doi: 10.56761/EFRE2022.S4-O-026701

Effect on the GaAs parameters of a photoconductive semiconductor switch with a silicon oxide layer when switched by 355-nm laser radiation

V.V. Barmin, V.YU. Konev, I.V. Romanchenko*

Institute of High Current Electronics SB RAS, Tomsk, Russia
**valery@barmin.club*

Abstract. The effect of defects in a silicon oxide (SiO_2) layer deposited by sputtering on the front side of a GaAs photoconductive semiconductor switch (PCSS) on its resistance in the open state was found. Switching of the PCSS was carried out by a laser pulse with duration of 5 ns with a wavelength of 355 nm on the reverse side of the PCSS. The effect is to reduce the required electric field for breakdown in the nonlinear mode and increase the resistance in the open state. With an increase in the electric field strength applied to the PCSS with SiO_2, an increase in resistance is observed to a threshold value, after which a sharp decrease occurs to a value comparable to the resistances without an oxide layer.
Keywords: PCSS, laser, GaAs, oxide layer

1. Introduction

When using high-voltage nanosecond generators, there has always been a switch resource problem [1, 2]. The main types of switches for such generators were gas switches, such as thyratrons, spark arresters, etc. As alternative, solid-state switches such as SOS and Drift Step Recovery Diode (DSRD) diodes have been developed, however, they also have disadvantages, such as the need for a reverse polarity pulse [3] or a pre-pulse with a high voltage rise rate [4]. Semiconductor solid-state high-voltage switches with galvanic separation for control, such as PCSS, allow you to create simple, reliable and compact nanosecond range generators using the Blumlein scheme [5]. Switching of GaAs-based optical high-voltage semiconductor switches using the blocking effect in the conductive states of a gallium arsenide crystal under the action of an external electric field [6] allows switching kiloampere currents at voltages of several tens of kilovolts with a short pulse duration and optical laser energy [7]. The external electric field required to observe the nonlinear gain mode in chromium-doped GaAs requires an electric field of 8–9.5 kV/cm at the time of switching [8]. The purpose of this work is to describe the effect of the SiO_2 layer on the surface of the PCSS crystal on the residual resistance and the electric field necessary for the transition from the blocking to the conducting state.

2. PCSS design

The switch crystal was provided by the technical department of the TSU Center for Research and Development “Advanced Technologies in Microelectronics” and was a rectangular parallelepiped with dimensions of 12×5×0.6 mm^3 (shown in Fig.1). It was made from GaAs plates uniformly doped with Cr during diffusion and having a resistivity of about 10^9 Ω·cm. The PCSS was a planar p-i-n diode, the cathode region of which was created by diffusion of zinc (p-type of conductivity), and the subcathode region by diffusion of silicon (n-type of conductivity). Ohmic contacts are made using AuGe alloy on the surface of the doped areas of the crystal, followed by electrochemical application of Au contact. To exclude surface breakdown at the stage of crystal manufacturing, a layer of SiO_2 was deposited on the front plane of a chromium-doped GaAs crystal by magnetron deposition. The PCSS case is made of VK-100 polycor, 1 mm thick, and consists of a base on which contacts are attached for connecting to an external circuit and a top cover that gives additional rigidity to the case. The mounting of the PCSS crystal is realized with the help of conductive glue.

The fabricated design makes it possible to switch the PCSS over the surface of the crystal located in the plane of the contacts, and through the thickness by irradiating the upper plane of the crystal with laser radiation and creating a large number of no equilibrium charge carriers in the thickness of the semi-insulating GaAs:Cr.

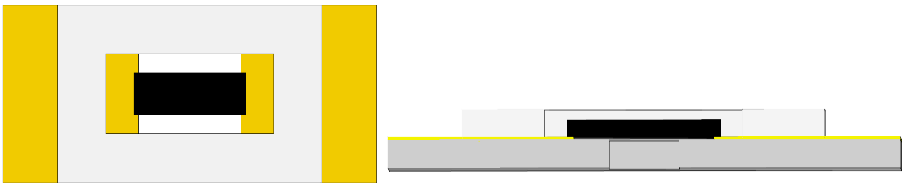

Fig.1. The design of the PCSS, top view on the left, and the sectional view of the PCSS is located on the right.

