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2020 7th International Congress on Energy Fluxes and Radiation Effects (EFRE)

Tomsk, Russia, September 14 – 26, 2020

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Study of The Switching Characteristics of Gas S-Diodes

Valery Barmin
Institute of High Current Electronics SB RAS
2/3 Akademichesky Ave., 634055, Tomsk, Russia
valery@barmin.club

Pavel Priputnev
Institute of High Current Electronics SB RAS
2/3 Akademichesky Ave., 634055, Tomsk, Russia
priputnevpavel@gmail.com

Vladimir Konev
Institute of High CurrentElectronics SB RAS
2/3 Akademichesky Ave., 634055, Tomsk, Russia
konevvy@yandex.ru

Sergei Maltsev
Institute of High Current Electronics SB RAS
2/3 Akademichesky Ave., 634055, Tomsk, Russia
honour@vtomske.ru

Ilya Romanchenko
Institute of High Current Electronics SB RAS
2/3 Akademichesky Ave., 634055, Tomsk, Russia
dr.romanchenko@gmail.com

Ilya Prudaev
Tomsk State University
36 Lenin Ave., 634050, Tomsk, Russia
funcelab@gmail.com

***Abstract*—In the study, the switching properties of avalanche GaAs S-diodes are investigated. We studied diode assemblies of various configurations. It is shown that when using two or more diodes connected in series, the edge of the voltage pulse can be sharpened to about 1 ns.**

***Keywords*—avalanche GaAs S-diode, pulse sharpening, delay time.**

I. Introduction

Semiconductor switching diodes are used in many fields of electronics and electrical engineering [1]. Avalanche S-diodes based on gallium arsenide are used in voltage pulse shapers with amplitudes of the order of several kilovolts and a front duration of about 500 ps, for example. It is of interest to find solutions for using this type of diode as a sharpener of the voltage pulse front with an amplitude of the order of several kilovolts.

First of all, GaAs semiconductor switching devices seem promising for use in devices with a repetition frequency of modulating pulses of the order of several kilohertz [2]. Ultrafast switching of the state of short edge of voltage pulses (from 0.05 to 2 ns) allows their use in ultra-wideband radar devices [3]. Using deep impurities, chromium and iron in n-type GaAs devices, pulsed avalanche S-diodes are obtained. The structure of these diodes is based on π-ν-n-type conductivity layers [4–6]. In previous studies, it was shown that avalanche S-diodes are capable of switching from a low-conductive state to a highly conductive state in about 500–700 ps when a voltage pulse with a front of about 20 ns is applied to them [7]. When two diodes are connected in series with a sufficient time isolation between them, when after the first diode is triggered, the second receives a pulse with a sharpened front equal to approximately 500 ps, the process of switching the second diode to a highly conductive state has its own delay, caused by internal processes in the semiconductor structure and charging time intrinsic capacitance of the p-n junction [7]. This delay is at least 4.5 ns. This process severely limits the use of GaAs avalanche diodes as sharpeners of voltage pulse edges.

In this work, we conducted experiments to reduce the diode switching time in the case of excitation by a voltage pulse with a short front.

The work was supported by the Russian Science Foundation (grant No. 18-38-20076).

II. Experimental Setup

A. Coaxial Microwave Cavity Design

Two coaxial chambers were used in the work, the designs of which are shown in Fig. 1.

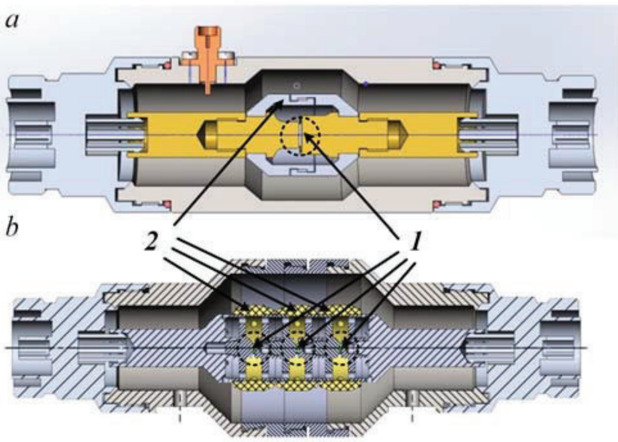

Fig. 1. Coaxial chambers designs: *1* - GaAs S-diodes, *2* - Plexiglas connecting sleeves.

