V. S. Dmitriev

MULTICOMPONENT OHMIC CONTACTS TO GaAs

The paper contains the results of the study of semiconductor wafer preprocessing, application and heat treatment modes of Ag-GE-In/n-n Ga As contacts impact on specific transient resistance.

Key words: *gallium-arsenide, ternary alloy, vacuum deposition, heat treatment, specific resistance, ohmic contact.*

Introduction

One of the most important technological operations, used for fabrication of semiconductor devices and integrated micro circuits, based on gallium –arsenide is the formation of ohmic contacts (OC) [1, 2]. For the creation of OC binary or more complex alloys on the base of copper, silver, gold, palladium with admixture of metals (cadmium, magnesium aluminium, indium and others [2 – 5]), easily oxidizing, are used.

Erosion strength of this group of alloys is based on protective action of oxide films, preventing evaporation but not preventing contact conductivity. The value of contact resistance of ohmic contact is determined, to a considerable extent, by the technology of its fabrication [3 – 11].

The aim of the given research is study and determination of the impact of semiconductor wafer preprocessing, modes of deposition and heat treatment of Ag-Ge-In/n-n^+GaAs contacts on specific transient resistance.

Experimental study

For investigation n-$n^+GaAs(111)B$ epitaxial monocrystal with epitaxial layer thickness of $d_{e.l.}$=2 mμ, carriers concentration in epilaxial layer $n_{e.l.}=2\cdot10^{16}$ cm^{-3}, carriers concentration in the substrate $n_{sub}=10^{18}$ cm^{-3} and mobility μ>5000 cm^2/(V·c) was used.

For OC creation to gallium-arcenide ternary alloy Ag-Ge-In (75%-20%-5% by weight, correspondingly) is chosen, where Ag-basic material, Ge-dopping admixture and In improves wettability. Silver alloys of the similar type are rather stable to corrosion, keeping low contact resistance [3 – 5, 8 – 12]. Silver under the action of electric charges oxidizes but silver oxides have good electric conductivity and easily dissociate (dissociation temperature~ 573 K). As a result, oxidization exercises minor impact on the stability of conduct resistance of silver contacts.

For fabrication of ohmic contacts it is necessary to get near the surface of semiconductor the concentration of admixtures 10^{18} cm^{-3}. There exists various methods [2] of increasing charge carriers concentration in the surface layers. Doping of the surface with metal occurs in the process of surface processing of the semiconductor in the solutions [13 – 16] ,containing admixtures of various metals.

Chemical smoothing of semiconductor substrate is performed to remove fins and decrease surface roughness. Characteristic feature of $GaAs$ compound is different dissolution rate of the semiconductor on the plane (11) with the facets A and B with different character of chemical bonds of substrate atoms. Applying the same etching agent side (III) B is polished (smooth, clear), side (III) A- dim with developed mosaic structure [14].

Comparative analysis of the known polishing etching agents showed that among etching agents , used for chemical smoothing [13 – 16] of $GaAs$, etching in sulfurous agent provides more qualitative surface.

In the process of chemical treatment of GaAs plates in sulfurous etching agent H_2SO_4:H_2O_2:H_2O (3:1:1) additional aging of the plate during (1...1,3)·10^3 seconds in dihydroxy-syccnic acid $HOOC$-$CH(OH)$-$CH(OH)$-$COOH$ .with further washing in hot , cold distilled and deionized water and in methyl alcohol is recommended. It is established that aging in dihydroxy-succinic acid during (1...1,3)·10^3 sec after chemical polishing in the mixture $3H_2SO_4$-$1H_2O_2$-$1H_2O$ decreases the value of specific contact resistance to $5\cdot10^{-5}$ ohm cm^2.

Impact of preliminary annealing of gallium-arsenide plates on specific contact resistance of the contact *Ag-Ge-In/n-n*$^+$*GaAs* at temperatures of 673…. 873 K during 30…150 sec is investigated (Table 1).

