PREPARATION AND CHARACTERIZATION OF AN ULTRAFAST PHOTOCONDUCTIVE SWITCH

CHẾ TẠO VÀ ĐẶC TRƯNG CỦA MỘT CHUYỂN MẠCH QUANG DẪN SIÊU NHANH

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TÓM TẮT

Các linh kiện quang bán dẫn phát các xung điện pico giây và femto giây đang là một chủ đề nghiên cứu rất mạnh trong hơn mười năm qua. Nhu cầu phát triển nhanh các đầu dò và chuyển mạch quang siêu nhanh được chú trọng. Trong báo cáo này, kỹ thuật chế tạo và đặc trưng của một chuyển mạnh quang dẫn siêu nhanh dùng để phát xung siêu dòng ngắn được đề cập cho các ứng dụng trong các linh kiện điện tử như transistor hiệu ứng trường nhanh, điốt đường hầm cộng hưởng nhanh và sóng hướng dẫn. Các xung dòng được phát ra bởi một chuyển mạch quang LT-GaAs và sau đó được dẫn qua một bộ phận sóng hướng dẫn đồng phẳng. Chiều dài xung được đo trực tiếp bằng phương pháp tự tương quan dòng quang điện. Một đáp ứng thời gian nhỏ hơn 10 pico giây tương ứng dải tần số điện từ THz đã được minh chứng.

Từ khóa: *chuyển mạch quang dẫn siêu nhanh, LT-GaAs, sóng hướng dẫn, dòng quang điện.*

ABSTRACT

The semiconductor photoconductive devices to generate picoseconds and sub-picoseconds electrical signals have been the subject of intense research for the last two decades. Primarily the fast-growing demand for ultrafast photo-switches and photodetectors are of interests. In this paper, the preparation and characterization of the ultrafast photoconductive switch for generation of short current pulses are mentioned, which will be applied in the characterization of components, such as fast field effect transistor, fast resonant tunneling diodes and the investigation of pulse propagation called waveguides Current pulses are generated by a low-temperature grown GaAs (LT-GaAs) photoconductive switch and then 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.

Key words: *Ultrafast photoconductive switches, LT-GaAs, waveguides, photocurrent.*

I. INTRODUCTION

A semiconductor photoconductive (PC) switch consists of two conductors which are separated by a high resistive semiconductor material (Si, GaAs). 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 (on a 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 (see a PC switch model in fig. 1).

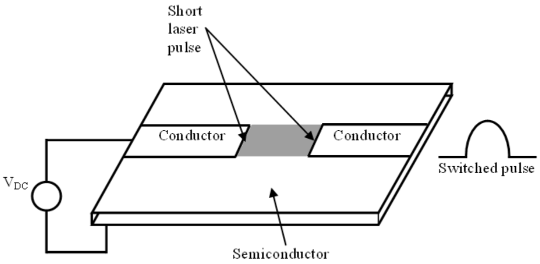

Fig. 1: Schematic semiconductor photoconductive switch in a stripline configuration.

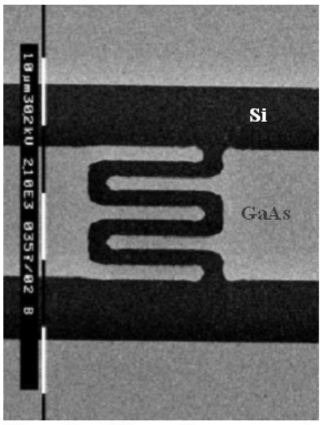

Fig. 2: *The photo-switch with a finger structure (SEM image).*

PC switches have unique properties over conventional high power switches. These include low trigger jitter, high speed response to laser pulse, picosecond rise time, GHz repetition rate, low inductance and capacitance, optical isolation of the trigger. The high power and ultrafast, high voltage switches using photoconductive switches trigged by ultrashort pulse lasers can be used in a large number of applications ranging from high speed detectors for communication, modulators, fast high voltage pulse generation, and time domain measurement to high power microware generation. Photoconductive switches as power generations have very wide applications to radar and communications due to their properties, which are resisting high voltage, high power, and ultra wideband.

