Effect of Sulfur Modification of GaAs Surface on Parameters of AuGeNi Ohmic Contacts

V.A. Kagadei, E.V. Erofeev*, and T.V. Zaretzkaya*

Institute of High-Current Electronics SB RAS, 2/3, Academichesky ave., Tomsk, 634055, Russia
Phone: +8(3822) 49-15-44, E-mail: vak@micran.ru
**Research Institute of Semiconductor Devises, 99a, Krasnoarmeyskaya str., Tomsk, 634034, Russia*

Abstract – The opportunity of the improvement of the AuGeNi/*n-i*-GaAs ohmic contacts parameters by the sulfur modification of the GaAs surface before film deposition is shown. The ohmic contacts deposited on the sulfur modifier surface have lower specific contact resistance compare with the traditionally produced ohmic contacts at all annealing temperatures. The contact pads morphology of the both types of the contacts is similar.

1. Introduction

In many cases, the chemical composition and atomic structure of GaAs surface define the parameters of AuGeNi ohmic contacts. The existence of the native oxide on GaAs surface can leads to non-homogeneous interaction of a metal film with GaAs surface along of the contact pad area. As a result the relief morphology of the contact pads surface and the local areas with low and high specific contact resistance are formed. The current distribution along of the pad area becomes also non-uniform, that in case of a high density current reduces the lifetime of the device. As known the *in situ* methods of the GaAs surface cleaning are not very acceptable at MESFET and *p*-HEMT based MIMIC production. From the other hand, it is known [1] that the treatment of the GaAs surface in the solutions containing S or Se is an effective method of the clean, electrically and chemically passivated surface production. The sulfur passivation decreases rate of a semiconductor surface oxidation at an exposition on an atmosphere (chemical passivation) and reduces a density of the surface states (electric passivation) [2]. Therefore can be suggested, that sulfur modification of GaAs surface before deposition of ohmic contacts metallization could be the effective method of the contact parameters improvement.

The work purpose is investigation of the effect of the GaAs surface modification by the sulfur solutions treatment on the electrical parameters of the AuGeNi ohmic contacts.

2. Experimental techniques

Samples of Si-doped *n-i*-GaAs ($n \cong 4 \cdot 10^{17}$ cm^{-3}, $d = 0.12$ μm) and n^+-GaAs ($n \cong 10^{18}$ cm^{-3}) were used in experiments. The two-layer resist mask with TLM patterns were produced by standard photolithographic techniques.

For the GaAs native oxides removal samples were processed in H_2SO_4 (1:10) water solution within 3 min. After the treatment, samples were rinsed in deionized (DI) water and drying in N_2 flow.

Samples have been divided into two groups – A and B. On the surface of the group A samples the AuGeNi film was deposited without additional processing. Samples of the group B before film deposition were dipped into sulfur contained solution for 10 min at room temperature. Then samples were rinsed in DI water for 3 min and drying in N_2 flow. After it, the samples were immediately placed in a vacuum chamber for film deposition.

The AuGeNi film (0.15 μm) was deposited by the thermal evaporation of the alloy AuGe (88%/12% wt) + Ni (10% wt) at the pressure $2 \cdot 10^{-6}$ Torr. The topology of the contact pads was formed by the lift-off process.

Samples were annealed in nitrogen at temperature $T = 300$–420 °C by the rapid thermal annealing during $t = 30$ s. Sequentially one *n-i*-GaAs sample from A group and one *n-i*-GaAs sample from B group was annealed and measured cycle by cycle with increase of annealing temperature in each cycle on 10–20 °C. Each n^+-GaAs samples was annealed once at defined time-temperature mode. Annealing time was $t = 30$ s, the range of the temperatures was $T = 280$–420 °C.

The surface morphology of the annealed contact pads was examined by method of scanning electron microscopy (SEM). Specific contact resistance ρ was measured by the TLM and Cox–Strack methods. The accuracy of the specific contact resistance measurement was 30%.

3. Results and discussion

In Fig. 1, the current-voltage characteristic of as-deposited AuGeNi contacts measured on samples of A and B groups are presented.

Samples from both groups have nonlinear characteristics. It testifies that at the metal-semiconductor interface there is a high potential barrier. The barrier height in case of group A samples is φ = 0.54 eV, and in case of group B samples is 0.52 eV. The decreasing of the barrier height on 0.02 eV leads to a difference in value of current (Fig. 1). It is possible to assume, that the barrier height variation is a result of the reduction of the surface states density and decreasing of the

native oxide thickness at AuGeNi/GaAs interface of B group samples.

