INSTITUTE OF
HIGH CURRENT
ELECTRONICS SB RAS

Parameters of subnanosecond pulse sharpening by a silicon high-voltage switch

Valery Barmin[1]*, Vladimir Konev*[1]*, Oleg Kovalchuk*[1]*, Sergey Maltcev*[1]*, Ilya Romanchenko*[1]*, Sergey Rukin*[2]

1-Institute of High Current Electronic Tomsk, Russia
2-Institute of Electrophysics Ekaterinburg, Russia

Effect of ultrafast delayed breakdown

-Electric field >300kV/sm [1,2]

-Avalanche breakdown voltage Um≈2Ub static breakdown voltage [4] -Time switch $t_s \ll t_n$ time of the carrier through the n-base [4]

-Minimum of rate of reverse voltage increase of >1 kV/ns for the diodes with smooth transitions [2] and that is more than 0,5 kV/ns for diodes with abrupt p-n junction [1-4]

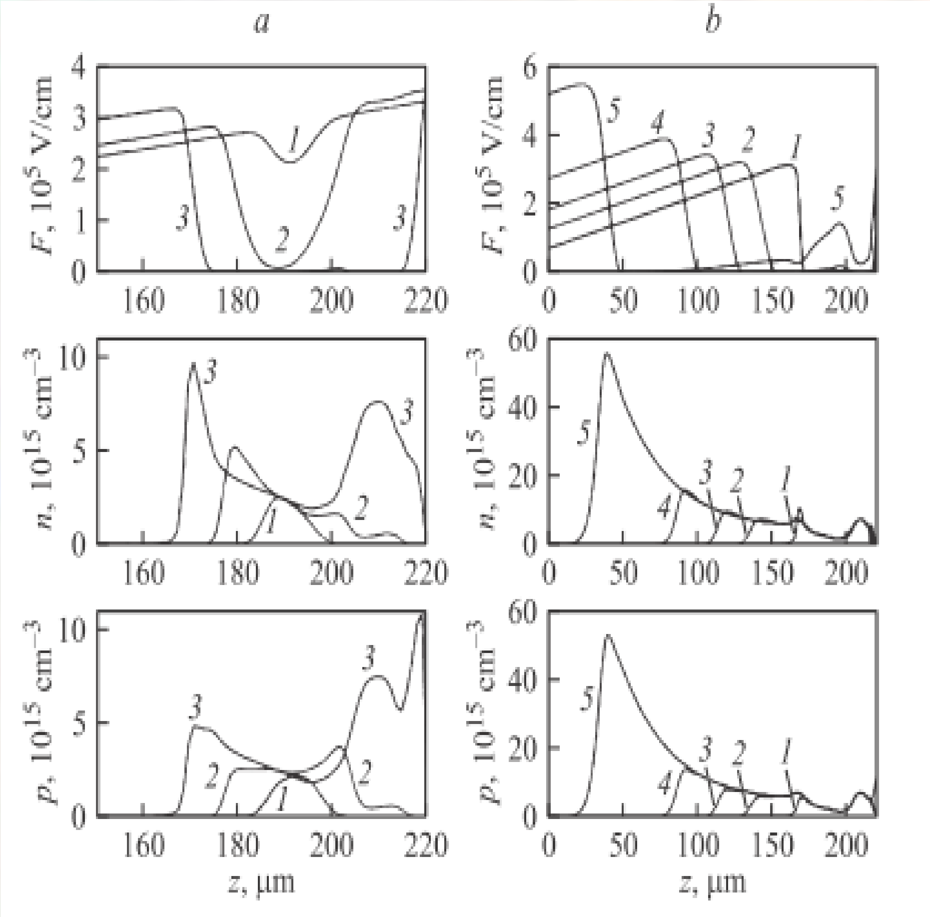


Fig.1 Distribution of the electric field E and carrier concentrations n and p in the structure base at different phases of the transition process. The base length of the inversely displaced p+ - n-n+ structure W = 220 μm, p+-n-transition is located on the right at z = 220 μm. a is the initial stage of breakdown, where the initial layer of electron-hole plasma is formed (curves 1, 2, 3 for t = 5.030, 5.065, 5.100 ns, respectively). b-phase propagation of the ionization front (curves 1, 2, 3, 4, 5 for t = 5.110, 5.150, 5.175, 5.200, 5.225 ns, respectively). Signal amplitude 3.5 kV with a growth rate of 0.5 kV/ns, base doping Nd = 10^{14} cm $^{-3}$, concentration of deep centers 10^{12} cm $^{-3}$, structure area S = 0.02 cm^{-2}.[4]

Background

- Many pulse devices in the nanosecond and picosecond ranges based on the ultrafast delayed breakdown effect have been created, but the theory of the effect has not been fully studied and requires further experimental and theoretical investigations

- The use of silicon diode structures with smooth transitions as part of high-power microwave generators in the subnanosecond range (5 to 7 GHz) with a duration of 200 ns and a pulse power of 300 kW [5].

