Switching (turn-on) dynamics of high-current high-voltage current switches based on GaAs/AlGaAs heterothyristors

© S.O. Slipchenko, I.V. Oreshko, A.A. Podoskin, I.V. Shushkanov, N.A. Pikhtin

Ioffe Institute,
St. Petersburg, Russia

E-mail: SergHPL@mail.ioffe.ru; ioreshko@mail.ioffe.ru

Received December 4, 2025
Revised February 27, 2026
Accepted March 30, 2026

Maximum blocking voltages and dynamic turn-on processes of current switches based on GaAs/AlGaAs heterothyristors with the thickness of weakly doped region increased to 8 μm were investigated using numerical simulation methods within the framework of the quasi-one-dimensional drift-diffusion model. The influence of the design of the weakly doped region of the collector junction of the $n-p-n$ transistor part while maintaining the total thickness of 8 μm was determined. It was shown that the maximum blocking voltage reaches ~ 180 V for the design of a composite p-base including a heavily doped layer ($p = 10^{18}\,\mathrm{cm}^{-3}$) with a thickness of 0.1 μm and a weakly doped layer ($p = 6 \cdot 10^{14}\,\mathrm{cm}^{-3}$) with a thickness of 8 μm. It was shown that, regardless of the design, close values of the maximum turn-on current of ~ 70 A and the width of the turn-on fronts of $\sim 1.5-1.6$ ns are achieved. However, the best values of residual voltage and turn-on delay are achieved in the design with an n-collector of the $n-p-n$ transistor part thinned to 0.2 μm and are ~ 1.86 V and 5.5 ns, respectively.

Keywords: thyristor, current switch, drift-diffusion model, dynamics, turn-on front, residual voltage, turn-on delay.

DOI: 10.61011/SC.2026.02.63750.8851

1. Introduction

Today quick-acting current switches operating in low-resistance load circuits are of substantial practical interest. First of all, this is due to the relevance of development of strong pulse sources of coherent optical radiation of infrared range for range finding, and also lidar systems used in unmanned vehicles. One of the important features of such systems is the required to generate optical pulses of the specified duration and amplitude. Currently the sources of coherent radiation with short pulses are of most interest, i. e. with pulses having total duration of $\sim 1-10$ ns. These requirements certainly dictate the need to use pumping currents with the duration not exceeding the specified values.

One of the potential methods to generate short pulses is the use of solid-state thyristor switches based on $A^{III}B^{V}$ compounds, which enable generation of currents with amplitude of up to hundreds of amperes and duration of up to 10 ns [1]. This makes it possible to implement a compact design of thyristor current switch/laser. These assemblies demonstrate the possibilities to generate pulses with durations in the range of $3-60$ ns and current amplitudes of up to 100 A [2,3], and also do not require any specialized matching drivers between the switch and laser.

Currently a rather wide spectrum of designs has been studied for low-voltage thyristor switches. The estimates of switching dynamics of current switches based on InP-homothyristors with thickness of p^0-base, which varies in the range of $1-2.6\,\mu$m [4], show that the average switching speed is in the range from 11 to 194 ns at maximum value blocking voltage of only 55 V, which, despite the value of amplitude current ~ 90 A, is seen to be clearly insufficient for generation of ultrashort pulses of pumping current. The studies of low voltage thyristor current switches based on AlInGaAsP/InP [5,6] heterostructures demonstrate that the maximum blocking voltage for such structures is $\sim 15-18$ V, and the current is just $\sim 6-8$ A with pulses having duration of < 3 ns, even though in hybrid assemblies may reach values of up to 80 A per pulse, with durations of < 100 ns. Therefore, there is a disagreement between the amplitude values and duration of the current pulse. Experimental studies of thyristors based on GaAs, conducted in papers [7–10], show that maximum blocking voltage at various topologies of mesa and methods for chemical treatmetn of the structures is $\sim 28-35$ B, even though potentially it is possible to increase the voltage to 200 V, when manufacturing the structure of optothyristor with ultrathick base ($\sim 200\,\mu$m). However, such structures show a very long switching front, at the level of ~ 120 ns, and also the time of switching delay for around several hundreds of nanoseconds at power supply voltage of 200 V [7,8] and current amplitude of only ~ 25 A, which is absolutely not compliant with the requirements of quick-acting sources of pulse current pumping. High current thyristor current switches based on GaAs/AlGaAs heterostructures [11–13] demonstrate the value of the maximum blocking voltage in the range of $55-65$ V and the value of amplitude current $\sim 17-24$ A at durations of current pulses at the level of $2.3-3.5$ ns.

The closing speed and current amplitude depend on parasitic inductances of the circuit, and also contact resistances, which may not be eliminated even if compact schemes are used. In this case the increase of the blocking voltage of the thyristor current switch will make it possible to increase both the peak current and the speed of the transition process in the circuit of the thyristor switch/laser diode assembly, provided that the high response rate of the thyristor switch as such will be maintained, which is important to increase the peak power and to reduce the duration of laser pulses. The possible method to increase the blocking voltage of the thyristor when high current amplitudes (> 30 A) are maintained, and also short (at the level of units of ns) pulse durations. is the use of high voltage high current thyristor switches with the increased thickness of the lightly doped area of the collector $p-n$-transition of the $n-p-n$-transistor part. For most considered experimental works the typical maximum thickness of the thyristor p^0-base is $\sim 3-4\,\mu$m [5,6,11–13]. In this paper, using numerical modeling within the drift-diffusion model, the effect of increased thickness of the p^0-base up to $8\,\mu$m on static and dynamic characteristics of high current high voltage current switches based on a GaAs/AlGaAs-heterothyristor, especially its maximum blocking voltage, current amplitudes, closing speed, and residual the working voltage. The solutions obtained and developed in this paper may further be used to create the integrated high voltage thyristor current switch/laser diode assemblies to generate short and ultrashort optic pulses.

