Optik 127 (2016) 6412–6418

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Electrical and photoelectrical characteristics of Au/GaN/GaAs Schottky diode

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ARTICLE INFO

Article history:
Received 3 March 2016
Accepted 20 April 2016

Keywords:
Au/GaN/GaAs
Photovoltaic effect
Schottky diode
Photoelectrical

ABSTRACT

The electrical and photovoltaic properties of Au/GaN/GaAs Schottky diode have been investigated in dark conditions and under illumination. The forward and reverse bias current (I–V) measurements were performed at room temperature. The diode has been fabricated in a simple way using nitridation process of GaAs substrate followed by an annealing process at 620 °C. The tin (Sn) Ohmic contact, was deposed on the back face of the sample with the use of NH_4Cl. The diode has been characterized by I–V measure. The results show that annealed samples with an Ohmic contact has lower values of the series resistance (Rs) and ideality factor n (16.22 Ω and 1.92, respectively) compared to the values obtained for the sample without metallization (9.2 kΩ, and 5.38). Furthermore, measurement of illumination impact on the device performance has been performed, in the forward bias the superposition principle is reflected in the samples which underwent annealing process. Furthermore some photovoltaic parameters were estimated, such as: short circuits current (I_{SC}), open-circuits voltage (V_{OC}) and fill factor (FF).

1. Introduction

Metal-semiconductor (MS) contact madeof III–V based semiconductors, such as: GaAs or GaN, is active topic in an electronic industry but at the same time is the subject of considerable controversy [1]. To the main applications of MS contacts we can include: microwave field effect transistors, high-temperature electronics, high-density optical data storage devices, space solar cells, blue/green diode lasers and light emitting diodes [2].

A good MS contact is essential for the successful operation of aforementioned electronic devices. Furthermore, an important role in controlling the electrical performances of semiconductor devices are Schottky contact and Schottky barrier height (SBH), which are important parameters that determine the electrical characteristics of the MS contacts [3]. It is well known that the electrical characteristics of a Schottky contact can be controlled mainly by its interface properties [4,5], and the overall performance of diodes depends on the surface and interface state density (Nss). For instance, GaAs surface can be covered with a layer of few nm of native oxide allowing to pin the surface Fermi level within the band gap of semiconductor. In this case the surface states act as recombination generation centers that cause a reduction of carrier lifetime, an increase of the device noise and of the leakage currents. Accordingly, surface of the device needs to be passivated in order

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http://dx.doi.org/10.1016/j.ijleo.2016.04.113

Table 1
Preparation procedure.

	Sample 1	Sample 2	Sample 3	Sample 4
GaAs concentration	4.9×10^{15} cm^{-3}	4.9×10^{15} cm^{-3}	4.9×10^{15} cm^{-3}	4.9×10^{15} cm^{-3}
Nitridation conditions	500 °C, 5W, 5 min	500 °C, 5W, 30 min	500 °C, 5W, 30 min	500 °C, 5W, 30 min
Annealing	620 °C at 60 min	620 °C at 60 min	620 °C at 60 min	–
GaN thickness	0.7 nm	2 nm	2 nm	2.2 nm
Schottky contact	Au	Au	Au	Au
Ohmic contact	Sn	–	Sn	Sn

to reduce electronically active surface states [6,7]. It has been reported, that the gallium nitride (GaN) has been successively investigated as an alternative interlayer for stable passivation of gallium arsenide (GaAs) surface [8].

Several papers previously published concerning the GaAs (100) nitridation, for instance Benamara et al. [9] solved the problem of contactless determination of interface state density ($N_{SS}(E)$) on GaN/GaAs (100) interfaces using the photoluminescence surface state spectroscopy (PLS^3) method. Zougagh et al. [10] and Ameur et al. [11] investigate the detailed electrical transport properties of Hg/GaN/GaAs structures using the I–V and C–V measurements. Rabehi et al. [12] investigated the formation of the GaN layer on the GaAs surface through calculation of the *N*ss with and without the presence of series resistance. Ebeoğlu [13] proposed wide band gap semiconductor GaN interfacial layer at Au/GaAs interface achieved by chemical anodic nitridation method for the calculation of the interface state density with and without taking into account the series resistance to see whether this interfacial layer has a passivation effect on I–V electrical characteristics and Au/GaN/GaAs Schottky contact has a rectification behavior or not.

