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On the Formation of Low-Resistivity Contacts for 4*H*-SiC Bipolar Devices

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The results of studies on the development of technological methods for the formation of low-resistivity contact systems to *n*- and *p*-SiC based on single and multilayer Ni-, Al- and Ti-compositions for 4*H*-SiC based bipolar devices are presented. It is shown that the formation of low-resistivity contacts based on Ni to *n*-4*H*-SiC ($\rho_c = 3.6 \cdot 10^{-4}\,\mathrm{Ohm} \cdot \mathrm{cm}^2$) and Ni/Al to *p*-4*H*-SiC ($\rho_c = 5.9 \cdot 10^{-5}\,\mathrm{Ohm} \cdot \mathrm{cm}^2$) is possible within a single cycle of vacuum annealing at 1000°C for 120 s. This technological solution makes it possible to reduce the number of high-temperature processes.

Keywords: 4*H*-SiC, *n*-type, *p*-type, ohmic contacts, RTA, TLM, specific contact resistivity.

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1. Introduction

An important task in the technology of SiC-devices (4*H*-SiC) for various applications is the creation of low-resistance ohmic and thermally-stable contacts to regions having different conduction types [1]. Although this issue has been thoroughly studied by now and the obtained results allow for creation of reproducible and reliable contact systems of a metal with 4*H*-SiC in JBS and MOSFET commercial devices, works in this area are continued and remain a topic for discussion [1,2]. Attention is called to certain discrepancies in the published experimental results as regards minimization of specific contact resistance (ρ_c) when using similar metals and their compounds, and as regards similar conditions of ohmic contact formation. This circumstance shows that process conditions of formation of ohmic contacts are unique and determined by a combination of process flow peculiarities: surface preparation method, metal deposition method, heat treatment modes and conditions. Moreover, an important factor that defines the value of ρ_c is the region of ohmic contact formation: a heavily doped substrate, epitaxial or ion-implanted layers. Nevertheless, a common feature for the manufacture of ohmic contacts to all the given types of SiC-regions is the metal deposition, followed by rapid high-temperature annealing (RTA: resistive, high-frequency, radiation or laser) at 900−1100°C in vacuum or in an inert atmosphere [3–5].

Various metals, combinations of metals, alloys and silicide compounds are used as a contact material for 4*H*-SiC. The most popular metal is Ni, which under heat treatment at > 900°C forms nickel silicide (Ni_2Si) as a result of solid-phase reactions, which provides a low-resistance ohmic contact to *n*-SiC [3,5], as well as ohmic contact to heavily doped ion-implanted layers of *p*-SiC with ρ_c usually by 1−2 orders higher than to *n*-SiC [6]. The use of this metal is of interest when creating a self-aligned contact of the Ni-SALICIDE type (self-aligned silicide) [7,8] through openings in SiO_2, for instance, in case of simultaneous formation of ohmic contacts to n^+- and p^+-regions of MOSFET source.

In addition to nickel, compounds based on Al/Ti [3], Al/Ti/Ni [9], Al/Ni [8] etc. are usually used for formation of low-resistance contacts to *p*-SiC. It should be noted that titanium and nickel in these multilayer compounds are used as upper covering layers, which hinder the formation of a well-developed microrelief [9].

The paper presents the results of studies in tryout of process techniques for formation of low-resistance contact systems to *n*- and *p*-SiC based on monolayer and multilayer Ni-, Al- and Ti-compositions for bipolar 4*H*-SiC devices for pulse power electronics [10] and UV-diodes [11].

2. Experimental procedure

The following metals and compounds were used to fabricate ohmic contacts: Ni for the contact to *n*-4*H*-SiC, Ni, Al/Ni, Al/Ti/Ni for the contact to *p*-4*H*-SiC. Contacts to *n*-SiC were formed on double-side polished *n*-4*H*-SiC substrates having the specific resistance of 0.02−0.03 Ohm · cm (Fig. 1, *a*). Properties of contacts to *p*-SiC layers were studied on multilayer double-side polished intended for the manufacture of high-voltage *p*−*n*-diodes with *p*-type drift region [10]. Ohmic contacts were formed to the upper p^+-epilayer (Fig. 1, *b*). *I*−*V* measurements and extraction of ρ_c were performed using the linear TLM-method (Transmission Line Method) as the simplest one in implementation and an optimal one for the studied objects, being a „metal on-homogeneously doped semiconductor"structure [12].

