Multichannel THz line detection by a microlens array excited photoconductive antenna array

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Abstract—We present multichannel THz ultrashort pulse detection by a photoconductive antenna array consisting of 16 photoconductive antennas. The efficient excitation of the photoconductive antennas has been realized by a microlens array which creates 16 single spots from the exciting fs-laser beam. The detected THz signal/noise ratio has been improved by an order of magnitude in comparison to an excitation by a line focus.

I. INTRODUCTION

FOR THz ultrashort pulse imaging a high scan speed in combination with a high signal/noise ratio is required. Several methods have been presented to accelerate the classical one channel THz pulse detection. For example 2D electrooptic sampling provides a short scan time, but the signal/noise ratio is low and there is a need for an expensive low repetition fs-laser amplifier system to generate high energy THz pulses. Recently eight channel balanced electrooptic detection has been presented to overcome this issue [1].

Another approach is to use a photoconductive antenna array as proposed in [2]. It consists of photoconductive antennas with a pitch of 500 µm and an active gate pulse excitation area of about 5 µm. Because it is excited by a line focus of fs-pulses, only a small part of the energy is used for the detection and more than 95% of the fs-pulse energy is lost.

Here we present for the first time THz line detection by a microlens array excited 16 channel photoconductive antenna array. By the combination of microoptics and optoelectronics the detection efficiency has been increased by nearly an order of magnitude in comparison to the excitation by a line focus. Using 16 channels the measurement time has been accelerated by more than an order of magnitude.

II. SETUP

The array is made of 16 photoconductive antennas with a antenna pitch of 500 µm as shown in Fig. 1b. Each photoconductive antenna consists of two electrodes with a distance of 40 µm and a middle gap of 5 µm (see Fig. 1a).

The microlens array is shown in Fig. 1c. It has been made by UV-moulding allowing an easy and cost effective replication of the microlens array for further applications [3]. The lenses have a pitch of 500 µm and a radius of curvature of about 799 µm. The substrate thickness has been calculated, that the foci of the lenses are at the backside of the substrate. So the microlens array can be attached directly to the lt-GaAs wafer of the photoconductive antennas.

The antenna was tested in a THz time domain system (see Fig. 2). The fs-laser has a wavelength of 1060 nm, an output power of about 10W and a pulse length below 100 fs [4]. About 10% of the laser power is frequency doubled to 530 nm by a thin BBO-crystal to excite photo carriers in the semiconductor material lt-GaAs (band gap about 870 nm) of the antenna. The beam of the fs-laser is splitted into a pump (1060 nm) and a gate beam (530 nm) by a dichroidic mirror. The pump beam is expanded and focused by a cylindrical lens to the surface emitter (p-InAs). The emitted line of THz-pulses is imaged by two off-axis parabolic mirrors to the photoconductive antenna array. The gate beam is also expanded and focused by cylindrical lens on the microlens array of the photoconductive antennas. The microlens array has been adjusted by a hexapod with a precision better than 0.5 µm and fixed.

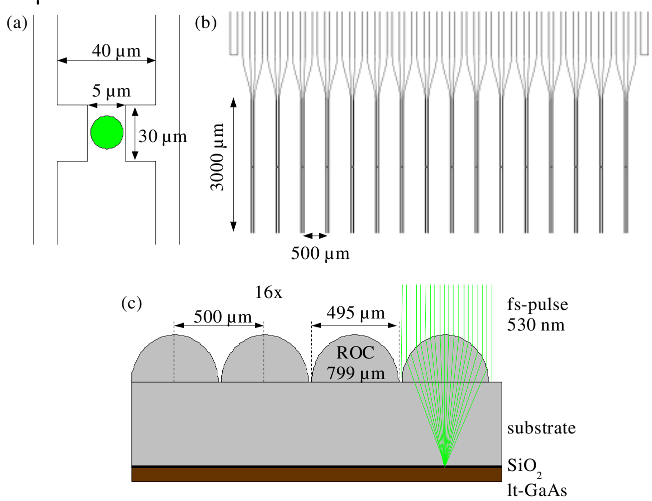

Fig. 1: (a) Photoconductive antenna; (b) array of photoconductive antennas; (c) microlens array consisting of 16 lenses attached directly to the lt-GaAs wafer.

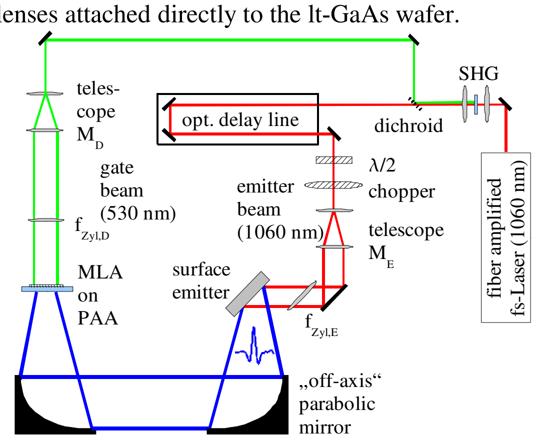

Fig. 2: Schematic setup for multichannel THz line detection by a microlens array (MLA) excited photoconductive antenna array (PAA).