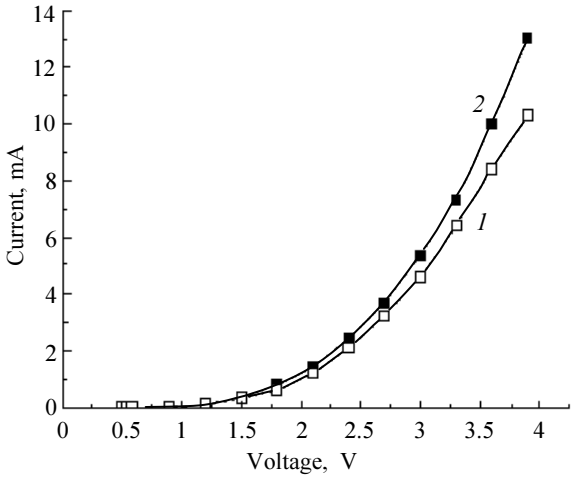

Fig. 1. Current-voltage characteristics of as-deposited AuGeNi contacts to *n-i*-GaAs: without (*1*) and with (*2*) sulfur treatment

In Fig. 2, the current-voltage characteristics of AuGeNi contacts after the rapid thermal annealing at 360 °C (t = 30 s) are shown.

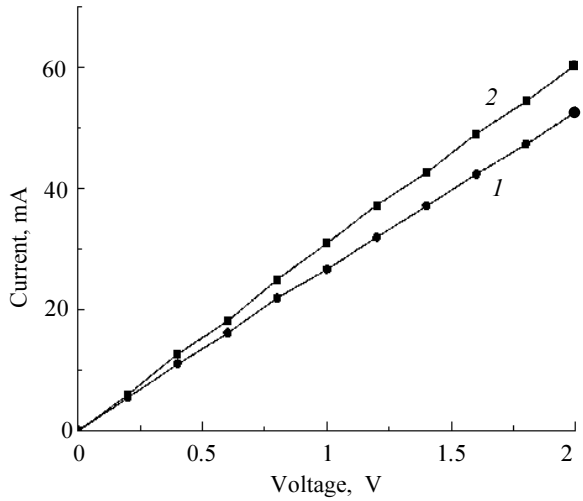

Fig. 2. Current-voltage characteristics of AuGeNi contacts to *n-i*-GaAs after annealing at 360 °C (t = 30 s): without (*1*) and with (*2*) sulfur treatment

The current-voltage characteristics of the contacts of a both groups are linear. The slope of straight lines is correlated with the specific contact resistance. For the B group samples higher currents through contact and correspondingly lower contact resistance are measured.

In Fig. 3, results of measurements of the specific contact resistance of AuGeNi ohmic contacts produced by thermal evaporation and annealed by RTA are presented.

The B group ohmic contacts produced on sulfur treated GaAs surface at all annealing temperatures shows smaller values of the ρ compare with the group A contacts.

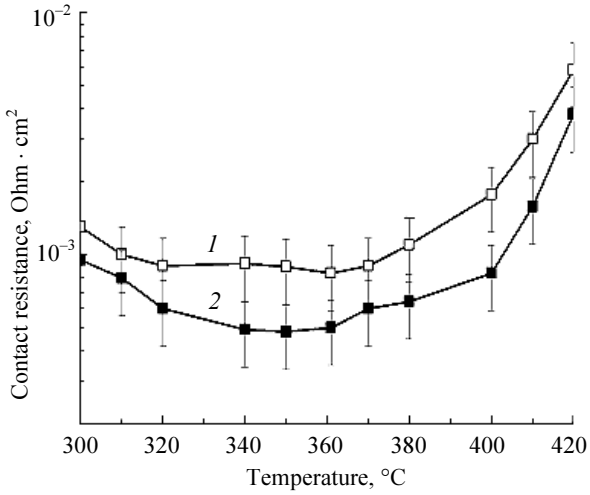

Fig. 3. Dependences of the specific contact resistance of the AuGeNi ohmic contacts to *n-i*-GaAs without (*1*) and with (*2*) sulfur treatment versus annealing temperature

At $T < 320$ °C the specific contact resistance for group B samples less than the similar value for group A samples on 10%, and at $T > 320$ °C on 150%. The reduction of the ρ value for $T > 320$ °C can be connected with the liquid phase formation in AuGeNi/GaAs system and the changing of the mechanism of the sulfur located on AuGeNi/GaAs interface influence on contact resistance. The reasons leads to decreasing of the specific contact resistance for group B samples are possible to formulate as follows:

– the electric passivation of the GaAs surface decreases of the surface states density and create a more energy stable structure on the interface;

– the chemical passivation of the GaAs surface decreases the oxidation rate during interoperational time and improves the conditions for interaction between the metal film and GaAs;

– the additional doping of the GaAs surface layer by sulfur atoms.

The sulfur doping reduces width of a metal/semiconductor potential barrier and, according to the field emission mechanism, the specific contact resistance too [2]. It is necessary to note, at $T < 320$ °C (Fig. 3) the reduction of ρ for group B samples most likely is connected with the first and the second, and at $T > 320$ °C – with the second and third reasons.

In Fig. 4, the similar data for n^+-GaAs samples are presented. It is visible, as early the sulfur treatment leads to reduction of ρ value.

However, the degree of reduction of contact resistance is essentially more (300–1000%) and the minimal ρ value is $3 \cdot 10^{-6}$ Ohm · cm^2.

