Terahertz Generation with an 830 nm all Semiconductor Femtosecond Laser System

C. Jördens[a], T. Schlauch[b], M. Li[b], M. R. Hofmann[b], M. Bieler[c] and M. Koch[a]
[a] Institut für Hochfrequenztechnik, TU Braunschweig, Germany
[b] Lehrstuhl für Photonik und THz-Technologie, Ruhr-Universität Bochum, Germany
[c] Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

***Abstract*—We present a THz time-domain spectrometer based on an 830 nm all semiconductor femtosecond laser system. Optical pulses with durations of less than 600 fs are used to gate standard LT-GaAs antennas. We achieve a signal to noise ratio of more than 40 dB in intensity and a bandwidth of 1.4 THz. Simulations based on the Drude-Lorentz model show a good agreement with the measured THz signals. Spectroscopic data on polymeric compounds and first THz images taken with our system will be presented as well.**

I. Introduction And Background

STANDARD THz time-domain spectrometers [1] are usually driven by Ti:sapphire lasers. These lasers are rather complex and expensive. Recently, the generation of THz radiation with fiber lasers [2] emitting at 1550 nm has been demonstrated. This source is more compact and cost-effective compared with Ti:sapphire lasers. But due to the change in the emission wavelength the antenna substrate must be replaced by a semiconductor with a smaller bandgap like LT-InGaAs. This material is difficult to fabricate, since its growth process is not as well understood as for the case of LT-GaAs. Furthermore, such material is more sensitive to electromagnetic discharge than LT-GaAs. Here, we present a novel THz time-domain spectrometer driven by an all semiconductor femtosecond laser system with an emission wavelength of 830 nm. The system is based on a laser diode, a tapered amplifier, and an external pulse compressor and fits on a breadboard forming a stable and transportable unit. Our system greatly enhances the cost-effectiveness as compared to systems based on standard Ti:sapphire lasers. Furthermore, the antenna fabrication process for our THz system can still rely on the highly developed and well understood LT-GaAs technology.

II. Results

The laser system [3] consists of a passively modelocked two-section laser diode in an external cavity, a tapered amplifier, and a compact external pulse compressor. The two-section laser diode comprises a gain and an absorber section; the latter is used as a saturable absorber. The external pulse compression allows for the compensation of the extensive chirp of the semiconductor laser. Pulse durations of less than 600 fs and an average optical power larger than 500 mW have been realized. With a repetition rate of 330 MHz this corresponds to a peak power exceeding 2.5 kW.

The semiconductor laser system is used to drive a standard THz time-domain spectrometer as described in [1]. The LT-GaAs based emitter and detector antennas are gated by 25 mW average optical power. The emitter antenna is biased with 30 V and consists of a coplanar stripline with a gap of 10 µm; the receiver is a 20 µm dipole with a 5 µm gap.

Fig. 1 shows the measured THz time trace and the corresponding spectral amplitude. We achieve a signal-to-noise ratio of more than 40 dB in intensity and a bandwidth of 1.4 THz. We have used an enhanced Drude-Lorentz model to theoretically describe the THz emission and propagation processes. First results obtained with this model are additionally plotted in Fig. 1. A good agreement between experiment and theory is obtained. Further simulations have revealed that that for pulse durations of more than 400 fs the THz bandwidth drops below 1.5 THz. Our investigations confirm that even longer pulses around 500 fs generate THz pulses with sufficient bandwidth for many applications in the field of non-destructive testing.

