MATERIALS CHARACTERIZATION AND TESTING

PROF. DR. GEORG VON FREYMANN
HEAD OF DEPARTMENT

NON-DESTRUCTIVE TESTING WITH MILLIMETER, TERAHERTZ AND OPTICAL WAVES

Quality control in industrial production processes is not only important for safety-relevant components, e. g. in aviation industry and medical technology but also supports resource-saving production by avoiding defective parts. Contact-free and non-destructive measurement allows further use of tested parts in the production process.

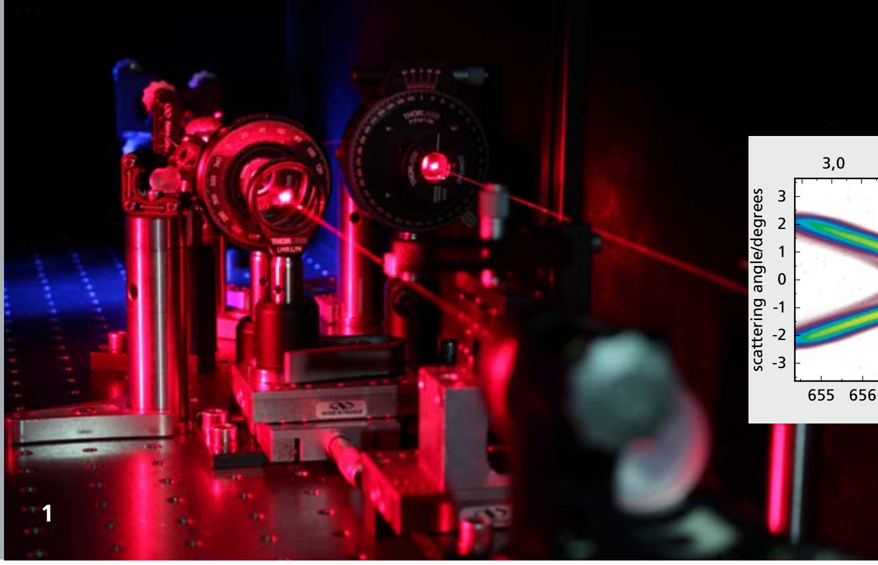
At the Materials Characterization and Testing department, we develop non-destructive and contact-free measurement methods which are optimized for application in production lines and enable reliable control of the production process. Our Terahertz layer thickness measurement systems are able to investigate thickness and material parameters of each individual layer. Our pipeline inspection systems check the wall thickness directly at the extruder. Our FMCW radar-based inspection system reliably detects defects in composite materials. Chemometric evaluation methods determine the composition of materials quickly and reliably from spectral data.

Our scientists, engineers and technicians use technologies ranging from optical coherence tomography (OCT) in the visible spectral range to time domain spectroscopy in the terahertz frequency range and electronic system concepts in the millimeter wave range for tailor-made customer solutions. The competence of our employees includes a detailed understanding of the process in such a way that application and evaluation software clearly presents the key target parameters and appropriate technological solutions can be identified for the respective application.

Contact
georg.von.freymann@itwm.fraunhofer.de
www.itwm.fraunhofer.de/en/mc

MAIN TOPICS

- Non-destructive testing
- Layer thickness measurements
- Chemical analysis



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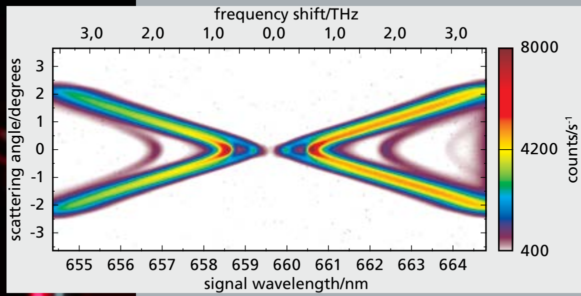

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QUILT – QUANTUM OPTICS IN THE TERAHERTZ SPECTRAL RANGE

1 *Experimental setup to verify photons generated by quantum optics*

2 *Angular spectrum recorded in the context of the project as indirect proof of quantum optical generation of terahertz photons*

Fraunhofer has a flagship project known as QUILT to conduct research on imaging processes in the terahertz spectral range based on quantum optics. "Schrödinger's Cat" has developed from a thought experiment to an exciting and practical reality. With our first experimental successes achieved in 2018, we are breaking new ground in the field of terahertz research.