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III. RESULTS

The efficiencies of the antenna excitation by a single spot of an aspheric lens, by a line focus of a cylindrical lens, and by a focus of one of the microlenses are compared.

For the excitation by a single spot of an aspheric lens the telescope, the cylindrical lens and the microlens array have been removed from the setup in Fig. 2 and replaced by an aspheric lens with a focal length of $f_{al}=11$ *mm* and a numerical aperture of *NA=0,25*. For an excitation by a line focus only the microlens array has been removed from the setup in Fig. 2.

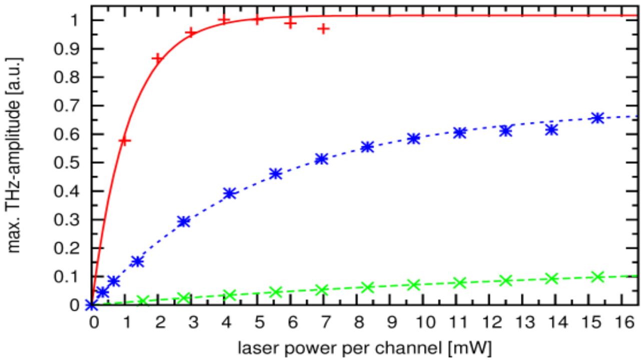

Fig. 3: THz-amplitude for an excitation by a line focus (green), by a focus of an aspheric lens (red), and by a focus of a microlens (blue).

THz electric field traces for all three kinds of excitation depending on excitation power have been measured time resolved. The THz-pulse maxima are plotted (without loss of generality) for the channel no. 9 in Fig. 3. The function

$$A_{THz}(P) = A(1-e^{-B\,P}) \qquad (1)$$

with the THz-amplitude A_{THz} [*a.u.*], the excitation power *P* [*mW*], and the parameters *A*,*B* have been fitted to the measurements. For the excitation by an aspheric lens the THz-signal increases for an excitation power to 5 *mW* following equ. (1). For a higher excitation power it slightly decreases in opposite to equ. (1), which is caused by the saturation of the carrier excitation inside the lt-GaAs layer. For the excitation with a line focus the detected THz-signal is more than an order of magnitude smaller than with the excitation by a single spot. With *5 mW* excitation power only 4% of the signal is achieved. The saturation of the slope starts for higher excitation powers than the excitation by a single spot. This is due to the bigger excited area of the chip, where only a small part of the excited area is used for the detection. For the excitation by a spot of a microlens the detected signal is still smaller than the one created by the aspheric lens, but nearly 7 times higher than with the line detection. At an excitation power of *5 mW* over 45% of the THz amplitude in comparison to the excitation by a spot created by an aspheric lens is measured. With higher excitation power even more than 65% THz amplitude can be achieved.

For a measurement with all 16 channels, a cylindrical silicon lens has been attached to the antenna. It focuses the THz-radiation to the detection points and helps to prevent back reflection inside the GaAs-wafer. The results are shown in Fig. 4. The envelope of the amplitudes shows the convolution of the pump- and the gate laser beam profile.

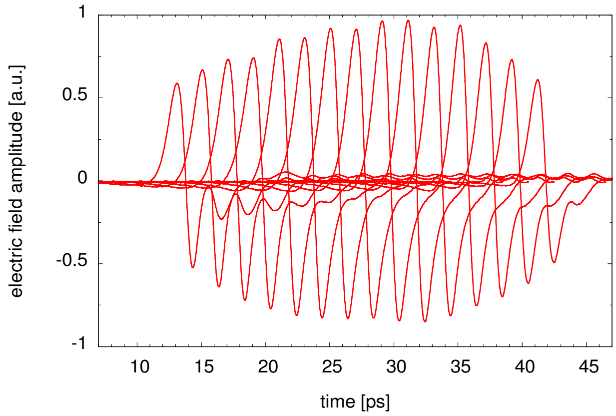

Fig. 4: Simultaneous measurement of 16 ultrashort THz-pulses. Each pulse was shifted *2 ps* in time for better overview.

IV. OUTLOOK

With the presented combination of photoconductive antennas and microlenses it is possible to build up THz ultrashort pulse detection arrays up to several hundred pixels. With 4 inch wafers of lt-GaAs and microlenses for example it is possible to build up to 200 pixels in a line with 500 *µm* spacing suitable for many THz-imaging applications. If 10 *mW* are taken for every detection channel, about 2*W* of laser power is needed for the excitation, which is easily available with fiber amplified lasers [5]. And even 2D arrays are possible leading to more than a thousand detection channels.

V. CONCLUSION

THz line detection by a photoconductive antenna array with 16 detection channels has been presented. Using a microlens array the efficiency has been increased more than 7 times in comparison to an excitation by a line focus and the scan time has been accelerated by an order of magnitude in comparison to single channel detection.

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