3. Modeling a chamber with equivalent load

When working with pulses in the nanosecond range at high voltage, a coaxial conductor design is most often used to decouple the generator responses to load changes in time; in this case, a segment of a high-voltage coaxial cable is also used as a high-voltage capacitance until switching. The use of a high-voltage coaxial cable to connect a planar PCSS requires evaluating the effect of the geometry of the double coaxial-to-microstrip junction and the Sylgard 184 potted chamber in which the switch is installed. The geometry of the chamber is calculated and optimized for the wave impedance of the coaxial path equal to 50 Ohm and the limiting electrical breakdown field of the sealant 19 kV/mm. For Electromagnetic modeling, a specialized software "CST studio" is used. The program calculated the field distribution in the chamber with the geometric equivalent of the PCSS consisting of a conductive material without resistance (PEC) with a poured compound. The calculation result is shown in Fig.2.

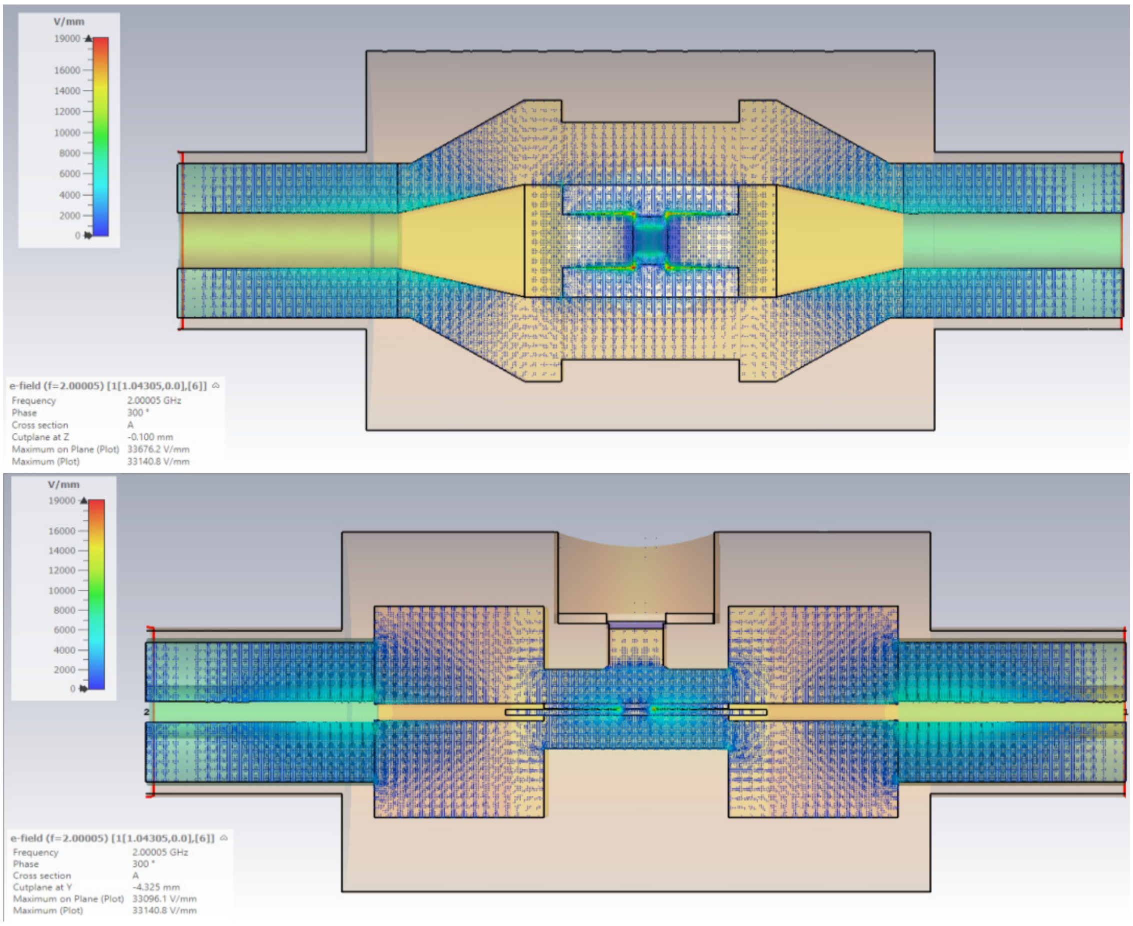

Fig.2. The result of EM field simulation in the PCSS chamber.

