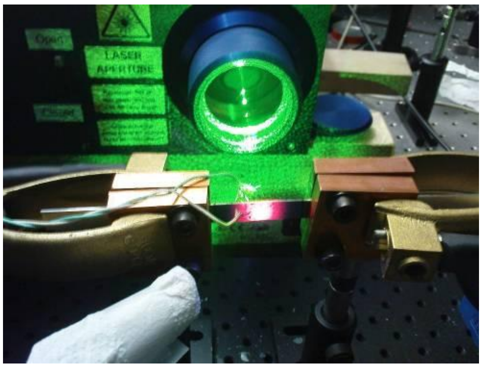
Typical Applications:



Contactless ultrasound measurement:

- Identification of sample-thickness
- Defect detection
- Determination of elastic properties

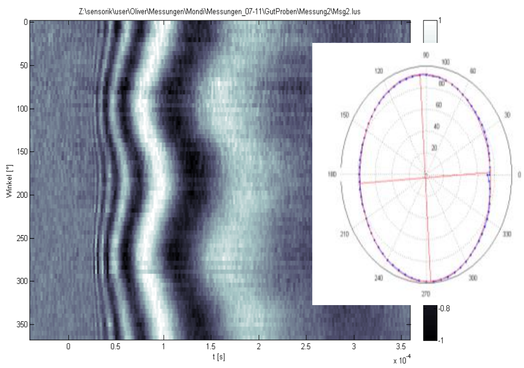
picture: echoes of a 1 mm thick steel panel



Ultrasound measurements on materials at high temperatures.

picture: observation of phase transition of steel during annealing:

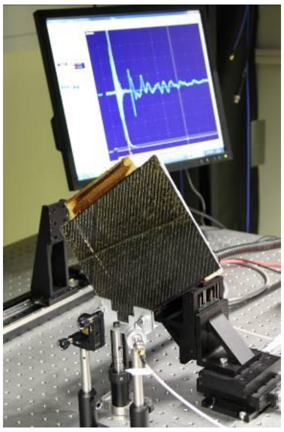
ferritic → austenitic → martensitic



Determination of the anisotropy of materials triggered by

- direction of rolling (steel or aluminium rolled strip)
- drying process of paper

picture: anisotropy of photocopying paper
Quality feature: axial directions of the anisotropy



Analysis of CFRP samples to detect:

- Defects
- Debondings / cracks
- Kissing bonds / weak bonds

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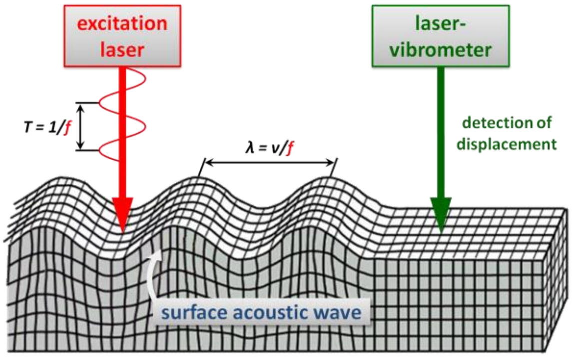
Characterization of thin coatings with modulated laser ultrasound

With the help of modulated laser ultrasound, layer thickness and elastic properties of thin films and coatings can be determined very precisely. Similarly, in this special case of laser ultrasound the measurement of coatings takes place without physical contact.

Motivation / initial situation

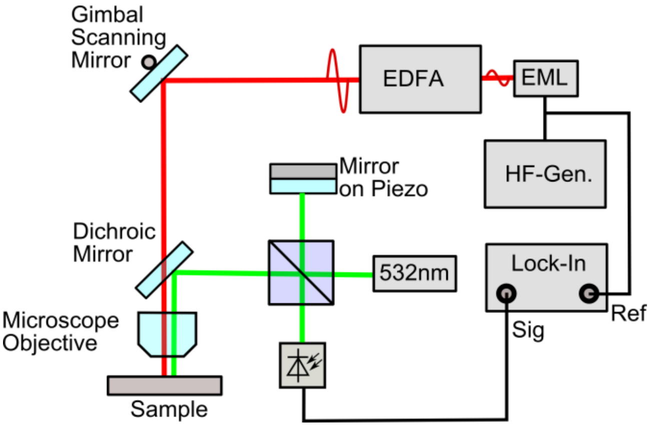
For the determination of thickness and/or elastic properties of very thin coatings (micron to sub-micron region) the accuracy of "standard" laser ultrasound is insufficient. To improve the measurement accuracy of "standard" laser ultrasound the energy of laser pulses have to be increased. However, this can lead to the destruction of the examined layers.