2. Model parameters

The object of the study was a GaAs/AlGaAs-heterothyristor. The initial design of the structure included: a heavily doped p-GaAs emitter ($N_A = 10^{18}\,\mathrm{cm}^{-3}$), a heavily doped n-GaAs collector ($N_D = 10^{18}\,\mathrm{cm}^{-3}$) with the thickness of $1\,\mu$m, a lightly doped p^0-GaAs base ($N_A = 6\cdot 10^{14}\,\mathrm{cm}^{-3}$) with thickness of $8\,\mu$m, a heavily doped p^+-base ($N_A = 10^{18}\,\mathrm{cm}^{-3}$) with thickness of 100 nm, a heavily doped broadband emitter from n-AlGaAs ($N_D = 10^{18}\,\mathrm{cm}^{-3}$) with thickness of 100 nm and with a fraction of Al $\sim 10\,\%$, and also a heavily doped n-GaAs emitter ($N_D = 10^{18}\,\mathrm{cm}^{-3}$). The image of the described structure of a heterothyristor and a closing scheme used in modeling is given in Figure 1.

The dynamics of structure closing was estimated within a quasi-unidimensional drift-diffusion model with account of saturation of the drift speed and collisional ionization. Description of the effect of field dependence of charge carrier mobility and saturation of drift speed was carried out using ratios [14]

$$\mu_n = \mu_{n0}\cdot\left[1 + \left(\mu_{n0}E/\upsilon_{\mathrm{sat},n}\right)^{\beta_n}\right]^{-1/\beta_n}, \tag{1a}$$

$$\mu_p = \mu_{p0}\cdot\left[1 + \left(\mu_{p0}E/\upsilon_{\mathrm{sat},p}\right)^{\beta_p}\right]^{-1/\beta_p}, \tag{1b}$$

where μ_{n0} and μ_{p0} — static mobilities of electrons and holes, $\upsilon_{\mathrm{sat},n}$ and $\upsilon_{\mathrm{sat},p}$ — speeds of saturation of electrons and holes (for GaAs $\upsilon_{\mathrm{sat},n} \approx \upsilon_{\mathrm{sat},p} = 10^7$ cm/s), β_n and β_p — adjustment parameters that depend on the material.

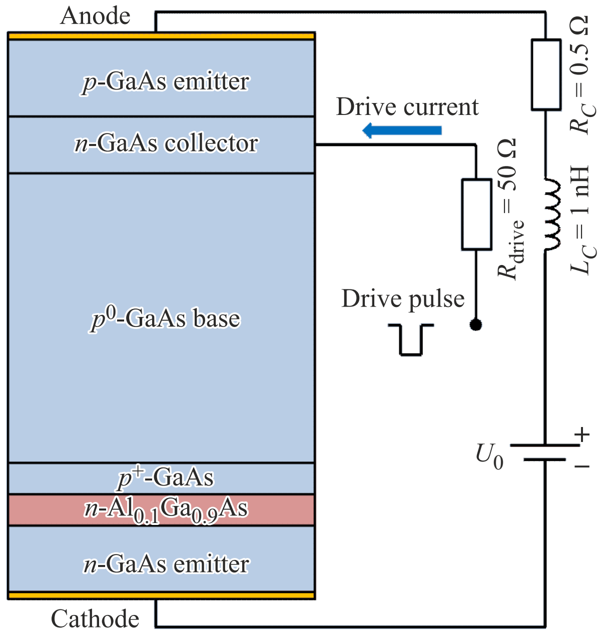

Figure 1. Image of initial design of GaAs/AlGaAs-heterothyristor structure and closing scheme.

The collisional ionization was taken into account by a local Selberherr model [15], being a variation of the classical model of collisional ionization developed by Chynoweth [16]. The coefficients of collisional ionization for the charge carriers of both types were estimated using formula

$$\alpha_{n,p} = A_{n,p}\cdot\exp\left[-(B_{n,p}/E)^{\gamma_{n,p}}\right], \tag{2}$$

where for GaAs $A_n = 1.889\cdot 10^5\,\mathrm{cm}^{-1}$, $A_p = 2.215\cdot 10^5\,\mathrm{cm}^{-1}$, $B_n = 5.75\cdot 10^5$ V/cm, $B_p = 6.57\cdot 10^5$ V/cm, $\gamma_n = 1.82$, $\gamma_p = 1.75$.

The speed of generation of non-equilibrium charge carriers by collisional ionization was calculated as such using expression

$$G_{\mathrm{imp}} = \alpha_n\cdot|\bar{J}_n| + \alpha_p\cdot|\bar{J}_p|, \tag{3}$$

where $\bar{J}_n$, $\bar{J}_p$ — densities of electron and hole currents, accordingly.