Table 1

Specific contact resistance ρ_c of *Ag-Ge-In/n-n*$^+$*GaAs* contacts, substrate of which was annealed

Temperature of preliminary annealing of *GaAs* -substrate, K	Specific contract resistance of contacts ρ_c, Ohm·cm^2				
	Batches of *GaAs*--plates				
	№1	№2	№3	№4	№5
673	$9\cdot10^{-2}$	$7\cdot10^{-2}$	$8\cdot10^{-2}$	$5\cdot10^{-2}$	$4\cdot10^{-2}$
698	$8{,}6\cdot10^{-2}$	$7{,}50\cdot10^{-2}$	$5\cdot10^{-2}$	$7{,}5\cdot10^{-2}$	$4{,}3\cdot10^{-2}$
723	$8\cdot10^{-2}$	$8\cdot10^{-2}$	$3\cdot10^{-2}$	$9\cdot10^{-2}$	$5\cdot10^{-2}$
748	$7{,}15\cdot10^{-2}$	$1\cdot10^{-2}$	$9\cdot10^{-3}$	$2\cdot10^{-2}$	$2\cdot10^{-2}$
773	$6\cdot10^{-2}$	$5\cdot10^{-3}$	$4\cdot10^{-3}$	$3\cdot10^{-3}$	$7\cdot10^{-3}$
798	$6\cdot10^{-3}$	$2\cdot10^{-3}$	$1\cdot10^{-3}$	$1\cdot10^{-3}$	$2{,}5\cdot10^{-3}$
823	$7\cdot10^{-4}$	$9\cdot10^{-4}$	$5\cdot10^{-4}$	$3\cdot10^{-4}$	$7\cdot10^{-4}$
848	$3\cdot10^{-4}$	$3\cdot10^{-4}$	$1\cdot10^{-4}$	$1{,}5\cdot10^{-4}$	$1{,}2\cdot10^{-4}$
873	$8\cdot10^{-5}$	$5\cdot10^{-5}$	$8\cdot10^{-5}$	$9\cdot10^{-5}$	$7\cdot10^{-5}$
Time of annealing, sec	30	60	90	120	150

It is established (Fig. 1) that preliminary temperature annealing of the substrate at 873 K during 60 sec in vacuum at residual pressure of $2\cdot10^{-6}$ Torr decreases the value of specific transient resistance of ohmic contacts to ρ_c=(5...7)$\cdot10^{-5}$ Ohm·cm^2.

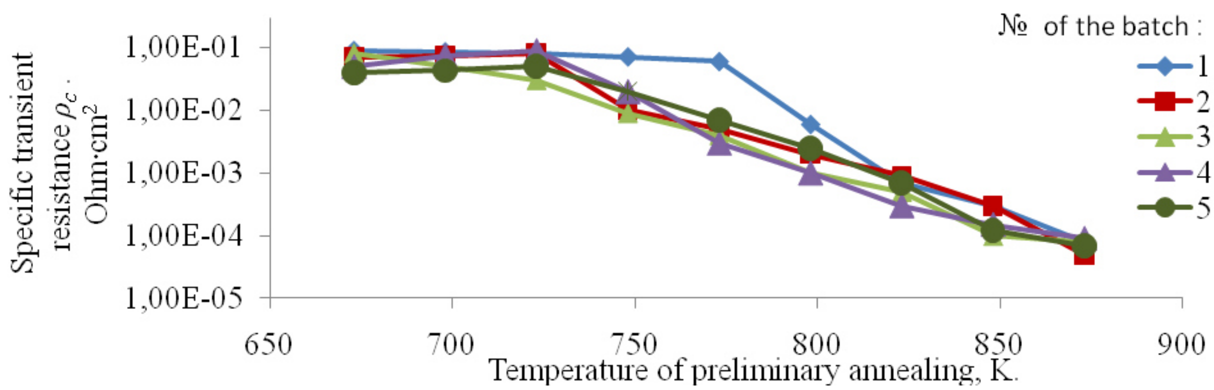

Fig. 1. Impact of preliminary annealing of the substrate on specific transient resistance of the contact *Ag-Ge-In/n-n*$^+$*GaAs*

Thus, it is proved, that the quality of ohmic contact improves if *GaAs* substrate after chemical treatment in sulfurous etching agent, is kept in dihydroxy-succinic acid during $1{,}2\cdot10^{3}$ sec and additionally annealed in vacuum with the degree not less than $1{,}2\cdot10^{-6}$ Torr at the temperature of 873 K during 60 sec.

Application of contact material was performed by vacuum evaporation method at residual pressure of at least $1.2\cdot10^{-6}$ Torr. Measurements of contact resistance was carried out by compensation method [17, 18]. Calculation of specific transient resistance of OC was performed on the base of equivalent circuits method [17, 18].

Formation of the structure of ohmic contact by means of annealing was carried out in vacuum with the degree of not less than (2...6)$\cdot10^{-6}$ Torr. Contact annealing to *GaAs* is necessary for introduction in the area of contact boundary the admixture or defects.