Chamber №1, shown in Fig. 1*a*, was designed to work with voltage pulses with an amplitude of about 2 kV. The microwave characteristics of the camera are given in [3]. Chamber No. 2, shown in Fig. 1*b*, was designed for voltage pulses with an amplitude of about 8 kV. Chamber No. 1 allowed the use of diode assemblies consisting of two elements. As can be seen from Fig. 1b, Chamber No. 2 could be

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converted to a chamber for one, two and three diodes connected in series. The S-parameters of the second chamber for three diodes are shown in Fig. 2.

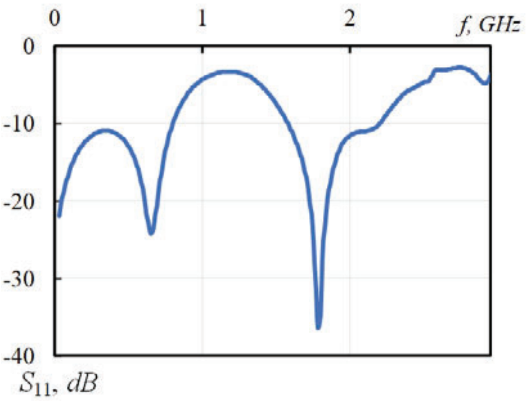


Fig. 2. Measured S-parameters of the chamber №2.

The second chamber was designed taking into account the possibility of filling it with vacuum oil.

B. Summary of the Measuring Installation

The concept of the experiment was to measure the delay time between the response time of the diode assembly and achieve the maximum conductivity of the diodes. The experimental design is shown in Fig. 3.

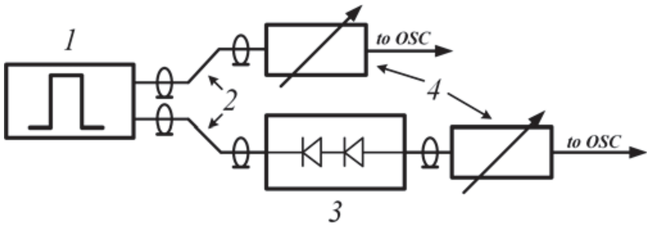


Fig. 3. Block diagram of the measuring installation: *1* - source of voltage pulses, *2* - high-voltage coaxial cables, *3* – S-diodes under test, *4* - coaxial attenuators.

As in [3], Telegartner high-voltage cable connectors, two coaxial attenuator assemblies of 50 dB each and a TDS6604 with 6 GHz band oscilloscope were used in this work.

The work used a voltage pulse source, described in detail in [3]. The source of modulating pulses allows you to adjust their amplitude from 200 V to 5.5 kV at a 50-ohm load.

C. Brief Description of the Diodes Used

In the experiments, the switching properties of GaAs avalanche diodes were studied, the photographs and schematic images of which are shown in Fig. 4.

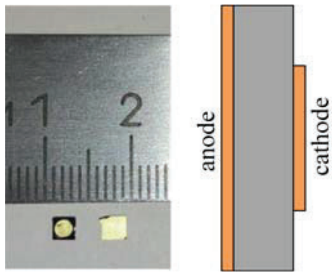


Fig. 4. Photos of diodes and their schematic image.

Fig. 4 shows the pads in yellow.

III. Experimental Results

A. Experiments with Chamber №1

During the experiments, the switching times from the closed state to the conducting state of a single diode, which was placed in the gap of the central conductor in the chamber No. 1, were compared, depending on its orientation. An assembly of two diodes with various combinations of orientation of the diodes was also placed in the chamber. Possible ways of placing diodes in the chamber are shown in Fig. 5.

