Scholar Journal
Available online:
www.journalsci.com
Journal of Science and today's world
ISSN 2322-326X

Research Article

Electronic spectroscopic study of the GaAs nitridation – Electronic Design and modeling associated

N. Bachir Bouiadjra[1*], Z. Benamara[1], A. Sellam[2], L. Bideux[3], C. Robert[3], B. Gruzza[3]

[1] Laboratoire de microélectronique appliquée, Université Djillali Liabès de Sidi Bel Abbès, 22000, ALGERIA
[2]Laboratoire IRECOM, Université Djillali Liabès de Sidi Bel Abbès, 22000, ALGERIA
[3] Laboratoire des Sciences des Matériaux pour l'Electronique et d'Automatique (LASMEA), UMR 6602, 24 Avenue des Landais, 63177, Aubière CEDEX, France

***Received:* 23 December 2012 / *Accepted:* 25 February 2013 / *Published:* 30 March 2013**

Abstract

Gallium nitride is one of the III-V semiconductors the most promising in many application areas. Indeed, because of its large direct bandgap (3,4 eV), it can be dedicated to both optoelectronic applications as transistors achieve hyper frequency. It allows the manufacture of components stable at high temperatures and high frequencies. In this work we are interested in the nitriding of gallium arsenide substrates of n-type in order to obtain a thin layer of GaN. The samples were chemically cleaned immediately introduced into the chamber ultra-high vacuum. They then undergo ionic cleaning in situ by argon ions. Spectrometric analyzes do show the absence of any impurities from the surface, in fact, it only detects the presence of gallium and arsenic. Before proceeding to the nitriding of our structures, deposition of gallium is conducted for 20 minutes to send then simultaneously nitrogen and gallium. Analyzes were performed elaborate structures

* Correspondence should be addressed to N. Bachir Bouiadjra, Laboratoire de microélectronique appliquée, Université Djillali Liabès de Sidi Bel Abbès, 22000, ALGERIA, Email: b_cler@yahoo.fr.

using X-ray photoelectron spectroscopy (XPS). Deposition of mercury (Hg) has been developed on the structures; we have then made an electrical characterization I-V to see the effect of nitriding on the resulting structure.

Keywords: GaAs, GaN, XPS, I-V characterization, Schottky diode

1. Introduction

A nitridation of GaAs is intensively studied in the last years as the first step of GaN layer deposition or a method for stabilization and passivation of a GaAs surface. Chemical and structural studies on a GaAs surface during and after nitridation. In this paper, we are interested in the nitridation of GaAs to obtain a Schottky diode rectifier perfectly. The I-V characteristic shows that our structure are Schottky diode rectifier whose electrical parameters are determined by a fitage of different regions of the characteristic; for our structure, we have determined the values of the series resistance, parallel resistance and the saturation current which are respectively 13Ω, 500Ω et $2{,}5.10^{-6}$ A. Modeling allowed us to define the modes of conduction in our developed structures.

2. Material and Methods

2.1. Sample Preparation

2.1.1. Cleaning samples

The gallium arsenide substrates used were commercial substrates which are in the form of circular plates of thickness of 400 µm and a diameter of about 50 mm. These substrates were made by Czochralski pulling and then cut along the (100) orientation. These samples are doped n-type carrier concentration is $N_d = 1{,}4\times10^{18}$ atomes/cm^3. It is necessary to chemically clean the substrates as they contain various impurities such as oxides and fats. The samples chemically cleaned were immediately introduced into the chamber ultra-high vacuum. They then undergo ionic cleaning in situ and characterized by photoelectron spectroscopy (XPS). All spectra were performed under excitation with X skate MgKα with energy hν = 1253,6 eV. To our experience, the ion cleaning with Ar + ions, is carried out with an argon ion kinetic energy of 1 keV, a current density of 3.8 µA/cm^2 beam, argon pressure in the chamber of 4.10^{-5} Torr with a cleaning time of 60 min.

3. Results and discussion

3.1. Study of the evolution of the Ga3d transition

Figures 1 and 2 show respectively the Ga_{3d} transition after chemical cleaning and after cleaning ion respectively. We have broken this transition in a single peak as the difference in energy doublet $Ga_{3d5/2}$ $Ga_{3d3/2}$ related to the spin-orbit coupling is small (0.44 eV) [1, 2, 3]. The peak position associated with the GaAs link is located at 19,2 ± 0,2 eV [4]. As shown in Figure 1, a GaAs substrate, although subjected to chemical cleaning has yet oxides. Indeed, there is a contribution located at 20,4 eV ± 0,2 eV which corresponds to the Ga-O bonds attributed to gallium oxide Ga2O3 [4,5]. The analysis also shows that the transition ion bombardment of the substrate does not involve the formation of metallic gallium on the surface. In fact, the Ga_{3d} transition has not a contribution of metalic gallium at 0,7 ± 0,2 eV [4] towards lower bond energies. The parameters of the decomposition peak shape and width at half height of a peak in a given transition are determined from the decay of the peak in the cleaned substrate. We considered that the width at half height of a transition is independent of the nature of the chemical bond. Note that the peak intensities of photoelectrons are measured relative to a reference sample or placed in the test chamber.