The impact of the substrate temperature on specific transient resistance of the contact in the process of contact material application by the method of thermal evaporation, annealing temperature velocity increase, temperature and the time of annealing , contact cooling velocity is studied. For calculation of specific transient resistance value the formula [17] was used:

$$\rho_k = \frac{R_\kappa b}{k \quad cth(ka)}, \qquad (1)$$

where R_c – complete resistance of the contact, P_c-specific transient resistance of the contact, a – width of the contact, b – length of the contact, ρ_{cc}-surface resistance of semiconductor. Values of k, corresponding to the values of R_c, are found from the graphic solution of the equation $y_1=cka$, $y_2=cth(ka)$, where $c=R_c \cdot b/(\rho_{cc} \cdot a)$.

Measurement limits of k numerical values are taken from the condition (17), that ρ_c/ρ_{sc} is less than one order (k=0,1÷10) in accordance with general requirements to the contacts. It is obvious, that in case, when the value of metal-semiconductor contact resistance $R_c>\rho_{sc}$, then specific contact resistance of the contact, reduced to the unit of the area, $\rho_{c\ red}>\rho_{sc}$, the phenomenon of spreading currents, passing across the contact, is observed in near contact area. At optimal mode p_c of the contact is «pure» at $\rho_c \le \rho_{sc}$. *If* $\rho_c>\rho_{sc}$ specific transient resistance consists only of transient resistance of spreading in near contact area.

Basic measurements error, in this case, expressed in % from rated value of measured resistance at the temperature of 293±2 K and relative humidity of the air 80%, did not exceed the following values : a±0,1% within the limits of 10^{-3}-10^{-2} Ohm, b) ±0,05% within the limits of 10^{-2}-10^{-8} Ohm.

The choice of optimal values of heat treatment of contacts to *GaAs* with $n_{e.l.}=2\cdot10^{16}$ cm^{-3} .is determined by the necessity to create the layer with increased concentration of electrons due to doping with germanium. Contact annealing mode must provide minimal specific transient resistance of the contact and shallow occurrence of metal-semiconductor interface.

Contact material deposition was carried out on preheated substrate (Table 2).

Table 2

Impact of substrate temperature on specific transient resistance of the contacts ρ_c *Ag-Ge-In/n-n$^+$GaAs*

Substrate temperature, K	Specific transient resistance, Ohm·cm^2		
	№ of the batch		
	1	2	3
423	$2\cdot10^{-2}$	$1{,}5\cdot10^{-2}$	$3\cdot10^{-2}$
453	$6\cdot10^{-5}$	$4\cdot10^{-5}$	$7\cdot10^{-5}$
483	$8\cdot10^{-4}$	$5\cdot10^{-4}$	$4\cdot10^{-4}$
513	$8\cdot10^{-3}$	$9\cdot10^{-3}$	$6\cdot10^{-3}$

By the results of research (Table 2) the best adhesion of contact material to gallium-arsenide was obtained at the temperature of the substrate 435 K, $\rho_c=(4...7)\cdot10^{-5}$Ohm cm^2.

The dependence of specific transient resistance of ohmic contacts ρ_c on the temperature and time of annealing in the range of temperatures 693… 943 K and time of annealing 60…300 sec. was studied (Fig. 2).

