HEAT-RESISTANT Au–TiB$_x$–*n*-GaN SCHOTTKY DIODES

A. E. Belyaev[1], N. S. Boltovets[2], V. N. Ivanov[2], V. P. Kladko[1], R. V. Konakova[1], Ya. Ya. Kudryk[1], A. V. Kuchuk[1], O. S. Lytvyn[1], V. V. Milenin[1], Yu. N. Sveshnikov[3]

[1]*V. Lashkaryov Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine*
41 Nauki Prosp., Kiev, 03028, Ukraine
e-mail: konakova@isp.kiev.ua, Ph.: +(380-44) 525-6182

[2]*State Enterprise Research Institute «Orion»*
8a Eugene Pottier St., Kiev, 03057, Ukraine
e-mail: bms@i.kiev.ua; Ph.: +(380-44) 465-0548

[3]*Close Corporation «Elma-Malakhit»*
Zelenograd, Russia

Abstract – We studied phase composition and parameters of the ohmic Au–TiB$_x$–Al–Ti–*n*-GaN and barrier Au–TiB$_x$–*n*-GaN contacts, both before and after rapid thermal annealing (RTA) at T = 870 °C for 30 s. The phase composition was studied with x-ray diffraction technique, while the parameters of the ohmic contacts were studied for the transmission line method (TLM) structures and those of the barrier contacts were studied by measuring the forward branches of I–V curves with further calculation of the Schottky barrier (SB) height φ_B and ideality factor n.

It was found that low-resistance ($\rho_c \approx (1 \div 3) \times 10^{-6}\ \Omega \cdot cm^2$) ohmic Au–TiB$_x$–Al–Ti–*n*-GaN contacts can be formed using RTA. It turned out also that, after RTA at T = 870 °C for 30 s, the SB retains its barrier properties practically unchanged, as compared with the initial sample that has not been exposed to RTA.

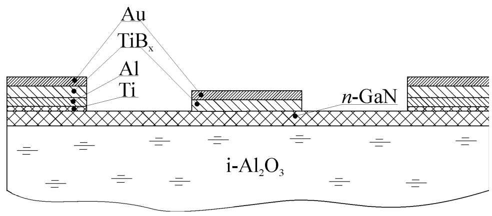
I. Introduction

Gallium nitride is a wide-gap semiconductor that has been used in optoelectronics for many years [1]. Owing to the advances of new high technologies, a real possibility for development of microwave diodes and transistors on the basis of gallium nitride and its solid solutions has appeared [2, 3]. The interest in such microwave devices is aroused, first of all, by the fact that they make it possible to expand the operating temperature range up to 800 °C. In this case, along with high heat resistance of the gallium nitride material, still more stringent requirements are imposed upon the barrier-forming and ohmic contacts. In this connection the search for the adequate materials for contact systems continues up to now [2-6].

Earlier we have studied the ohmic and barrier contacts (made with amorphous interstitial phases TiB$_x$, ZrB$_x$, NbN$_x$, and TiN$_x$) to the Si, GaAs, InP and SiC microwave diodes. There were practically no interactions between phases in these contacts up to temperatures more than twice the operating ones [7, 8]. In this work the previous experience was applied to formation of ohmic and barrier contacts to the *n*-GaN epitaxial layers grown on sapphire (α-Al_2O_3).

II. Sample and Experimental Procedure

Using photolithography, the planar Schottky diodes (SDs) were made on the *n*-GaN epitaxial film (thickness of ~1 μm, free charge carrier concentration of ~10^{17} cm^{-3}) grown on sapphire. A Schottky barrier (SB) was made using magnetron sputtering of TiB$_x$ (up to a thickness of 0.05 μm) followed by sputtering of a gold metallization layer (contact layer) 0.2 μm thick. The ohmic contacts were prepared on the basis of Ti–Al–TiB$_x$–Au metallization. The subsequently sputtered Ti (0.05 μm) and Al (0.02 μm) layers were exposed to rapid thermal annealing (RTA): they were fired at a temperature T = 870 °C for 30 s. After this the TiB$_x$ (0.1 μm) and gold (0.2 μm) layers were sputtered. The diode structure geometry is shown in Fig. 1.



