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Concept of a measuring system for diagnostics of photoconductive semiconductor switches parameters

***Abstract**. The article presents the concept of a measurement system for testing the characteristics of photoconductive semiconductor switches in the blocking state and conduction state for the system voltage up to 90 kV. The results of the research obtained so far for the gallium phosphide switch (GaP), carried out for the supply voltage up to 1 kV, and for the voltage range increased to 10 kV thanks to the system created in accordance with the concept presented in the article, are also presented.*

***Streszczenie.** W artykule przedstawiona została koncepcja układu pomiarowego do badania charakterystyk półprzewodnikowych łączników fotokonduktancyjnych w stanie blokującym i stanie przewodzenia dla napięcia układu do 90 kV. Zaprezentowane zostały także, dotychczas otrzymane wyniki badań łącznika wykonanego z fosforku galu (GaP), przeprowadzone dla napięcia zasilania do 1 kV oraz dla zakresu napięć zwiększonego do 10 kV dzięki zastosowaniu układu stworzonego według przedstawionej w artykule koncepcji. (**Koncepcja układu pomiarowego do diagnostyki parametrów półprzewodnikowych łączników fotokonduktancyjnych**).*

Keywords: photoconductive semiconductor switch, impulse systems, switch diagnostics.
Słowa kluczowe: półprzewodnikowy łącznik fotokonduktancyjny, układy impulsowe, diagnostyka łączników.

Introduction

The photoconductive semiconductor switch (PCSS) is an electrical switch, optically controlled and operated by the phenomenon of photoconductivity. A PCSS is made of a semiconductor material with a thickness of 0.5 to 1 mm which is connected to the electrical circuit by ohmic contacts mounted on the surface. After illumination of the area between contacts, called switch gap, by the photon flux, the concentration of charge carriers increases, which reduces the resistance of the semiconductor material up to several orders of magnitude [1, 2]. An overview of the basic PSCC structures is presented in paper [3], and the solution used in the research is presented in Figure 1.

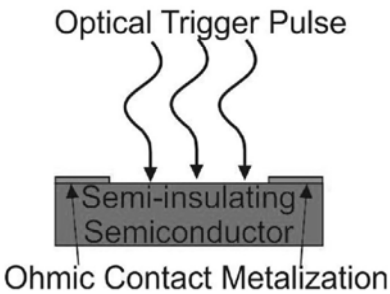

Fig. 1. Structure of photoconductive semiconductor switch

In recent years, there has been a growing interest in the possibility of using PCSS switches in pulse systems and in the power industry to control the transmission of electricity in a hybrid switch system [4]. The aim of pulse systems is to transport large amounts of electric energy in a very short period of time. Such systems are used both in applications for military use, such as microwave generators and electromagnetic weapons, as well as for civilian use, where they are used in automation of control of electronic systems [5, 6]. PCSS switches have many advantages over spark gap switches, traditionally used in pulse systems, and over high voltage mechanical switches used in power industry. They are characterized by high voltage durability, thanks to which, the operating voltage of switches in the open state can reach up to 100 kV. Due to the possibility of going into a state of reduced resistance, the current in the conduction state can reach 1 kA [7, 8]. During operation with the described parameters, they enable delivering power of tens of megawatts over a period of nanoseconds, with possible repetition rate of 1 kHz. An important problem of traditional spark gap switches is the inability to precisely control the moment of switching, while in the mechanical switches a dispersion of switching time occurs [9, 10]. These problems do not occur in PCSS switches, because the control takes place by means of a photon flux with the appropriate energy, which allows for precise switching of the system by means of an optical pulse. An important advantage of the discussed system is also the fact that the control and operation circuits of the switch are isolated from each other [2, 4, 11].

Depending on the purpose of the switch in a given system, determination of the relevant characteristics curves is essential, in order to properly select the switch for the system. For this purpose, it is necessary to create an appropriate diagnostic system, giving the opportunity to examine these characteristics.

Measurement system for testing PCSS switches

The aim of the measuring system for testing PCSS switches is the ability to make measurements for high voltage values in the system and to record the course of the system reaction to the impulse that triggers the switch in the conduction state. Due to the lack of a dedicated measurement system for testing PCSS switches, the own concept of the measurement system was developed. Based on which a system was built to measure the characteristics of PCSS switches in the blocking and conduction state, for a system supply voltage of up to 10 kV. The schematic diagram of the developed measurement system is shown in Figure 2.