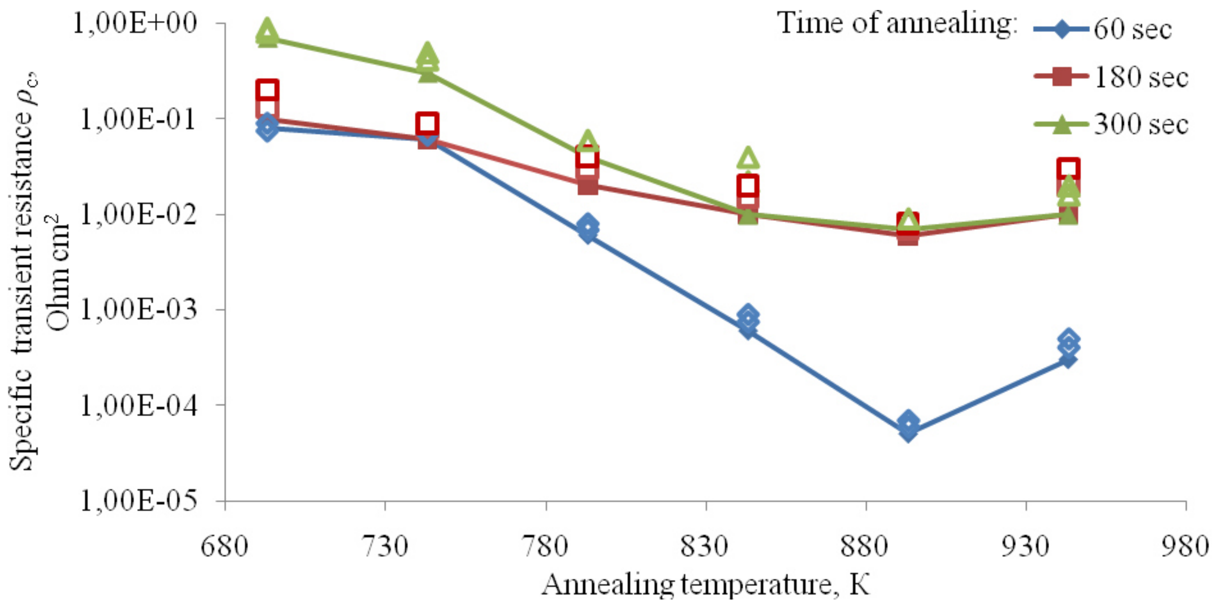

Fig. 2. Impact of the temperature and time of annealing on specific transient resistance ρ_c of *Ag-Ge-In/n-n*$^+$*GaAs* contacts

It is established, that time and temperature of contact structure annealing greatly influence the quality of ohmic contact. The best results ρ_c=(5...7)·10^{-5} Ohm cm^2 are obtained at the temperature of annealing 893 K and time of annealing 60 sec.

Linearity of VAC of the manufactured ohmic contacts was not violated in case of heating to the temperature of 453 K (Fig. 3).

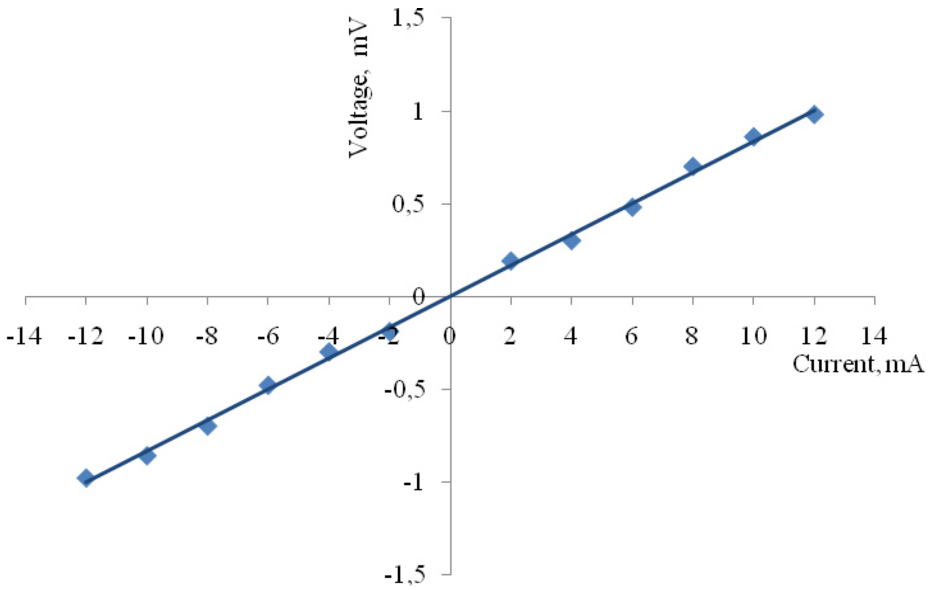

Fig. 3. Voltage-current characteristic of ohmic contact *Ag-Ge-In/n-n*$^+$*GaAs*
T_{an}=893 K, T_{an}=60 sec

The impact of the rate of annealing temperature increase in the range of 4.8….7.2 K\s and velocity of contact cooling in the range 465..475 K\s on the value of specific transient resistance of ohmic contacts ρ_c was studied (Fig. 4).

