

Non-alloyed ohmic Cr/Pt/Au contacts to GaN based structures

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Abstract. The study of non-alloyed ohmic contacts based on Cr/Pt/Au is presented. Metallization was made on the epitaxial (Sample A) and ion-doped (Sample B) GaN layers. The deposited Au/Pt/Cr/n-GaN contacts exhibited an ohmic behavior with specific contact resistance $2.8 \times 10^{-6} \Omega \cdot \text{cm}^2$ and $3.5 \times 10^{-7} \Omega \cdot \text{cm}^2$ for the samples A and B respectively. The diode structures were made using Cr/Pt/Au system.

1. Introduction

The direct-gap semiconductor gallium nitride and solid solutions based on it are promising materials for creating devices in various areas of electronics. The use of nitride structures is currently not limited to optoelectronic applications. Such structures are used to develop the component base of power and microwave electronics, such as Schottky diodes and microwave elements. However, in order to realize the advantages of nitrides for obtaining highly efficient devices, an advanced technology is needed to obtain stable ohmic contacts to the semiconductor. Low specific resistivity, high reliability at elevated temperatures and good reproducibility of ohmic contacts are the most important factors that limit the output characteristics of devices. To date, a large number of metallization systems have been proposed and studied for the formation of ohmic contacts of instrumental structures based on gallium nitride. Among them, the most widespread is the Ti/Al-based system. Such metallization can be described as Ti/Al/X(Ni, Ti, Mo, Pt, Pd)/Au [1, 2]. To obtain low-resistance contacts based on this metallization system, one needs to select the thickness of individual layers and the temperature-time processing regimes [3]. As a rule, annealing temperatures for such systems are in the range 800-900 °C.

The use of high-temperature treatment for multilayer metallization systems (above 800 °C) leads to a deterioration in the morphology of the metallization surface, which makes it difficult to carry out further operations to form the gate region. The presence of an uneven edge in ohmic contacts ultimately affects the parameters of the instrument structures. At the same time, a decrease of annealing temperature leads to an increase in contact resistance. To solve this problem, it is necessary to develop a technology for creating ohmic contacts without high-temperature treatments.

2. Experimental method

For the experimental work, epitaxial structures of gallium nitride grown on 2 inch sapphire substrates by the method of chemical vapor deposition from the gas phase using organometallic compounds were used. In the framework of the work, the parameters of ohmic contacts formed on epitaxial and ion-doped GaN layers are compared (Figure 1).



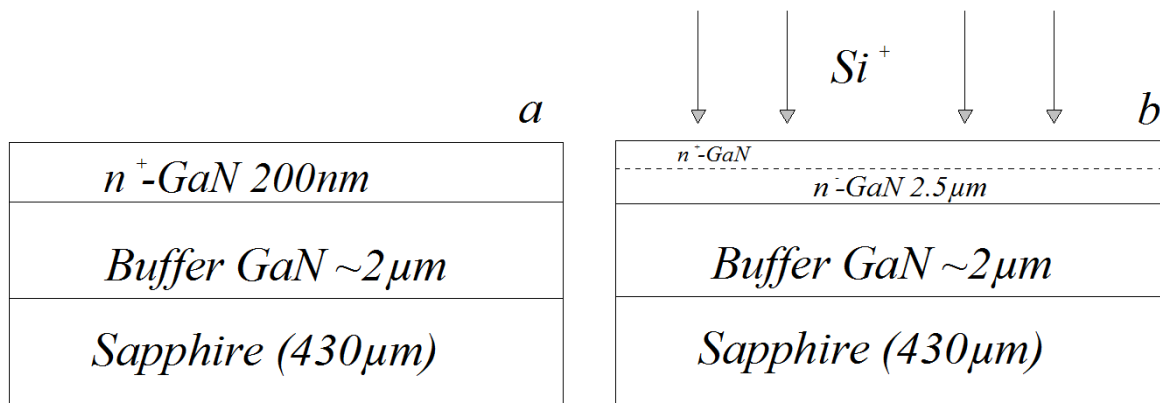


Figure 1. Initial GaN structures: *a* - structure with epitaxial n^+ layer; *b* - structure with ion-doped n^+ layer.