To calculate electron transport within the drift-diffusion model, it is also necessary to correctly specify the speeds of charge carrier recombination in the layers of the heterostructure. Analysis of a wide circule of articles [17–20] shows that for heavily doped GaAs/AlGaAs layers the life time of the charge carriers, which recombine in a non-radiative manner using Shockley–Read–Hall mechanism, with a strong precision may be assumed to be equal to 1 ns. For clarity, all important electrophysical parameters of the calculated structure of the GaAs/AlGaAs-heterothyristor are given in the table.

The thyristor was closed by supplying an electric pulse of control via the n-collector of equivalent $n-p-n$-transistor with amplitude of ~ 6 V, time response of 1 ns and total duration of $2\,\mu$s. The calculations were carried out with

Electrophysical parameters of modeled structure GaAs/AlGaAs-heterothyristor

Layer	p-emitter	n-collector	p^0-base	p^+-base	n-barrier	n-emitter
Material	GaAs	GaAs	GaAs	GaAs	AlGaAs	GaAs
Al fraction, %	0	0	0	0	10	0
E_g, eV	1.424	1.424	1.424	1.424	1.549	1.424
μ_{n0}, $cm^2/(V \cdot s)$	8000	8000	8000	8000	6000	8000
μ_{p0}, $cm^2/(V \cdot s)$	400	400	400	400	300	400
$\upsilon_{sat,n}$, cm/s	10^7	10^7	10^7	10^7	$7.7 \cdot 10^6$	10^7
$\upsilon_{sat,p}$, cm/s	10^7	10^7	10^7	10^7	$7.7 \cdot 10^6$	10^7
C_{rad}, $cm^3 \cdot c^{-1}$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-10}$	$1.6 \cdot 10^{-10}$	$2 \cdot 10^{-10}$

account of the effective $R-L$ circuit, which accounted for resistance of ~ 0.5 Ohm and inductance of ~ 1 nH, and also limiting resistance on a control electrode, which was assumed to be equal to ~ 50 Ohm (see Figure 1). Within the quasi-unidimensional approximation the equivalent surface area of the calculated thyristor was accepted to be equal to $200 \times 200\,\mu m^2$, which is close to the dimensions of real structures of GaAs/AlGaAs-current switches [3,4].

3. Results and discussion

Numerical modeling was conducted for a series of thyristor structures with different design of p-base and n-collector. The following structures were considered: St-1 — initial design (see description in Section 2), St-2 — design of a structure with a collector $p-n$-transition n^0/p^0, formed by layers with doping level of $6 \cdot 10^{14}\,cm^{-3}$ and thickness of 4/4 μm, St-3 — design of the structure with the concentration of doping impurity in the p^+-base, decreased down to $10^{17}\,cm^{-3}$, St-4 — design of the structure with the absent layer of the p^+-base, St-5 — design of the structure with the heavily doped part thinned down to 0.2 μm of the n-collector.

In accordance with the objectives of the paper relative to the analysis of the closing dynamics of high voltage thyristor current switches, it was decided in the first part of the article to estimate the maximum blocking voltage for all structures, in order to define the structures that are not fit for operation at high voltages. Static modeling of a thyristor with the initial design of the heterostructure (St-1) shows that the maximum blocking voltage for it is ~ 180 B. For St-2 and St-5 the value of the maximum blocking voltage as a whole remains at the same level of ~ 180 V. A radically different situation is observed for the structures with the decreased doping level of the p^+-base (St-3) and absent p^+-base as such (St-4). In the case of the structure St-3 the maximum blocking voltage is ~ 65 B instead of the initial 180 V in St-1. At the same time for the structure St-4 it is even worse, and the maximum blocking voltage hardly reaches 22 V. Numerical values of blocking voltages St-3 and St-4 illustrate well the significant effect of doping and the fact of p^+-base layer presence as such on the limitation of the range of operating voltages of the thyristor switch. This effect depends on the „protective“ action of the p^+-n-transition formed between the p^0-base and n-$Al_{0.1}Ga_{0.9}As$-broadband emitter (see Figure 1). The thing is that the presence of this intermediate later prevents development of a „direct contact“ between the lightly doped p^0-base and heavily doped n-$Al_{0.1}Ga_{0.9}As$-emitter, the appearance of which causes a significant penetration of a built-in field of a collector $p-n$-transition inside the lightly doped base, which in its turn may lead to closing of the $n-p^0$ collector and p^0-n base-emitter transitions even at relatively low values of supply voltage. These results allow concluding on the inefficiency of the structures St-3 and St-4 from the point of view of usage as high voltage quick-acting thyristor current switches.

Analysis of dynamics in GaAs/AlGaAs-thyristor structures was carried out using two basic values — current and voltage depending on time. Within this paper the analysis is limited to the consideration of the process of thyristor closing, which, as evidenced in practice, is sufficient to assess its response rate as a thyristor switch. The highest working voltage was accepted as equal to the maximum blocking one, obtained in static calculations, i. e. ~ 180 V. Based on the experimental data, the least supply voltage, at which the process of thyristor closing is observed for the structures of such design is ~ 10 V. Specific dependences of the closing dynamics in terms of current/voltage on supply voltage for „high voltage“ structures St-1, St-2 and St-5 are given in Figure 2.

