Study of the Multilayer Ohmic Contacts to *n*-*i*-GaAs with Ti Diffusion Barrier

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Abstract – The opportunity of the improvement of Ge/Au/Ni ohmic contacts to *n-i*-GaAs parameters at incorporation of Ti diffusion barrier in the multilayer metal film is shown. The ohmic contact base on Ge/Au/Ni/Ti/Au has a lower specific contact resistance and smoother surface morphology at annealing temperatures.

1. Introduction

The production of the ohmic contacts with linear current-voltage characteristics, ultra-low contact resistance and smooth morphology of the contact pads is a challenge of the compound semiconductor microelectronics. In proportion as a technology node reduction, the requirements to parameters of ohmic contacts to their thermal stability and lifetime are increase [1]. The conventional Ge/Au/Ni ohmic contact is using for GaAs devices widely. Limiting characteristics of the Ge/Au/Ni ohmic contact in many cases are defined by deposition methods and the processes occurring during thermal annealing, in particular: i) by the formation of intermetallic unstable high-resistance phases on the interface; ii) by the mixing of the metal films and GaAs leading to increasing of the transition layer thickness and compensation of the charge carriers; iii) by the formation of thick melting region [1]. The first disadvantage and partly the second one could be eliminate by the introduction to the multilayer ohmic contact of the diffusion barrier film based on thermally stable metal, for example, Ti [2].

The work purpose is investigation of the opportunities of the Ge/Au/Ni ohmic contacts improvement by incorporation in multilayer metal film of the diffusion barrier based on Ti film.

2. Experimental techniques

For increasing of the specific contact resistance measurement accuracy the Si-doped samples *n-i*-GaAs ($n \cong 4 \cdot 10^{17}$ cm^{-3}, $d = 0.12$ μm) were used in experiments. The two-layer resist mask with TLM patterns was formed by standard photolithographic techniques. For the GaAs native oxides removal the samples were processed in H_2SO_4 (1:10) water solution within 3 min. Then samples were rinsed in deionized (DI) water and drying in N_2 flow.

Three types of the multilayer ohmic contact (Ge/Au/Ni, Ge/Au/Ni/Au and Ge/Au/Ni/Ti/Au) were investigated. Metal films were deposited by the electron beam or the thermal evaporation methods in a vacuum with a base pressure $4 \cdot 10^{-6}$ Torr. Thickness of layers varied in a range from 20 up to 200 nm and was for Ge film – 40 nm, Au – 80 nm, Ni – 20 nm, Ti – 50 nm, Au – 200 nm. The control of the deposition speed and the layers thickness *in situ* was carried out by the quartz monitor. The topology of the contact pads was formed by the lift-off process. Samples were annealed in nitrogen environment in furnace at temperature $T = 280$–460 °C during time $t = 5$ min or by the rapid thermal annealing ($T = 340$–440 °C, $t = 30$ s). The surface morphology of the annealed contact pads was examined by methods of the optical microscopy and the scanning electronic 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 Figure 1 the results of the specific contact resistance measurements of the Ge/Au/Ni, Ge/Au/Ni/Au and Ge/Au/Ni/Ti/Au ohmic contacts produced by thermal evaporation and annealed in the furnace is presented.

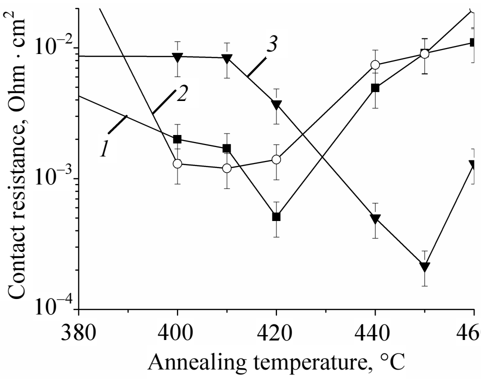


Fig. 1. Dependence of the specific contact resistance of Ge/Au/Ni (*1*), Ge/Au/Ni/Au (*2*) and Ge/Au/Ni/Ti/Au (*3*) ohmic contacts produced by thermal evaporation versus the annealing temperature ($t = 5$ min)

The temperature dependences has a traditionally curves shape with the ρ value minimum. With the annealing temperature raise the interdiffusion between multilayer metals film and GaAs is increase. This leads to reduction of the specific contact resistance, down to minimal value of ρ. The subsequent growth of the temperature leads to ρ increasing as a result of the high-resistance intermetallic phases formation. In case of Ge/Au/Ni/Au and Ge/Au/Ni/Ti/Au contact, it may be caused by the gold penetration from the top layer to the GaAs surface.

The minimal value of the specific contact resistance for Ge/Au/Ni contacts is $5 \cdot 10^{-4}$ Ohm · cm^2 at 420 °C. The Ge/Au/Ni/Ti/Au contact in a point of a minimum has smaller resistance ($2 \cdot 10^{-4}$ Ohm · cm^2), however this value is reached at a larger annealing temperature ($T = 450$ °C).

The Ge/Au/Ni/Au contact has the greatest value of the specific contact resistance in a point of the minimum ($\rho = 1.2 \cdot 10^{-3}$ Ohm · cm^2 at $T = 410$ °C). It is obvious, that such high contact resistance is connected with strong penetration Au from the top layer to GaAs surface.