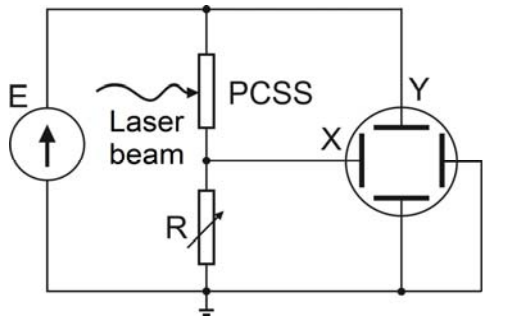

Fig. 2. Schematic diagram of the system for testing photoconductive semiconductor switches

The measurement system used so far consists of the METREL MI 3210 TeraOhm XA meter used as a DC voltage source and, at the same time, a current and resistance meter in the blocking state, a specially prepared handle for the tested PCSS sample, providing the possibility to connect a resistor with selected parameters to the circuit in series and an oscilloscope used to measure voltage drops on the tested switch and resistor in the conduction state, as well as to record the response of the system to the laser pulse initiating the conduction state. The METREL meter allowed to measure the characteristics of the PCSS switches in the blocking and conductive state for the voltage from 50 V to 10 kV and currents in the range from 0.1 nA to 5 mA. Since the maximum possible supply voltage during tests in the system was 10 kV and is much smaller than those found in systems for use in which the tested switches are intended, it became necessary to build a measurement system allowing testing for higher voltage values. In the next measurement system, a high voltage generation module will be used as a voltage source, which is part of a new high voltage laboratory of the Military University of Technology electronics department and will enable measurements for up to 90 kV voltage supply.

Measurement results

The gallium phosphide (GaP) switch was tested. Figure 3 shows the appearance of the PCSS sample prepared for measurements.

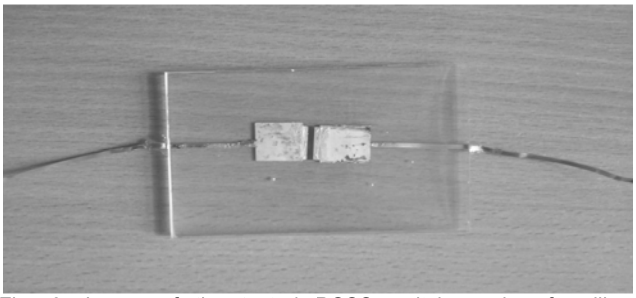

Fig. 3. Image of the tested PCSS switch made of gallium phosphide.

The test sample consist of a semiconductor made in the form of a chip, with a surface of 1 cm × 1 cm and a thickness of 0.5 mm, to which copper electrodes were fixed with use of a gold-based paste acting as ohmic contacts. The electrodes were made of electrolytic copper and the distance between them was 2 mm. Before fixing, they were cut into strips with a thickness of 0.3 mm, a width of 10 mm and a length of 15 mm, to which strips with a thickness of 0.2 mm, width 2 mm and length 100 mm were attached, to easily connect the sample to the measuring system. The whole structure was then chemically cleaned and covered with a layer of silver. Before attaching the electrodes, the surface of the semiconductor was cleaned mechanically and chemically, and then polished and dried. These operations were designed to remove oxides from the semiconductor surface, and to improve the quality of electrodes. After connecting the electrodes, the GaP sample was coated with a 200 nm layer of SiO_2 to better protect against external factors, as well as to increase the recombination velocity of the carriers on the surface of the semiconductor. The whole sample has been embedded in a transparent coating made of resin to further protect against external factors.

The first tests of the photoconductive semiconductor switch made of gallium phosphide were made for a voltage in the blocking state from 100 V to 1 kV with a step of 100 V. For each measuring point a series of three measurements was made.

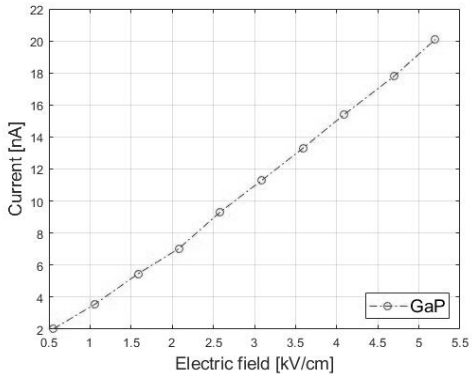

Fig. 4. Characteristics of the dark current as a function of the electric field strength of the tested PCSS switch (GaP) in the blocking state, at 300 K for the supply voltage up to 1 kV.

Figure 4 shows the results of dark current measurements depending on the strength of the electric field. The obtained graph shows that for the values of the electric field strength from 0.55 to 5.2 kV/cm the characteristics of the tested sample run linearly and the sample works in the blocking state. The maximum current value obtained for the electric field of 5.2 kV/cm, was 20.1 nA, which is a satisfactory result.

The next stage of the research was carried out in a system built on the basis of the concept presented in the article. The characteristics in the blocking state were measured in the range from 0.5 to 10 kV with a step of 500 V. The obtained results of the dark current dependence as a function of the intensity of the electric field are shown in Figure 5.

