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Investigations of photoresponse signals of LT-GaAs photodetector

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In this paper, we demonstrate our electro-optic sampling system constructed for characterization of high-speed photodetectors based on low-temperature-grown GaAs (LT-GaAs). Changes in the shape of electrical signals for different optical powers, voltage biases and positions of a probe beam have been shown. The obtained photoresponse of the investigated photodetector exhibits 0.9 ps (full width at half maximum).

Keywords: electro-optic sampling, ultrafast photodetectors, low-temperature-grown GaAs (LT-GaAs).

1. Introduction

Current material growth techniques such as molecular beam epitaxy (MBE) and metal-organic chemical vapor deposition (MOCVD) allow for fabrication of ultrafast photodetectors. Low-temperature-grown GaAs (LT-GaAs) [1, 2], the material with a short carrier lifetime, is being chosen as a preparation material for fast and sensitive photodetectors [3], photoconductive switches [4] and for generation of THz pulses [5]. The Auston switches, which exhibit the response time of 200 fs, belong to the fastest devices [6]. In order to measure signals with such a temporal resolution, an electro-optic sampling technique is used. The electro-optic sampling system has been first constructed by Valdmanis *et al.* [7] and then frequently applied in many experimental studies of fast photodetectors, coplanar transmission lines and electrical signals of THz frequency. The amplitude and width of the generated electrical pulse depend on a number of parameters such as the optical pulse duration, the charge carrier lifetime and concentration, transit time between the electrodes as well as the RC time constant of the transmission line circuit [8]. In this paper, we demonstrate the electro-optic sampling system constructed for measurements of the temporal responses of high-speed photodetectors based on LT-GaAs.

2. Experimental

The investigated photodetector was fabricated from LT-GaAs grown by molecular beam epitaxy on GaAs substrates. The photodetector had a metal–semiconductor–metal structure. The structure was patterned on the LT-GaAs material using conventional photolithography and a lift-off technique. Ti/Au contacts of thickness of 50/600 nm had a finger geometry, with finger width of 11 μm and spacing of 17 μm; the size of the finger structure was 250 μm × 250 μm (Fig. 1).

The response of the LT-GaAs photodetector was measured with an electro-optic sampling system (Fig. 2).

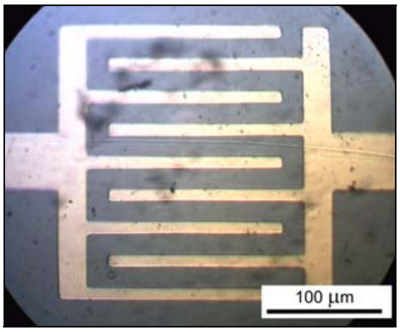

Fig. 1. Photograph of the investigated photodetector.

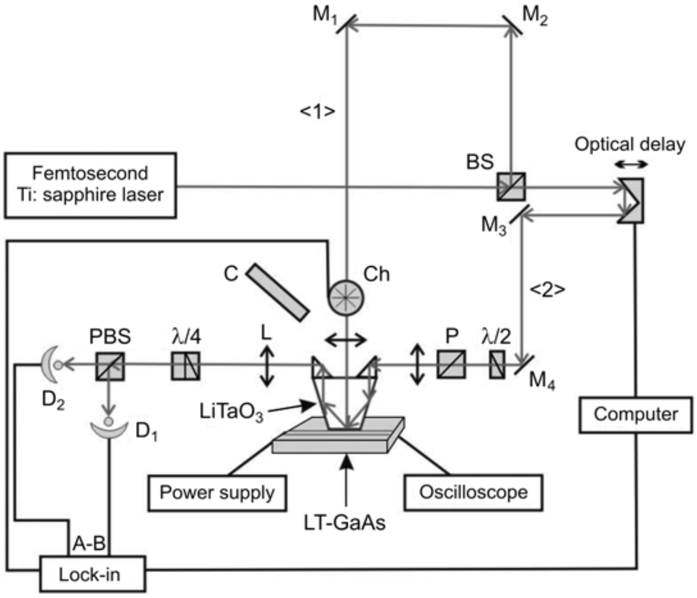

Fig. 2. The configuration of the electro-optic sampling system; BS – beam splitter, L – lens, D_1 and D_2 – photodiodes, M_1–M_4 – mirrors, $\lambda/2$ – half-wave plate, P – polarizer, Ch – chopper, C – camera, $\lambda/4$ –quarter-wave plate, PBS – polarizing beam splitter, $\langle 1\rangle$ – pump beam, $\langle 2\rangle$ – probe beam.