In Fig. 2, the measurement results of the specific contact resistance of the Ge/Au/Ni and Ge/Au/Ni/Ti/Au ohmic contacts, deposited by electron beam evaporation and annealed by rapid thermal annealing are presented.

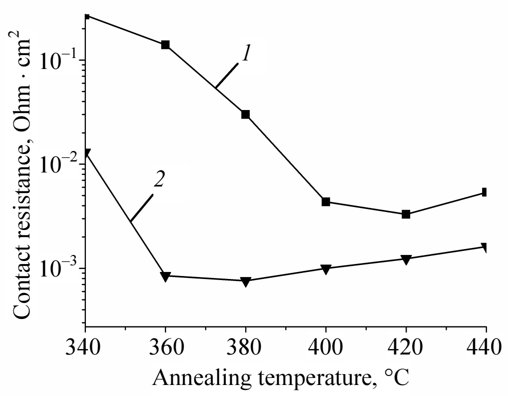


Fig. 2. Dependence of the specific contact resistance of ohmic contacts Ge/Au/Ni (*1*) and Ge/Au/Ni/Ti/Au (*2*) produced by e-beam evaporation versus the rapid thermal annealing temperature ($t = 30$ s)

There are some differences in the curves shape compare with the curves in Fig. 1. The Ge/Au/Ni/Ti/Au contact shows the lowest contact resistance after annealing at 380 °C. For achievement of the lowest contact resistance value for Ge/Au/Ni contact the annealing temperature should be increased up 420 °C. Like in the previous case, the ohmic contact with the diffusion barrier shows smoother surface morphology and lower contact resistance in compare with Ge/Au/Ni contact.

Figure 3 shows the ρ measurement results of Ge/Au/Ni/Ti/Au ohmic contacts versus the time of the rapid thermal annealing. The lowest contact resistance is achieved after annealing during 30 s. The variation of annealing time from 10 up to 60 s changes ρ less than factor two.

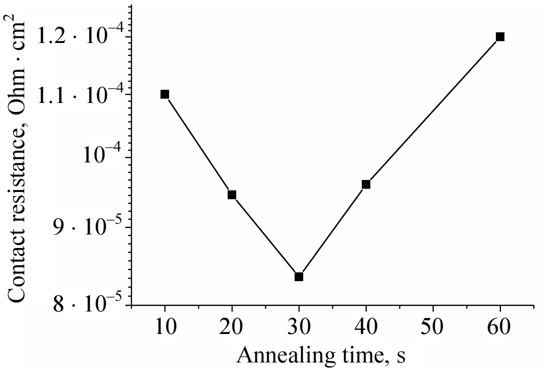
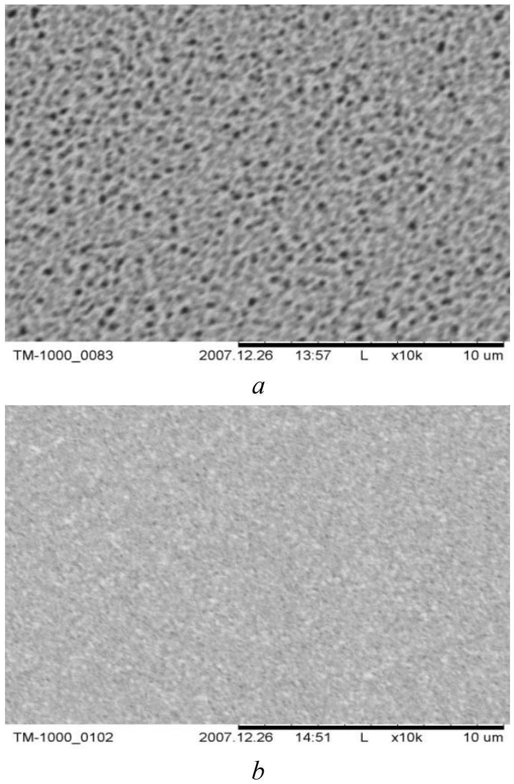


Fig. 3. Dependence of the specific contact resistance of the Ge/Au/Ni/Ti/Au ohmic contacts deposited by e-beam evaporation versus the time of the rapid thermal annealing ($T = 420$ °C)

In Figure 4 the surface morphologies of annealed Ge/Au/Ni and Ge/Au/Ni/Ti/Au ohmic contacts is presented. Both types of contact metallization were deposited by the layer-by-layer thermal evaporation.



a

b

Fig. 4. SEM images of the Ge/Au/Ni (*a*) and Ge/Au/Ni/Ti/Au (*b*) ohmic contact pads surface produced by thermal evaporation and annealed at 460 °C during 5 min

From the analysis of the grey contrast distribution across of the contact pads area follows, that Ge/Au/Ni/Ti/Au contact has more homogeneous distribution of specific contact resistance and smoother morphology of the surface, than Ge/Au/Ni contact.

4. Conclusions

It has been shown, that incorporation of the Ti diffusion barrier in multilayer metal film of the ohmic contact allows to reduce the minimal value of the specific contact resistance by factor 2.5–4.5, and to achieve the smoother morphology of the contact pads surface.

References

[1] T.V. Blank and Y.A. Goldberg, Semiconductors physics and technique **41**/ 11, 1281–1308 (2007).

[2] V.V. Milenin, R.V. Konakova, and V.N. Ivanov, Zh. Tekh. Fiz. **70**, 11 (2000).