The goals of my work are as follows:

- Experimental determination of the minimum rate of the reverse voltage rise on a diode structure with smooth n-p junctions that allows observing the effect of ultrafast switching.

- Estimation of losses when two structures are switched on sequentially for use in microwave generators built on dispersion lines.

MEASURING EXPERIMENTAL

A. Brief description of the measuring unit

For measurement the time diagrams was used oscilloscope R&S RTP084 of operating range at 8 Ghz. Previously, each of the D-dot was calibrated with a high-voltage capacitive divider ACA-6039 Atacom and 3 attenuators of 20 db Weinsel Associates WA21-20-43 with a measured maximum error of 0.11%.

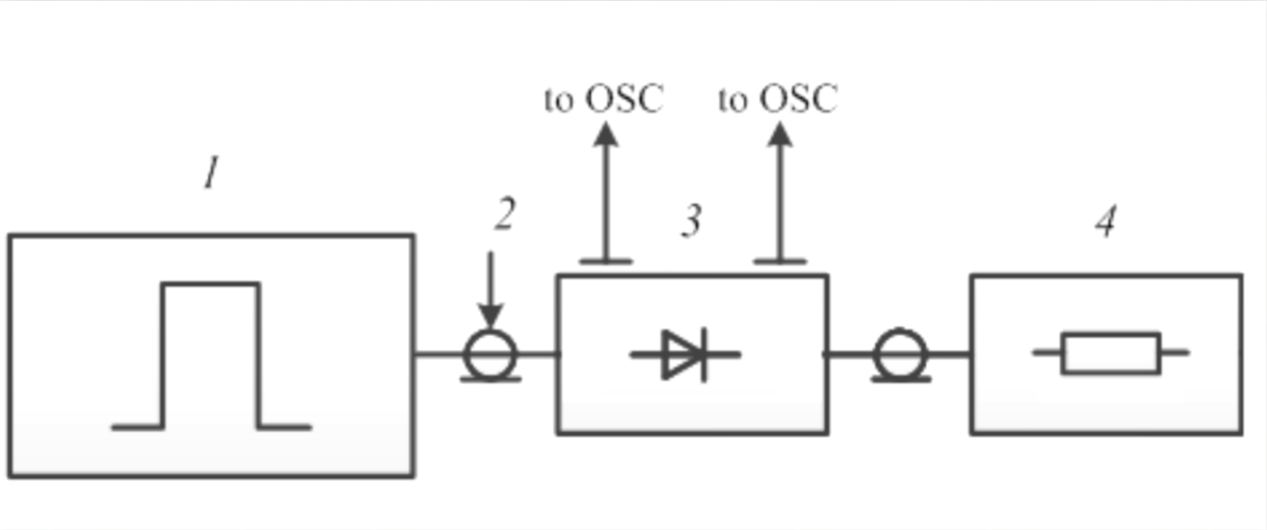
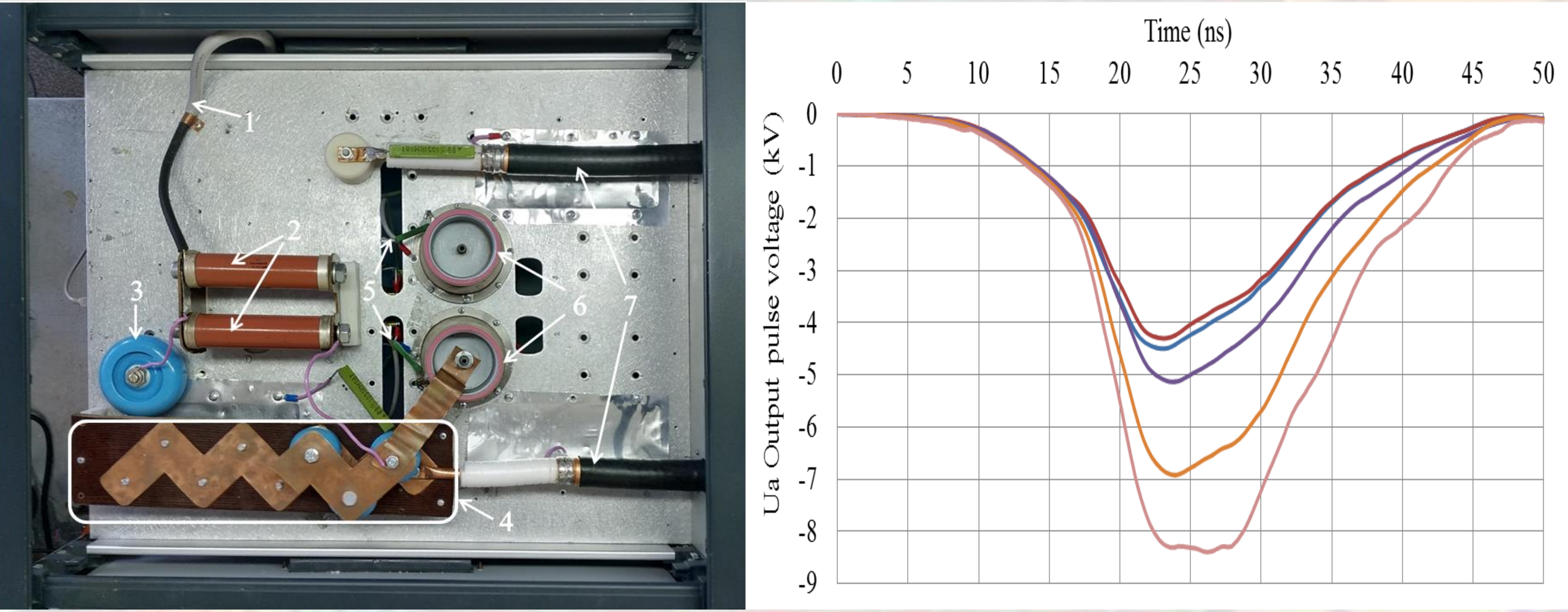


