ULTRAFAST PULSED TERAHERTZ SENSING FOR THE CONTACT-FREE CONTROL OF COMPOSITES AND ADHESIVE ASSEMBLIES

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Abstract. We present a ground breaking Terahertz Time-Domain spectrometer (THz-TDS) and illustrate its performance by the non-destructive evaluation of fibre reinforced plastics and adhesively joined assemblies. Operated as imaging device this technology gives in a direct way access to the inner structure of dielectric materials and reveals manufacturing defects or fatigue damage in short acquisition time.

Electromagnetic radiation of THz frequencies allows the contact-free testing of dielectric volumes and buried or coated metallic surfaces without ionizing effect. THz-TDS is a particular powerful tool for NDT as it provides a multitude of information useful at the same time for imaging, material characterisation and spectroscopic analysis. Amplitude and time of flight of the ultrashort THz pulse in the time domain, as well as the spectrally resolved amplitude and phase information available by Fourier-Transformation, enable the analysis of complex objects. In many cases, three dimensional monitoring is possible with one-sided access to the object. THz-TDS has been applied to aircraft composites, and its ability to detect mechanical and heat damage, voids, delamination, water or moisture contamination has been shown.

The single shot THz pulsed sensor “STRIPP” developed in our group reduces the acquisition time drastically relative to the repetitive solutions: the ultrashort detection window of some tens of picoseconds is recorded within one single laser shot. The measurements are performed at high stability and acquisition of kHz rates, without moving parts. With this leap in technology, the potential of terahertz radiation can be further exploited in industrial environments. We recently analysed an object and the integrity of its structural sub-units during free fall. The here presented applications illustrate further the performance of the technology, particular its ability to determine the thickness of substructures with micrometre precision, to localize precisely defects as delamination and inclusions. So, the high contrast of ultrafast THz pulses on dielectrics enables the localization and analysis of polymers that are buried in another polymer. In general, “STRIPP” can be used for the design, quality control and inspection of aerospace components.

Electromagnetic waves with Terahertz (THz) frequencies or corresponding sub-millimetre wavelengths are situated in the range between the infrared and microwaves. They combine advantages of these neighboured spectral regions as high penetration depth in dielectrics and low scattering on micro-structured media. With optical generation schemes, free space propagation with good beam quality and accordingly diffraction limited imaging with high spatial resolution can be achieved. As THz radiation is non-ionising, electrically non-conductive objects can be analysed, including their internal structure without the need of costly shielding. These properties render the THz frequency range interesting for control devices as alternative to existing methods or for new applications of non-contact testing.

During the last two decades, important progress on different approaches of THz generation and detection has closed the so-called THz gap – formerly a label for this long-time hardly accessible range between optics and electronics. The spectral region with its unique properties and advantages is now used in various fields of sciences and applied research [1,2]. Besides security applications, THz technologies for non-destructive testing (NDT) are about to enter markets as pharmaceutics and the composites industries [3]. In this context, THz-Time Domain Spectroscopy (THz-TDS) plays a particularly important role; it provides a multitude of information useful for imaging, material characterisation and spectroscopic analysis. In the traditional approach, the electromagnetic field of an ultra-short THz pulse is scanned point by point with a shorter optical laser pulse on the picosecond scale; the optical probe pulse is delayed with a retroreflector mounted on a mechanical translation stage. Amplitude and time of flight of the ultrashort THz pulse in the time domain as well as the spectrally resolved amplitude and phase information available by Fourier-Transformation allow analysing complex objects; defects inside dielectrics as ceramics, polymers, wood, etc. can be revealed and often identified, even if hidden in multi-layered structures. In many cases, three dimensional monitoring of dielectric volumes is possible in reflection mode.

Our recently developed approach of THz-TDS, the single shot THz pulsed sensor STRIPP (Single Shot THz Sensing for Rapid Industrial Product and Process Control), reduces the acquisition time drastically relative to the available, repetitive solutions. Thanks to the use of a temporarily stretched supercontinuum as a single probe pulse for the whole THz waveform, no moving part is required in this approach [4]. The measurements can be therefore performed at high throughput (laser repetition rate of 1 kHz) and stability. We analysed recently an object and the integrity of its structural sub-units during free fall [4,5]. The potential of the single shot technology for the aerospace sector is demonstrated by the precise and rapid control of adhesive bonds on possible inclusions [6], and by the detection and analysis of defects of machined composites like Glass Fiber Reinforced Polymer (GFRP) [7].

The ability and performance of STRIPP to control composites and adhesive assemblies is illustrated by the example shown in figure 1. The sample consists of two plates of GFRP each of 1.5 mm thickness that are inhomogeneously glued together with methyl methacrylate.

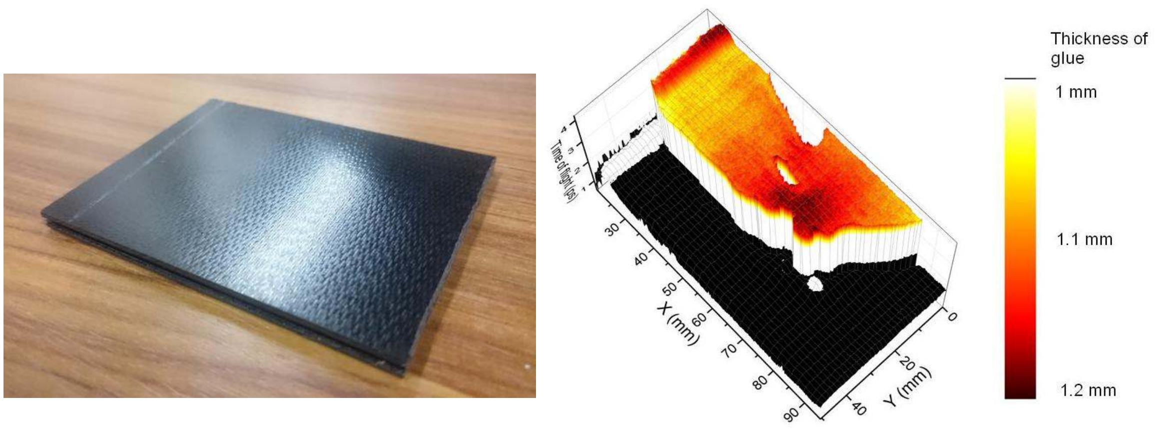

Fig. 1. Left: photo of two plates of GFRP glued by methyl methacrylate. Right: precise 3D reconstruction of the profile of glue between the plates thanks to fast scanning with the technology STRIPP.

The sample was placed on a two dimensional translation system and so analysed by raster scanning in transmission mode. Thanks to the ultrashort acquisition time and the kHz acquisition rate, the full sample was analysed within 40 seconds. A single scan gives access to multiple parameters of the sample. Here on the right of figure 1, the recorded time of flight of the terahertz pulse, in combination with the knowledge of the refractive index of methyl methacrylate, gives access to the thickness of glue on each point with micrometre precision. The 3D-profile of glue is so reconstructed with high precision. Areas without glue and inclusions of air are also revealed (black area on the image and white areas in the coloured zone).

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