The decomposition parameters of the Ga_{3d} transition are [1]:

- Width at half-height : 1,8 ± 0,2 eV ;
- Peak shape : 20% gaussien – 80% lorentzien.

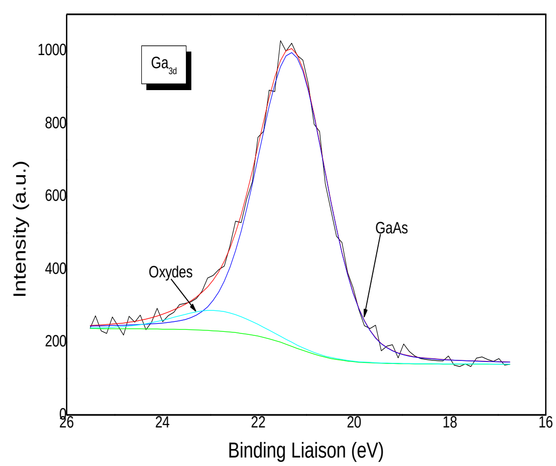

Figure 1. Spectrum of the Ga_{3d} transition after chemical cleaning

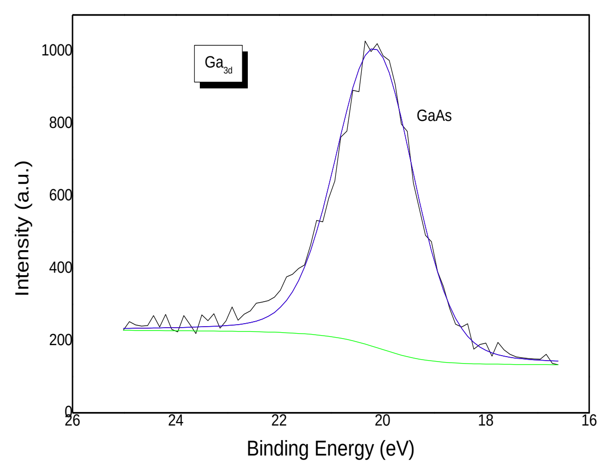

Figure 2. Spectrum of the Ga_{3d} transition after

3.2. Study of the As3d transition

This transition is shown in Figure 3. It represents the XPS spectrum of the As_{3d} transition cleaning after 60 min with argon ions. It includes only the contribution As-Ga bonds which is located at 40,8 ± 0,2 eV [4, 6]. This contribution is divided into doublet $As_{3d5/2}$ and $As_{3d3/2}$ related to spin-orbit coupling with the gap in the doublet is 0,7 eV and which the area ratio is between 1,2 and 1,4. The parameters of the decomposition peak shape are [1] :

- Width at half-height : 1,6 ± 0,2 eV ;
- Peak shape : 50% gaussien – 50% lorentzien.