GaAs used as the ultrafast PC material has a distinct advantage of the high dark resistivity (10^7~10^8 Ω.cm). This is very important for applications of PC switches. For example, the efficiency of a PC power generation increases with the bias electric field and is limited by the breakdown field of the PC power generation. For PC detector, the noise in signal current of a PC power generation is inversely proportional to the dark resistivity. In addition, the optical band gap of GaAs is 1.43eV at room ternperature corresponding to a wavelength of 876nm and GaAs as a photoconductive switch material can absorb light strongly with absorption coefficient in the range under 876nm. The possibility to use inexpensive and maintenance-free pulsed fiber laser systems with a small footprint would significantly contribute to the proliferation of imaging applications based on pulsed terahertz radiation.

In this paper, we report a ultra-fast PC switch and a simple optical correlation technique which is capable of measuring the speeds of fast photo-switch and the characteristic results of a GaAs ultra photoconductive switch via the MBE technology.

II. METHOD AND MODEL

According to the above proposed model, we here focused on the low-temperature-grown GaAs, it is a well established ultrafast photoconductive material for generating and detecting pulsed terahertz radiation. In the following the preparation details and dimensions of the on-chip devices are given. The photoconductive switches are prepared by optical lithography on a 1 µm thick LT-GaAs film grown by molecular beam epitaxy (MBE) on a semi-insulating 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 70fs and 140fs respectively. In the next step, by using optical lithography, a 22.5 µm wide center conductive strip (5 nm Ti/ 30 nm Al) with a gap of 3 µm is evaporated onto the LT-GaAs substrate.Fig. 3 shows a scanning electron microscope (SEM) image of the metal-semiconductor-metal (MSM) gap and its dimensions. The photocurrent nonlinearity can be exploited to determine the capture time of photoexcited charge carriers using autocorrelation techniques. We use the setup of fig. 4 and the real experimental model in fig. 5. An optical parametric oscillator, pumped with a mode-locked Ti:sapphire laser (coherent) emits pulses of ~150 fs duration at

76 MHz repetition frequency. The pulse train is split into two parts of equal intensity as shown.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

The experimental geometry of this model is given schematically for the photocurrent autocorrelation experiment in figure 4. Two pulses delayed by a time τ illuminate the MSM gap and the photocurrent is determined. The electrical pulses are generated by the femtosecond laser illumination of the MSM gap and then transmitted through the coplanar waveguide. The advantage of the photocurrent autocorrelation technique presented here is that as opposed to other techniques (e.g. picosecond electro-optic or photoconductive sampling using a dual photoconductor circuit) the same sample geometry as for the magneto-optic sampling can be used to charcterize the electric pulse length. Only a single photoconductor is needed for the photocurrent autocorrelation measurement. A prerequisite is that the photocurrent increases non-linearly with the rise of laser power as seen in figure 6 at a constant voltage, the photocurrent saturates for high fluence. Also, a dependence of photocurrent on laser power as shown in figure 7. Because of the high defect density of the of LT-GaAs film, the MSM contact has ohmic-like characteristics. T. F. Carruthers et al. found the photocurrent autocorrelation experiments the time dependent carrier density can be

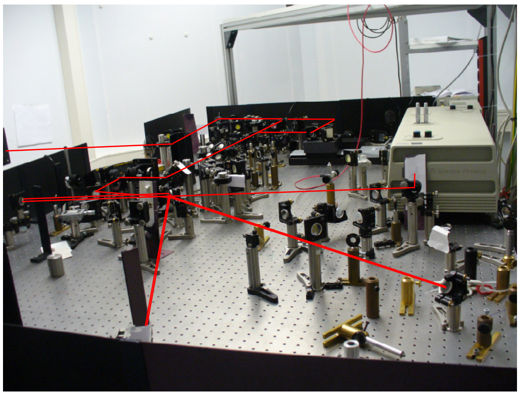

Fig. 5: *Experimental setup with laser path for the autocorrelation measurements (Laser Lab at Kaiserslautern University).*

