A Fiberstretcher Operating as an Optical Delay Line in a Fiber-coupled THz Spectrometer

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Abstract— **We demonstrate the use of a fiber stretcher as an optical delay line in a fiber-coupled THz spectrometer. No measurable dispersion effects occur when extending the fiber. Measurements of the terahertz pulses at a stretching frequency of 20 Hz show the great potential of such a device for future all-fiber terahertz systems.**

I. Introduction And Background

IMPLEMENTING terahertz spectrometers into rough industrial environments is still a challenge. Up to date, most THz systems are free space setups. Even Picometrix` T-Ray system[1] is only partially fiber-coupled. Yet, strong vibrations and considerable temperature fluctuations badly influence the performance of such systems. Although a few THz spectrometers exist that are designed for quasi-industrial use, a very robust all fiber system is still missing.

When building a fiber-coupled THz spectrometer dispersion management and the realization of the optical delay line are crucial issues. Recently, THz systems have been presented[2] that are based on fs fiber lasers operating at 1550 nm. This allows for the introduction of dispersion compensating fibers. Using two fs lasers that are synchronized and operating at slightly varying repetition rates[3] is one possible solution to generate a pulse delay without any misalignment of the laser beam. Hence, an all fiber system operating with two lasers and a center pulse wavelength of 1550 nm holds tremendous potential for industrial implementation. However, the cost of such a system with two lasers is high as the laser is the most expensive part of a terahertz spectrometer.

Here, we present a fiberstretcher to generate optical pulse delays. In comparison to a second laser this device is cost-effective. Still, no misalignment occurs as the laser beam is guided inside the fiber. In principle, the stretching frequency of such a device is tunable from 0 to up to 20 kHz. We present design details and experimental results demonstrating its capability.

II. Design and Results

Our stretcher consists of two aluminum half shells which are separated by a piezo actuator. We wound about 21 m of glass fiber around the half shells. While winding, a constant force is applied to the fiber in order to slightly pre-stretch it and to avoid winding uncertainties. The position of the fiber is fixed by gluing it onto the half shells. The maximum piezo extension is about Δx = 30 µm which leads to a theoretical fiber elongation of about 4.9 mm. In contrast to commercially available fiberstretchers[4], we use a polarization maintaining fiber that is designed to operate at 800 nm. The stretching frequency of the presented device is tunable to up to several ten Hertz. Other designs to achieve a larger fiber elongation and diverse stretching frequencies of up to 20 kHz are possible.

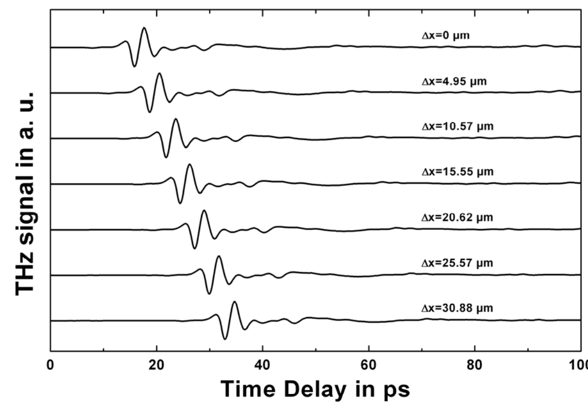

Fig. 1: THz pulses that are delayed due to the fiber extension of Δx

Fig. 1 shows a series of THz pulses measured with a partially fiber-coupled terahertz spectrometer[5]. We implement the fiberstretcher into the emitter arm of this setup in addition to the already existing standard mechanical delay line which is realized by a retro reflector mounted onto a linear stage. For performance verification, the terahertz pulses are scanned by using the standard delay line. The fiber length of the stretcher is varied for every single measurement. As can be seen in Fig. 1, the THz pulses are delayed for larger fiber extensions. However, no distortion of the pulses is detected. Hence, no measureable dispersion effect is observed for a fiber elongation of about 0.037 % corresponding to an effectively stretched fiber length of 10.7 m[6].