A commercial Ti:sapphire laser (Tsunami, Spectra Physics) was used as a source of 80 fs optical pulses at 795 nm wavelength and 80 MHz repetition rate. The laser beam was split by a beam splitter into two beams: a probe and a pump beam. The pump beam, after traveling through a chopper, was directed to the investigated photodetector. The photodetector response was analyzed with the probe beam that arrived with a certain time delay, changed by a variable, computer-controlled delay line. After passing through the half-wave plate and polarizer, the polarization direction of the probe beam entering an electrooptic $LiTaO_3$ crystal made the angle of 45° with the crystal optical axis. The $LiTaO_3$ crystal was 2 mm high; the sizes of upper and bottom surfaces were of 2.5×2.5 mm and 0.83×0.83 mm, respectively. An electrical signal generated by a pulse of the pump beam changed the birefringence of the $LiTaO_3$ crystal (Pockels effect). As a result, the polarization of the probe beam undergoing a total internal reflection at a bottom facet [9] altered. The change in polarization was decoded by a polarizing beam splitter. Two conventional photodiodes were used to measure the probe beam intensity. The difference in the electrical signals from these photodiodes was collected by a lock-in amplifier. The photoresponse signal of the investigated photodetector was plotted on a computer monitor as a function of time delay arising from different optical paths for pump and probe beams.

3. Results

An example photodetector response is given in Figure 3.

The measurement was performed for a bias voltage of 20 V and excitation beam power of 37 mW. The photoresponse exhibits a 0.9 ps full-width-at-half-maximum (FWHM). Such a fast response could be obtained by illuminating only a small semiconductor area close to the finger structure. The wiggles of order of 0.2 mV following the pulse might be caused by electrical signal reflections from the bottom

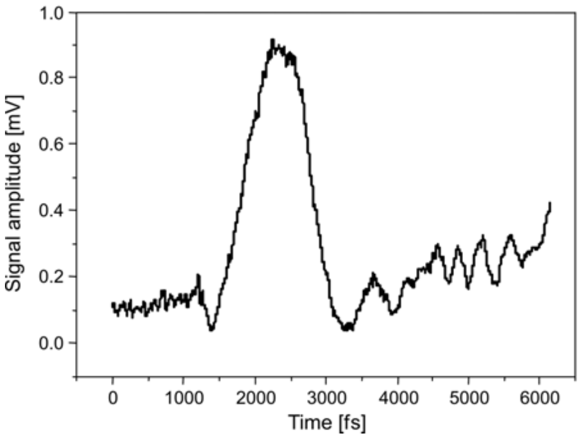

Fig. 3. Example photoresponse of the investigated photodetector.

surface of the $LiTaO_3$ crystal [9]. They might also arise from the fact that the electric field was not sampled at the electrode edge but in the area between the electrodes.

The amplitude and wiggles of the photoresponse signals depend on the spatial positions of probe and pump beam spots relative to each other and to the finger structure [10]. In order to obtain optimal signal with the largest amplitude, the pump beam should be placed at the positive electrode edge, *i.e.*, at the highest electric field region and the probe beam should be placed close to it. The measurements of the photoresponse signals were preceded by the optimization of the beam spot positions. Figure 4 presents the signals measured for three different positions of the probe beam along an *x*-axis shown in Fig. 5 and for the pump beam located close to the edge of a positive electrode.

In position 1 the probe beam is located in the middle of the region between the electrodes and the obtained signal shows a negative shoulder. In position 3 the probe beam is located just above the pump beam and a positive shoulder appears

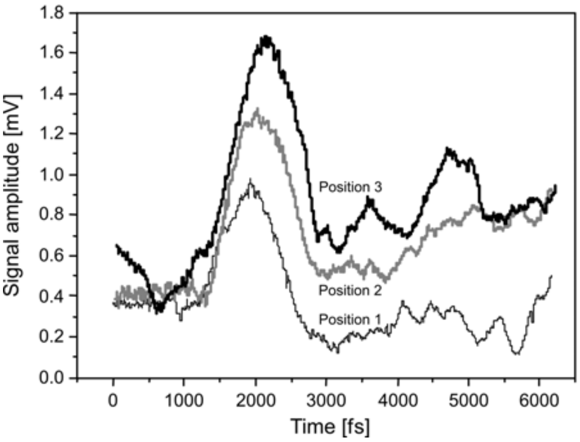

Fig. 4. Photoresponse signals for different probe beam positions for voltage bias of 18 V and optical power of 37 mW.