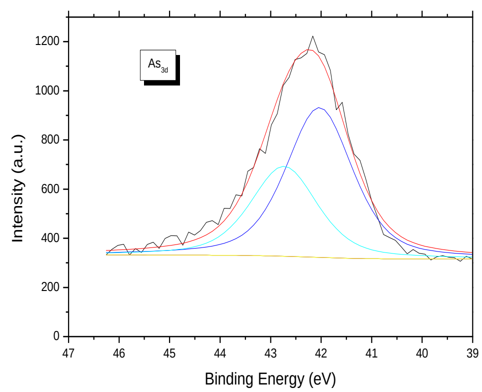

Figure 3. Spectrum of the AS_{3d}

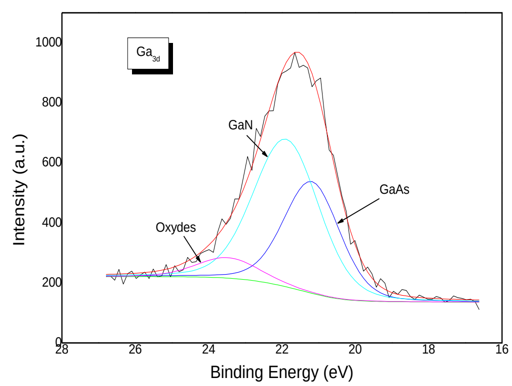

Figure 4. Spectrum of the Ga_{3d} transition

3.3. Study nitriding substrates

We studied the nitridation of GaAs using as a source of nitrogen production assets, the source type radio-frequency plasma. We prepared samples nitrided at a temperature of 550 ° C and a pressure of 2×10^{-4} Pa. Figure 4 shows the spectrum of the Ga_{3d} transition after nitriding. This transition has a new contribution at 0,7 ± 0,2 eV towards higher binding energies. It corresponds to the Ga-N bonds [2, 7]. The parameters used for the decomposition Ga_{3d} nitrided were kept identical to those of Ga_{3d} cleaned. This transition also includes a contribution due to oxides of gallium. The oxidation rate is 13% of the surface of the GaN bonds. This oxidation is attributed to experimental conditions such that the residual pressure of oxygen in the deposition chamber.

Figure 5 shows the N_{1s} transition. It includes a contribution located at 397 eV associated with Ga-N bonds [8] and a contribution located at 2.5 eV to higher energies. This contribution is attributed to bonding states of (N-Ga-O) type content in the nitride film.

The decomposition parameters of the N_{1s} transition are [1] :

- Width at half-height : 2,2 ± 0,2 eV ;
- Peak shape : 50% gaussien – 50% lorentzien.

Figure 6 shows the As_{3d} transition. It comprises in addition to the associated pair of links with the substrate, a contribution located at 1,4 ± 0,2 eV, to higher energies. This contribution is probably due to connections arsenic oxides [9].

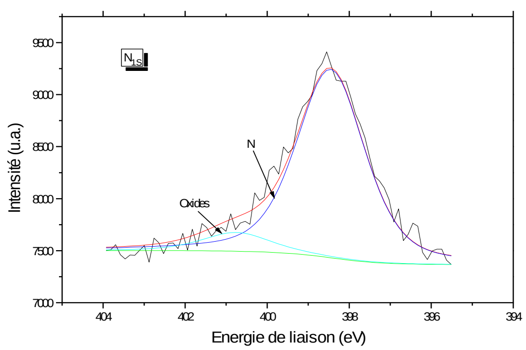

Figure 5. Spectrum of the N_{1S} transition

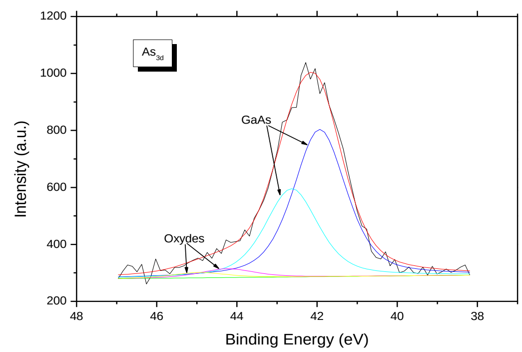

Figure 6. Spectrum of the As_{3d} transition

3.4. Electrical characterization

3.4.1. Numerical modeling

The main process of electrical conduction observed in a Schottky diode are;

The thermionic emission of carriers who can cross the barrier. The expression that connects the current potential applied directly on the diode is [10]:

$$I(V) = I(0) \times \exp\left(\frac{q \times V - R_S \times I}{n \times K_B \times T}\right) \qquad (1)$$

Where V is the direct applied bias, n is the ideality factor, Rs is the series resistance of the diode, I(0) is the saturation current. With ideality factor near 1. The recombination of carriers on deep centers generation-recombination. The current follows, again, the law of variation given by equation (1), with ideality factor near 2. The tunneling of electrons through the potential barrier of semiconductor to the metal. The tunnel effect can be observed, under direct polarization in the case of a degenerate semiconductor. The equation of tunnel current is given by the following equation [10]:

$$Itu(V) = Itu(0) \times \exp\left(\frac{V - R_S \times I}{E_0}\right) \qquad (2) \qquad \text{where : } E_0 = E_{00} \times \coth\left(\frac{q \times E_{00}}{k_B \times T}\pi\right)$$

$$\text{With : } E_{00} = q \times \frac{\hbar}{2}\sqrt{\frac{N_d}{\varepsilon_0 \varepsilon_s m_e^*}}$$

If there is a highly conductive layer at the metal-semiconductor interface, which is the origin of leakage currents in the diode, the current may be due to the effect of a parallel resistance R_p. The term of this current is [10] :

$$I_{R_P}(V) = \frac{V - R_S \times I}{R_p} \qquad (3)$$

This is more likely when the level of reverse current is high enough.