Analyzing the dynamics of current/voltage in Figure 2, a, it is easy to note that the supply voltage value significantly affects the closing characteristics of the GaAs/AlGaAs-thyristor current switch. For the focused numerical evaluation of the thyristor dynamic properties, we will consider the following basic characteristics: amplitude current value, i. e. current in the closed state; residual voltage value, i. e. voltage left on the thyristor in the closed state; closing front, i. e. the difference between the moments of time, when the current through the structure gains, accordingly, 95 and 5 % of its amplitude value; and also the value of the total closing time, being the sum of the closing front and the closing delay time, i. e. the difference between the moments of time, when the current through the thyristor gains 5 % of the amplitude value, and when a control signal was supplied to the control electrode. You can see from Figure 2 that the

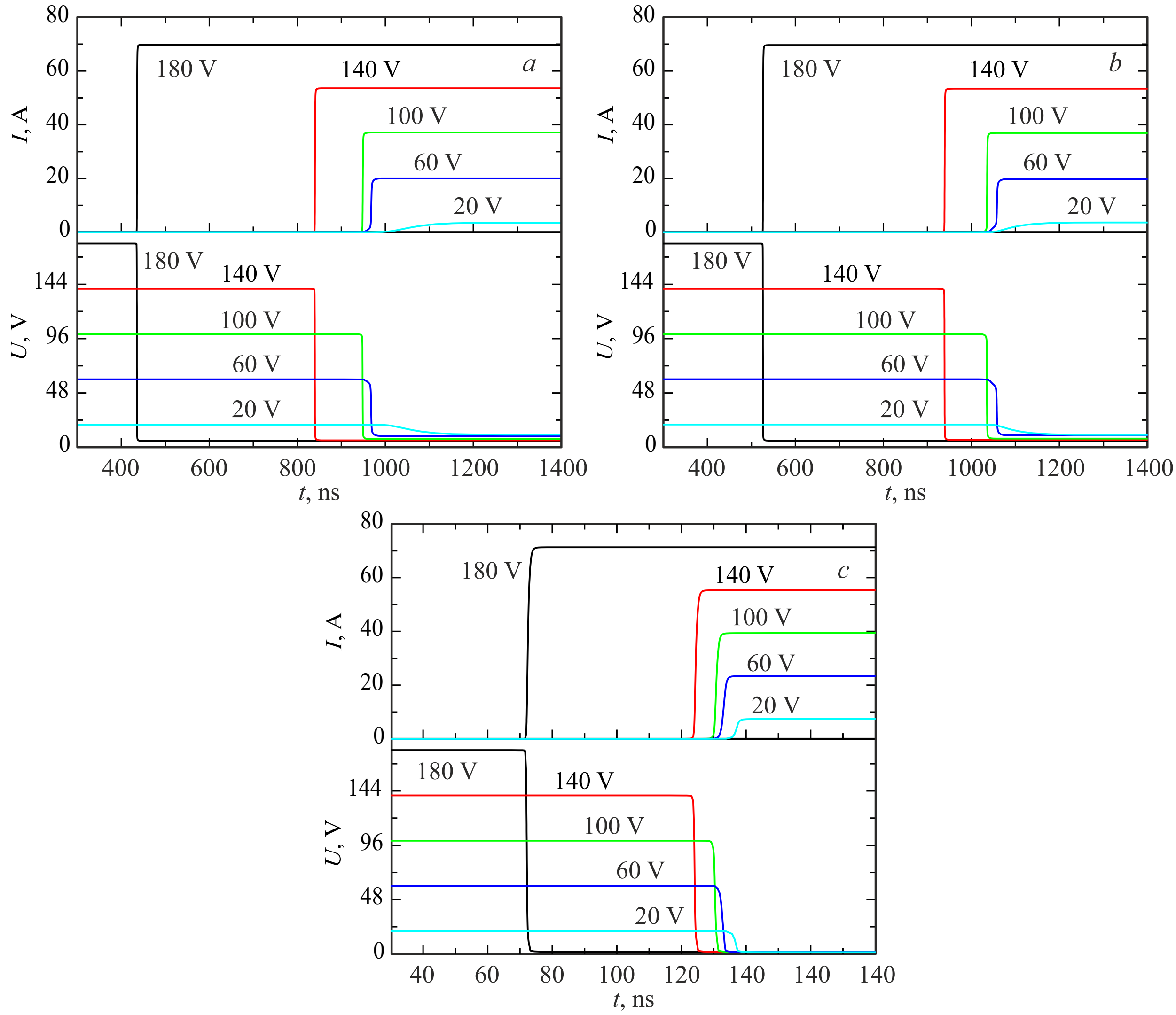

Figure 2. Closing dynamics by current and voltage of structures St-1 (a), St-2 (b) and St-5 (c).

decrease in the supply voltage causes increase in the closing delay time and widening of the closing front.