Fig.2 shows that large EM field strengths are located in the corners of gold contacts deposited by sputtering on a polycor base, which is a potential breakdown point of the compound. To analyze the agreement, the calculation of a waveform was carried out for the same chamber design with PCSS and compound, the result is shown in Fig.3.

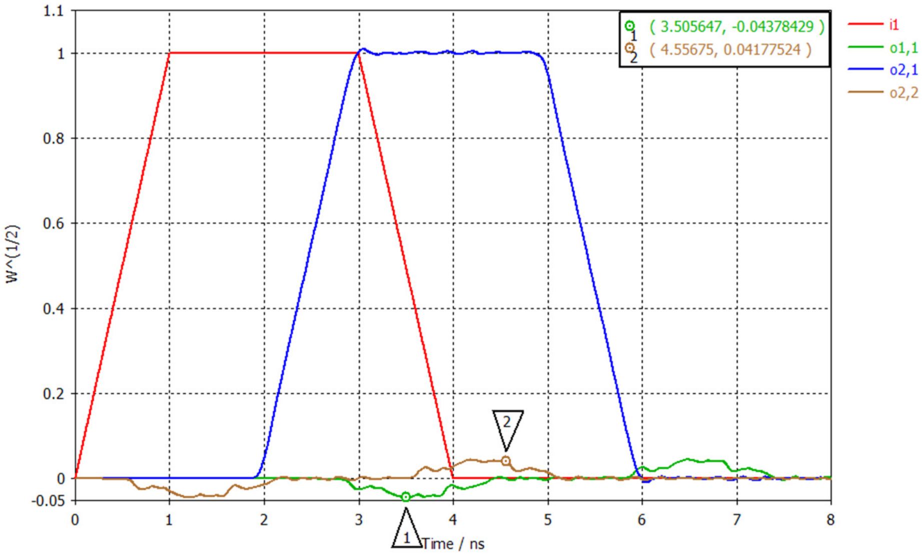

Fig.3. Calculated waveforms of the pulse passed through the chamber with PCSS, where the red waveform is the input signal, the blue waveform is the output signal, the brown waveform is the reflected signal from the input port, the green waveform is the reflected signal from the output port.

The simulation results show that the maximum amplitude of the reflected signal does not exceed 4.5% or 27 dB. According to the results of the calculation, the design of the chamber was designed. It is shown in Fig.4.

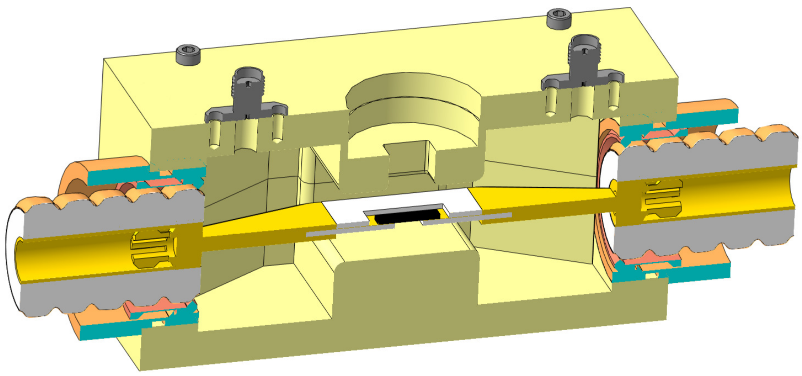

Fig.4. 3D model of the chamber design for the installation of the PCSS.

4. Experiment execution

The experiment uses the following equipment: DTL-375QT laser ($\lambda = 355$ nm), thyratron modulator providing resonant charging up to 30 kV, RFA-7/8 coaxial cables, AT-20-4 high-voltage attenuator for 20 kV, Radiall attenuators with a power of 25 W (3 dB) and 30 W (6 dB and 30 dB), an Agilent DSO9254A oscilloscope, a high-voltage capacitive divider Aktakom ACA-6039 and a coaxial microstrip chamber for installing a PCSS.

The method of conducting the experiment was as follows, the modulator controlled via the Ethernet interface using a PC, generates a high-voltage pulse to charge a piece of RFA-7/8 coaxial cable that connects the modulator to the PCSS camera, and also generates a TTL-level synchronization pulse to trigger the DTL-375QT laser. In the program, with an accuracy of 10 ns, the delay of the triggering pulse of the TTL level is set so that at the moment of the beginning of laser irradiation coincides with the highest amplitude value of the high-voltage charging pulse.

