Ohmic contacts to n-type 4H- and 6H-SiC

V I Egorkin, A V Nezhentsev, V E Zemlyakov, V A Gudkov and V I Garmash
National Research University of Electronic Technology, Moscow, 124498, Russia

Abstract. In this paper, the electrical properties of TiAl- and Ni-based ohmic contacts formed on n-type 4H- and 6H-SiC were studied. The dependence of the contact resistance on technological process was investigated. Ohmic contacts were formed by electron-beam deposition to different surfaces of silicon carbide. Short-term plasma-chemical etching of the active layer was used to improve TiAl-based contact to C-surface 4H-SiC. Using of Ni-based contacts to the Si-surface and TiAl-based to C-surface makes it possible to obtain a resistance of about $10^{-4}$ Ohm*cm$^2$. We got the process of making good ohmic contacts to 4H- and 6H-silicon carbide.

1. Introduction
Researchers make low-resistance contacts for the majority of wide-spread semiconductor materials. But for materials that have been relatively recently used for serial production of semiconductor devices, in particular for silicon carbide, the problem of obtaining low-resistance ohmic contacts, despite a considerable amount of experimental data, is still relevant. Work is under way to obtain ohmic contacts to silicon carbide with improved performance characteristics. Nickel-based metallization is the most common used for ohmic contacts manufacturing to the n- and p-layers of silicon carbide. It makes possible to obtain ohmic contact with a resistivity of about $10^{-4}$ Ohm*cm$^2$. Annealing leads to the reaction of nickel with silicon carbide, resulting in the formation of a Ni$_2$Si compound, which plays a decisive role in the ohmic contact formation to n-type SiC [1-3]. Ti-based metallization the second frequently encountered. The characteristic resistance is $10^{-4}$ Ohm*cm$^2$. Polytype and crystallographic surface affects the level of the contact resistance. This article shows the results of obtaining ohmic contacts to different faces and polytypes of SiC. We determined the most optimal combination of parameters for ohmic contacts to 4H- and 6H-silicon carbide.

2. Experiment
For the experiments, 6H-SiC Lelie crystals were taken with a donor concentration of $2.5*10^{18}$ cm$^{-3}$. We used doping with nitrogen ions (800 mKCl/cm$^2$), to increase the carrier concentration. Implantation was performed on the Lada-30 ion implantation unit. As a result, we obtained a concentration of donors in the near-surface region $>5*10^{19}$ cm$^{-3}$. We also used 4H-SiC crystals with initial carrier concentration $5*10^{19}$ cm$^{-3}$. We used lithographs to create a pattern of metallization. We also used a mask if the dimensions of the sample did not allow us to perform lithographic processes. The contacts were made by an electron-beam evaporation Kurt J. Lesker unit. We used two types of metallization: nickel-based and titanium-based. Contact metallization in the first case consisted of 100 nm of nickel, in the second 25 nm of titanium and 150 nm of aluminum. Contacts are four circles in one straight line with a diameter of 200 microns in steps of 1000 microns. We performed heat treatment (1000°C) after deposition. The annealing was carried out in a nitrogen atmosphere. The contact resistance was determined by the four-probe method [4]. Schematic diagram of the method is shown in Figure 1 [4].
where \( a \) is the contact radius, \( d \) is the distance between the contact centers. This equality holds for \( a << d \).

In all cases, the contacts after heat treatment were ohmic, except for one. TiAl-based contact to C-surface 4H-SiC had nonlinear I-V characteristic. The manufacturing process was repeated with special surface treatment. Short-term plasma-chemical etching of the active layer was used. Plasma-etching of silicon carbide was carried out on a Corial 200L unit in an inductively coupled plasma (ICP). Etching included two stages: Surface cleaning in argon plasma (300 seconds) and etching in a fluorine-containing plasma (SF6) with the addition of oxygen (120 seconds).

3. Results
The measured resistances for different crystallographic surfaces, metallizations and polytypes of silicon carbide are shown in table 1.

| Surface | Metallization (nm) | Resistance (Ohm*cm²) |
|---------|--------------------|----------------------|
| Si      | Ni (100)           | 2.56*10⁴             | 2.91*10⁴ |
| C       | Ni (100)           | 5.16*10⁴             | 4.15*10³ |
| Si      | TiAl (25/150)      | 3.71*10⁴             | 5.43*10³ |
| C       | TiAl (25/150)      | 2.50*10⁴             | 5.37*10³ |

An optical microscope was used to study the surface morphology. Images are shown in figure 2 and figure 3. The unevenness of the edge is caused by the unevenness of the mask used in the deposition. The presented contacts have a good surface morphology.
In Figures 2 it can be seen that the morphology determine by the type of metallization. The silicon carbide polytype has practically no noticeable effect. Small differences are observed for titanium-based metallization. After the annealing, it will behave differently for polytypes of silicon carbide.

4. Conclusion
We investigated the influence of crystallographic surface, metallization and polytype of silicon carbide on the ohmic contacts characteristics. It was established that it is possible to obtain low-resistance contacts to both polytypes and crystallographic surfaces. Ni-based metallization is more suitable for Si-surface. It allows to get resistance of about $3 \times 10^{-4}$ Ohm*cm$^2$ for both polytypes. TiAl-based metallization is more suitable for C-surface. It allows to get resistance $2.5 \times 10^{-4}$ Ohm*cm$^2$ for 6H-polytype. We used short-term plasma-chemical etching of the active layer for 4H-polytype, and it allows to get resistance $5.37 \times 10^{-4}$ Ohm*cm$^2$. Resistance to 6H-SiC is slightly lower. In our opinion, this is a consequence of the difference in the band gap of the semiconductor. Also, the contacts have
an acceptable surface morphology. This makes it possible to carry out lithographic processes in the future.

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