This problem can be avoided by the application of modulated laser ultrasound. Here, a continuous wave laser is amplitude modulated at certain frequencies. Using adapted detection electronics lead to considerably improved signal to noise ratio and therefore increased measurement accuracy, while thermal load on the sample surface is reduced.

Measuring principle:

The electro-absorption modulated laser diode (EML) provides an amplitude modulated laser signal, which is amplified with an erbium doped fiber amplifier (EDFA). This laser signal generates modulated laser ultrasound in the specimen. For the detection a Michelson interferometer is adapted and the measured electronic signals are analyzed with a Lock-in amplifier, which is locked to the frequency of the excitation laser.



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TERAHERTZ TECHNOLOGY FOR INDUSTRIAL APPLICATIONS

Terahertz (THz) technology is currently close to its application in industry. It has several advantages that make it a tool for the contactless and non-destructive investigation of many nonconductive materials (e.g., plastics, paper / cardboard, ceramics, chemicals, pharmaceuticals):

- High penetration depths, e.g., for plastics in the range of cm (advantage over neighboring IR)
- Better spatial resolution (mm to sub-mm) compared to adjacent microwaves
- Non-ionizing (advantage over x-rays)

Facts

- THz radiation is located in between the microwaves and infrared (IR) in the electro-magnetic spectrum.
- THz radiation is strongly absorbed and/or reflected by water (polar substances) and by conducting materials.

Technology

We apply a time-resolved measuring principle, in which pulsed THz radiation is deployed (via a femtosecond pulse laser). This technique allows for depth-resolved and spectral information.

Scope of Applications

THz-physical Properties

- Determination of layer thickness (e.g. coatings, multi-layered boards and composite tubings, tablets)
- Index of refraction, absorption coefficient

THz-Spectroscopy (chemical properties)

- Qualitative and Quantitative characterization and identification via fingerprinting, e.g. of explosives, crystalline substances (e.g. active pharmaceutical ingredients), polymers, oils
- Analytics: Optical Isomers (chiral), conformational isomer (e.g. chair/boat), polymorphs, as well as their phase transitions and determination of mixing ratio
- Water content and water of hydration

THz-Imaging (see examples on rear side)

- Polymers and plastics, paper / cardboard, ceramics, textiles, foodstuff etc.
- Investigation of inclusions, defects, etc. (position, depth)
- Quality of interfaces (e.g., between plastics, plastic – metal)
- Delaminations / defects in GRP materials, etc.

Polarization sensitive measurements (also imaging)

- E.g. determination of fiber orientation in fiber reinforced polymers

Hyperspectral Imaging

- Combination of imaging and spectroscopy as well as determination of physical properties

New!

- Fiber-coupled system for the physical separation of detector head and measurement and monitoring system

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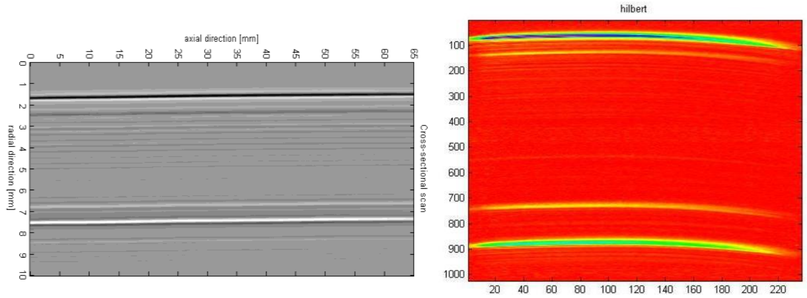
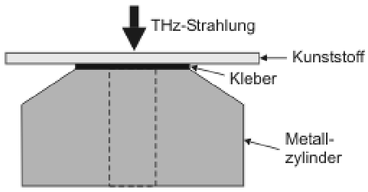
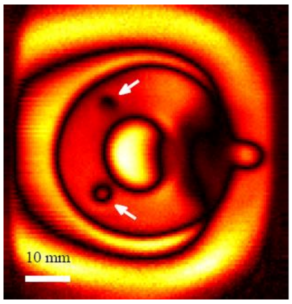
Examples of Applications