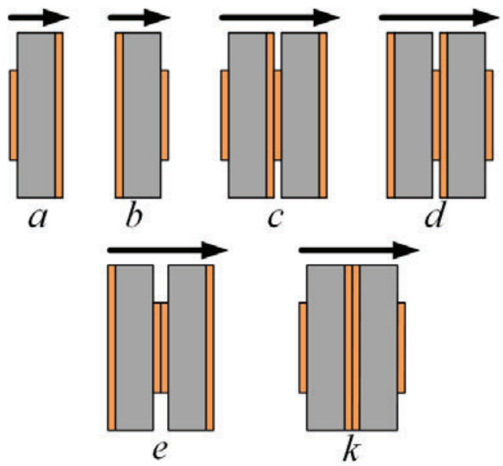


Fig. 5. Possible ways of placing diodes in the resonator chamber No.1: *a* - reverse connection of a single diode, *b* - direct connection of the diode, *c*, *d*, *e*, *k* - combinations of switching on two diodes.

In the figure, the arrows show the direction of propagation of the voltage pulse.

Fig. 6 shows the synchronized waveforms of the pulse incident on the diode and the passage of a single diode for cases *a* and *b*. It can be seen that in case *b*, the front of the transmitted pulse at a level of 0.1–0.9 is much shorter and amounts to 700 ps.

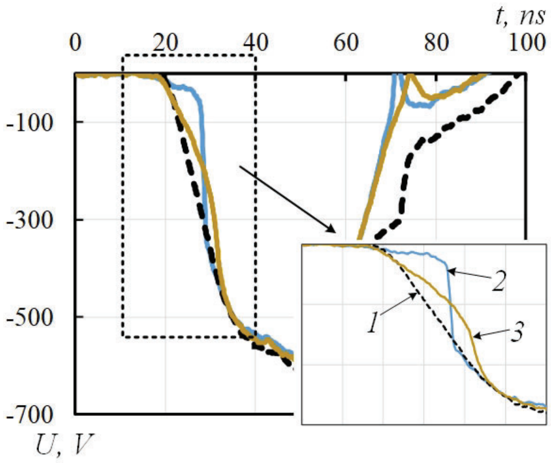
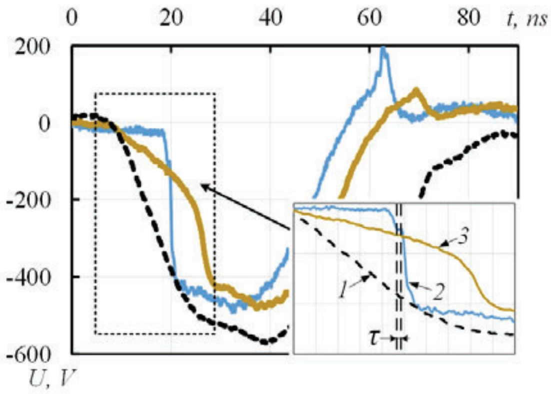
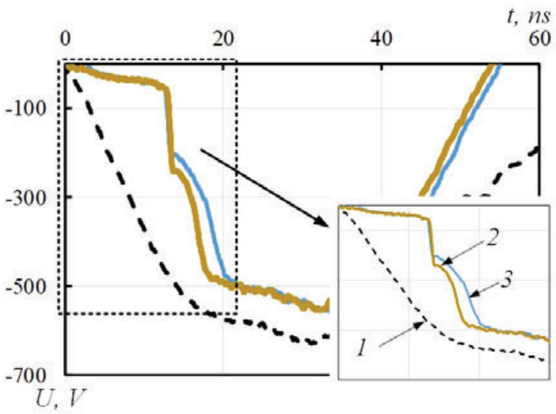


Fig. 6. Possible ways of placing diodes in the resonator chamber No.1: *a* - reverse connection of a single diode, *b* - direct connection of the diode, *c*, *d*, *e*, *k* - combinations of switching on two diodes.



(*a*)



(*b*)

Fig. 7. Oscillograms of voltage pulses: *1* - incident pulse to an assembly of 2 diodes, *2* - pulse after assembly, corresponding to Fig. 5c and Fig. 5e respectively, 3 - pulse after assembly, corresponding to Fig. 5d and Fig. 5k.

Fig. 7 shows the oscillograms of the diodes incident on the assembly and the transmitted voltage pulses corresponding to the switching configurations *c*, *d*, *e*, *k* in Fig. 5, respectively. It can be seen that the diode response delay (blue voltage pulse in Fig. 7*a* and Fig.7*b*) does not exceed 0.8–1.0 ns. For the assemblies shown in Fig.5*e* and 5*k*, there is no section corresponding to the time delay.

