Detection of Individual Terahertz Pulses at 80 MHz Repetition Rate

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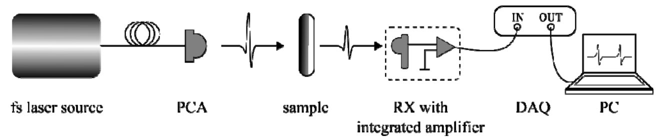
Abstract — **We present a novel technique to detect individual terahertz pulses at a repetition rate of 80 MHz. Our setup combines a femtosecond fiber laser, an InGaAs-based terahertz emitter, a zero-bias Schottky detector, and a high-speed data acquisition unit. The detected pulses consist of two lobes with half-widths of 1-2 ns, which is much shorter than the inverse repetition rate of the laser. The system lends itself for high-speed terahertz transmission measurements, e.g. to study wetting dynamics in real time.**

I. INTRODUCTION

In recent years, time-domain terahertz (TD-THz) instrumentation has undergone an impressive performance boost. As of today, users can choose commercial systems from a rather broad range of vendors. One common principle of all state-of-the-art systems is a "pump-probe" design: A transmitter "translates" a short laser pulse into terahertz radiation, which – on the receiver side – is sampled with a time-shifted copy of the laser pulse. This concept necessitates a time delay, which is either realized via a mechanical stage, or by synchronizing the pulse trains of two femtosecond lasers. Whilst mechanical delays achieve typical measurement rates between 10 Hz and 500 Hz [1, 2], systems based on synchronized repetition rates reach into kilohertz regimes [3]. Still, in both cases, the speed of the time delay remains the bottleneck in terms of attainable data rates.

However, there exists a need for terahertz observations at "extreme" speeds. One example involves the study of protein dynamics in water, where solved biomolecules unfold within milli- or microseconds, and the terahertz absorption properties of the protein-liquid mixture change on the same time scale. In an industrial setting, monitoring the properties of samples on fast conveyor belts calls for truly "ultrafast" means, too, in particular if a high spatial resolution is desired.

We have developed an alternative to traditional pump-probe spectrometers which is 4 to 7 orders of magnitude faster: By using a high-bandwidth Schottky diode as terahertz receiver, we eliminate the need for a delay stage altogether. Whilst we sacrifice any spectral information contained in the incident terahertz pulse, the terahertz amplitude itself is detected at an unprecedented rate. Owing to sufficiently strong terahertz emitters, our setup requires neither lock-in detection nor pulse picking or signal averaging, and consequently, amplitude measurements of individual terahertz pulses become feasible. The measurement speed is only limited by the repetition rate of the femtosecond laser, which – in our setup – equals 80 MHz. The concept lends itself to the observation of dynamic processes with a temporal resolution as short as a few nanoseconds.



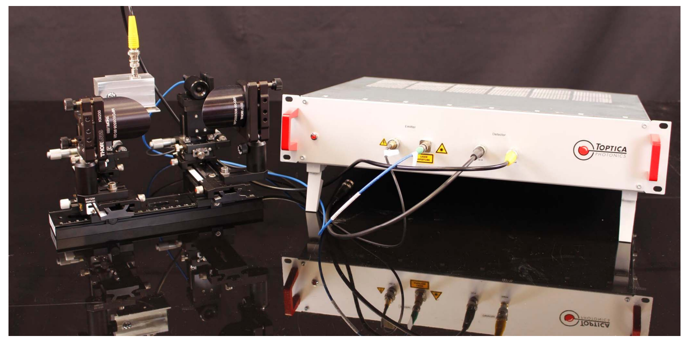


Fig. 1. Sketch and photograph of the setup. PCA = photoconductive antenna, RX = Schottky receiver, DAQ = data acquisition unit, PC = external computer for data processing. – The photo shows the PCA and RX mounted in an optomechanical setup. The white box on the right-hand side houses the laser and the data acquisition unit.

II. SETUP

Our measurement setup (Fig. 1) comprises four core components: (i) a compact femtosecond fiber laser (TOPTICA Photonics, "FemtoFErb 1560"), (ii) an InGaAs-based photoconductive terahertz emitter (Fraunhofer Heinrich Hertz-Institute, THz-P-TX), (iii) a zero-bias Schottky diode with integrated amplifier (ACST GmbH) and (iv) a fast data acquisition unit (LeCroy, "Waverunner").

The laser emits short pulses with ~80 fs halfwidth, 80 MHz repetition rate and a center wavelength of ~1.5 µm. A polarization-maintaining optical fiber delivers the pulses to the terahertz emitter. The fiber assembly includes dispersion-compensation means to provide an optimum pulse shape at the location of the antenna.

The photoconductive antenna features a high-mobility InAlAs/InGaAs multilayer heterostructure and a strip-line antenna geometry. It generates terahertz radiation with an average power of approx. 60 µW [4]. The spectral width spans ~6 THz, with a power maximum at frequencies around 450 GHz.

The receiver unit consists of a zero-bias Schottky diode with a useable frequency range of 50 GHz – 1.2 THz, and a fast oscilloscope with a data rate of 5 GS/s. Even though the terahertz pulses are broadened and low-pass filtered in the receiver, the detection is still sufficiently fast to resolve individual terahertz pulses.

