

Characterization of Ohmic contacts on GaN/AlGaIn heterostructures

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Abstract

The surface morphology and electrical resistance of the contacts on semiconductor devices are strongly influenced by metallization scheme and annealing conditions. In this work is presented an investigation of Ohmic contacts formed by metal–semiconductor alloying on epitaxial GaN/AlGaIn heterostructures. After the deposition of metallic multi-layers (Ti, Al, Au and Pt), the process of rapid thermal annealing was carried out in nitrogen, argon and forming gas atmosphere.

A series of the samples with different sequences of metallic layers and diverse thicknesses was prepared by employing electron beam evaporation and lift-off deposition techniques. The chemical composition of the samples before and after annealing was studied by means of X-ray photoelectron spectroscopy (XPS) and Auger electron spectroscopy (AES) techniques combined with low energy Ar⁺ ion sputtering. The sputtering has been carried out in two different modes: by using constant (square) or gradually narrowed sputtered area. The changes in the chemical state of constituent elements and compositional profiles of the contacts after thermal annealing were revealed from the obtained results. Among the technological problems, influencing on the quality of the contact, were found to be the oxidation and nitridation of the contact surface during thermal annealing, as well as the intermediate sub-layers of Al and Ti oxides, formed during the deposition of metallic multi-layered structure.

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1. Introduction

The production of metal contacts is a fundamental aspect in the continuous improvement of the fabrication of GaN-based electronic and optical devices, such as visible LEDs, HEMTs and metal–semiconductor FETs. It is well-known that the performance of the devices with p–n junction (as GaN-based LEDs and HEMTs) is drastically influenced by the contacts resistance and could be substantially improved by reducing the resistance between the metal and semiconductor [1–3]. Moreover, the good contacts must be stable and present a linear current–voltage dependence. Some studies of the contacts based on the single metal layer (Au, Pt, Ti, etc.) have been done by using various experimental techniques [4,5].

In the recent years, the multi-layer structures of different metals have been widely used for the production of Ohmic contacts in the GaN/AlGaIn high electron mobility transistor (HEMT) devices [6]. Most of these metallization schemes include Ti as a first metal-layer on the ion-etched surface of GaN or AlGaIn [5,7–10]. Titanium has been chosen since it presents a low ionisation potential which permits to produce a metal–semiconductor junction with Schottky barrier height of 4.25 eV, a value which is lower than the barriers for other metals, in such a way favouring the migration of the electrons from semiconductor to the contact. In order to prevent the formation of native oxides on the Ti layer, it is common to deposit the subsequent layers of other metals (Al, Au and Pt), where the aluminium is normally deposited on the titanium and the most external layer is usually Au.

After the deposition of metallic multi-layer, a high temperature short-time treatment (rapid temperature pulse (RTP)) in ultra pure N₂ or Ar atmosphere is performed in order

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Table 1
Multi-layer composition of the samples

Layer	Scheme A	Scheme B	Scheme C	Scheme D
1 (top)	40 nm Au	55 nm Au	50 nm Au	5 nm Ti
2	40 nm Pt	45 nm Ti	20 nm Ti	40 nm Au
3	45 nm Ti	100 nm Al	40 nm Pt	40 nm Pt
4	100 nm Al	20 nm Ti	45 nm Ti	45 nm Ti
5	20 nm Ti	–	100 nm Al	100 nm Al
6	–	–	20 nm Ti	20 nm Ti

to improve the adhesion metal–semiconductor and to permit the formation of alloyed of the deposited metals, that protects the underlying Ti layer. During this process, it is expected the formation of TiN sub-layer on the semiconductor surface, the formation of TiN sub-layer. This sub-layer results in an excess of N vacancies in the AlGa_{0.85}N close to the interface which is considered to be the reason for the low resistance of the contact [11].

The intent of the present work is to obtain the information about the formation of the contacts on the surface of GaN/AlGa_{0.85}N heterojunction. In particular way have been investigated the modifications, caused by the RTP treatment at high temperature, comparing the chemical composition of the multi-layer contacts before and after this treatment. For this purpose, were used the measurements of X-ray photoelectron spectroscopy (XPS) combined with Ar⁺ ion sputtering. Further information have been obtained by using Auger electron spectroscopy (AES), which permits to investigate different surface zones of the GaN wafer with metallic contacts.