In the structure shown in Fig. 1a, an epitaxial layer of gallium nitride with a charge carrier concentration of $4 \cdot 10^{18} \text{ cm}^{-3}$ is used. In the sample in Fig. 1b, the n^+ GaN layer was made by ion doping. To form the layer, the technology of ion implantation of Si^+ in GaN was used [4]. Embedding of the impurity was carried out with an energy of 50 keV and a dose of 10^{15} cm^{-2} . To prevent the channeling effect, the wafers were placed at an angle of 7° to the normal of the incident beam. To activate the embedded impurity, photon annealing was used. The annealing was carried out at 1250° C during 1 minute in nitrogen atmosphere [5]. As a protective coating, before the photon annealing, a SiO_2 film was deposited on the GaN surface. After activation, the concentration of charge carriers in the n^+ GaN layer was $2 \cdot 10^{19} \text{ cm}^{-3}$.

As a metallization of ohmic contacts for the structures under consideration, a Cr/Pt/Au-based system was used. The contacts were formed by electron-beam deposition of the metallization system using liftoff photolithography. The quality of the ohmic contacts was estimated from the specific contact resistance determined by the TLM method [6].

3. Measurement results

The resistance of the contacts was measured using test elements at the semi-automatic station Cascade Microtech. As a measuring part for the control of parameters on a direct current, we used a meter for the characteristics of semiconductor devices Agilent B1505A.

After deposition, the contacts showed ohmic characteristics with a resistance of $2.8 \cdot 10^{-6} \Omega \text{ cm}^{-2}$ and $3.5 \cdot 10^{-7} \Omega \text{ cm}^{-2}$ for samples with epitaxial and ion-doped n^+ GaN layers, respectively. To evaluate the parameters of contacts, a study was made of the effect of annealing on the characteristics of the contacts. The annealing was carried out in the temperature range $400 - 800^\circ \text{ C}$ during 1 minute.

The characteristics of the tested samples are shown in Figure 2.