- composite polymer tubings [1]
  - Tube left: 3 layers, total layer thickness: 2 mm, outer layer: 0.5 mm
  - Tube right: 3 layers, total layer thickness: 2 cm, outer layers: 1.5 and 3 mm

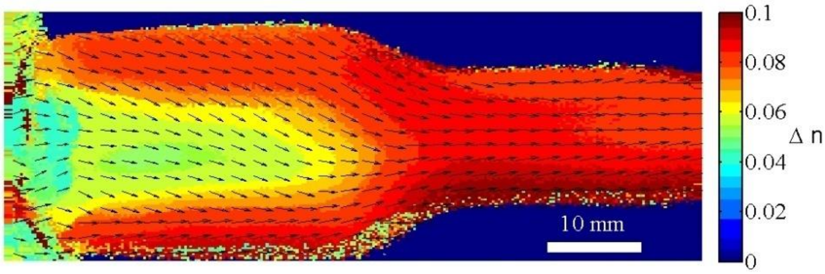


- Adhesive layer (automobile industry; left: without, right with defects; [2])





- Fiber-reinforced polymers; [3]



Referenzen:

[1] Probe: Institut für Polymer Extrusion und Building Physics, Johannes Kepler Universität Linz.
[2] S. Katletz, M. Pfleger, H. Pühringer, N. Vieweg, B. Scherger, B. Heinen, M. Koch, and K. Wiesauer, „Efficient Terahertz En-face Imaging“, Opt. Express 19, 23042–23053 (2011).
[3] S. Katletz, M. Pfleger, H. Pühringer, M. Mikulics, N. Vieweg, O. Peters, B. Scherger, M. Scheller, M. Koch, and K. Wiesauer, „Polarization sensitive terahertz imaging: detection of birefringence and optical axis“. Opt. Express 20, 23025–23035 (2012). doi:10.1364/OE.20.023025.

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TERAHERTZ TECHNOLOGY

Motivation / Initial Situation:

The frequency range of terahertz (THz) radiation, located between the microwave and infrared band of the electro-magnetic spectrum, has become accessible in an efficient way only recently. For this reason, THz technology is a highly actual field of research.

One interesting physical property of THz radiation is its large penetration depth for many non-conducting materials, such as plastics, polymers, paper, cardboard, ceramics or textile tissues. Furthermore, many substances show characteristic absorption pattern ("fingerprints") at THz frequencies. In addition, THz radiation is non-ionizing, in contrast to x-rays. These reasons make THz technology a highly promising tool for contact-less and non-destructive investigation and characterization of materials.

THz technology comprises different areas, which are THz imaging, THz spectroscopy (time-domain spectroscopy, TDS), as well as a combination of both (THz spectroscopic imaging, THz hyper-spectral imaging).

Principle:

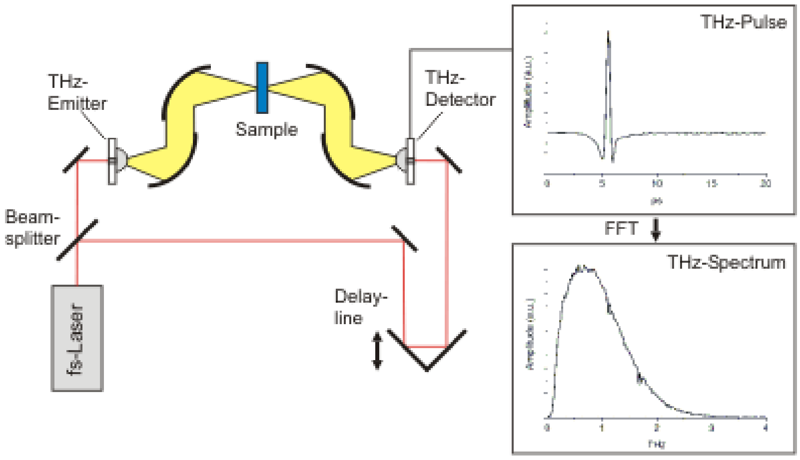

Figure 1:
Left: schematic setup of a pulsed THz system.
Top right: THz pulse.
Bottom right: THz spectrum.