Figure 3 shows the dependencnes of all basic dynamic characteristics on the working voltage for all modeled high voltage structures. Analyzing the dependences of current amplitude on supply voltage (see Figure 3, a), you can note that the value of current through the thyristor in the closed state grows according to the quasi-linear law with the growth of the working voltage. You can also see that for all three modeled high voltage structures the achieved current amplitude is approximately same in the entire range of supply voltages. Besides, the structure with the n-collector thinned down to 0.2 μm shows slightly higher values of the current at the same values of the supply voltage. In general at the working voltage of 180 V equal to the maximum blocking one, the current amplitude reaches ~ 70 A.

Dependences of the residual voltage on the value of the working voltage show that as the supply voltage decreases, the structures St-1 and St-2 behave in a similar way — at the maximum working voltage (180 V) the value of the residual one is $\approx 5.6-5.8$ V, which corresponds to 3–3.2% of the supply one, further the value of the residual voltage grows non-linearly and at 40 V reaches the maximum of $\sim 14-16$ V (see Figure 3, b), which corresponds to $\approx 35-40$ % of the supply voltage, after which it starts decreasing sharply, and at the minimum supply voltage of ~ 10 V reaches values of $\sim 5-6$ V, i. e. 50–60 % of the supply.

Nevertheless, despite the non-linear change of the value of the residual voltage vs. the supply voltage, if it is considered as percentage, it becomes clear that St-1 and St-2 structures are characterized with higher residual voltage, which increases with the decrease in the supply voltage. Achieved values of residual voltages indicate the presence of local areas with high intensity of electric field in the structure. To visualize these areas, spatial dependences were built: electric field intensities, charge carrier concentrations, and rates of collisional ionization at

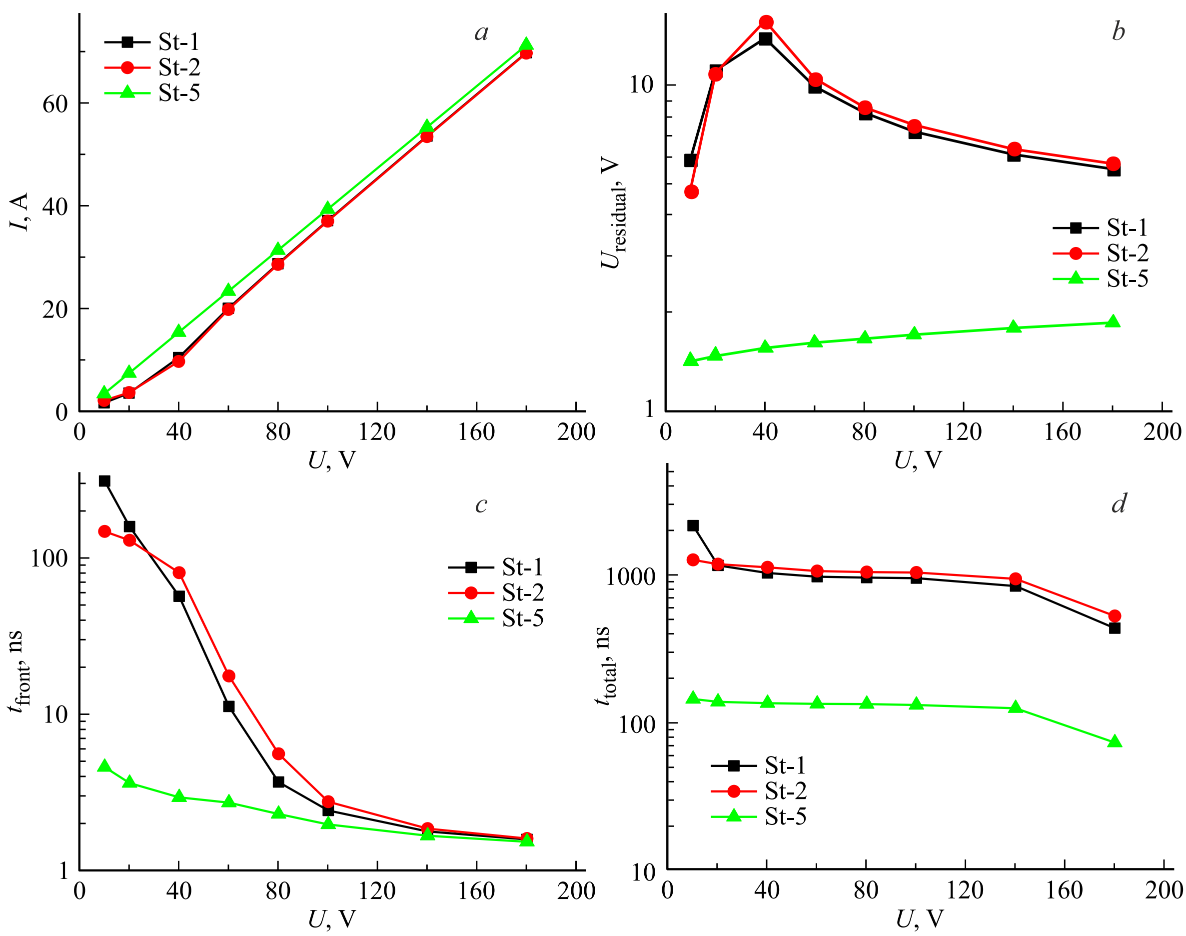

Figure 3. Dependences on working voltage for modeled structures: *a* — current amplitude, *b* — residual voltage, *c* — closing front width, *d* — total closing time.

different moments of time using the example of the St-1 structure. As two reference points in the timé scale, 0 ns (thyristor off) and 600 ns (thyristor fully on) were taken, and also two intermediate points — 445.9 and 446.2 ns, which characterize the moments of time, when the thyristor closes. All formulations were made for the supply voltage of 180 V (Figure 4).