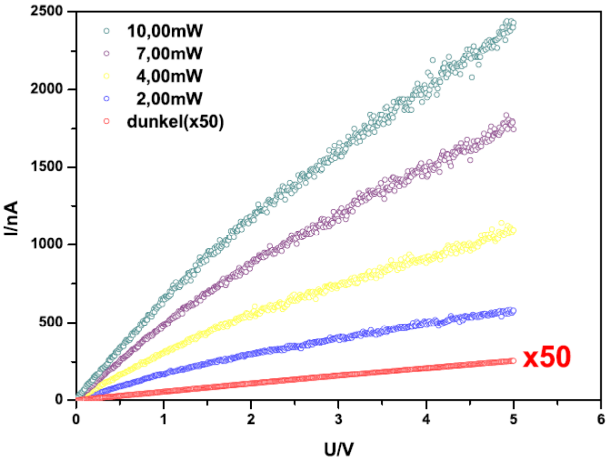

Fig. 6: *Dark and photocurrent characteristics of the LT-GaAs photo-switch structure under illumination varying the laser power.*

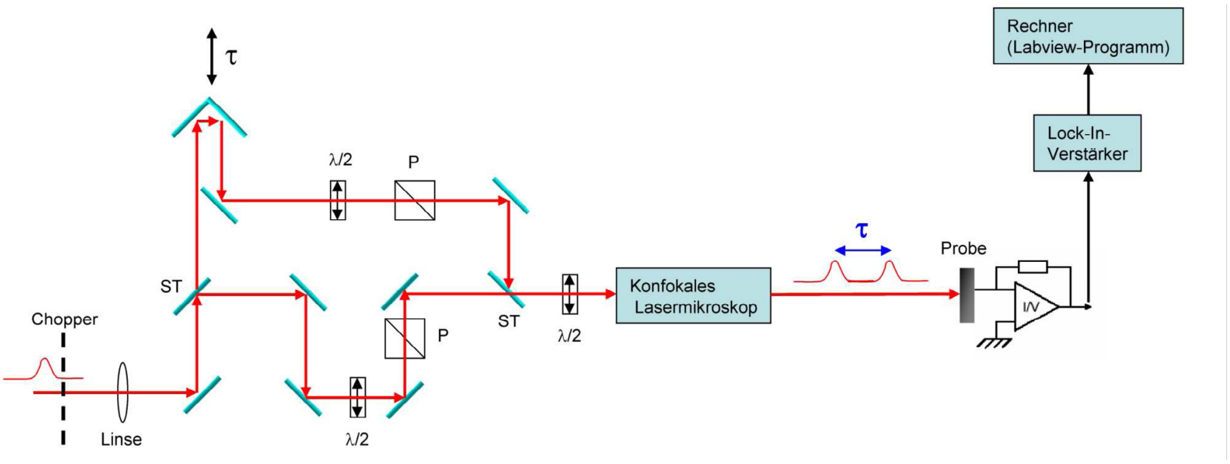

Fig. 4: *Schematic of the optical setup for the autocorelation measurements(Laser Lab-Kaiserslautern Uni.)*

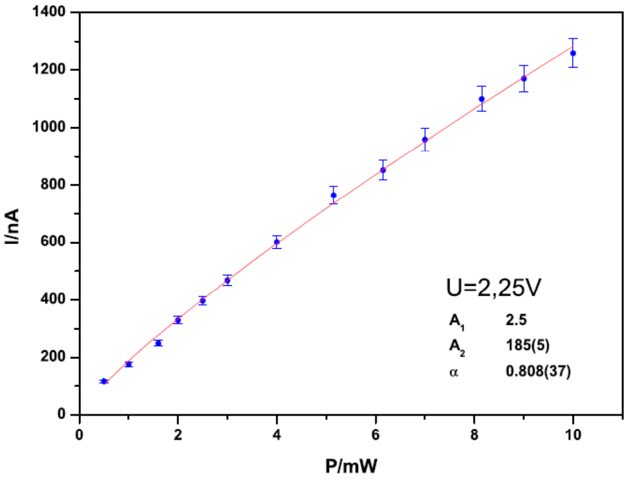

Fig. 7: *Photocurrent versus laser power characteristics of the LT-GaAs photo-switch at 2.25V.*