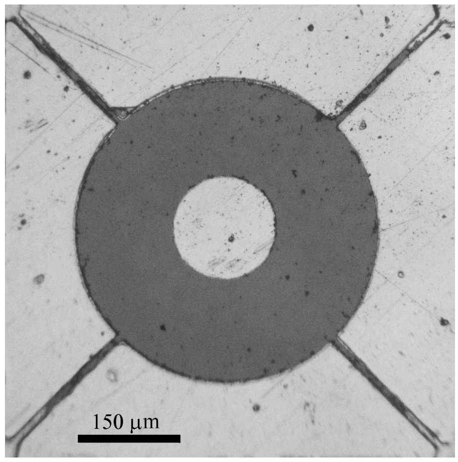


Fig. 1. Layered structure of the contacts (a) and layout of the diode structure (b)

III. Result of Measurements

We took, both before and after RTA, the forward and reverse branches of I–V curves from which the SB height φ_B and ideality factor n were determined. The phase composition of the contacts was studied with x-ray diffraction (XRD) technique for the Al_2O_3–*n*-GaN–Ti–Al–TiB$_x$–Au and Al_2O_3–*n*-GaN–TiB$_x$–Au test structures (before and after RTA). The XRD patterns for the Al_2O_3–*n*-GaN–TiB$_x$–Au structures were studied ex-situ using an x-ray diffractometer Philips X'Pert-MPD (Cu$_{K\alpha}$-radiation, wavelength λ = 0.15418 nm) in the Bragg–Brentano geometry. The Al_2O_3–*n*-GaN–Ti–Al–TiB$_x$–Au structures were studied using a diffractometer «Дрон-3М».

The XRD patterns of the ohmic contacts formed using RTA (Fig. 2) have several peaks: (002) and (004) from the GaN epitaxial layer; (111), (200) and (220) from Au; (220) and (440) from $AuGa_2$, (220) and (400) from TiN, (0006) and (0012) from Al_2O_3 and a «smeared» peak that seems to stem from the x-ray amorphous phases Al_3Ti and TiB$_x$. According to these results and the literature data, the ohmic contact is formed with a layer that appeared due to RTA near the Ti–GaN and Ti–Al interfaces in conformity with the following reactions:

$$Ti + GaN \rightarrow TiN_x + GaN_{1-x} \text{ and } Ti + 3Al \rightarrow Al_3Ti.$$

The results of XRD studies presented in Fig. 2 correlate with the concentration depth profiles of the compo-

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nents of n-GaN–Ti–Al–TiB_x–Au ohmic contacts that were obtained in [7] using Auger electron spectroscopy. The contact resistance for the TLM structures measured after RTA was $(1\div3)\times10^{-6}\ \Omega\cdot cm^2$, i. e., more than two orders of magnitude below that in the initial samples.

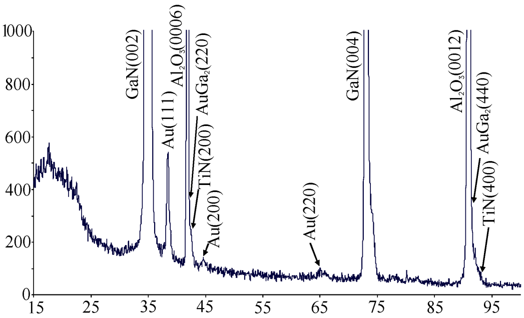

Fig. 2. XRD patterns of the GaN–Ti–Al–TiB_x–Au contact

The XRD patterns for the Al_2O_3–n-GaN–TiB_x–Au barrier contacts (taken both before and after RTA) (Fig. 3) have three peaks: (i) (0002) from the GaN epitaxial layer, (ii) (0006) from the α-Al_2O_3 substrate, and (iii) from the Au (111) film. One can see from Fig. 3 that RTA at T =870 °C resulted in structural changes in the Au film only: an increase of the Au (111) peak height indicates presence of the [111] texture that is related to heat-induced increase of the gold grain size. The TiB_x film is in the x-ray amorphous state, both before and after RTA. Formation of other phases due to the metallurgical processes in the metallization layers was not detected. This fact indicates thermal stability of these layers.