Fig. 2. The block diagram of the measurement scheme:
1 - source of rectangular voltage pulses, 2 - high-voltage coaxial cables,
3 - coaxial resonator with two D-dot and test diodes, 4 - 50-Ohm coaxial load

B. Source of high-voltage rectangular pulses



a

b

Fig. 3.a)The construction of a high-voltage generator of rectangular voltage pulses:
1 - the output cable of a high-voltage DC source IPV-0.1-30-0.1 P,
2 - charging resistors with 1 MOhm, 3 - damping capacitor K15U-1 with 20 kV and 330 pF,
4 - forming line, 5 - output cables of control modulators to the thyratron grid,
6 - thyratrons TPI3-10K / 25, 7 - output coaxial cables of the generator with “Telegartner” cable connectors
3.b) the typical output pulses from the generator

C. Coaxial cavity design

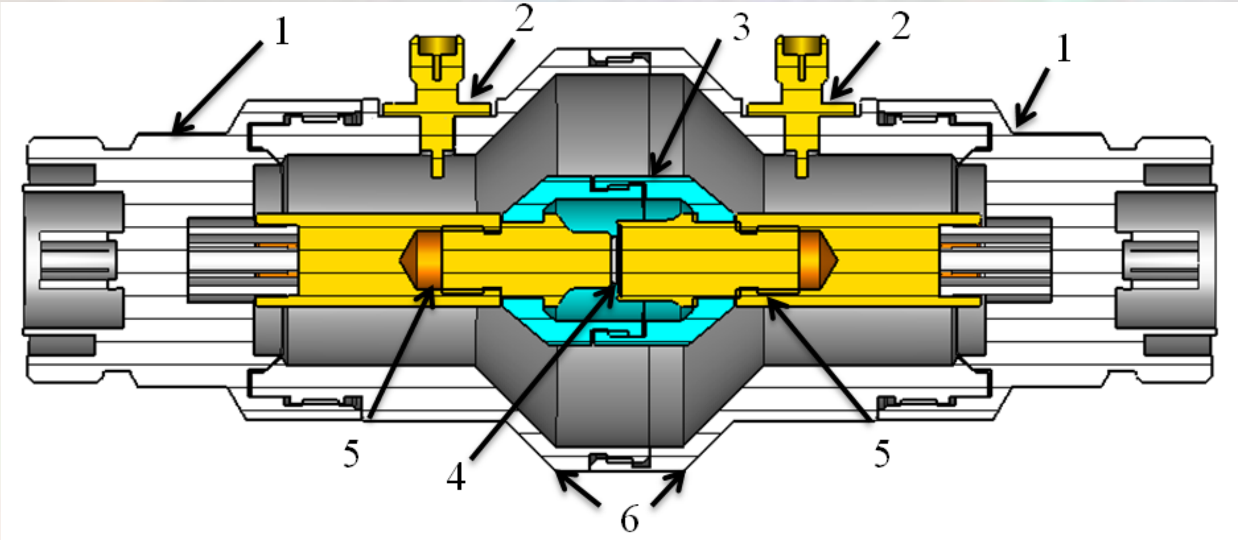


Fig. 4. The view of resonator section: 1 – “Telegartner“ connectors, 2 - D-dot installation location, 3 - plexiglass housing, 4 - silicon diode or copper washer, 5 - central conductor, 6 - external conductor halves