At the initial moment of time (0 ns) the strong field domain occupies almost the entire p^0-base (see Figure 4, *a*). In process of closing, as a result of extraction from the *p*-emitter and collisional ionization at the collector-base boundary, many non-equilibrium holes are generated in the p^0-base . These holes under the effect of the electric field drift towards the p^0-base/p^+-base boundary. However, the heavily doped locking p^+-layer from GaAs and the barrier formed by the p^+-GaAs/*n*-AlGaAs heteroboundary prevent their active leakage from the base. Therefore, excessive positive charge arises in the p^0-base. This charge induces the built-in electric field opposite in polarity to the field of the base-collector p^0-n-transition, which reduces the potential barrier it formed, and then the through current through the structure increases. On the built dependences this effect is displayed as gradual spatial „compression" of the strong field domain at times of 445.9 and 446.2 ns (see Figure 4, *a*). Distributions of collisional ionization speed in the course of thyristor start qualitatively follow the progress of intensity curves (see fig. 4, *b*), also gradually „being pressed" to the boundary base–collector boundary, which is directly related to the fact that the area of the base is reduced, where the value of the field intensity is sufficient for the generation of carriers by collisional ionization, and its spatial amplitude at the base–collector boundary, same as for the field intensity, is growing.

One of the specific consequences of the strong field domain „collapse" is the occurrence of the quasi neutral electron-hole plasma in the p^0-base in the closed state (see Figure 4, *c*), which is formed by non-equilibrium holes and electrons injected from the *n*-emitter. You can see that at the initial moments of time (445.9 ns) the holes in the base are somewhat fewer than electrons, since the process of injection through the forward-biased p^+-n-transition happens more intensively than extraction through the backward-biased p^0-n-transition. However, as the speed of collisional ionization increases (see Figure 4, *b*) at the base–collector boundary, the generation of non-equilibrium holes and the ever-increasing through current in the course