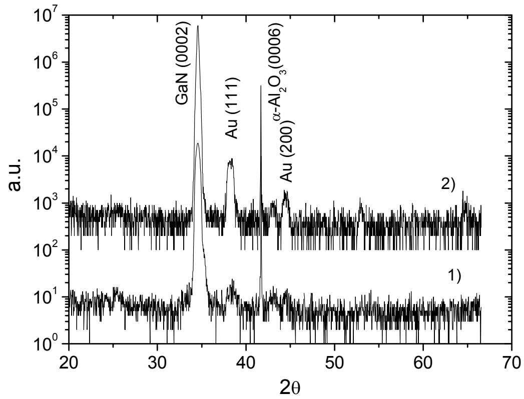

Fig. 3. XRD patterns of the Al_2O_3–n-GaN–TiB_x–Au contact before (1) and after RTA at T = 870 °C for 30 s (2)

The above results were confirmed with measurements of SD I–V curves which practically did not change after RTA. The forward branch of the I–V curves of the Au–TiB_x–n-GaN SDs taken both before and after RTA can be described with a single exponential portion, with SB height values of (0.8÷1.2) V for different samples, and ideality factor values $n \approx 1.34\div1.68$, respectively.

IV. Conclusion

Thus our results show that RTA at T = 870 °C leads to formation of heat-resistant ohmic contacts made on the basis of the Ti–Al–TiB_x–Au metallization and does not change the parameters of the n-GaN–TiB_x–Au barrier contacts.

IV. References

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ТЕРМОСТОЙКИЕ ДИОДЫ ШОТТКИ Au–TiB_x–n-GaN

А. Е. Беляев[1], Н. С. Болтовец[2], В. Н. Иванов[2], В. П. Кладько[1], Р. В. Конакова[1], Я. Я. Кудрик[1], А. В. Кучук[1], О. С. Литвин[1], В. В. Миленин[1], Ю. Н. Свешников[3]

[1]*Институт физики полупроводников им. В. Е. Лашкарёва НАН Украины пр. Науки, 41, г. Киев, 03028 , Украина e-mail: konakova@isp.kiev.ua; тел.: +(380-44) 525-6182*

[2]*Государственное предприятие НИИ «Орион» ул. Эжена Потье, 8а, г. Киев, 03057, Украина e-mail: bms@i.kiev.ua, тел.: +(380-44) 465-0548*

[3]*ЗАО «Элма-Малахит» Зеленоград, Россия*

Аннотация – До и после быстрой термической обработки (БТО) при T = 870 °С в течение 30 с исследовались фазовый состав и параметры омических n-Au–TiB_x–Al–Ti–n-GaN и барьерных Au–TiB_x–n-GaN контактов. Фазовый состав исследовался методом рентгеновской дифракции, параметры омического контакта – на TLM структурах, барьерного – путем измерения прямых ветвей вольтамперных характеристик (ВАХ) и расчета из них высоты барьера Шоттки φ_B и фактора идеальности n.

Установлено, что в результате БТО можно формировать низкоомные омические контакты Au–TiB_x–Al–Ti–n-GaN с $\rho_c \approx (1\div3)\times10^{-6}$ Ом·см^2. Оказалось также, что после БТО при T = 870 °С в течение 30 с барьер Шоттки сохраняет барьерные свойства практически неизменными, по сравнению с исходным (не прошедшим БТО) образцом.