Contacts for TLM-measurements were manufactured in the following sequence: RCA-cleaning of the SiC surface, 200 nm thick SiO_2 deposition, photolithography and openings in the SiO_2 layer, metal deposition lift-off for and TLM-topology formation (Fig. 1, *c*). In order to study the impact of annealing temperature on ρ_c, the wafers were cut into

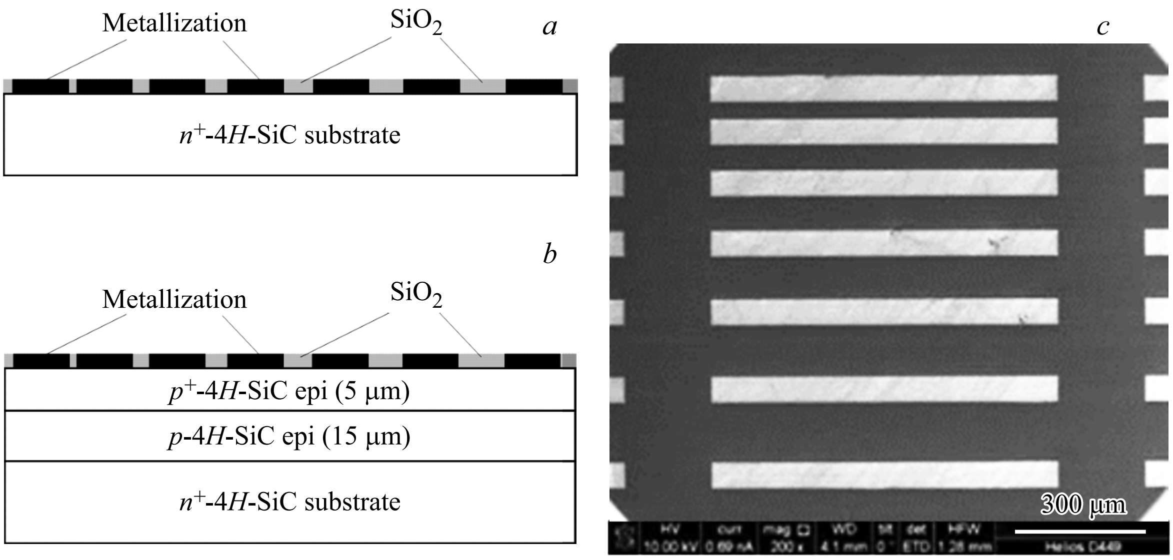

Figure 1. Schematic diagrams of test structures for studying contact resistances to n-4H-SiC (a), p-4H-SiC (b) and photography of their TLM-topology (c).

small-area samples so that the quantity of TLM-elements was at least 10 per sample.

High-temperature annealing of Ni/n-SiC, Ni/p-SiC, Ni/Al/p-SiC, Ni/Al/Ti/p-SiC samples was performed in vacuum at 800, 850–1100°C for 120 s.

3. Experimental results

I–V characteristics of the obtained samples were measured using the procedure for specific contact resistance determination by the TLM-method [12]. As an example, Fig. 2 shows I–V curves for as-deposited non-annealed Ni/n-SiC, Ni/p-SiC, Ni/Al/p-SiC, Ni/Al/Ti/p-SiC samples. It can be seen that the characteristics are not linear and virtually symmetrical in relation to the coordinate center. Their form corresponds to I–V characteristics of back-to-back Schottky barrier diodes made on heavily doped substrates or epitaxial layer. A non-linear current-voltage characteristic is stil observed on the samples annealed at 800°C (Fig. 2, a). Starting from the annealing temperature of 850°C and higher, the samples' current-voltage characteristics become linear (ohmic), which allows for correct determination of specific contact resistance by the TLM-method.

The calculation of specific contact resistance using the linear TLM-method has shown that the minimum values of ρ_c for the Ni/n-SiC, Ni/p-SiC, Ni/Al/p-SiC, Ni/Al/Ti/p-SiC samples are achieved at the annealing temperature of 1000°C (Fig. 3), which is probably optimal for the formation of low-resistance ohmic contacts. Figure 3 shows that the minimum specific contact resistance for Ni/n-SiC was $3.6 \cdot 10^{-4}$ Ohm $\cdot$ cm^2. This value is typical for ohmic contacts to n-SiC [1–4]. The Ni (200 nm)/Al (50 nm)/p-SiC samples among the studied contact systems to p-SiC had the smallest $\rho_c = 5.9 \cdot 10^{-5}$ Ohm $\cdot$ cm^2. This value is several