3.4.2. Electrical measurements

To study the effect of nitriding of electronic devices based on GaAs, I-V characterization was made on nitrided GaAs on GaAs chemically cleaned and non-nitrided. For an electronic device, a ball of mercury is applied onto the two structures. The result of the direct I-V characterization is shown in Figure 7. This figure shows that we have a current gain important for the structure based on GaAs nitrided structure which corresponds to a rectifier. We explain this in that the nitridation of GaAs has the effect of preventing oxidation of the surface. In addition, the GaN layer obtained is very thin (≈ 30Å), so the resulting structure is actually a Schottky diode Hg/GaAs with a GaAs surface treated by nitriding. Figure 8 shows the direct and reverse I-V characteristic of the Hg/GaN/GaAs structure on a semi-logarithmic scale. This figure shows that the direct characteristic contains two parts corresponding to two different conduction models. For bias voltages greater than 0.55 V, the characteristic is dominated by the series resistance effect with a conduction due to the phenomenon of generation-recombination because the ideality factor is about 2. However, for low direct bias voltages and under reverse bias, the various adjustments experimental results show that the current observed may be related to an effect of parallel resistance that the reverse current is relatively high. A fitage of the experimental curve with modeled curves (see Figure 9) to determine the reverse saturation current, the series resistor, the parallel resistor and the potential barrier height which are respectively measured at :
$I_S = 2{,}5.10^{-6}$ A ; Rs = 13 Ω ; Rp = 500 Ω ; $\Phi_{BN} = 0{,}63$ eV .

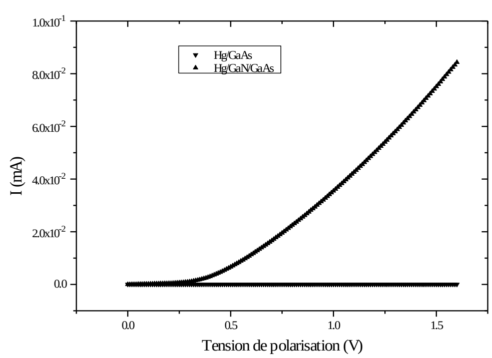

Figure 7. Direct I-V Characteristics for Hg/GaAs and Hg/GaN/GaAs structures

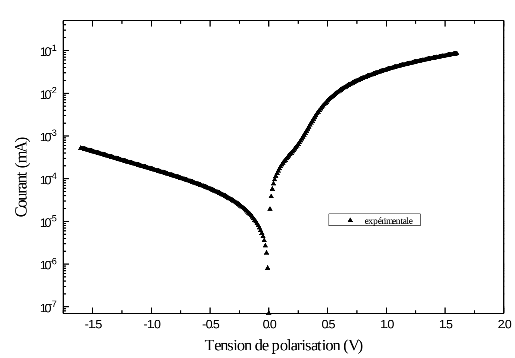

Figure 8. Direct and reverse I-V Characteristic for the Hg/GaN/GaAs structure

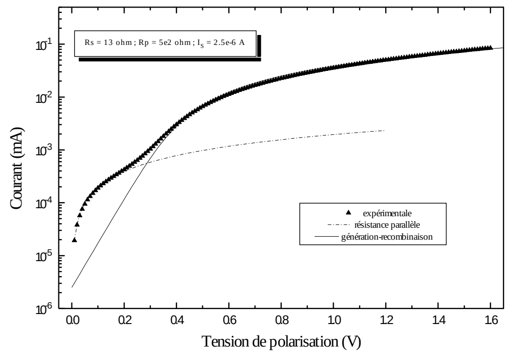

Figure 9. Direct I-V Characteristics modeled and experimental

4. Conclusion

In this work, we have demonstrated the effectiveness of the process of nitriding of GaAs for obtaining the first GaN layers. We have demonstrated the interest of the photoelectron spectroscopy (XPS) for the control of surface evolution based treatments applied to the surface of the substrates. This analysis also enables us to know the elements present on the surface as well as the elements which are connected. We noticed that the nitridation of GaAs at the same time causes the oxidation of the surface oxidation that we assigned to experimental conditions such that the residual pressure of oxygen in the deposition chamber. I-V Electrical measurements on two structures type Hg/GaAs et Hg/GaN/GaAs ; the second structure looks rectifier with high current gain while the first structure did not. We also model the I-V characteristic obtained for the structure Hg / GaN / GaAs to determine some electrical parameters of the developed structure.

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