Abstract—We present a time-domain terahertz spectrometer based on 1550 nm fiber laser technology and InGaAs photoconductive switches. The system features a voice-coil delay stage, which offers a high scanning speed of up to 60 traces per second. Owing to a precise reconstruction of the time axis, the system achieves a high dynamic range: a single pulse trace of 50 ps is acquired in only 44 ms, and transformed into a spectrum with a peak dynamic range of 60 dB. With 800 averages, the dynamic range increases to 90 dB and the measurement time still remains as short as 35 seconds.

I. INTRODUCTION

Any time-domain terahertz applications require systems with high bandwidth, high signal-to-noise ratio (SNR) and fast measurement speed. Terahertz spectrometers operating at 1.5 µm take full advantage of mature and cost-efficient telecom components and are thus well suited for real-world applications [1]. However, state-of-the-art time-domain spectroscopy (TDS) systems usually achieve the targeted SNR via time-consuming signal averaging methods. Measurements under rapidly changing environmental conditions—e.g. varying temperatures, magnetic fields, or gas concentrations—thus call for a system that combines fast measurement speed with a top-level SNR performance and high bandwidth.

We have realized a compact, fiber-coupled THz-TDS system [2] based on 1.5 µm fiber laser technology and InGaAs/InAlAs photoconductive switches [3-6]. Due to a precise reconstruction of the time axis, the system drastically reduces jitter noise, which results in a high dynamic range and broad bandwidth.

II. SYSTEM DESIGN AND PERFORMANCE

The system comprises a femtosecond fiber laser with dispersion compensation. The laser radiation is centered at 1560 nm, the repetition rate is 100 MHz and the pulse width is typically 80 fs. The laser provides approx. 60 mW power at the polarization-maintaining fiber output. A 50 / 50 fiber splitter divides the output into an emitter and a detector branch (Fig. 1). Both optical paths feature fiber-coupled mechanical delay stages: the receiver path includes a slow, long-travel delay and the emitter path a fast, scanning delay. The latter consists of a voice-coil-driven corner-cube mirror combined with a digital position sensor. The sensor records 50000 time stamps per second with a resolution of 1.3 fs. Data acquisition is accomplished both during the forward and the backward movement of the mirror, which minimizes the “dead time” of the system. The precise timing resolution gives rise to the high accuracy of the time scale, which results in a superior dynamic range when multiple traces are averaged.

![Fig. 1. Schematic representation of the terahertz time domain spectrometer](image1)

A Time-Domain Terahertz Spectrometer with 90 dB Dynamic Range

Nico Vieweg¹, Florian Rettich¹, Anselm Deninger¹, Helmut Roehle², Roman Dietz, and Thorsten Göbel²

¹TOPTICA Photonics AG, D – 82166 Gräfelfing, Germany
²Fraunhofer Heinrich Hertz Institute, D – 10587 Berlin, Germany
described in [4-6]. The receiver antennas are based on LT-grown and Beryllium-doped InAlAs/InGaAs MLHS, with a doping concentration of \( n_{\text{rec}} = 2 \times 10^{18} \text{ cm}^{-3} \). A strip-line antenna geometry with a 100 \( \mu \text{m} \) photoconductive gap was chosen for the emitter, and a dipole geometry with 10 \( \mu \text{m} \) gap for the receiver. Both transmitter and receiver feature a mesa-structured gap region.

The system achieves a bandwidth of > 4.5 THz, with a signal peak at approx. 480 GHz (Fig. 2). A single trace of 50 ps is acquired in only 44 ms. Via the control software, the sampling time can be flexibly adjusted between 15 ps and 200 ps. Fig. 3 shows the dependence of the peak dynamic range (PDR) on the number of averaged time traces. For a single measurement, i.e., an acquisition time 44 ms, the PDR is ~ 60 dB. This value increases with the number of averages \( N_{\text{ave}} \) (PDR \( \propto \log(N_{\text{ave}}^{1/2}) \)) and reaches 90 dB for 800 averages, still within a short acquisition time of 35 s.

Fig. 4 shows a photograph of a polyamide step wedge and a 100 mm x 40 mm terahertz image. Red and blue colors reveal regions with highest and lowest transmission, which corresponds to the thinnest and thickest parts of the sample. Two dark blue spots mark air bubbles, which are not visible from the outside. This result demonstrates the suitability of the system for non-destructive testing.

III. CONCLUSION

In conclusion, we have designed and characterized a compact, fiber-coupled terahertz time-domain spectrometer operating at an excitation wavelength of 1.5 \( \mu \text{m} \). The system combines mature telecom technology and photoconductive switches based on InAlAs/InGaAs multi-layer heterostructures. Owing to a highly precise mechanical delay stage, the spectrometer offers a peak dynamic range of 90 dB, which presents, to the best of our knowledge, a record for commercial TD-THz systems.

REFERENCES