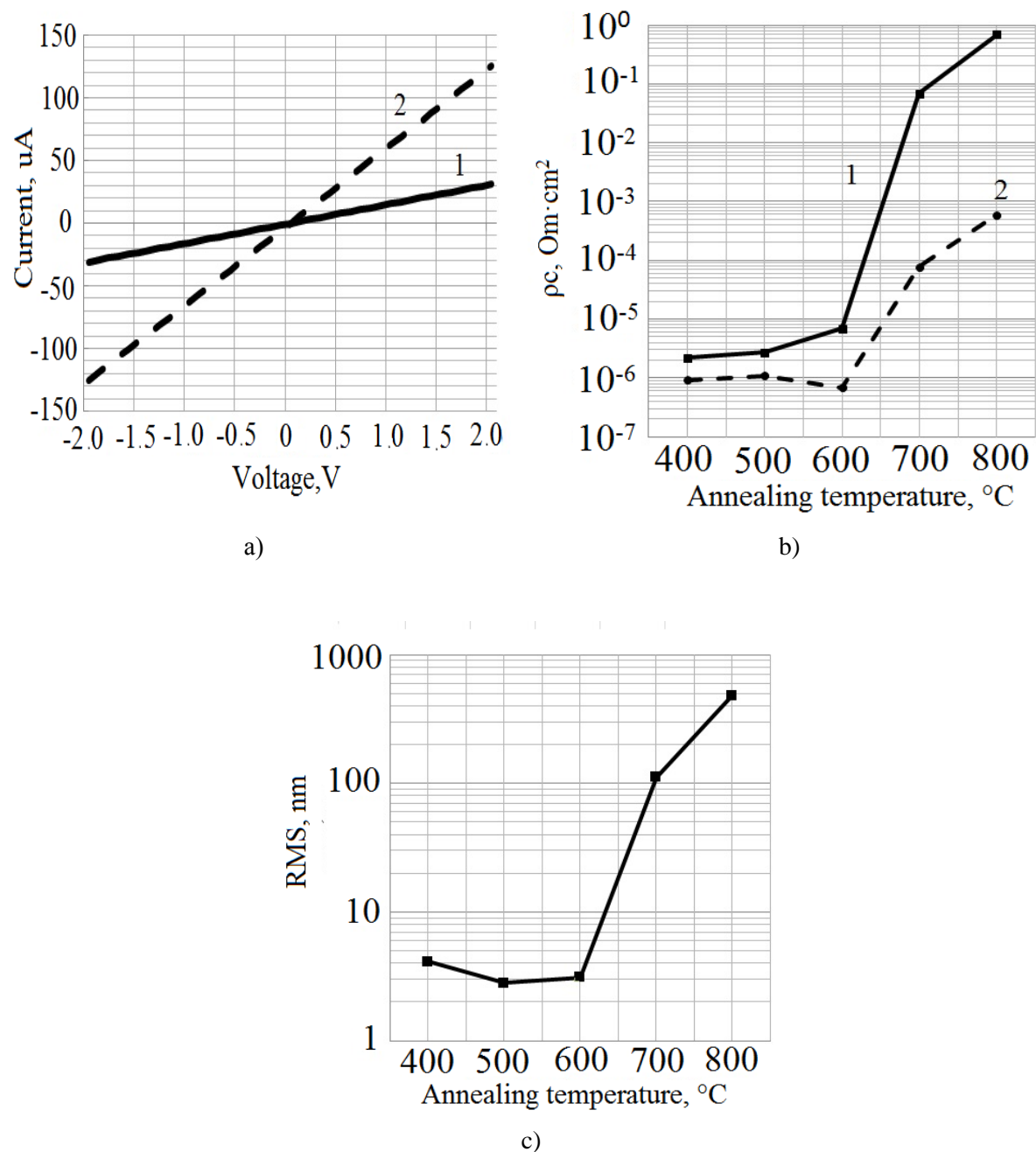


Figure 2. Effect of the heat treatment on the characteristics of the contacts for GaN samples

1 - epitaxial layer of GaN; 2 - ion-doped GaN layer:

a - current-voltage characteristics of contacts to the structures;

b - the effect of the annealing temperature on the contact resistance of the contacts;

c - the influence of the annealing temperature on the value of the root-mean-square roughness of the surface.

The contacts obtained show ohmic characteristics up to an annealing temperature of 600 $^{\circ}\text{C}$, while the specific contact resistance changes comparatively little. The contacts become nonohmic at annealing

temperatures from 700° C. Deterioration of characteristics is caused by the processes of diffusion of metals into a semiconductor under high-temperature treatment. As shown in Fig. 2c, there is a sharp deterioration in the surface morphology, determined by the rms surface roughness. We also compare the system based on Cr/Pt/Au with the Ti/Al/Ni/Au-based system of the contacts to epitaxial layers of gallium nitride. In this case, Ti/Al/Ni/Au contacts show nonohmic characteristics after deposition and heat treatment up to 600° C. At high temperatures, there is a noticeable interaction of metals in the metallization system, leading to a decrease in the contact resistance, as shown in Fig. 3. To obtain ohmic contacts in the case of Ti/Al/Ni/Au system, heat treatment at a temperature above 600°C is needed.

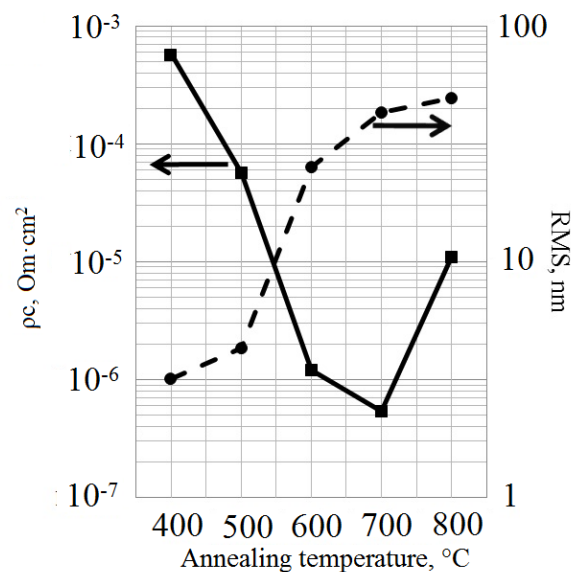


Figure 3. Effect of heat treatment on the characteristics of contacts for the system Ti/Al/Ni/Au.