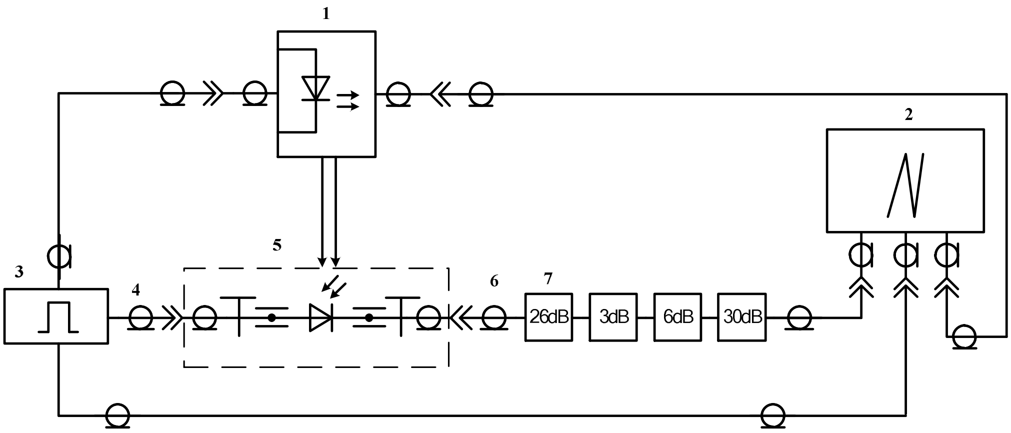

Fig.5. Scheme of the experiment on switching PCSS to a load of 50 Ohms: 1 – DTL-375QT YAG laser, 2 – DSO9254A oscilloscope, 3 – source of high-voltage voltage pulses, 4 and 6 – RFA-7/8 high-voltage coaxial cable, 5 – camera for PCSS, 7 – AT-20-4 high-voltage attenuator.

A laser beam with a front of 1 ns and a duration of 7 ns with an energy of 25 μJ per pulse irradiates the middle part of the PCSS crystal at a distance of 1 m with a shift to the p region indicated in red in Fig.6.

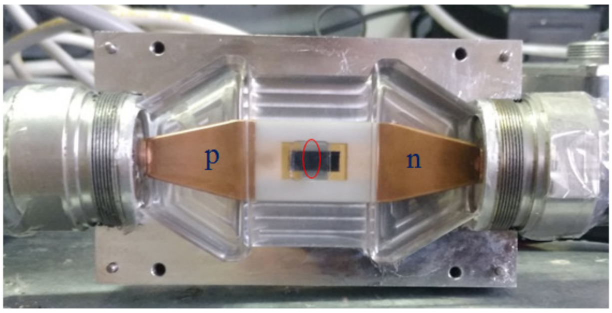

Fig.6. Chamber with installed PCSS.

At the moment of irradiation, laser radiation photons are absorbed in the crystal, which leads to the generation of electron-hole pairs near the crystal surface. The resulting charge carriers in the high-resistance region create conduction between the p-region and the n-region, which leads to the discharge of the coaxial cable through the high-voltage attenuator AT-20-4 with an impedance of 50 Ohm, with a limiting measurement voltage of 20 kV and an attenuation coefficient of 26 dB. Additionally, to attenuate the signal, 3 more Radiall attenuators with ratings of 3dB with a power of 25 W, 6 dB and 30 dB with a power of 30 W are used. The attenuated signal with a total attenuation of 65 dB is recorded by an Agilent DSO9254 digital oscilloscope with a bandwidth of 2.5 GHz. At the same time, a sync pulse from the laser triggering unit and a charging pulse from the modulator are recorded using a capacitive high-voltage divider Aktakom ACA-6039.

The formation of pulse charging was carried out by a high-voltage modulator. Its operating principle is as follows: a high-voltage capacitor KBG-P $C = 25$ nF with an operating voltage of 10 kV is charged from a high-voltage source (INSITEK IPV-0.1-30-1.0P) to a voltage of 1 to 5 kV. Then the capacitor is discharged through the thyratron TPI 3-10k/25 to the primary turn of a high-voltage transformer with a transformation ratio of 9, forming a high-voltage half-wave with a halfheight duration of 250 ns on the secondary winding connected to a piece of coaxial cable RFA-7/8 with a length of about 3.5 meters.