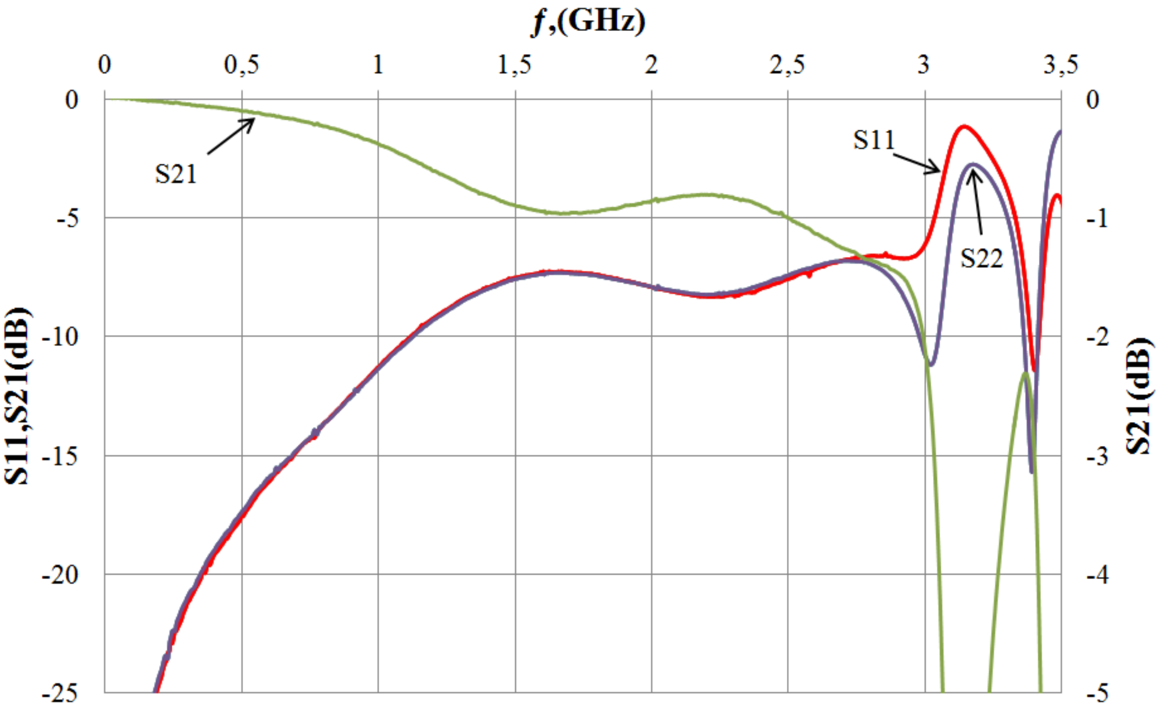


Fig. 5. S-parameters of the coaxial cavity

RESULTS

A. Experimental technique and silicon diodes

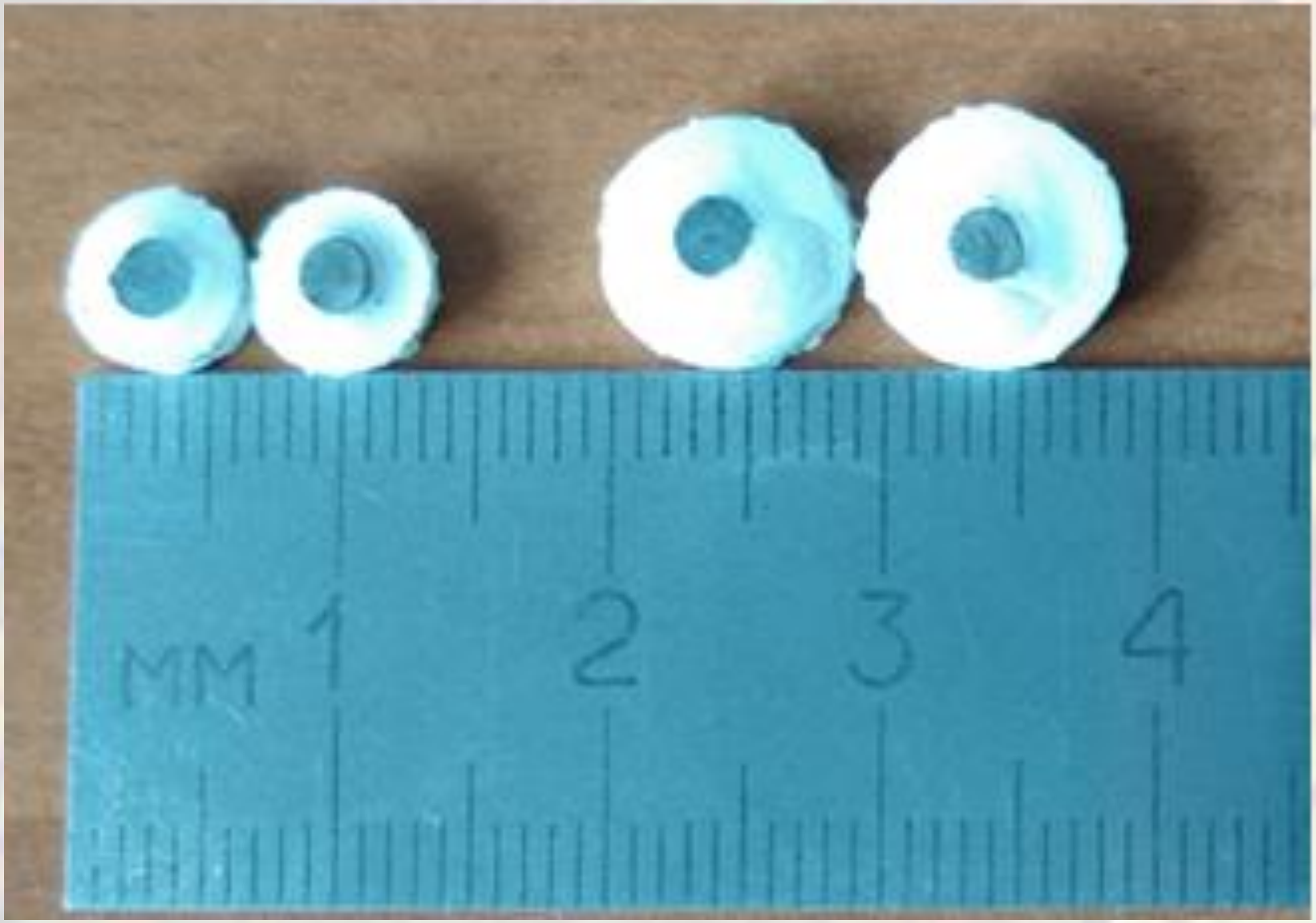


Fig. 6. The view of Si diodes: a diode soldered to molybdenum plate with a diameter of 6 mm (on the left), a diode soldered to a plate with a diameter of 9 mm (on the right).