Many THz systems work with pulsed, broadband THz radiation and time-resolved detection schemes. A typical THz-TDS setup is shown in Fig. 1.

For excitation of pulsed THz radiation, a femtosecond (fs-) pulse laser is applied. One part of the fs-laser beam illuminates a THz emitter (e.g., a photo-conductive switch). The emitted THz radiation is focused on the sample, is transmitted, re-collimated and focused onto a THz detector (e.g., photo-conductive switch, electro-optic crystal).

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For time-resolved detection of the THz signal, the second part of the fs-laser beam illuminates the detector. By moving a delay-line in the optical path of the laser beam, the time delay between excitation and detection of the THz pulse is varied, and the THz pulse is sampled in a time-resolved way (see Fig. 1).

The THz spectrum is obtained by Fourier transform (FFT) of the time-resolved signal (see Fig. 1). From the phase and the amplitude information, the frequency-dependent THz material parameters (refractive index and absorption coefficient) can be directly obtained.

For THz imaging, additionally a lateral raster-scanning of the sample is performed, and the signal is analyzed and displayed in a spatially resolved way. The lateral resolution of the THz beam is in the range of 1 millimetre, due to the THz wavelength (1 THz has a wavelength of 300 µm).

Aims / Results:

An application of THz imaging in the field of material investigations is the investigation of plastics, glass-fibre composite materials or ceramics. There, defects or inclusions in the millimetre range can be detected inside the sample, although if the sample appears opaque for visible light. In particular the exploitation of the polarization properties of THz radiation provides the possibility of obtaining information about birefringence and consequently, about anisotropies or strain inside a material – information that are difficult to be obtained with other methods. One application is the analysis of fibre orientations in GFC materials.

The potential of spectroscopic THz measurements lies in the detection and analysis particularly of crystalline substances, such as drugs, illicit drugs, explosives or nutritional additives. Especially paper or plastic packaging is no obstacle for these measurements, and the sample can be analyzed through the packaging. It is noted that polar substances, such as water, exhibit strong absorption for THz waves. This limits the investigation of substances containing water (e.g., biological tissue). Another possibility for material characterisation is the determination of the frequency-dependent THz refractive index and absorption coefficient, which (for known sample thickness) can be obtained directly from the THz-TDS measurements.

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Customer Solutions

RECENDT cooperates with national and international leading companies as well as with small and medium-sized enterprises (SMEs). In particular, the SMEs as the backbone of the Austrian economy are in the focus of our technology transfer services.

We offer

Research and technology consulting for your company

- an initial meeting on site at your company
- an assessment of your technological problem
- to develop a common solution statement (phase approach)
- the use of available funding opportunities

Development within the framework of projects

- with professional project management
- within a predefined timeframe
- with calculable costs
- with comprehensive documentation
- in full confidentiality

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- Access to a well-structured network of research and development facilities.

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Phase approach – step by step to success

Step by step to success

An important function of RECENDT is to make high-tech solutions available to local businesses independent of their size.

RECENDT offers companies a 3 phased approach which encompasses the entire R&D process chain. Each phase contains jointly defined steps and a clear goal. The partner company receives results at the end of each phase, thus giving them a sound basis to make decisions about further action – this creates clarity in project and interface development as well as cost transparency.

Phase 1: Identification & Selection

Identification of measurable parameters which are significant for the process or product
Selection of possible technologies for the measurement of parameters

Phase 2: Evaluation & Conception

Evaluation of the usefulness of technologies in the process environment
Conception of a measuring system based on evaluation of technologies

Phase 3: Development & Integration

Development of the measuring system tailored to the client
Integration of the measuring system on site at the partner company

Advantages of this method of implementation

- Clarity and transparency
- Shorter implementation times
- Transparency in cost structure
- Flexibility in the development

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