B. Experiments with Chamber №2

Fig. 8 schematically shows the option of turning on the diodes in chamber №2. The experiments were carried out with one diode, then with two and three. The recorded waveforms for each of the cases are presented in Fig. 9 and Fig. 10. In Fig. 9, the incident voltage pulse is indicated in blue for cases of one diode and an assembly of two diodes. In Fig. 10, the voltage pulse incident on an assembly of three diodes is shown in black. It can be noted that an increase in the number of diodes in the chamber leads to an increase in the breakdown voltage of the entire assembly, which in turn leads to an increase in the time delay τ between the incident pulse and the passing one. In the case of an increase in the amplitude of the incident pulse, the delay time decreases, but the risk of destruction of the diode structure increases. The durations of sharpened fronts do not exceed 2 ns in all cases.

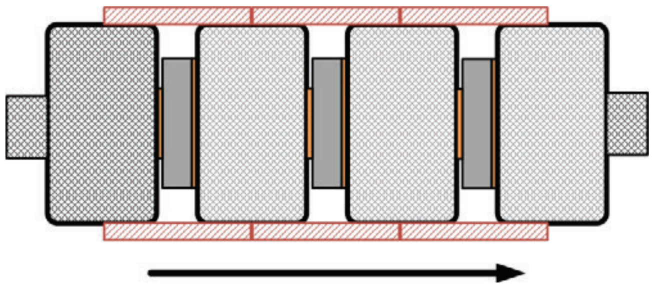


Fig. 8. The location of the diodes in the chamber №2. In burgundy, bushings made of plexiglass are indicated, gray shading indicates the center conductor.

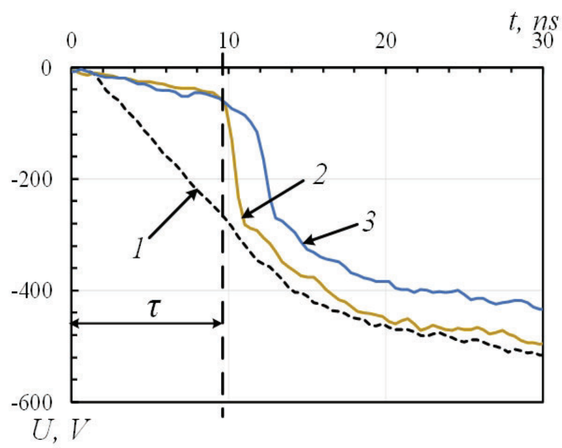


Fig. 9. Oscillograms of voltage pulses: *1* - incident pulse to the diode assembly; *2* - pulse after assembly, including only one diode, *3* - pulse after assembly, including two diodes.

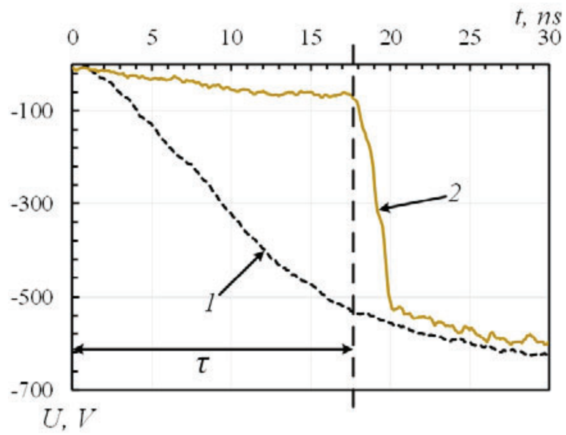


Fig. 10. Oscillograms of voltage pulses: *1* - incident pulse to the diode assembly; *2* - pulse after assembly, including three diodes.

IV. Discussion

The experiments showed that in the case of different configurations of the series connection of two and three avalanche gallium arsenide diodes in one resonator chamber, the process of switching the second diode to a highly conductive state has a significantly lower delay than in the case of a significant isolation between them. The duration of the edge of the sharpened pulse does not exceed 2 ns, and in the best case it can reach about 700 ps. This result means that assemblies of several gallium arsenide diodes connected in series can be used as sharpening elements in voltage pulse shapers with subnanosecond fronts.

Acknowledgment

The work was supported by the Russian Science Foundation (grant No. 18-38-20076).

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