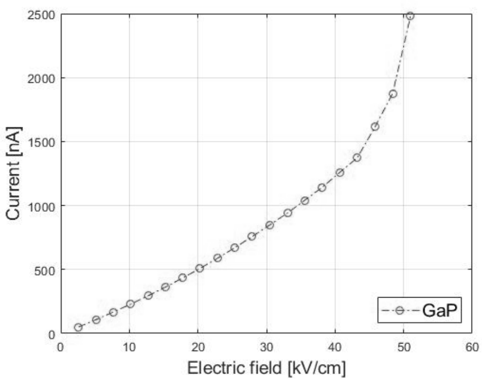

Fig. 5. Characteristics of the dark current as a function of the electric field strength of the tested PCSS switch (GaP) in the blocking state, at 300 K for the supply voltage up to 10 kV.

Analysing the blocking characteristics obtained in Figure 5, it can be noticed that for electric field values from 2.58 to 43.23 kV / cm the characteristic is linear, while in the range from 43.23 to 51 kV / cm there is a visible increase in the current value. The maximum current reached in the blocking state was 2.48 μA for an electric field strength of 51 kV / cm.

In the next step of the research, the sample was measured in the conduction state. The influence of the laser beam energy change on the value of the conducted current and the course of the system response to the impulse switching the tested sample into conduction state were measured. For this purpose, for a system voltage of 10 kV and a selected length of the laser beam, a series of five measurements for the energy of the laser beam from 200 to 440 μJ were carried out and the voltage waveforms were recorded on the resistor connected in series to the PCSS switch.

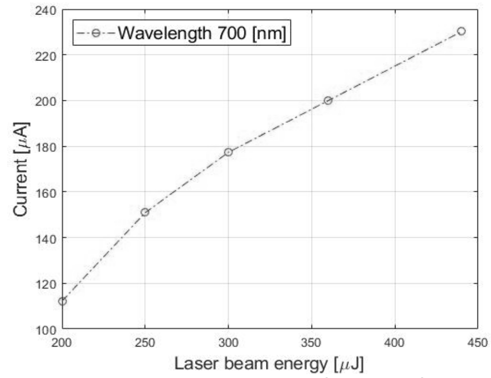

Fig. 6. The current characteristic as a function of the laser beam energy of the tested PCSS switch in the conduction state, at a temperature of 300 K for a 10 kV supply voltage.

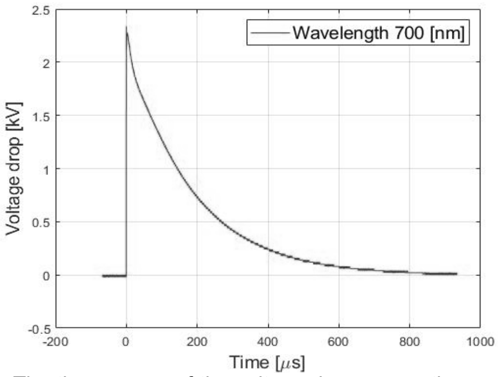

Fig. 7. The time course of the voltage drop across the resistor over time, for a beam energy of 200 μJ at 300 K for a 10 kV supply voltage. The moment in which the laser beam is turned on is at the point t = 0.

Figure 6 shows the current waveform as a function of the energy of the laser beam with a length of 700 nm. It shows that in the studied range of beam energy changes, the current increase is similar to a linear one, potentially making the process of controlling the current conducted through the switch in the chosen system easier. The maximum current value was obtained for the beam energy of 440 μJ and was equal to 230.2 μA, which is more than 90 times greater than value obtained during the tests in the blocking state. Figure 7 shows the registered response of the system on the resistor, to an optical pulse switching the sample into conduction state. The optical pulse was a laser beam with a length of 700 nm, and the pulse duration was 10 ns. As shown in Figure 7, the time of spontaneous transition of the sample into the blocking state after switching on is about 800 μs, which means that the sample stays in the conduction state for a longer period of time than the duration of the switching pulse. We can see that the process of the transition of the sample into the blocking state, comprises 3 time constants, the length of which are approximately 25 μs, 125 μs and 650 μs, respectively. The maximum voltage drop registered on the resistor equalled to 2.337 kV and was reached after 34 ns, which means that the process of fully switching the sample to conduction state continued for about 24 ns after switching off the laser.

Conclusion

In the presented results of the PCSS switch studies, for a 10 kV supply voltage, a current of 230.2 μA was achieved in the conduction state in the order of 34 ns. The current value in conduction state is about 90 times greater than the one achieved in the blocking state, which equalled to 2.48 μA. The possibility to increase the conducted current by almost two orders of magnitude during the order of nanoseconds is satisfactory, however, it is necessary to verify the result obtained in the higher voltage values. The time of switching the sample back into the blocking state, after illuminating it with a laser beam was about 800 μs, which allows potentially to reach the switching frequency of the tested PCSS switch, at the level of 1.25 kHz. This result is consistent with the expected one after the analysis of the literature, and sufficient for the application of the switch in pulse systems or in the systems of high voltage switches in the power industry. The potential increase in frequency should be possible by lowering the PCSS switch operating temperature. In the next stage of the research, the switch tests will be carried out at voltages up to 90 kV, thanks to the application of the high voltage generation module, as a voltage source in the system described in the article.

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