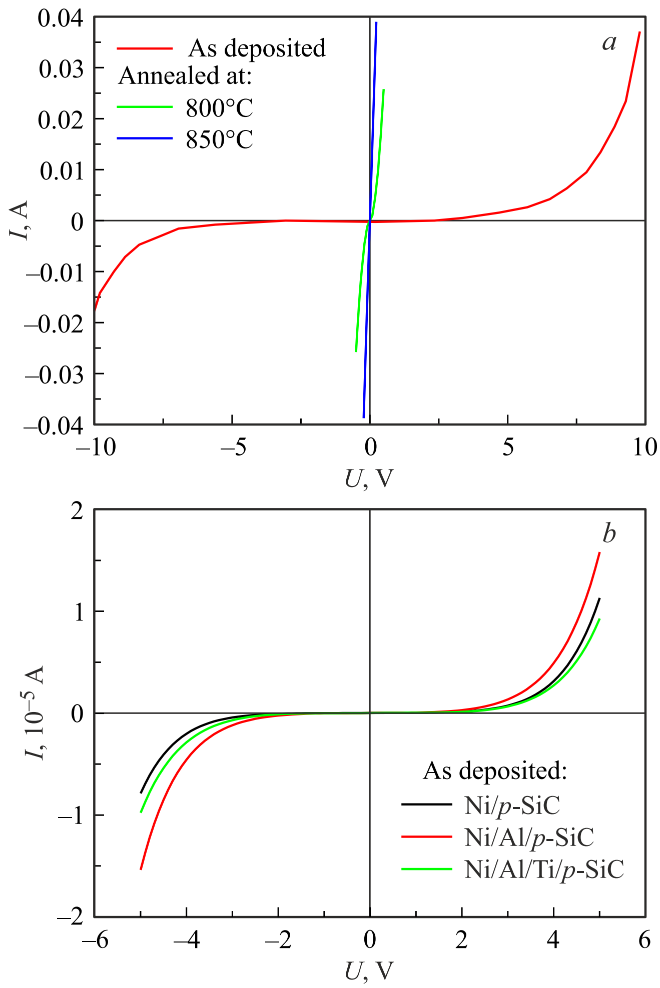

Figure 2. Current-voltage characteristic of contact systems: Ni/n-SiC (a) and Ni/p-SiC, Ni/Al/p-SiC, Ni/Al/Ti/p-SiC (b).

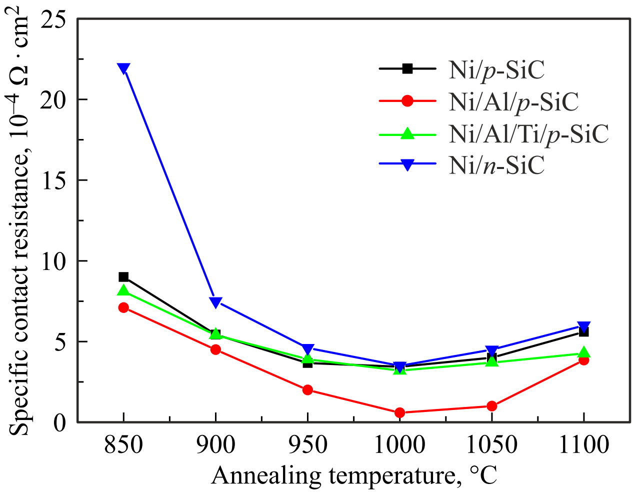

Figure 3. Plots of specific contact resistance for: Ni/*n*-SiC, Ni/*p*-SiC, Ni/Al/*p*-SiC, Ni/Al/Ti/*p*-SiC vs. annealing temperature.

times lower than specific contact resistance as compared to the composition based on Ni and Ni/Al/Ti which is widely used in the SiC-device technology [8]. As mentioned earlier, this result reflects the individual peculiarities of process operations during the formation of contact systems.

4. Conclusion

The studied contact systems have shown a low value of ρ_c to *n*-SiC and *p*-SiC, which allows for the use in the creation of device structures. It has been shown that the formation of low-resistance contacts based on Ni to *n*-4*H*-SiC and Ni/Al to *p*-4*H*-SiC is possible in a single process cycle of vacuum annealing at 1000°C for 120 s. This process solution makes it possible to reduce the number of high-temperature processes in the manufacture of bipolar devices based on 4*H*-SiC.

Conflict of interest

The authors declare that they have no conflict of interest.

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