Using the obtained data, instrument structures of Schottky diodes were formed. The Ni/Au (0.07/0.3 μm) system was used as the metallization of the barrier contacts. The diameter of the Schottky contact was 500 μm . Passivation of the structure was carried out by a film of silicon nitride 150 nm thick, obtained by plasma-chemical deposition using a gas mixture of monosilane, ammonia and nitrogen. The study of the current-voltage characteristics of the structures obtained (Fig. 4) shows the perspectives of using the ion doping technology for the formation of subcontact regions. From the current-voltage characteristic, the value of the direct voltage drop at the direct current level of 100 A/cm² was estimated. For structures with ohmic contacts based on Cr/Pt/Au, it is 0.7 V, and for ones based on Ti/Al/Ni/Au it is 1.35 V. From the current-voltage characteristics, the Schottky contact parameters are determined. The Schottky barrier value for structures with ohmic contacts based on Cr/Pt/Au was 0.63 eV, and the nonideality coefficient was -1.15. These parameters are close to theoretical values.

4. Conclusion

Thus, in the course of the work, a Cr/Pt/Au metallization system was investigated to form ohmic contacts to epitaxial and ion-doped gallium nitride layers. It is shown that the use of this system makes it possible to obtain ohmic contacts to GaN without the use of high-temperature annealing. This system makes it possible to obtain contacts with a specific contact resistance of the order of $2.2 \cdot 10^{-6} \Omega \cdot \text{cm}^2$ for the epitaxial n⁺ GaN layer and $9.1 \cdot 10^{-7} \Omega \cdot \text{cm}^2$ for the ion-doped n⁺ GaN layer. Diode structures with the use of non-alloyed Cr/Pt/Au metallization were fabricated, their characteristics were measured and a comparison was made with the characteristics of structures with a Ti/Al/Ni/Au system. The advantage of the Cr/Pt/Au system is demonstrated.

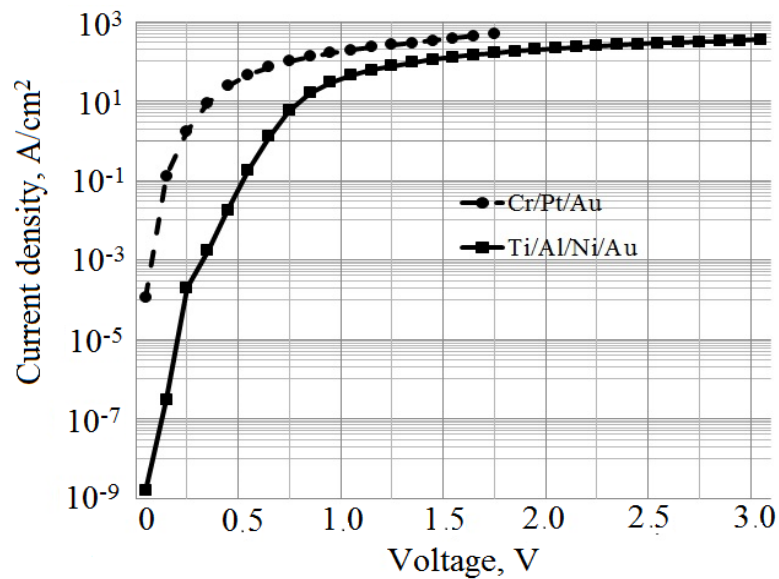


Figure 4. Current-voltage characteristics of diode structures with ion-doped subcontact layers for different ohmic contact systems.

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