Fabrication, characterization and application of fast photoconductive switches

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I. Introduction

A photoconductive switch consists of two conductors which are separated by a high resistive semiconductor material (Si, GaAs) (fig. 1). When one conductor is charged, a short-pulsed (fs) laser is used to illuminate the semiconductor completely. When the gap is illuminated, charge carriers (electron-hole pairs) are created nearly instantaneously (fs time scale), making the semiconductor material conducting. A current can now start to run, also on the time scale of the laser pulse, from the charged conductor through the semiconductor material to the other conductor. The use of semiconductor photoconductive devices to generate picosecond and subpicosecond electrical signals has been the subject of intense research for the last two decades, primarily motivated by the fast-growing demand for ultrafast, integrated optoelectronic photoswitches and photodetectors. The paper deals with the preparation and characterization of fast photoconductive switches for generation of short current pulses. These switches will be used in the characterization of fast components, such as field effect transistor [1], resonant tunneling diodes [2] and the investigation of pulse propagation called waveguides [3]. Current pulses are generated by a low-temperature grown GaAs (LT-GaAs) photoconductive switch and guided through a coplanar waveguide. The pulse length is directly calibrated using photocurrent autocorrelation. An ultra-fast response time (within less than 10 ps) to the sub THz electromagnetic field pulse is shown.

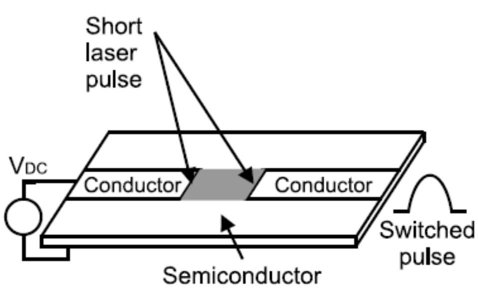

Fig. 1: *Schematic semiconductor photoconductive switch in a stripline configuration.*

II. Experiment

1. Modeling setup

Our work here focused on the low-temperature-grown GaAs, it is a well established ultrafast photoconductive material [4]. At first, the photoconductive switches are prepared by optical lithography on a 1 µm thick LT-GaAs film grown by molecular beam epitaxy (MBE) on a semiinsulating GaAs wafer at 200 °C and annealed at 600 °C for 10 minutes inside the chamber in As-rich conditions. Characterization of the photo-carrier lifetimes by time-resolved reflectivity measurements reveal two dominating relaxation times of the carriers of 70 fs and 140 fs respectively. In the next step, by using optical lithography, a 22.5 µm wide center conductive strip with a gap of 3 µm is evaporated onto the LT-GaAs substrate. Fig. 2a) shows a scanning electron microscope (SEM) image of a photoconductive switch. The photocurrent nonlinearity can be exploited to determine the capture time of photoexcited charge carriers using autocorrelation techniques. We use the setup of fig. 2b). An optical parametric oscillator, pumped with a mode-locked Ti:sapphire laser emits pulses of ~150 fs duration at 76 MHz repetition frequency. The pulse train is split into two parts of equal intensity as shown.

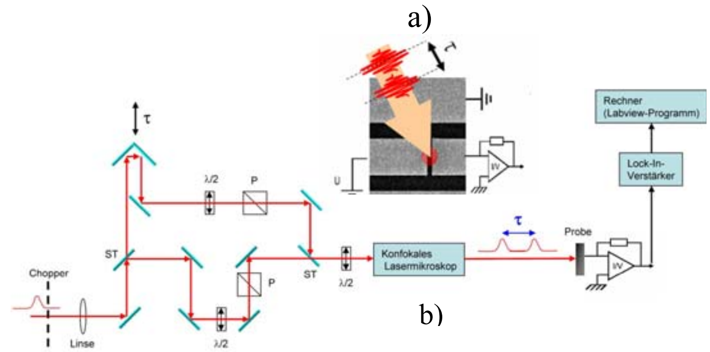

Fig. 2: *Schematic of the optical setup for the autocorrelation measurements(Laser Lab-Kaiserslautern Uni.)*

2. Experimental results

Experiments show that the photocurrent increases non-linearly with the rise of laser power (fig.3 and fig.4) at a constant voltage, the photocurrent saturates for high fluence. It has been shown in [5] that from the photocurrent autocorrelation experiments the time dependent carrier density can be extracted.

Therefore, the photocurrent autocorrelation curve can be analyzed using an exponential decay function where the time constants are related to carrier relaxation times. In the following we allow two relaxation times (I_1 and I_2) to describe the experimental data, then the photocurrent as a function of the delay time τ between the laser pulses is given by:

$$y(\tau) = I_0 - I_1 e^{-|\tau|/\tau_k} - I_2 e^{-|\tau|/\tau_l} \qquad (1)$$

where I_0 is the maximum photocurrent (fig. 5). The parameter set I_1, τ_k and I_2, τ_l characterize the electrical pulse decay. It is found that the first relaxation time of τ_k=1-1.5 ps is related to the carrier recombination time. The ratio of the current amplitudes is about $I_1 : I_2$ > 1.5:1. For a finger-switch geometry, where the gap region is curved in order to increase the optically active area, the second, slower decay (τ_l=5-25ps, dependent on the alignment) can be suppressed.