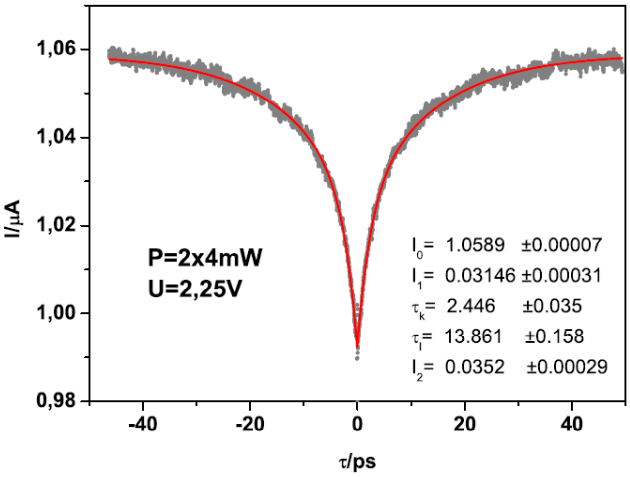

Fig. 8: *Photocurrent autocorrelation measurement on the photo-switch with an output of 4mW per beam part and a bias of 2,25V with I_0, I_1 and I_2 respectively, the fit was made according to formula (1) (red line).*

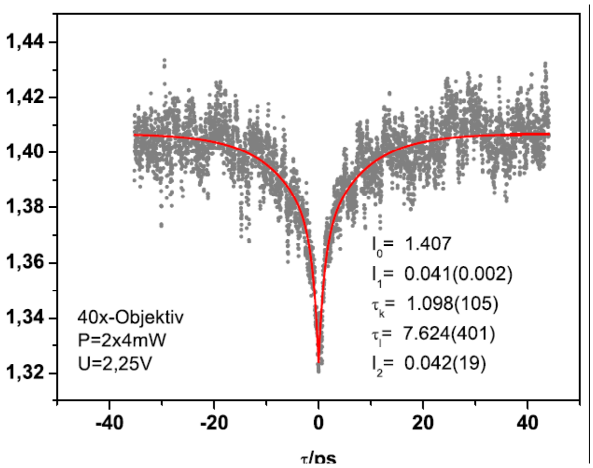

Fig. 9: *Photocurrent autocorrelation measurement on the photo-switch with an output of 4mW per beam part and a bias of 2,25V with I_0, I_1 and I_2 respectively, the fit was made according to formula (1) (red line).*

extracted.

Also, the dark photocurrent characteristics of the LT-GaAs photo-switch under illumination varying the laser power is negligible (magnified up to 50 times), as shown in fig. 6.

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 (see in fig. 7). 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=1-1.6 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.

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. The characteristic of the PC switch has been studied in the different various parameters. We prepared a single finger structure with GaAs based switch on Si Substrate (see a SEM image in fig. 2). A photocurrent autocorrelation measurement for our model was done. These experimental results could well compare with the history studies. We showed an ultra-fast response of the PC switch through the optical correlation technique. The photocurrent depends on the delay time τ between the laser pulses and parameters of I_0, I_1, I_2. Figures form 8 to 11 show the photocurrent autocorrelation with I_0, I_1 and I_2 respectively. The solid line shows the analysis using a double exponential decay of

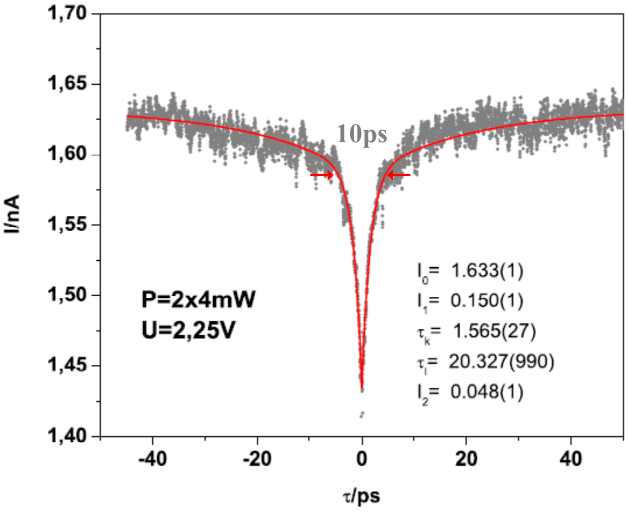

Fig. 10: *Photocurrent autocorrelation measurement on the photo-switch with an output of 4mW per beam part and a bias of 2,25V with I_0, I_1 and I_2 respectively, the fit was made according to formula (1) (red line).*

