1.5 µm Wavelength All-Fiber Terahertz Time-Domain Spectrometer

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***Abstract*—The worldwide first all-fiber THz time-domain spectrometer for operation at 1.5 µm is presented. Applications up to 3 THz are demonstrated. Key devices are photoconductive antennas based on novel LT InGaAs/InAlAs multi-layer structures.**

I. Introduction And Background

TIME-DOMAIN terahertz spectrometers typically comprise expensive titan-sapphire lasers and bulky free-space optics [1,2]. Significant advantages regarding price, size, flexibility, and stability can be expected if fiber lasers and complete fiber coupling could be applied. To the best of our knowledge, we report on the worldwide first all-fiber-coupled terahertz spectrometer operating at 1.5 µm telecom wavelengths.

The key device for realizing such a system is a novel material for photoconductive antennas which makes them suited for exploiting the 1.5 µm telecom wavelength. The material consists of thin layers of low-temperature MBE-grown InGaAs on InP, embedded in intermediate layers of InAlAs (see Fig. 1).

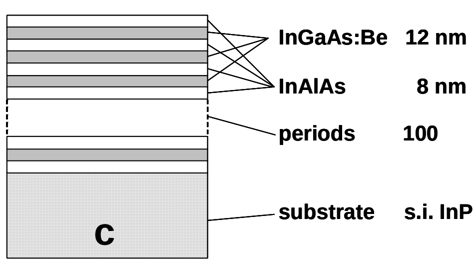

Fig. 1. LT-InGaAs multilayer structure

II. LT-InGaAs Devices

The common problem of LT-InGaAs/InP is its high dark-conductivity, making THz applications impossible. In our approach the LT-InGaAs is embedded between InAlAs layers which have a higher bandgap than InGaAs and thus are transparent for 1.5 µm. The InAlAs contains deep electron traps which can capture the carriers out of the InGaAs. However, this works only if the photoconductive InGaAs layers are thin (e.g. 8 nm) in order to have the trapping centers close to the photoexcited carriers. A multilayer structure thus is necessary for achieving sufficient absorption and photocurrent. Exploiting this approach the sheet resistance of the LT InGaAs could be increased by several orders of magnitude (Fig. 2). For comparison, the value of Fe-implanted InGaAs used elsewhere is also included [3,4].

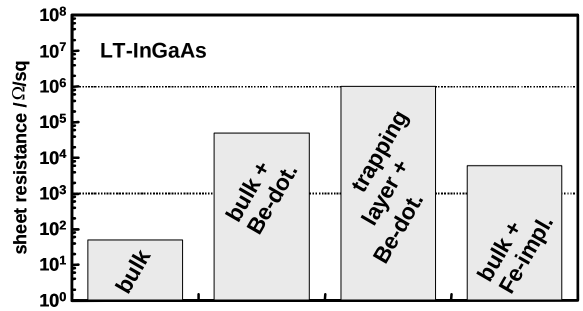

Fig. 2. Resistivity of differently processed InGaAs

THz antennas of stripline-type (transmitter) and bow-tie-type (receiver) have been integrated onto the developed new material. The photoconductive antennas then were used to build fiber-coupled transmitter and receiver modules, as shown in Fig. 3. With these modules a very compact THz time-domain spectrometer has been assembled, whose scheme is depicted in Fig. 4. The applied fiber-ring laser from Menlo Systems is pre-compensated by the manufacturer as to deliver its optimum narrow pulses (100 fs) after a fiber length of 10 m. A commercial tunable fibre delay line is used. The transmitter bias is modulated to allow lock-in detection of the received signal.

Fig. 3. Transmitter/Receiver module

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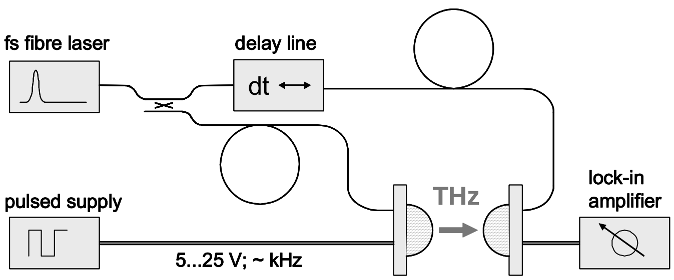

Fig. 4. Scheme of spectrometer system

III. System Characteristics

The received signal versus time delay is shown in the insert of Fig. 5. A terahertz pulse with a FWHM of 750 fs is detected. The data was recorded with the following settings: transmitter voltage 25 V, average optical power at transmitter 10 mW, at receiver 6 mW, lock-in integration time 30 ms, 8 times averaging of each reading, delay-line step-size 50 fs. A typical Fast-Fourier transform spectrum of the pulse response without object between the terahertz lenses is seen in Fig. 5. The spectrum of the system with the present generation of photoconductive antennas peaks at 0.35 THz and extends up to 3 THz. This demonstrates the ultrafast photoresponse of our new material.

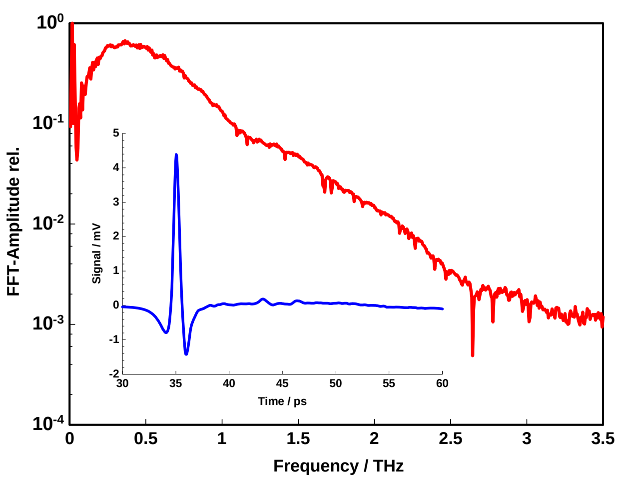

Fig. 5. FFT spectrum and pulse trace (insert)

As an example for a spectroscopic application, we operated the THz path with and without nitrogen purging and calculated the ratio of the measured spectra. The result of this experiment is shown in Fig. 6. We obtained clearly resolved absorption lines of the water vapor in the laboratory atmosphere.

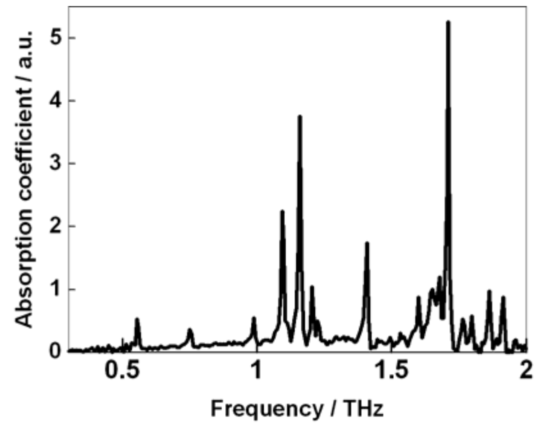

Fig. 6. Absorption spectrum of water vapor

IV. Summary

Novel InGaAs/InAlAs based photoconductive antennas for 1.5 µm operation have been developed. The devices were applied for assembly of a fibre-coupled THz time-domain spectrometer. Operation up to 3 THz and an application example demonstrate the excellent performance of material and spectrometer. The way is open towards flexible, handheld terahertz instruments based on mature 1.5 µm telecom technology [5].

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