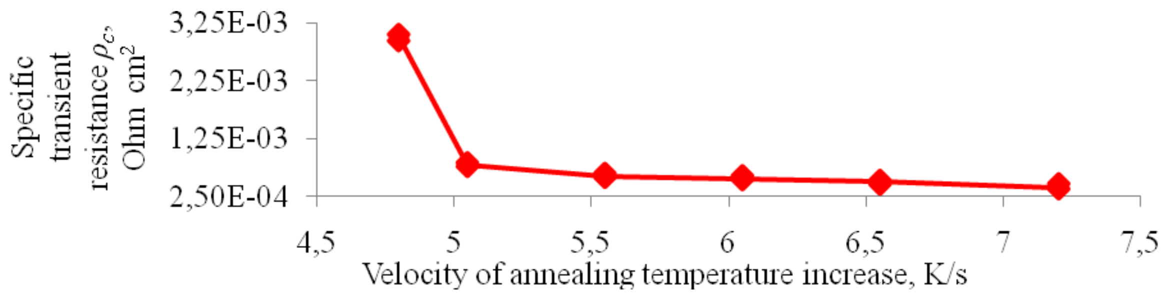

Fig..4. Dependence of specific transient resistance of ohmic contacts pc on the velocity of annealing temperature increase.

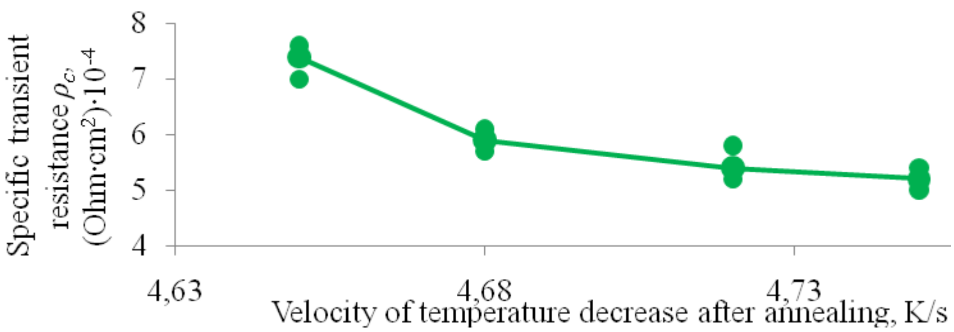

Fig. 5. Dependence of specific transient resistance of ohmic contacts pc on the velocity of contact cooling

It is established, that the increase of annealing temperature velocity from 5.55 K/s to 7.2 K/s leads to a slight decrease of specific transient resistance value (Fig. 4). Recommended velocity of annealing temperature increase 7.2 K/s.

Variation of contact cooling rate after annealing within the interval of 4.72, 4.75 K/s (Fig. 5) does not practically influence the value of specific transient resistance . Recommended velocity of contact cooling after annealing 4.75 K/s.

Conclusions

It is proved, that the additional aging in dihydroxy succinic acid after treatment in sulfuroms etching agent and preliminary annealing in vacuum of GaAs substrate at 873 K during 60 sec. decreases specific transient resistance of ohmic contact *Ag-Ge-In*/*n-n*$^+$*GaAs* .

Ohmic barrier junctions, based on ternary allow *Ag-Ge-In* (75% *Ag*, 20% *Ge*, 5% *In*) in *GaAs* c $n_{e..l..}$=2·10^{16} см$^{-3}$ provide rather low contact resistance ρ_c =(5...7)·10^{-5} Ohm·cm^2 and linearity of VAC in the process of contact material deposition on the substrate, heated to the temperature of 453 K and annealing of the obtained structure at 893 K during 60 sec. in vacuum at residual pressure of at least 1.2·10^{-6} Torr, velocity of annealing temperature growth 7.2 K/s , and velocity of contact cooling after annealing 4.75 K/s.

REFERENCES

1. Low noise gallium arsenide amplifiers under the influence of electromagnetic interference of high intensities [Electronic resource] / S. V. Platonov, N. V. Permiakov, B. I. Selesniov [et al.] // Bulletin of Novgorod State University. – 2012. – № 67. – P. 29 – 32. – Access mode to the resource: http://www.novsu.ru/file/1010219. (Rus).

2. Sze S. M. Physics of Semiconductor Devices, 3rd Edition / S. M. Sze, K. K. Ng. – Hoboken : A John Wiley & Sons, Inc., 2007. – 815 p.

3. Ti/Pd/Ag Contacts to n-Type GaAs for High Current Density Devices [Electronic resource] / P. Huo, I. Rey-Stolle // Journal of Electronic Materials. – 2016. – Vol. 45, № 6. – P. 2769 – 2775. – Access mode to the

resource : http://dx.doi.org/10.1007/s11664-016-4432-6.