The first part of the experiments was performed by the PCSS with an oxide layer on the front side of the switch. Switching of the PCSS was carried out by irradiation with pulsed laser radiation of the crystal plane where there are no contacts. Based on the results of the experiments, a curve of dependence of the internal resistance of the switch in the conducting state on the charging voltage was plotted (Fig.7).

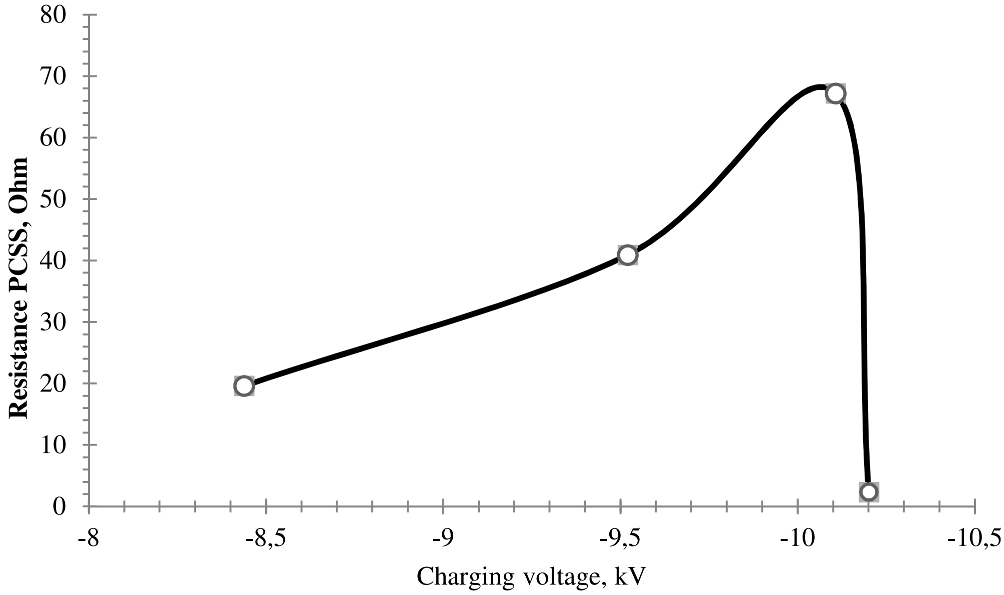

Fig.7. Dependence of the internal resistance of the switch on the charging voltage with the applied layer SiO_2.

To assess the effect of the oxide layer, it was etched from the front surface of the PCSS crystal and the experiment was repeated. As a result, the dependence of the internal resistance on the level of the charging voltage without an oxide film was obtained, shown in Fig.8.