2. Experimental

Table 1 illustrates three different multi-layer schemes used for the production of metallic contacts. These schemes follow a general metallization technology, widely adopted for the contacts production on GaN-based HEMTs. In addition, all the treatments of the investigated samples are listed in Table 2. The samples #3 and #6 were produced in order to investigate the influence of the substrate. The micro-contacts of real devices (sample #7) were produced by using a standard photolithography.

The heterostructures, used for this study, consisted of AlGa_{0.85}N ($d = 30$ nm) and GaN with different thicknesses (see Table 2) on sapphire substrate. The samples #1, #2 and #6 were produced by using the commercial heterostructures (QinetiQ

Ltd., UK), while for the samples #3, #4, #5 and #7 were used the heterostructures produced at the University of Lecce by using the MOCVD.

The metallic layers were deposited by using an e-beam evaporator Balzers BAK 600 in the following way:

- (1) ion bombardment of the AlGa_{0.85}N/GaN surface in order to eliminate the contamination from the atmosphere;
- (2) deposition of Ti (20 nm) and Al (115 nm);
- (3) ion bombardment of the Al surface in order to remove the layer of native oxides, caused by opening of the deposition chamber to insert the next target;
- (4) subsequent deposition of other metals, following the metallization schemes from Table 1.

Every sample was cut in two pieces, one of these pieces was treated by RTP in different atmospheres (see Table 2). For RTP treatment, the samples were placed into graphite crucible covered with SiC and were heated in a furnace Heatpulse 410, produced by the AG associates.

All the samples have been fixed on the standard VG Escalab sample holder stub by means of a Cu foil mask (with a window of 3 mm diameter). The selected-area XPS (SA-XPS) measurements and Ar⁺ ion sputtering were performed in a VG Escalab MkII spectrometer (5 channeltron detection system) and an unmonochromatized radiation source of Al K α (1486.6 eV). The electrostatic lenses were operated in the selected-area mode, providing photoelectron collection from the sample area of about 1 mm². The binding energy (BE) scale was calibrated by measuring the reference peaks of Au 4f_{7/2} (84.0 eV) from the samples and C 1s (285 eV) from the initial contamination of the sample surface. The pressure of 5×10^{-8} Pa into the analysis chamber was increased up to 2×10^{-5} Pa for ion sputtering with a differentially pumped Ar⁺ ion gun. The Ar⁺ ion beam of 2.0 keV energy, operated at a current density $j = 3 \mu\text{A}/\text{cm}^2$, was rastered over an area of 3 mm $\times$ 3 mm.

AES/SAM experiments were performed by using the same spectrometer. The submicron-spot electron gun, a LEG 200, was operated at 8 keV and 1–10 nA current. Auger spectra were registered in a constant retard ratio (1:4) analyser mode. Surface chemical images were obtained as peak height minus background height ($P - B$).

3. Results and discussion

The depth profile of the sample #1, showed in Fig. 1, reveals a typical multi-layered composition of deposited metals. The scale of sputtering depth has been calculated by using as a reference the nominal thickness value of Au top-layer. The sputtering rates for other metals have been calculated by using the relative sputtering rates determined for the Escalab MkII [12]. Obtained values of the thickness, presented in Fig. 1, are in a good agreement with the nominal values for separate layers. Every layer is uniform in-depth and the interfaces between the layers are narrow enough. Starting from Al_xGa_{1-x}N layer and going up towards the surface, the first

Table 2
Treatments of the samples

Samples	Scheme	RTP (atmosphere)	Heterostructure
#1	A	No	Al _{0.15} Ga _{0.85} N/GaN ($d = 2 \mu\text{m}$)
#2	A	Yes (N ₂)	Al _{0.15} Ga _{0.85} N/GaN ($d = 2 \mu\text{m}$)
#3	B	No	Al _{0.25} Ga _{0.75} N/GaN ($d = 1 \mu\text{m}$)
#4	B	Yes (N ₂)	Al _{0.25} Ga _{0.75} N/GaN ($d = 1 \mu\text{m}$)
#5	B	Yes (Ar)	Al _{0.25} Ga _{0.75} N/GaN ($d = 1 \mu\text{m}$)
#6	B	No	Al _{0.15} Ga _{0.85} N/GaN ($d = 2 \mu\text{m}$)
#7	D	No	Al _{0.25} Ga _{0.75} N/GaN ($d = 1 \mu\text{m}$)
#8	C	Yes (N ₂), photolithography	Al _{0.25} Ga _{0.75} N/GaN ($d = 1 \mu\text{m}$)

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