Classical imaging in the visible spectral range benefits from the wide availability of good detectors. Whether in digital cameras, PCs, or smartphones: the majority of households own several optical imaging systems with millions of detectors.

Imaging difficulties using terahertz waves

However, imaging in the terahertz spectral range is still a major technical challenge. Often, we are forced to rely on scanning methods since only a single or just a few detectors can be operated. In practice that means the scenes to be recorded are scanned with a single detector and these traces, subsequently, have to be put together.

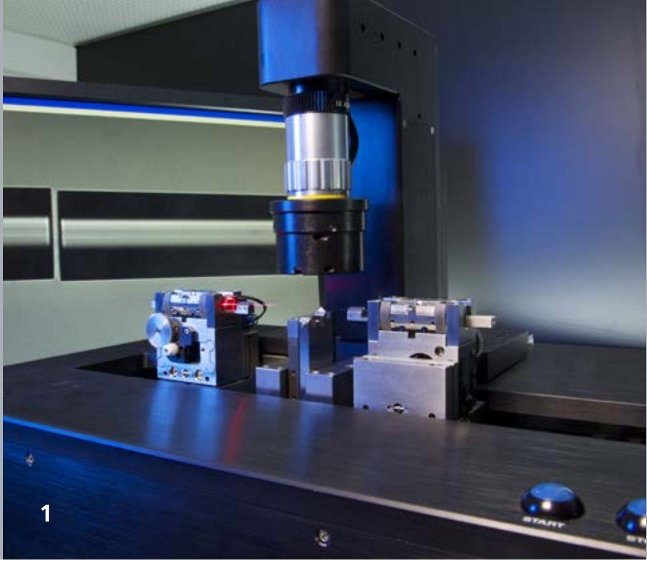
Quantum optics provides a solution

Using the phenomena of quantum optics, we can transfer the properties of photons (light particles) to other photons. If we succeed in transferring the properties of difficult detectable photons over to the easier to detect photons, for example, those in the visible range, we can identify them and avoid the detector availability problem.

Initial success

Inspired by outstanding basic research on the subject of quantum optics, the aim of our flagship project is to transfer these concepts to the terahertz spectral range. The first experimental challenge was to generate suitable photon pairs, something we achieved last year.

The next steps mean entering into uncharted scientific territory. The interaction of photons in the terahertz range with visible photons must be verified. For this, we take advantage of the good detectability of visible photons to indirectly detect and utilize terahertz waves. If this step succeeds, a new access to the terahertz spectral range and its many applications will be made possible.



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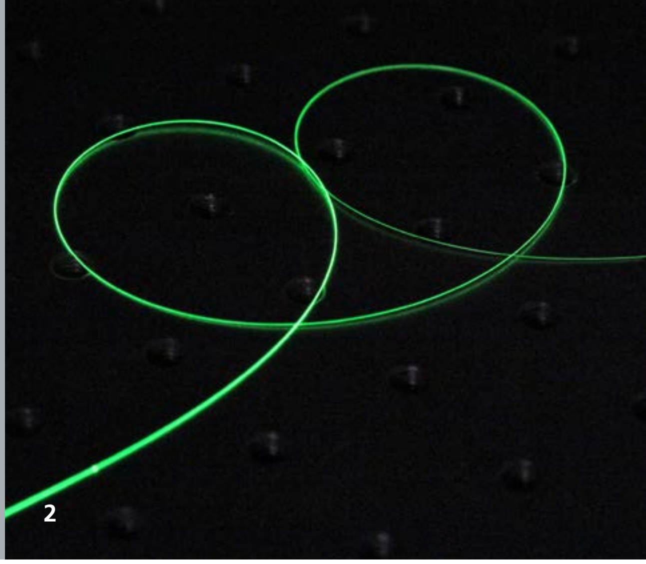

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SLAPCOPS – LASER CONCEPT FOR TERAHERTZ MEASUREMENT SYSTEMS

Time-resolved measurement of signals in terahertz time domain spectroscopy requires two variable laser pulses with a time delay between them. Until now, a mechanical displacement unit or two light sources achieve the necessary time delay. We have built a laser system working without a mechanical positioning unit and just one laser. Introducing the SLAPCOPS system.