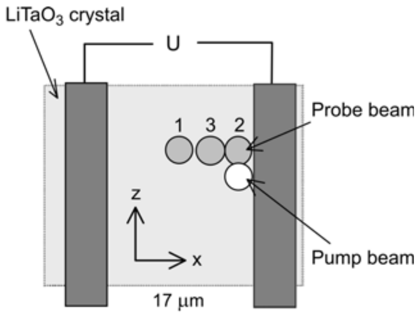

Fig. 5. Different probe beam positions along an *x*-axis.

in the photoresponse signal. In position 2 both beams overlap and the collected signal is optimal without a distinct asymmetry.

The photoresponse signals of the LT-GaAs photodetector were examined as a function of the pump beam power and voltage bias. Figure 6 shows the signals obtained for different pump powers at applied voltage of 25 V. For powers $P < 43$ mW an increase in the response time can be noticed. In this range a linear increase in the signal amplitude was also observed (Fig. 7). This is a consequence of a growing number of photogenerated carriers. For optical powers $P > 43$ mW the photodetector signal saturates because all of the carriers have been excited and further increase in optical power does not lead to any additional generation.

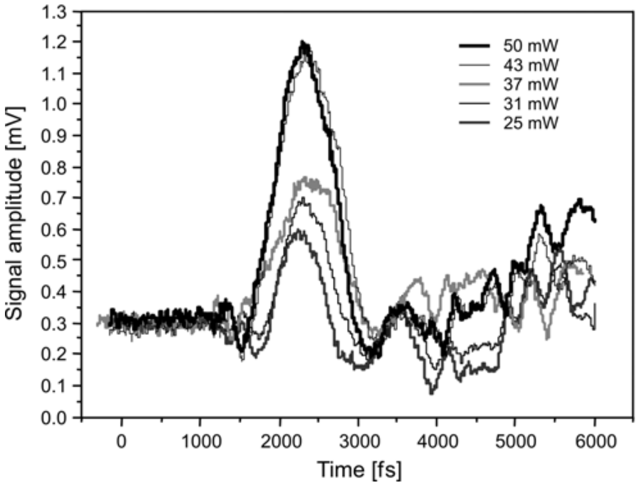

Fig. 6. Photoresponse signals for different pump beam powers.

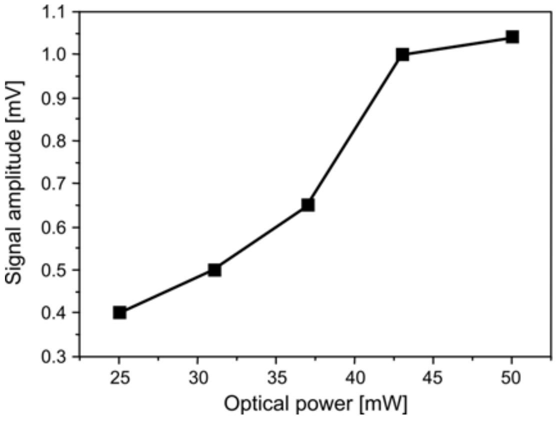

Fig. 7. Signal amplitude changes with pump beam power.

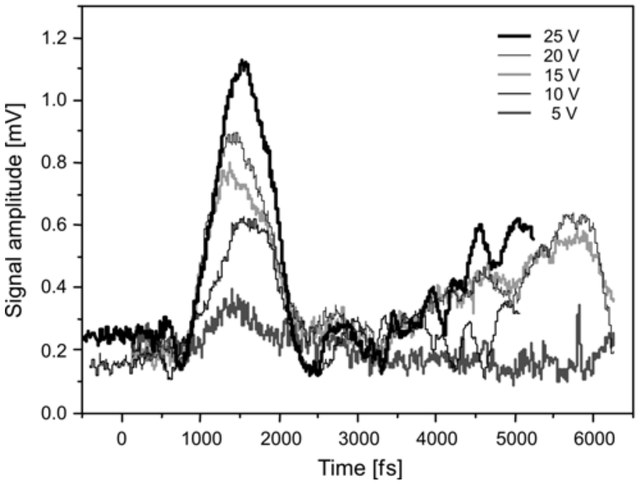

Fig. 8. Photoresponse signals for different biases.