B. Experimental results

The waveforms of the pulse front sharpening at the minimum growth rate

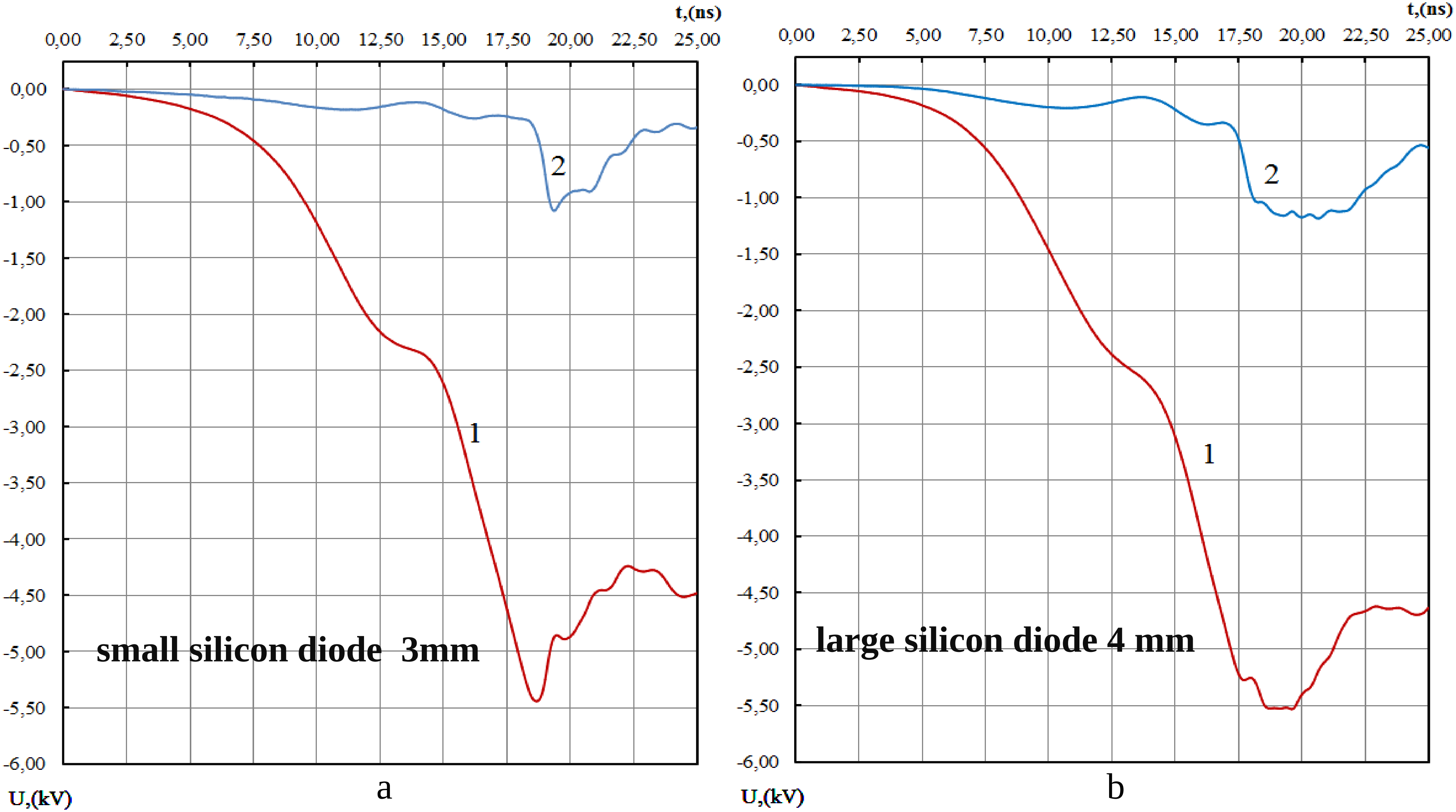


Fig. 7. The waveforms of the pulse front sharpening at the level of 0.25-0.90: for a small silicon diode (a) input pulse with rise time of 7.38 ns and an amplitude of 5.38 kV (1), sharpened pulse with rise time of 0.83 ns and an amplitude of 1.05 kV (2); for a large silicon diode (b) input pulse with rise time of 7.35 ns and an amplitude of 5.52 kV (1) sharpened pulse with rise time of 3.21 ns and an amplitude of 1.12 kV (2).