The majority of systems developed and in use now in the department are based on ultrashort pulsed lasers in conjunction with optical delay units. These two components are necessary to record processes on a scale of picoseconds. (One second consists of a trillion picoseconds, a time scale that currently cannot be achieved with electronic systems). Terahertz pulses are electromagnetic pulses lasting one picosecond, which enable a thickness analysis of multi-layer coatings like automobile paint, in a non-contact and non-destructive manner – a fundamental advantage over other technologies.

Lower costs, higher measurement rates

Ultrashort pulsed lasers and delay units continue to dominate the cost of many terahertz measurement systems. Our researchers have found an innovative approach while working on a PhD project that combines these two components into a single, less expensive device.

In addition to the cost advantage, much faster measurements are possible with the new measuring device. The new method also provides a high degree of flexibility that facilitates uncomplicated solutions to a variety of measurement problems. The patented invention also permits the measurement of very thick layers or even walls in a single measurement, which was not readily feasible with conventional terahertz systems. The optical systems currently in use can supply approximately 50 measurements per second, whereas the SLAPCOPS system enables more than 1000 measurements per second.

International scientific success

The scientific success of SLAPCOPS is already assured by presentations at international conferences and several publications in prestigious journals. To protect our established know-how in this area, we have filed intellectual property applications and several patents have been granted.

1 *Fiber splicing device connecting two fiber ends; the connection process is a basic prerequisite for implementing fiber lasers.*

2 *Characteristic green glow of an active fiber, representing a key component of the SLAPCOPS laser system*

FLEXIBLE PIPE INSPECTION WITH TERAHERTZ TECHNOLOGY

1 *Pipe inspection system for testing wall thickness during production*

2 *The pipe being inspected for wall thickness at four selectable positions*

Improved quality and efficiency: An inline control check of pipe-wall thickness during extrusion enables the optimization of the production process. Early in 2018, we supplied a newly developed pipe control system to a global market leader, marking a milestone in the history of coating thickness measurement.

In addition to non-contact coating-thickness measurement of multi-layer paint coatings, recent developments in wall-thickness measurement during the pipe extrusion process have proven to be a promising application for terahertz technology. Our inline measuring system enables the customer to test the pipe-wall thickness directly after the extrusion of the plastic and to readjust the settings so as to optimize the production quality and efficiency.

Simultaneous measurement on four channels

The project launched with ambitious requirements for the early phase. The previous system, designed for a single sensor, had to be expanded for the simultaneous measurement of four channels allowing for four positions around the pipe to be checked at the same time. This requirement posed challenges for the integrated fiber optics as well as the collection and evaluation of measurement data.

The mechanical design had to feature the required flexibility to freely select these four positions and handle numerous different pipe diameters. The symmetrical arrangement of the system and the integrated monitor arm allow it to be installed and operated from either side of the production line.

Expansion to other market segments

The intuitive user interface – designed according to customer requirements – allows for convenient operation via a touch screen. A customer-specific interface to the manufacturer’s plant control system guarantees optimal integration of the measuring system.

We provide our system with application-specific adjustment capability; we offer our system not only to pipe manufacturing companies, but also to hose producers. Because these two markets are so diverse, we see good opportunities ahead for additional customer-specific implementations.

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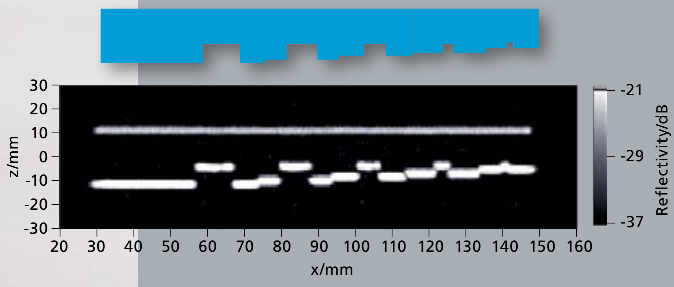

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HANDHELD TERAHERTZ SENSOR FOR MOBILE USE

The special properties of terahertz waves include the ability to penetrate electrical insulators such as ceramics, glass, and plastics. This ability has an advantage over the established methods based on x-rays, ultrasound, or thermography, which all have limitations, especially, when assessing modern fiber reinforced plastics. A solution is now available in the form of the mobile, terahertz handheld scanner, which can also examine structures in hard to access places and detect defects in plastics.