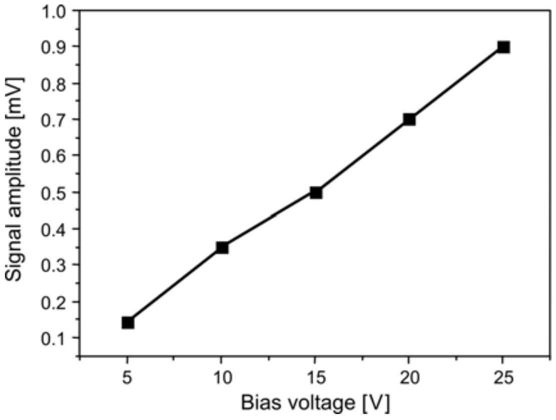

Fig. 9. Signal amplitude changes with bias voltage.

The changes in the signal amplitude with voltage (Figs. 8 and 9) were determined for the beam power of 37 mW in the range from 5 to 25 V. Higher biases were not applied because of an electric breakdown risk.

The obtained results show a linear dependence for all of the voltage biases, in accordance to Ohm's law. The characteristics given in Fig. 8 indicate that the response time of the photodetector is independent of the voltage and has a constant value of 0.9 ps FWHM.

4. Conclusions

The constructed electro-optic sampling system was used for measurements of the photoresponse signals of LT-GaAs based photodetector. The obtained response time of the photodetector is 0.9 ps FWHM. It has been shown that the shape of the signals is affected by a mutual position of probe and pump beams. The optimal signal is obtained when both beams overlap and are positioned close to a positive electrode. A linear increase in the signal amplitude has been observed for moderate optical powers and for all biases used. The response time of the photodetector is independent of the voltage biases used but increase with the optical power.

References

[1] Mikulics M., Xuemei Zheng, Adam R., Sobolewski R., Kordoš P., *High-speed photoconductive switch based on low-temperature GaAs transferred on SiO_2-Si substrate*, IEEE Photonics Technology Letters **15**(4), 2003, pp. 528–530.

[2] Lee C.H., *Picosecond optoelectronic switching in GaAs*, Applied Physics Letters **30**(2), 1977, pp. 84–86.

[3] Xuemei Zheng, Ying Xu, Sobolewski R., Adam R., Mikulics M., Siegel M., Kordoš P., *Femtosecond response of a free-standing LT-GaAs photoconductive switch*, Applied Optics **42**(9), 2003, pp. 1726–1731.

[4] Mourou G., Knox W., *High-power switching with picosecond precision*, Applied Physics Letters **35**(7), 1979, pp. 492–494.

[5] Shen Y.C., Upadhya P.C., Linfield E.H., Beere H.E., Davies A.G., *Ultrabroadband terahertz radiation from low-temperature-grown GaAs photoconductive emitters*, Applied Physics Letters **83**(15), 2003, pp. 3117–3119.

[6] Keil U., Dykaar D.R., *Ultrafast pulse generation in photoconductive switches*, IEEE Journal of Quantum Electronics **32**(9), 1996, pp. 1664–1671.

[7] Valdmanis J.A., Mourou G., Gabel C.W., *Picosecond electro-optic sampling system*, Applied Physics Letters **41**(3), 1982, pp. 211–212.

[8] Holzman J.F., Vermeulen F.E., Elezzabi A.Y., *Ultrafast photoconductive self-switching of subpicosecond electrical pulses*, IEEE Journal of Quantum Electronics **36**(2), 2000, pp. 130–136.

[9] Keil U.D., Dykaar D.R., *Electro-optic sampling and carrier dynamics at zero propagation distance*, Applied Physics Letters **61**(13), 1992, pp. 1504–1506.

[10] Sano E., Shibata T., *Mechanism of subpicosecond electrical pulse generation by asymmetric excitation*, Applied Physics Letters **55**(26), 1989, pp. 2748–2750.

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