B. Experimental results

Waveforms obtained on a single diode

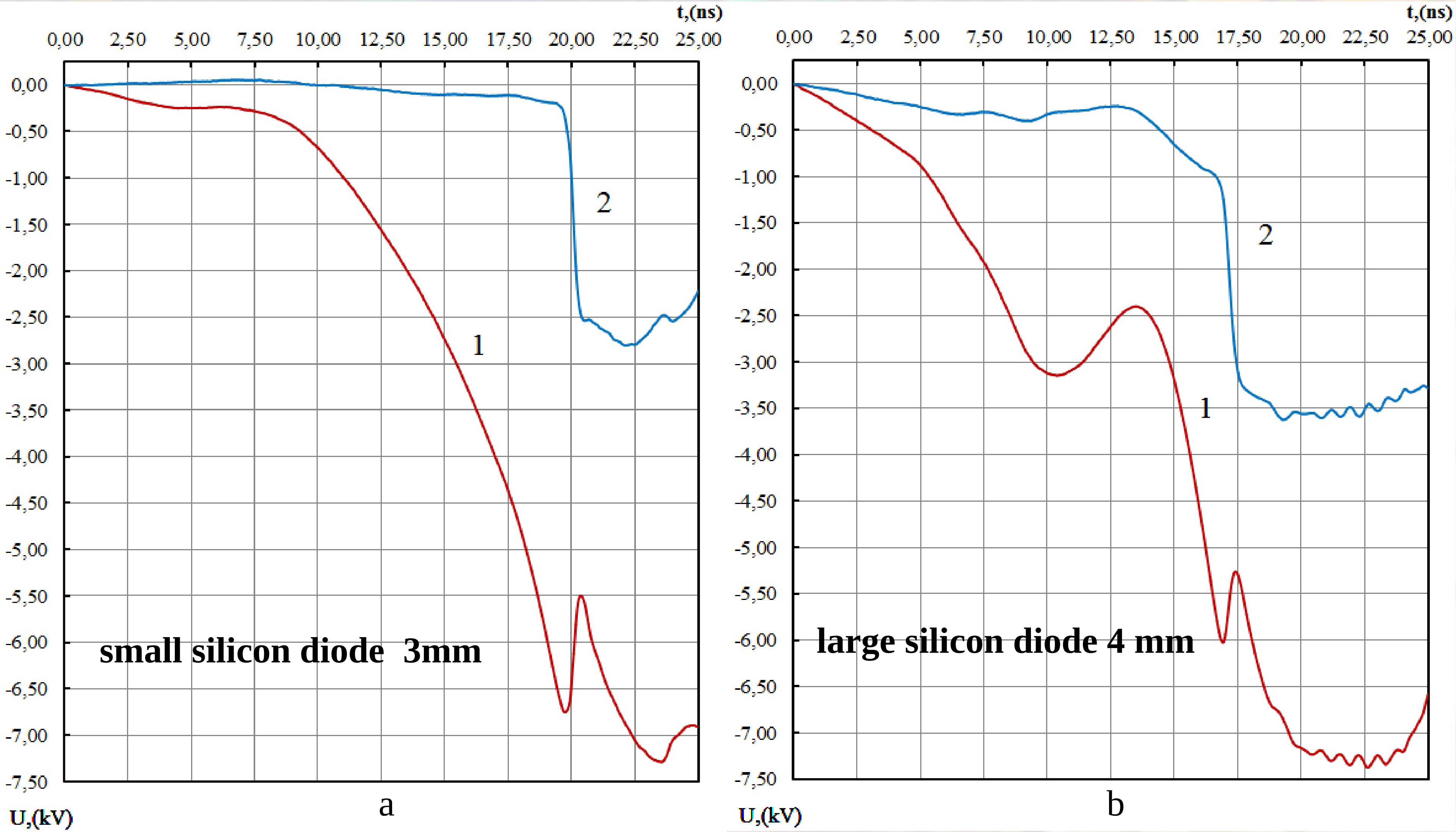


Fig 8. The waveforms of the pulse front sharpening at the level of 0.25-0.90: for a small silicon diode (a) input pulse with rise time of 8.41 ns and an amplitude of 7.22 kV (1), sharpened pulse with rise time of 0.53 ns and an amplitude of 2.79 kV (2); for a large silicon diode (b) input pulse with rise time of 11.35 ns and an amplitude of 7.34 kV (1) sharpened pulse with rise time of 1.61 ns and an amplitude of 3.55 kV (2).