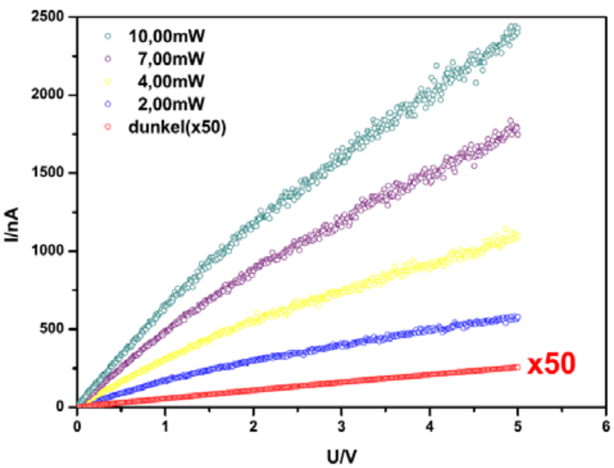

Fig. 3: *Dark and photocurrent characteristics of the LT-GaAs photoswitch structure under illumination varying the laser power.*

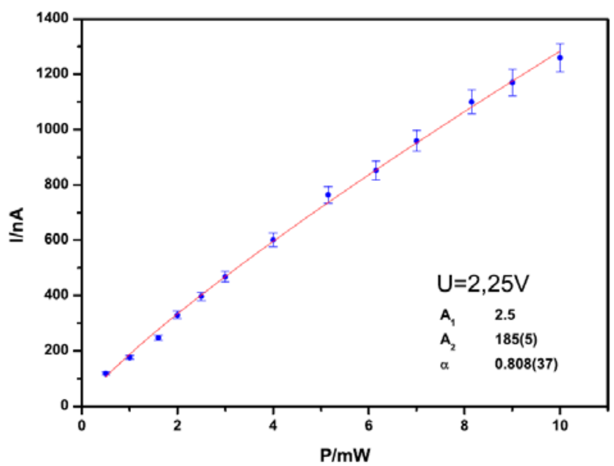

Fig. 4: *Photocurrent versus laser power characteristics of the LT-GaAs photoswitch at 2.25V.*

Therefore from the geometry dependence we conclude that antenna effects of the metallization interacting with the fs-light pulse are responsible for the second, slower contribution. Fig. 5 shows the photocurrent autocorrelation. The solid line shows the analysis using a double exponential decay of the photocurrent towards zero delay τ between the two laser pulses illuminating the gap.

Photoconductive switches based on low-temperature-grown GaAs is of special interest for applications up to THz bandwidths and is widely used [6]. Besides, this study is also able to be used to investigate the magnetization dynamics of magnetic nanostructures and devices such as tunneling magnetoresistive (TMR) elements. Magnetic excitations in micro/nanostructures will be studied by time-resolved Kerr spectroscopy. Especially, photoswitch is best suited for hybrid optoelectronic and ultrafast electronic systems since it can be placed at virtually any point on the test circuit.

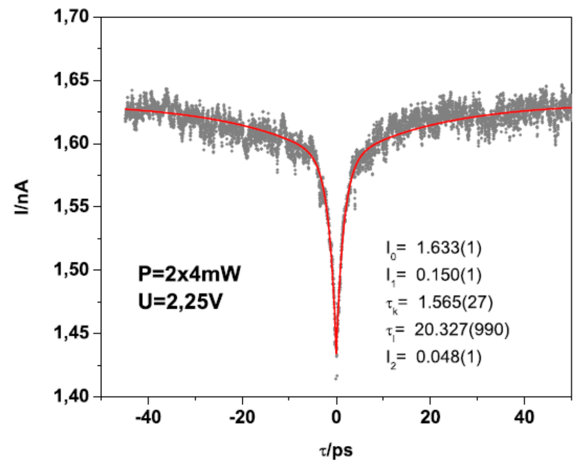

Fig. 5: *Photocurrent autocorrelation measurement on the photoswitch with an output of 4mW per beam part and a bias of 2,25V, the fit was made according to formula (1) with Origin Software.*

III. Conclusions

In conclusion, a photoconductive switch has been successfully fabricated and demonstrated to have a sub-picosecond time resolution. All time-resolved measurements provide independent similar time scales for the pulse. Preliminary measurements of the pulses can be with the photoconductive sampling a total expected pulse duration of less than 10ps, which corresponds well with the auto-correlation measurements of specific time scales.

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