The time delay of the THz pulses for different piezo extensions is shown in Fig. 2. It demonstrates the linear relation between the piezo extension and the fiber elongation. In contrast to the theoretical maximum fiber elongation of 4.9 mm, we recalculate a maximum extension of 3.6 mm. Hence, about 20 % of the piezo actuator elongation is absorbed by the compression of the fiber cladding and the glue being pressed against the aluminum half shells.

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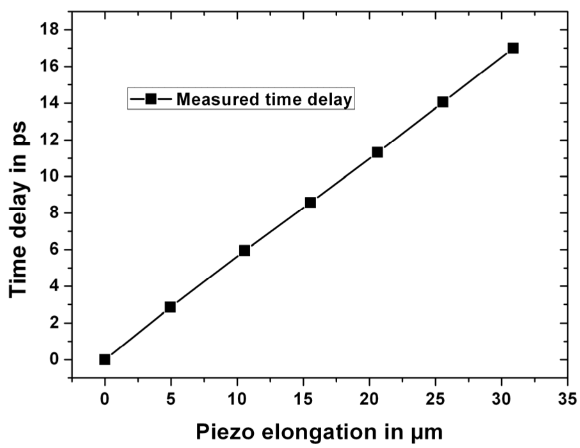

Fig. 2: Time delay of the THz pulse for different piezo elongations Δx

In order to demonstrate the capability of a fiber stretcher operating as a fast delay line we scan the terahertz pulse with a stretching frequency of 20 Hz. The sampling rate is 20 kHz and the scanned time window is about 20 ps. The time axis is corrected by the characteristic hysteresis curve of the piezo that is simultaneously detected while performing the measurement. Fig. 3 shows the measured terahertz pulses. As no lock-in technique can be used when sampling with such a high rate, a single measurement is quite noisy. Averaging 20 measured THz pulses, which takes only one second at this scanning frequency, leads already to a tremendously increased signal to noise ratio. This result shows the high accuracy of the fiber stretcher. After averaging over a time period of 10 s no further improvement of the signal-to-noise ratio could be detected.

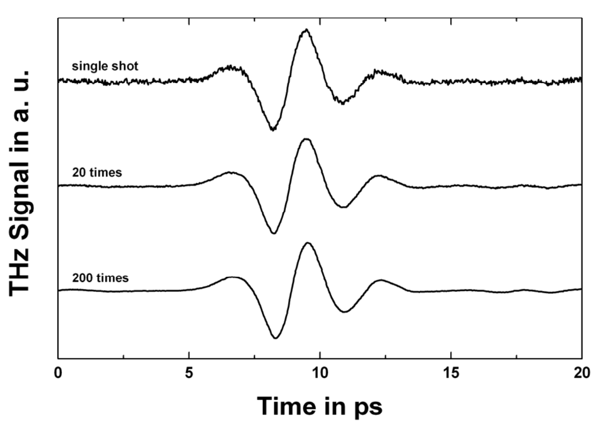

Fig. 3: THz pulses measured at a scanning frequency of 20 Hz. The signal-to-noise ratio is already tremendously increased by averaging 20 THz pulses

III. SUMMARY

A fiber stretcher is demonstrated operating as an optical delay line in a fiber-coupled THz spectrometer. No measurable distortion of the THz pulse is detectable at a fiber elongation of about 0.037 % leading to a time delay of roughly 20 ps. During the stretching procedure about 20 % of the piezo actuator elongation is absorbed by the compression of the cladding and the glue being pressed onto the aluminum half shells. Measurements that are performed at a scanning frequency of 20 Hz show the capability of the fiber stretcher as a fast delay line. The high accuracy of the device already leads to a very good signal-to-noise ratio when averaging over a time period of one second.

In summary, a fiber stretcher holds great potential as a cost-effective optical delay line in all-fiber THz systems.

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[6] Note: Only the fiber in between the aluminum half shells is stretched.