B. Experimental results

Waveforms obtained on a two diodes

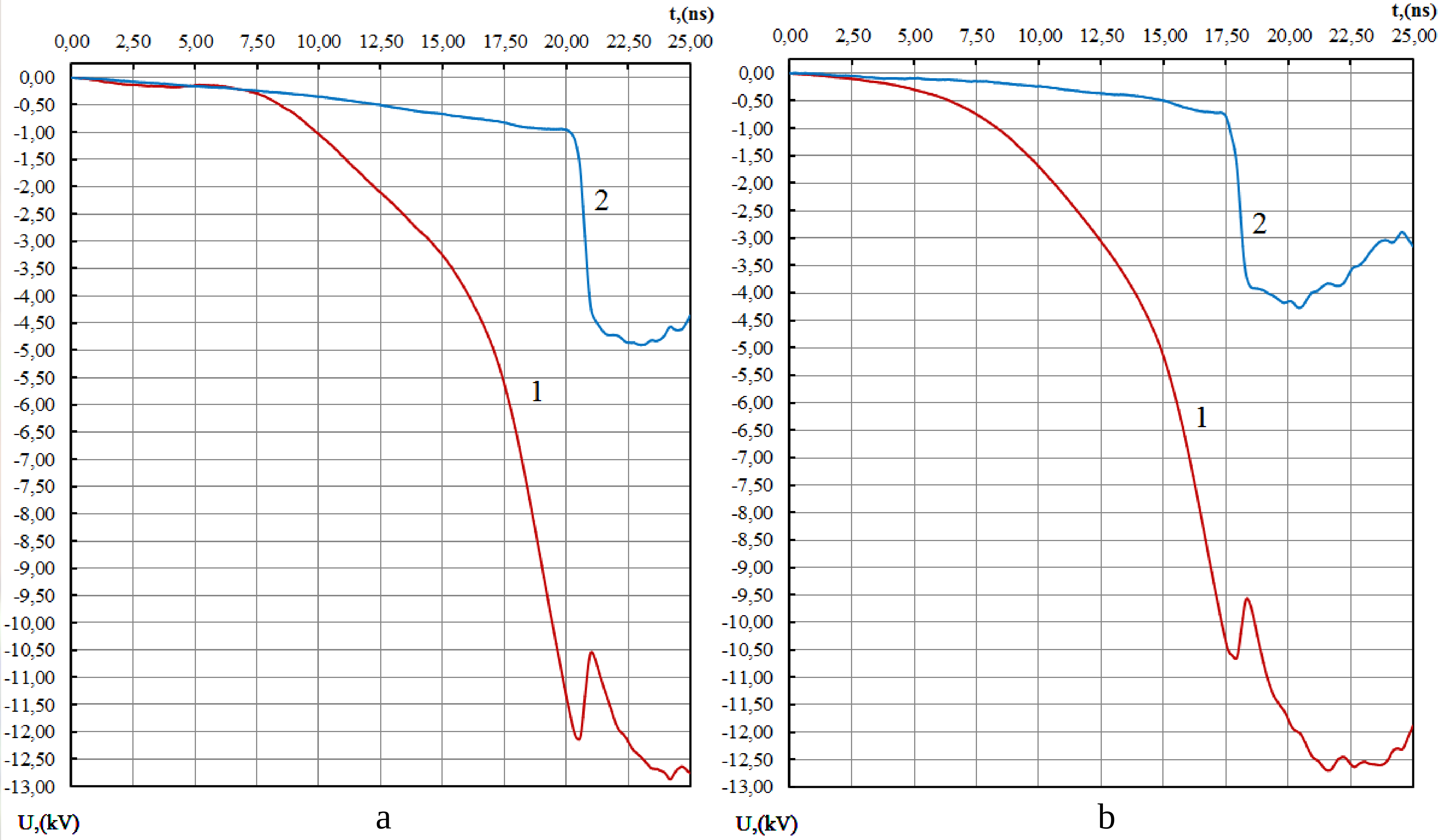


Fig. 9. The waveforms of the pulse front sharpening at the level of 0.25-0.90: for a small silicon diode (a) input pulse with rise time of 6.84 ns and an amplitude of 12.75 kV (1), sharpened pulse with rise time of 0.72 ns and an amplitude of 4.91 kV (2); for a large silicon diode (b) input pulse with rise time of 6.81 ns and an amplitude of 12.66 kV (1) sharpened pulse with rise time of 0.74 ns and an amplitude of 4.26 kV (2).

CONCLUSION

- Pulse front sharpening of the small diode is 8.89 times with a maximum growth rate of du /dt≈0.845 kV/NS with an input pulse front duration of 7.38ns and 2.29 times for a large diode with a maximum growth rate of du /dt≈0.873 kV/ns with an input pulse front duration of 7.35ns.

- High residual voltage in two consecutive switching diodes, limits the use of these diodes in the investigated mode for microwave generators based on dispersion lines.

- Presented results of a high residual voltage with half-height pulse duration of about 15ns are in agreement with numerical modeling of picosecond diode avalanche sharpeners in the switching mode of fast-growing high-voltage pulses of sub-microsecond duration [6].

- Output pulses with duration of more than 5 ns can be explained by the mechanism of double avalanche injection proposed in the aforementioned numerical simulation [6].

REFERENCES

1. A.I. Gusev, S.K. Lyubutin, S.N. Rukin, B.G. Slovikovsky, S.N. Tsyranov, “On the picosecond switching of a high-density current (60 kA/cm2) via a si closing switch based on a superfast ionization front," Semiconductors, vol. 48, pp. 1067-1078, 2014.
2. S.K. Lyubutin, S.N. Rukin, B.G. Slovikovsky, S.N. Tsyranov, “Ultrahigh-power picosecond current switching by a silicon sharpener based on successive breakdown of structures," Semiconductors, vol. 44, pp. 931-937, 2010.
3. A.F. Kardo-Sysoev, “New power semiconductor devices for generation of nano- and subnanosecond pulses,” in Ultra-Wideband Radar Technology, edited by J. D. Taylor (CRC Press, Boca Raton, London, New York, Washington, 2001), ISBN: 0-8493-4267-8.
4. I.V. Grehov, P.B. Rodin, “Triggering of superfast ionization fronts in silicon diode structures by field-enhanced thermionic electron emission from deep centers”, Technical Physics Letters, Vol 37, pp. 849-853, 2011
5. S.K. Lyubutin, S.N. Rukin, B.G. Slovikovsky, S.N Tsyranov, “Generation of powerful microwave voltage oscillations in a diffused silicon diode ” Semiconductors, Vol 47(5) pp. 670-678, 2013
6. M.S. Ivanov, N.I. Podolskaya, P.B. Rodin, “Double Avalanche Injection in Diode Avalanche Sharpeners” Physics of semiconductor devices, Vol 54, pp. 345-349, 2020

Thank you for your attention!!!