Fiber coupled terahertz time domain spectroscopy system based on InGaAs/InAlAs photoconductors with 100 dB dynamic range

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***Abstract*—We present an all fiber coupled terahertz (THz) time domain spectroscopy (THz-TDS) system operating at 1.5 µm wavelength with very high dynamic range. The broadband THz radiation is generated by a high mobility InGaAs/InAlAs heterostructure photoconductive emitter. For the detection a low temperature grown (LTG) Be-doped InGaAs/InAlAs heterostructure is employed. Both, detector and emitter, are packaged into fiber-coupled housings. The system reaches a dynamic range in excess of 100 dB and a spectral bandwidth of 6.5 THz.**

I. INTRODUCTION

OVER the past decade THz-TDS systems employing photoconductive emitters and receivers have evolved from expensive and bulky scientific setups restricted to laboratory environments to stable and cost-effective systems allowing for a much more wide spread use, e.g. in industrial applications. To a great part this evolution was spurred by the development of InGaAs based photoconductors allowing for an excitation with 1.5 µm femtosecond fiber laser sources [1]-[3]. Recently, high mobility InGaAs/InAlAs heterostructure based photoconductive emitters were shown to emit several tens of microwatts [4]. Furthermore, LTG Be-doped InGaAs/InAlAs heterostructures were shown to exhibit carrier life times in the range of 200 fs [5] which makes them suitable for broadband THz detectors [6]. Additionally, a fast THz spectrometer based on a high precision mechanical delay and a field programmable gate array (FPGA) with high bitrate analog-digital converters (ADC) was demonstrated to allow for very fast measurements with high dynamic range (DR) [7].

In this paper we demonstrate a THz-TDS system employing above mentioned developments with a peak dynamic range (PDR) in excess of 100 dB and a spectral bandwidth of approx. 6.5 THz.

RESULTS

For the measurements the photoconductive emitter and detector chips were packaged into fiber coupled modules to improve their stability and the adjustability of the THz path while maintaining perfect optical coupling. The photoconductive antennas were excited by an erbium doped femtosecond fiber laser with a repetition rate of 100 MHz and approx. 90 fs of optical pulse width at a central wavelength of 1550 nm. The emitted THz radiation was collimated and subsequently focused onto the active area of the detector by a set of two 90° off-axis parabolic mirrors. The emitter was a 100 µm strip-line mesa-antenna based on high mobility InGaAs/InAlAs heterostructures similar to those published in [3], [4]. These high mobility emitter antennas show a strong dependence of the emitted THz power on the spot position, similar to the anode enhancement behavior observed in LT-GaAs and Si-GaAs [8], [9]. Furthermore, we observed a strong influence of the spot size on the emitted THz radiation in dependence of the position and the applied bias field strength. We attribute this behavior to intervalley scattering and screening effects. In case of an optimum spot size and spot position on the emitter for a bias voltage of 120 V and 35mW optical excitation, we measured an emitted average THz power in excess of 0.1 mW. The power measurement was carried out with a pyroelectric thin-film detector which exhibits a flat frequency response in between 100 GHz and 5 THz and is hence and adequate detector for broadband THz sources [10].

For the coherent measurement of the emitted THz field we employed a photoconductive dipole mesa-antenna with a 10 µm photoconductive gap. The photoconductive material of the detector was a low temperature grown (LTG) InGaAs/InAlAs heterostructure with an additional Be-doping concentration of $5\text{x}10^{18}$ cm^{-3} in order to obtain ultra-fast electron trapping into ionized arsenic antisite defects [5], [6]. The optical excitation power for the coherent measurement was 20 mW at both emitter and detector. The optical delay was realized by a voice coil driven shaker with a high precision optical position sensor to reduce noise caused by time position errors. The detector current was amplified by a trans-impedance amplifier and recorded by a FPGA with 24 bit ADCs. For a measurement window of approx. 60 ps, the THz pulse traces were recorded with a measurement rate of 16.6 Hz. Fig. 1 shows a pulse trace and the corresponding Fourier spectrum obtained from an average of 1000 single traces recorded at 16.6°Hz, i.e. approx. 60 s of total measurement time.

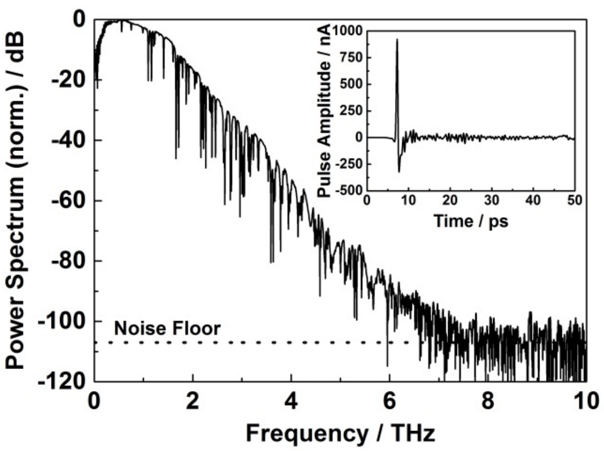

Fig.1. THz pulse trace (inset) and corresponding Fourier spectrum at 20 mW optical excitation power for both emitter and detector. The total measurement time was approx. 60 s.

In this case the maximum DR of the THz spectrum well exceeds 100 dB and shows a maximum usable bandwidth of approx. 6.5 THz.

SUMMARY

We presented a fast THz-TDS measurement system with a maximum dynamic range in excess of 100 dB and a bandwidth of approx. 6.5 THz. This was realized by the combination photoconductive high mobility THz emitters with THz powers in excess of 0.1 mW, ultra-fast, low-noise photoconductive detectors and a high precision measurement system with a voice coil optical delay and an FPGA with 24 bit ADCs for data acquisition.

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