III. Results

Fig. 2 presents amplitude traces of individual terahertz pulses, transmitted through air ("reference", black) and three different plastic samples. The bi-polar pulse shape is an artifact, caused by electric ringing in the signal amplification circuit. The pulses appear broadened (halfwidth of positive and negative lobes ~1 ns and 2 ns, respectively), however we note that the setup is capable of providing quantitative transmission data on a time scale as short as 10 ns. The three samples depicted in Fig. 2 – 2 mm PA, 3 mm PA and 5 mm GFC – attenuate the peak intensity by 43%, 55% and 88%, respectively.

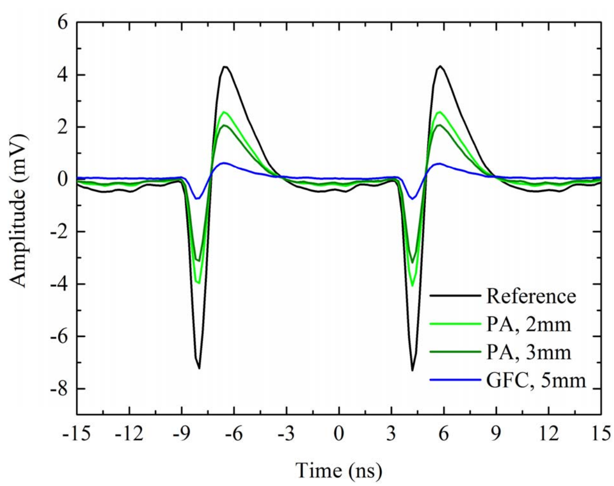


Fig. 2. Terahertz amplitudes measured at a pulse rate of 80 MHz. Shown is a reference trace and pulses transmitted through three different samples (PA: polyamide, GFC: glass fiber composite).

In a proof-of-principle experiment, we used the setup to monitor the wetting dynamics of different samples – a sponge and a sheet of tissue paper –, which were placed in the terahertz beam and moistened with water. Since a time resolution on the millisecond level suffices to resolve the absorption dynamics of our case studies, we chose to average 1000 consecutive terahertz pulses; in other words: we slowed the system down to data rates of ~10 µs, which is still orders of magnitude faster than conventional TD-THz instruments. Figure 3 shows the peak intensity of the terahertz pulses, i.e. the sum of positive and negative lobes, versus time. The blue and red lines represent the water absorption dynamics for the tissue paper and sponge, respectively. Calculating 90%/10% values of the transmittance decay, we obtain absorption time constants of 606 ms for the sponge and 137 ms for the tissue paper [5].

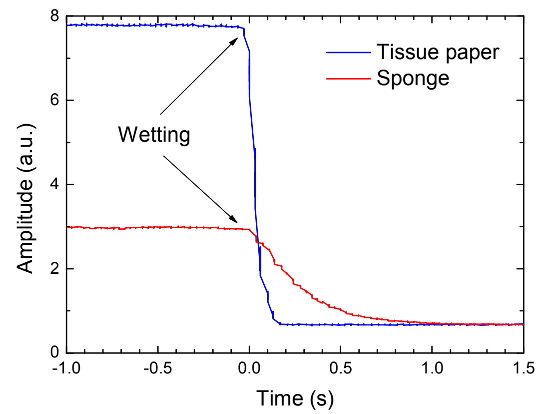


Fig. 3. Absorption dynamics of a sheet of tissue paper (blue trace) and a sponge (red trace) wetted with water.

IV. Summary

We have presented a TD-THz measurement system capable of resolving individual terahertz pulses at a repetition rate of 80 MHz. The temporal resolution achieved was only limited by the repetition rate of our laser. Whilst the spectral content of the terahertz pulse is lost due to low-pass-filtering in the detection circuit, the system assesses terahertz field intensity values at an unprecedented rate. This enables transmission measurements on nanosecond time scales, not only in research labs but, owing to the high mechanical stability of the components, even in harsh industrial environments. We envisage that the technique will open new perspectives both for the observation of ultrafast biological processes, such as protein dynamics, and for non-destructive testing applications on rapidly moving samples, e.g. conveyor belts or paper machines.

References

[1]. N. Vieweg et al., "Terahertz-time domain spectrometer with 90 dB peak dynamic range," *J Infrared Milli. Terahz. Waves*, vol. 35, pp. 823-832, 2014.

[2]. G.J. Wilmink et al., "Development of a compact terahertz time-domain spectrometer for the measurement of the optical properties of biological tissues," *J. Biomed. Opt.*, vol. 16, pp. 047006-1 – 047006-10, 2011.

[3]. R.J.B. Dietz et al., "All fiber-coupled THz-TDS system with kHz measurement rate based on electronically controlled optical sampling," *Optics Lett.*, vol. 39, pp. 6482-6485, 2014.

[4] R.J.B. Dietz et al., "64 µW pulsed terahertz emission from growth optimized InGaAs/InAlAs heterostructures with separated photoconductive and trapping regions," *Appl. Phys. Lett.*, vol. 103, pp. 061103-1 – 061103-4, 2013.

[5] F. Rettich et al., "Field intensity detection of individual terahertz pulses at 80 MHz repetition rate," *J Infrared Milli. Terahz. Waves*, vol. 36, pp. 607-612, 2015.