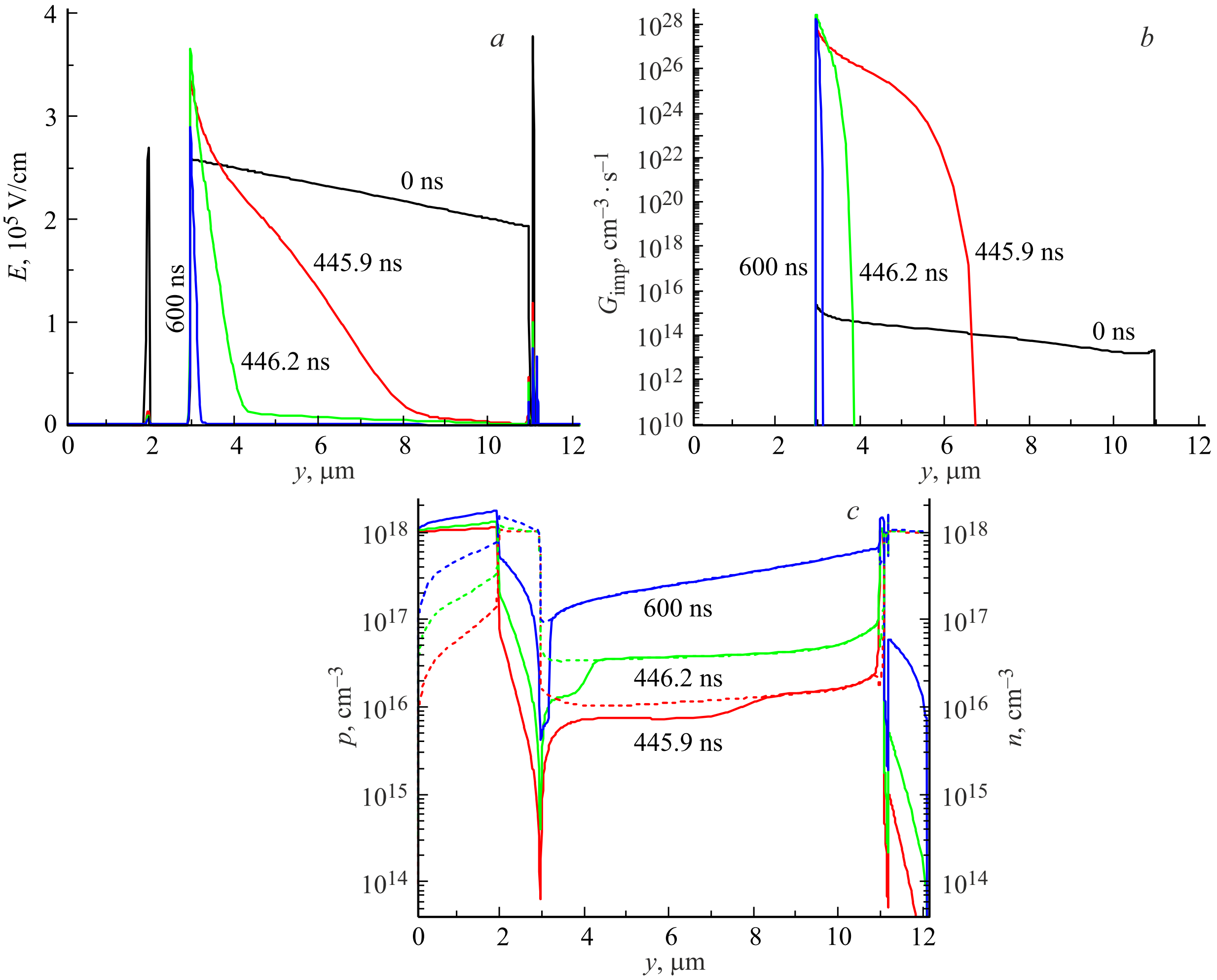

Figure 4. Spatial dependences for the St-1 structure at the supply voltage of 180 V at different moments of time: *a* — module of electric field intensity, *b* — rate of collisional ionization, *c* — concentrations of charge carriers (solid lines — holes, dotted lines — electrons).

of closing balance the injection from the *n*-emitter. In the end in the fully closed state (600 ns) the electron and hole concentrations are practically equal in the larger part of the base volume, except for the narrow (~ 300 nm) layer near the base–collector boundary as such (see Figure 4, *c*). The thickness of the layer, where the quasi neutrality is damaged, matches well with the area of the residual domain of the strong field (see Figure 4, *a*) and its corresponding area of the residual collisional ionization (see Figure 4, *b*). It is the presence of the high intensity of the electric field in the closed state at the base–collector boundary that provides for the achieved value of the residual voltage for the St-1 and St-2 structures.

The local peak of the residual voltage at $U \sim 40$ V for St-1 and St-2 (see Figure 3, *b*) is also related to the dimensions of the area of the space charge near the $n-p^0$-collector transition in the closed state (residual domain), at different levels of the supply voltage. It is found that as the working voltage reduces from 180 to 40 V inclusive, the electric field intensity amplitude at the collector transition in the closed state decreases slightly compared to the expansion of the space charge area. Since the residual voltage on the structure is in fact the integral from the spatial distribution of the electric field intensity, the expansion of the area of the space charge in a combination with the relatively minor reduction of the spatial amplitude of intensity increases the value of this integral and accordingly the absolute value $U_{residual}$, which is observed in Figure 3, *b* at $180 \geq U \geq 40$ V. In the course of the further decrease of the supply voltage from 40 to 10 V the width of the space charge area in the vicinity of the collector transition in the closed state practically stops changing, whereas the field intensity amplitude decreases substantially (~ 4 times for St-1). This effect causes decrease of the integral of the spatial distribution of intensity, namely, the decrease of the residual voltage in the structure, which is seen in Figure 3, *b* as the drop of the residual voltage value at $U < 40$ B for St-1 and St-2.

If the structure with the thinned *n*-collector (St-5) is considered, you can note that it behaves totally differently compared to the St-1 and St-2 structures: its residual voltage will not increase with the decrease of the supply voltage, but will on the contrary decrease according to the weak quasiexponential law (see Figure 3, *b*), and the difference between the initial and final values is only 0.44 V, and the maximum absolute value of the residual voltage is achieved, accordingly, at the maximum working voltage of 180 V and is $\sim$ 1.86 V, which is $\sim$ 1 % of the supply voltage. The highest relative value of the residual voltage is observed at the working voltage of 10 V and is 1.42 V, i. e. $\sim$ 14 % of the working one. Based on these estimates, one may conclude that according to the residual voltage value the structure with the 0.2 μm n-collector shows the best result, and then the GaAs/AlGaAs-thyristor key based on the St-5 structure must theoretically experience less overheating when operating at the same supply voltages as the St-1 and St-2 structures.

The analysis of the front width demonstrates that when operating at high blocking voltages, in the range of $\sim$ 180–140 V, the closing fronts of all three working structures are approximately the same (see Figure 3, *c*) and lie in the range of 1.5–1.7 ns. However, as the supply voltage decreases, the closing speed starts decreasing, accordingly, the closing front widens, at the same time for the St-5 structure at 10 V voltage this widening is the least from all and is only $\sim$ 4.6 ns vs almost 148 and 311 ns for St-2 and St-1 at the same 10 V supply voltage value. It is unsurprising that the shortest closing front in the St-5 structure is observed at the highest working voltage of 180 V and is only 1.5 ns. For the St-1 and St-2 structures the closing fronts at 180 V of supply are somewhat larger in width and are equal to 1.58 and 1.6 ns accordingly.

Consideration of the total closing time shows that according to this parameter as well the structure with the thinned n-collector proves itself to be better than the structure with the initial design or the structure with the composite n^0/p^0-base. Thus, for the St-5 structure the closing time in the entire range of working voltages does not exceed 150 ns, whereas for the St-1 and St-2 structures in the low voltage mode it reaches thousands of nanoseconds. Closing times in Figure 3, *d* are obtained for the control pulse amplitude of 135 mA. If required, the closing delay time may be decreased substantially at the expense of increasing the control current pulse amplitude. Therefore, the calculations were carried out for the closing delay times for three considered structures (St-1, St-2, St-5) at the maximum supply voltage (180 V) depending on the control pulse amplitude that varied form 135 to 210 mA (Figure 5).