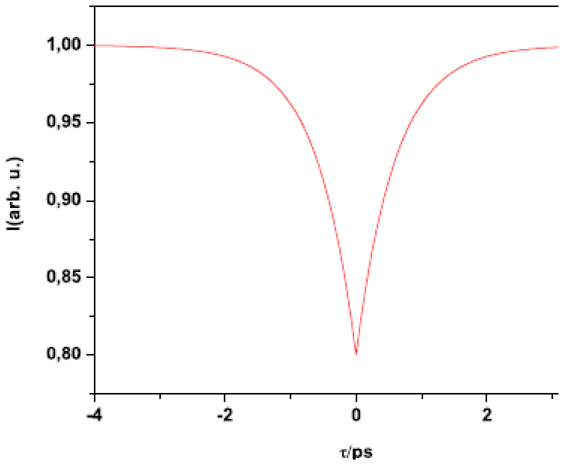

Fig. 12: Simulated autocorrelation signal for a photo-switch with a lifetime of τ_e=600fs.

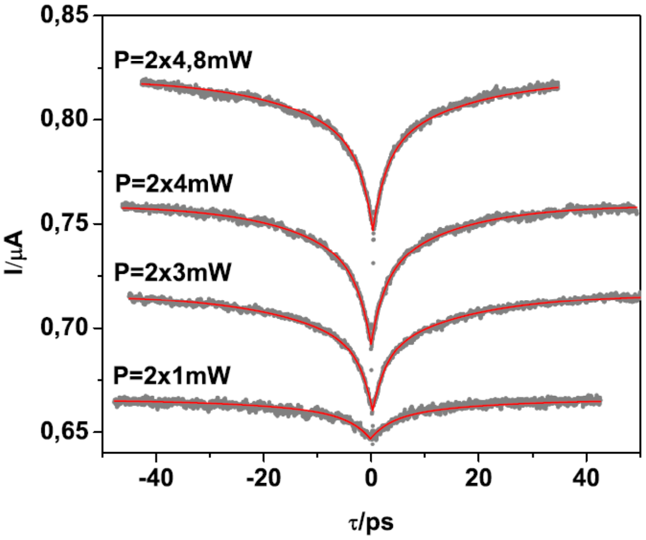

Fig. 11: *Photocurrent autocorrelation measurement on the photoswitch for different pump powers and a bias of 2,25V, the fit was made according to formula (1) (red lines).*

the photocurrent towards zero delay τ between the two laser pulses illuminating the gap. Also, a photocurrent autocorrelation measurement on the photo-switch for different pump powers as shown in figure 11.

In order to see completely a picture about our model of the photo-switch in this study, a simulated autocorrelation response with a lifetime of τ_e=600fs was shown in fig. 12. This result agrees well with the experiment.

Generally, the fundamentals of micro-and nanostructuring of thin films placed in this work of us. For optical lithography exposure system was built, which after determining the necessary process parameters of the structure of product sizes allow up to 3µm. In the electron beam lithography, the linewidth of the used resist system designed and written with the data obtained from the first nanostructures. From the minimum line width achieved is currently a maximum resolution of 50nm. The developed methods of optical lithography have been used to produce fast photoconductive switches on LT-GaAs. For their characterization, a system for measuring IU-characteristic curves was constructed.

An extension of the structure with a confocal laser microscope, which achieves a resolution of a few micrometers, it was possible to focus a laser beam directly on the waveguide gap of the switch and take the IU-characteristics under excitation of photoelectrons. To determine the time scales, it was necessary a pump-probe setup for measurement of the autocorrelation with a Ti: Sa laser to build. The relevant time scales for the switching time of the switch was determined by exploiting the nonlinearity of the photocurrent on τ_k~1, 6 ps and τ_l~20ps.

IV. SUMMARY

In summary, a photoconductive switch has been successfully fabricated and demonstrated to have a sub-picoseconds 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. 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, photo-switch is best suited for hybrid optoelectronic and ultrafast electronic systems since it can be placed at virtually any point on the test circuit.

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