Figure 5 shows the scanning electronic microscopy images of the ohmic contacts surface for B (*a*, *c*) and A (*b*, *d*) groups samples after rapid thermal annealing at $T = 380$ °C. It is visible, that the images of the contact surface of both groups are similar.

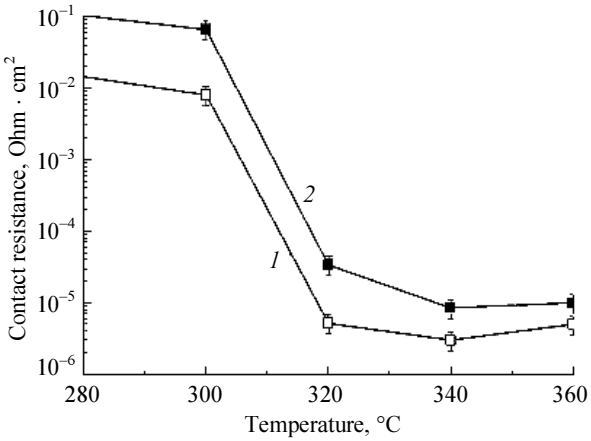

Fig. 4. Dependences of the specific contact resistance of the AuGeNi ohmic contacts to n^+-GaAs with (*1*) and without (*2*) sulfur treatment versus annealing temperature

However, on the contact surface B group sample the more light background and the local light spots compare with the sample from A group (see Fig. 4) are observed.

It testifies that contact resistance of the B group samples below, than group A samples.

4. Conclusions

That have been shown, that the ohmic contacts deposited by thermal evaporation of the alloy AuGeNi on sulfur treated GaAs surface at all annealing temperatures (from 280 up to 420 °C) have by factor 1.5–5 the smaller specific contact resistance, than the contacts produced by film deposition on not modified GaAs surface.

The morphology of the contacts surface in both cases is similar.

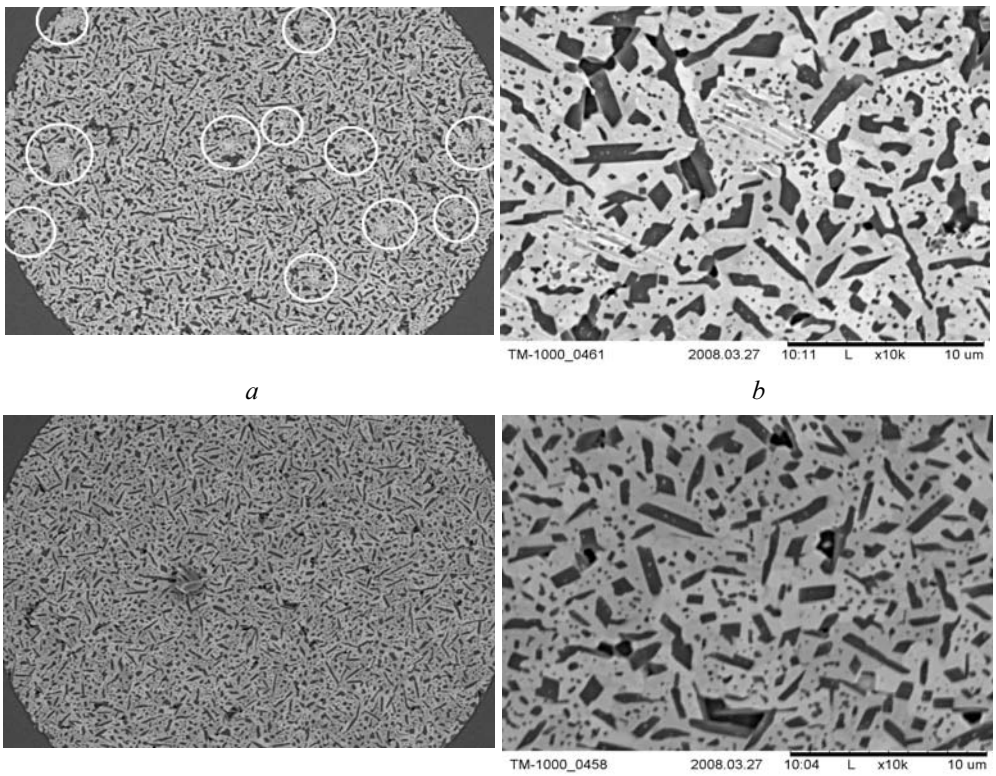

Fig. 5. SEM images of the surface of AuGeNi ohmic contacts with (*a, b*) and without (*c, d*) GaAs surface sulfur treatment after rapid thermal annealing at 380 °C (30 s)

References

[1] V.N. Bessolov and M.V. Lebedev, Semiconductors Phys. Techn. **32**/11, 1281–1299 (1998).

[2] T.V. Blank and Y.A. Goldberg, Semiconductors Phys. Techn. **41**/11, 1281–1308 (2007).