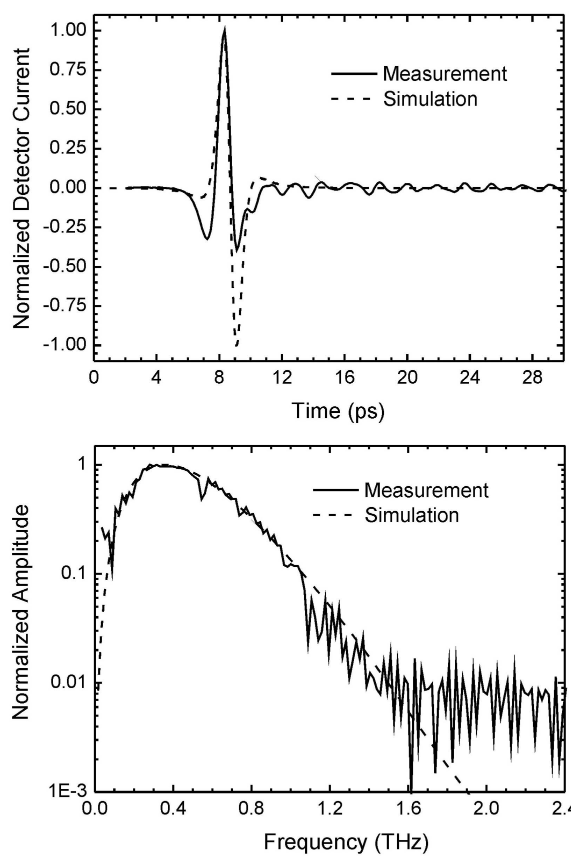

Fig. 1: THz time-domain signal and corresponding frequency spectrum: Measurement (solid line), Simulation based on Drude-Lorentz model (dashed line).

So far the THz system was used for spectroscopic

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measurements of plastics with different additive contents [4] as well as for imaging applications. We investigated pure polypropylene and polypropylene which was filled with 40 wt% of $CaCO_3$. The refractive index is 1.75 and 1.52 for polypropylene with and without $CaCO_3$, respectively (cf. Fig. 2). To demonstrate imaging applications a sample was taken, which consists of the metal logo of our institute (IHF) on a 5 mm thick polyethylene substrate. Fig. 2 depicts the transmitted THz intensity in a frequency interval between 0.5 and 0.75 THz. One can clearly identify the metal structure of the logo in the THz image at regions of reduced THz transmission. These two examples demonstrate the successful operation of the all semiconductor laser based THz system.

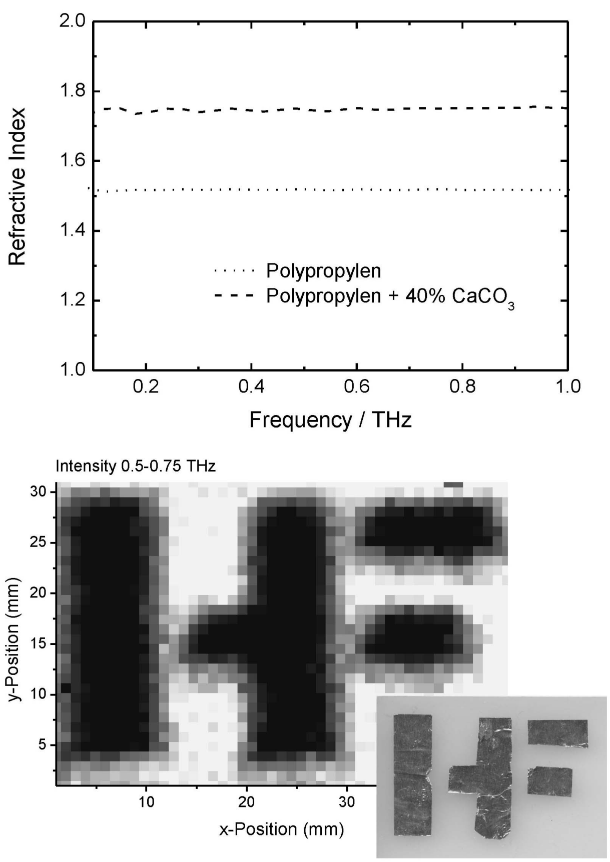

Fig. 2: Refractive index of polypropylene w/o $CaCO_3$ and THz transmission image of a metal structure with the capital letters IHF (see inset).

III. CONCLUSION

We presented a THz time-domain spectrometer driven by an all semiconductor femtosecond laser system. With optical pulses of 600 fs we generate THz pulses with a bandwidth of 1.4 THz and a signal to noise ratio of 40 dB in intensity. Simulations based on the Drude-Lorentz model confirm the experimental results. Such a THz spectrometer based on an all semiconductor femtosecond laser holds great potential for the development of rugged, portable and cost-effective THz systems for applications in non-destructive testing. This project was supported by the German minister for education and research within the project “Femtodiode”.

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