Overcoming the limits of ultrasound systems

Many applications demand measuring methods that are suitable for rapid and mobile use. Often, ultrasound is chosen for this reason. Water and gel are common coupling media to minimize the high losses when passing from air to a material. However, this is not possible for ceramics and foams. Fortunately, terahertz-measuring systems are non-contact, require no coupling medium and can even be used to examine hollow structures.

Innovative handheld scanners

The handheld scanner is a complete terahertz system for non-destructive on-site testing. Thanks to its compact, lightweight design, it is easily transported and ideal for use with non-movable samples as well as in various location within the production. Single-sided sample access is sufficient as the system operates in reflection. The housing of the sensor protects from dust and spray water, which facilitates use in a manufacturing environment. An integrated touch screen ensures ease of operation and a clear display of all measurements.

When the handheld scanner is moved over a sample, it continuously records A-scans (thickness profiles) while the position sensor simultaneously registers the location. By linking these two data readings, the associated B-scans are created (spatially resolved cross sectional images). The position sensor corrects for uneven movements of the scanner.

Pipe inspection during production

The handheld scanner is already in use in some production settings, for example, to inspect pipes directly after extrusion and to ensure a real-time process control. In this case, ultrasound cannot be used because of the high pipe temperatures and the plastic core present inside the pipe. Another example is the post-welding inspection of pipe insulation.

1 *Handheld terahertz sensor, consisting of a computer and measuring head. No other device is required for operation, only a power outlet and the right power cord.*

2 *A B-scan of a stepped wedge with flat bottom holes made of PE (bottom) and schematic cross section (top). Diameters of the holes range from 2 to 10 mm; always set at 2 mm increments. Step height is 1 mm.*

NEWS

TALENTA GRANT FOR NINA SCHREINER

The Fraunhofer TALENTA speed up program supports female scientists who wish to pursue a position with management or technical responsibilities. Our PhD candidate Nina Schreiner demonstrated the motivation and potential to meet all requirements: She is doing research in the field of terahertz measuring systems and plans to complete her doctorate next summer. After that is done, she will become the head of the topic area "Radar-based thickness measurements". The support program is goal oriented and lasts for two years, giving her the time and freedom to become accustomed to the leadership role.

ALTERNATIVE SYSTEM CONCEPT: INCOHERENT QUASI TIME-DOMAIN SPECTROSCOPY (IQTDS)

Although the terahertz technology has developed well beyond its infancy, not all technical options for implementing system concepts have been exhausted. In our efforts to minimize system costs, we recently realized a novel concept in the field of optical terahertz measuring systems that does not require a laser source. The initial results are very promising, so further testing and integration in measuring systems is expected soon. One patent has already been registered.

SHORTER EVALUATION, GREATER STABILITY

Very short measuring and evaluation times are essential when using measurement systems for inline quality control of production. A joint project between the Materials Characterization and Testing department and the CC High Performance Computing achieved great success in measuring coating thickness: The improved evaluation software enables evaluation times of less than 1 ms for four-layer coatings with commercially available notebooks. Originally, the evaluation time was in the second range. The parallel use of several sensors or the use of new measuring methods such as SLAPCOPS can significantly increase the measuring rate up to 1,000 thickness measurements per second.

Combined with better stability, the improvement in the measuring time allows real time evaluation of recorded signal data and creates the potential to open up further fields of application for terahertz measurement technology and to further expand the Materials Characterization and Testing department.

Front, left to right: Samuel Weber, Shiva Mohammadzadeh, Dr. Daniel Molter, Caroline Cappel, Nina Schreiner, Ute Rein-Rech, Dmytro Kharik, Oliver Boidol, Mirko Kutas, Michael Kocybik, Carsten Matheis, Prof. Dr. Georg von Freymann, Dr. Joachim Jonuscheit, Jens Klier, Marie-Therese Braun, Sebastian Bachtler, Stefan Weber, Andreas Keil, Ph.D., Claudia Busch-Crolly, Dr. Fabian Friederich, Björn Haase, Alexander Theis, Tobias Pfeiffer, Dominik Gundacker