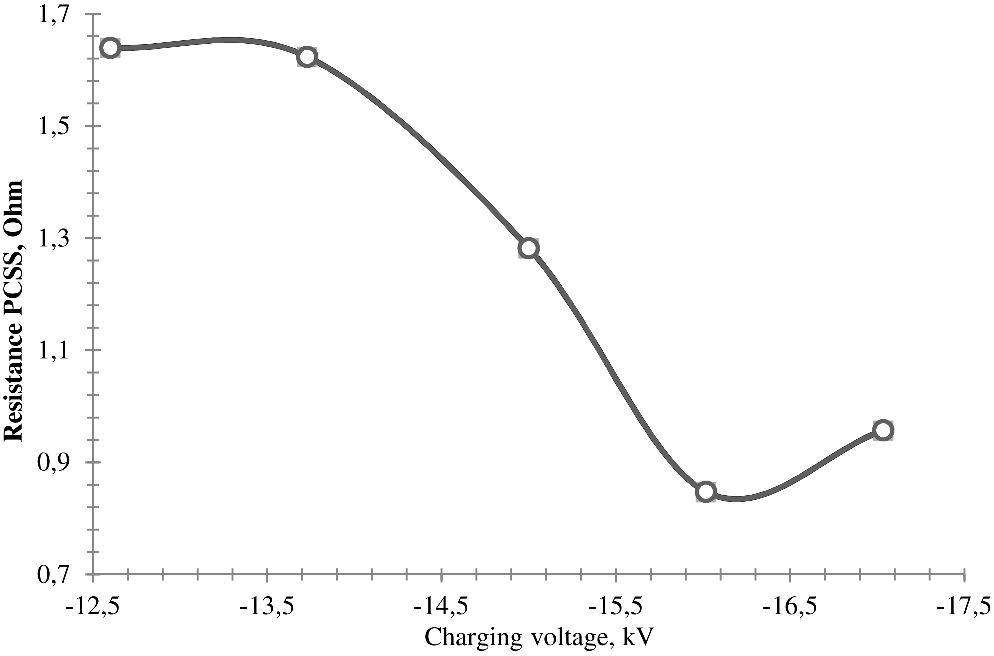

Fig.8. Dependence of the internal resistance of the switch on the charging voltage without a layer SiO_2

During the experiments, there were attempts to switch the PCSS by irradiating it from the front side, but they were not successful. Considering that 99 % of laser radiation is absorbed in GaAs with a thickness of 50 nm [9], the presence of defects from the etching of the oxide film, which led to partial recombination of electron-hole pairs, can serve as an explanation. In the case of an oxide film, the distortion of the film surface can serve as a basis, which leads to uneven scattering of laser radiation and does not allow obtaining the necessary number of charge carriers to obtain a nonlinear amplification mode.

5. Conclusion

Analyzing the obtained data with an oxide film, it can be seen that the field required to achieve a nonlinear amplification mode corresponds to the value given in [8]. The electric field in this case is easy to outrun, since the gap between the electrodes is 1 cm, however, the internal resistance of the switch increases until the field at the PCSS reaches 10 kV/cm, then switching with avalanche ionization occurs, which sharply reduces the internal resistance to 2.3 Ω. Experiments without an oxide film have shown that in order to achieve a nonlinear regime, a larger electric field of 12.6 kV/cm is required compared to the PCSS having an oxide layer. A possible explanation is the effect of intrinsic recombination radiation in GaAs:Cr with a wavelength of about 900 nm. Part of the generated radiation is reflected from the defects obtained during the deposition of the oxide layer, generating new charge carriers in the crystal during photon absorption. Thus, switching the PCSS at a lower electric field. The internal resistance without an oxide layer, as can be seen, is less and is 1.64 Ω. With an increase in the electric field, it decreases to 0.85 Ω, but when it reaches 17 kV/cm, it increases to 0.96 Ω. The increase in resistance may be due to additional losses on defects in the thickness of the GaAs:Cr structure.

Acknowledgements

The authors are grateful to I.A. Prudaev for the help in setting up the experiment and fruitful discussions. The work carried out within the state assignment of Ministry of Science and Higher Education of the Russian Federation (project No. FWRM-2022-0002).

6. References

[1] Grekhov I.V., *Pulse switching of high powers by semiconductor devices,* [in Russian]. (Moscow: Energoatomizdat, 1987).

[2] Mesyats G.A., *Pulsed Energy and Electronics,* [in Russian]. (Moscow: Nauka publishing house, 2004).

[3] Lyubutin S.K., Mesyats G.A., Rukin S.N., Slovikovsky B.G., *Rep. of the Academy of Sci.*, **360**, 663, 1998; doi: 10.1109/PPC.1997.679417

[4] Grekhov I.V., Efanov V.M., Kardo-Sysoev A.F., Shenderey S.V., *Sov. Tech. Phys. Lett.*, **9**(4) 188, 1983. (Engl. Transl.).

[5] Wei Wang, Liansheng Xia, Yi Chen, Yi Liu, Chao Yang, Mao Ye, Jianjun Deng, *Appl. Phys. Lett.*, **106**, 022108-1, 2015; doi: 10.1063/1.4906035

[6] Zutavern F., et al., *11th IEEE Int. Pulsed Power Con.*, Baltimore, USA, 959, 1997; doi: 10.1109/PPC.1997.674517

[7] Thim H. W., Knight S., *Appl. Phys. Let.*, **11**, 83, 1967; doi: 10.1063/1.1755046

[8] Chowdhury Animesh R., Ness Richard, Joshi Ravi P., *IEEE Trans. on Elec. Dev.*, **65**, 3922, 2018; doi: 10.1109/TED.2018.2856803

[9] Jellison G.E. Jr., *Opt. Mat.*, **1**, 151, 1992; doi: 10.1016/0925-3467(92)90022-F