In the present work we report the electrical and photoelectrical properties of diode, based on GaAs and created additional interface GaN layer using chemical processes. The thin GaN film is realized by nitridation of GaAs substrates with different thicknesses and variable conditions of nitridation process. The I–V characteristics and the optoelectronic properties of the fabricated Au/GaN/GaAs Schottky diode have been investigated at room temperature. The analysis of these characteristics allows the determination of the electrical parameters, such as: saturation current, ideality factor, barrier height; in addition optoelectronic properties such as open circuit voltage or short circuit current were estimated as well.

2. Experimental procedures

Commercially available GaAs ($N_d = 4.9 \times 10^{15}$ cm^{-3}, thickness 400 ± 20 µm, face 100) wafers have been used in this work.

Before sample fabrication the substrate was cleaned according to the following procedure:

the substrates were subsequently cleaned chemically in concentrated H_2SO_4 and H_2O with ultrasonication treatment, rinsed with hot and cold methanol, dried with nitrogen gas, and treated with argon plasma (ion energy: 1 keV, sample current: 5 µA/cm^2) for 1 h in UHV chamber. In order to reconstruct of the surface of the GaAs, the substrate was heated for 1 h at 500 °C before the nitridation process.

A singular glow discharge source, described in detail elsewhere [14], was used for the nitridation process. Low power (5–10 W) nitrogen continuous plasma was produced by a high voltage (about 2.5 kV) and a majority of N atomic species were created (nitrogen pressure: of 10^{-4} Torr, sample current: 1 µA/cm^2. Nitridation process was carried out at a power of the glow discharge source 5 W for 5 and 30 min in the UHV chamber. The temperature during the process was kept at 500 °C. Finally, in situ annealing was realized for 1 h at the temperature of 620 °C.

The home-built UHV chamber was equipped with a XPS system (dual anode Al–Mg X-ray source and hemispherical electron energy analyser), which allows to determine the chemical composition and crystal structure of the studied samples. The XPS experiments were performed using a Mg Kα source (1253.6 eV) at an incident angle of 55° (normal detection, pass energy of the analyzer: 20 eV)The details of preparation procedure of the samples are shown in Table 1.

Estimation of the GaN thickness (0.7, 2 and 2.2) is performed by comparing experimental spectra and a theoretical model of the XPS peak intensity. It is based on the analysis of Ga3d, As3d and N1s core levels in the GaAs substrate and determination of values of Ga3d/As3d and N1s/Ga3d peak surface ratio variations [12].

The fabricated structure was tested electrically with an Au contact, where the area and thickens of the contact are 4.41×10^{-3} cm^2 and 100 nm, respectively. The Ohmic contact, was deposited on the back side of the sample with the use of NH_4Cl, and followed by annealing at 350 °C for5 min. During heating process of NH_4Cl solution thermally decomposes into a gaseous mixture of NH_3 and HCl. HCl is effective in preventing of the formation of oxides and other impurities on the surface of GaAs, from the other hand the presence of NH_3 leads to better diffusion of Sn into the GaAs layer [12].

The I–V measurements were performed using a HP4155B semiconductor parameter analyzer in the dark conditions and under illumination, at room temperature. In order to study the properties of fabricated devices (under illumination), the He–Ne laser of 1 mW power and 632.8 nm wavelength was used. The wavelength of 632.8 nm was chosen to be greater than the optical band gap of GaAs. The Schematic structure of the Au/GaN/GaAs diode, fabricated in this study is shown in Fig. 1.