As the control signal amplitude increases, the closing delay time of the thyristor decreases for all considered designs of the heterostructure. Comparing the modeled thyristors between each other, it is easy to note that the situation with the closing delay times is to a great extent similar to the dynamic characteristics in Figure 3 — delay values for St-1 and St-2 behave in the same manner with the growth of the control current amplitude and are quite close by absolute values, which are at the level of dozens–hundreds of nanoseconds (see Figure 5). Whereas St-5 shows substantial differences — in the entire range of control signal amplitudes the closing delay time is substantially shorter than for St-1 and St-2, and does not exceed 100 ns. The highest value, $\sim$ 72 ns is achieved by the closing delay time for the St-5 structure at the minimum control pulse amplitude (135 mA), whereas for St-1 and St-2 with the same control current there are delay times $\sim$ 435 and 526 ns accordingly. As the control current amplitude increases to 210 mA, the closing delay time for St-5 becomes equal to $\sim$ 5.5 ns, vs 26.9 and 31.9 ns for St-1 and St-2. Therefore, selecting the control signal amplitude for the St-5 structure with the collector thinned to 0.2 μm, you can achieve highly low inertia closing of the thyristor with the closing front width at the level of $\sim$ 1.5 ns and the closing delay time of $\sim$ 5.5 ns, i. e. the total time of thyristor closing will be $\sim$ 7 ns.

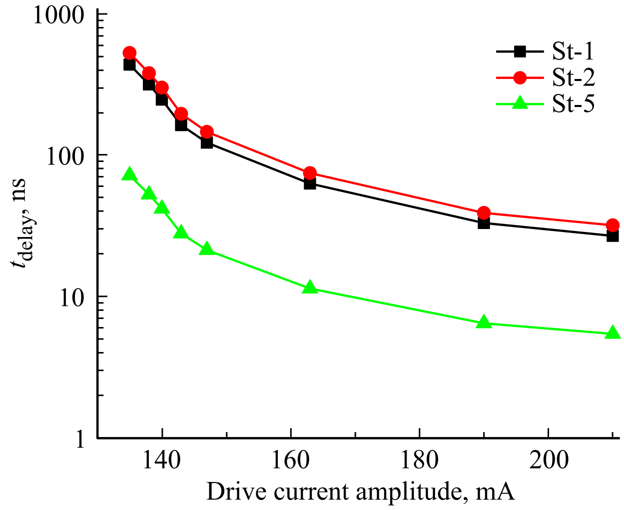

Figure 5. Closing delay time depending on control pulse amplitude at the maximum working voltage of 180 V.

4. Conclusion

Based on the conducted calculations of various GaAs/AlGaAs structures of the high voltage thyristor current switch with the 8 μm p^0-base within the quasi unidimensional model one can conclude on the substantial effect of the parameters in the layers directly adjacent to the p^0-base, on the range of the working voltages of the thyristor, especially presence/absence of the heavily doped p^+-insert and the thickenss of the n-collector layer. The static calculations of the maximum blocking voltage of the thyristor show that it makes most sense to develop a structure with a p^+-insert between the p^0-base and the n-AlGaAs-emitter, besides, the doping level of this layer should be increased to $\sim 10^{18}$ cm^{-3}. Otherwise, it is not possible to achieve high voltage mode of operation on a thyristor (with voltages of > 60 V).

The conducted analysis of the closing dynamics for different thyristor structures makes it possible to conclude that out of all modeled GaAs/AlGaAs structures for the high current high voltage thyristor current switches the structure with the *n*-collector thinned down to $0.2\,\mu$m has the highest speed of closing — the width of its closing front in the low voltage area ($U_{\text{supp}} \approx 10\,$V) is $\sim 4.6\,$ns, and in high voltage one ($U_{\text{supp}} \approx 180\,$B) it reaches up to $\sim 1.5\,$ns. The calculations of the closing delay times for the structure with the 0.2-μm collector show that their value may be decreased down to 5.5 ns at the expense of the control pulse amplitude down to 210 mA. Therefore, the total time of thyristor closing will only make $\sim 7\,$ns, whereas the other considered structure will require dozens of nanoseconds, even at superhigh control pulses. Simultaneously with this with the collector thinned down to $0.2\,\mu$m demonstrates the least level of residual voltage in the working range of supply voltages (from 10 to 180 V), which in the worst case scenario (at $U_{\text{supp}} \approx 10\,$V) does not exceed 14 % of the supply voltage value. At the same time the least relative residual voltage equal to 1.86 V, i.e. $\sim 1\,\%$ of the supply voltage, achieved in the mode of the maximum working voltage $U_{\text{supp}} = 180\,$V. It is also interesting that for all the studies designs the close values are achieved for the current amplitude in the closed state. For example, for supply voltage of 180 V the current amplitude of St-5 structure is $\approx 71.3\,$A, while the time for the St-1 and St-2 structures— $\sim 69.7-69.8\,$A.

Conflict of interest

Authors declare no conflict of interest.

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Translated by M.Verenikina