4. Kawamura M. Electrical and morphological change of Ag–Ni films by annealing in vacuum / M. Kawamura, M. Yamaguchi, Y. Abe, K. Sasaki // Microelectronic Engineering. – 2005. – Vol. 82, № 3 – 4. – P. 277 – 282.

5. Christou A. Solid phase formation in Au: Ge/Ni, Ag/In/Ge, In/Au: Ge GaAs ohmic contact systems / A. Christou // Solid-State Electronics. – 1979. – Vol. 22, № 2. – P. 141 – 149.

6. Dmitriev V. S. Impact of the interface on the parameters of ohmic contact / V. S. Dmitriev, L. B. Dmitrieva // Materials of X International Scientific practical conference «Actual research and development-2014» / V. S. Dmitriev, L. B. Dmitrieva. – Sofia : «Bel Grad-BG» OOD. – 2014. – Vol. 28. – P. 79 – 82. – (ISBN 978-966-8736-05-6). (Rus).

7. Thermal stability of Ag films in air prepared by thermal evaporation / L. Jing, L. Fachun, L. Limei [et al.] // Applied Surface Science. – 2007. – Vol. 253, № 17. – P. 7036 – 7040.

8. Sugawara K. Comparison of the agglomeration behavior of Ag(Al) films and Ag(Au) films / K. Sugawara, M. Kawamura, Y. Abe, K. Sasaki // Microelectronic Engineering. – 2007. – Vol. 84, № 11. – P. 2476 – 2480.

9. Vartanian T. A. Delayed action of illumination on the relaxation of granular silver film at thermal annealing / T. A. Vartanian, N. B. Leonov, S. G. Prizhibelskiy // Optical Journal. – 2013. – Vol. 80, № 2. – P. 24 – 28. (Rus).

10. Electrical and structural investigations of Ag-based Ohmic contacts for InAlAs/InGaAs/InP high electron mobility transistors [Electronic resource] / W. Zhao, L. Wang, I. Adesida // Applied Physics Letters. – 2006. – Vol. 89, № 7. – P. 072105–1–072105–3. – Access mode to the resource : http://dx.doi.org/10.1063/1.2337102.

11. Kawamura M. Electrical and morphological change of Ag–Ni films by annealing in vacuum / M. Kawamura, M. Yamaguchi, Y. Abe, K. Sasaki // Microelectronic Engineering. – 2005. – Vol. 82, № 3 – 4. – P. 277 – 282.

12. Kim H. C. Improvement of the thermal stability of silver metallization / H. C. Kim, T. L. Alford // Journal of Applied Physics. – 2003. – Vol. 94, № 8. – P. 5393 – 5395.

13. Markin B. V. Impact of chemical treatment on the composition of GaAs surface / B. V. Markin, V. V. Chikun // Electronic engineering. Series 1. Electronics of SHF. – 1990. – № 4. – P. 19. (Rus).

14. Physical chemical methods of senriconductors surfaces treatment / [B. D. Luft, V. A. Perevotchikov, N. M. Vozmilova et al.]. – M. : Radio and Communication, 1982. – 136 p. (Rus).

15. Patent 2319798of Russian Federation, IPC H 01 L 21/302. Method of obtaining atomically-smooth surface of gallium-arsenide substrate / Bezriadin N. N., Kotov G. I., Starodubtsev A. A., Strygin V. D., Arsentiev I. N.; applicant for a patent and patent holder Voronezh State Technological Academy. – № 2006116830/15 ; claimed 16.05.06 ; published 20.03.08, Bul. № 8. (Rus).

16. Patent 2402103 of Russian Federation, IPC H 01 L 21/316. Method of GaAs surface etching / Erofeev E. V., Ishutkin S. V., Kagadey V. A., Nosaeva K. S.; applicant for a patent and patent holder CJSC «Scientific production company Mikran». – №2009133993/28 ; claimed 10.09.09 ; published 20.10.10, Bul. № 29. (Rus).

17. Niskov V. J. Measurement of transient resistance of ohmic contacts to thin layers of semiconductors / V. J. Niskov // Devices and experiment technique. – 1971. – № 1. – P. 235 – 237. (Rus).

18. Niskov V. J. Resistance of ohmic contacts to thin layers of semiconductors / V. J. Niskov, G. A. Kubetskiy // Physics and semiconductors engineering. – 1970. – Vol. 4, № 9. – P. 1806 – 1808. (Rus).

Dmitriev Vadim – Head of Scientific Training Laboratory of the Department of Microelectronic Information Systems.

Zaporizhia State Engineering Academy.