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ScienceDirect
Vacuum 82 (2008) 794–798
VACUUM
SURFACE ENGINEERING, SURFACE INSTRUMENTATION & VACUUM TECHNOLOGY
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Structural and electrical properties of Au and Ti/Au contacts to n-type GaN

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Received 2 July 2007; received in revised form 20 November 2007; accepted 20 November 2007

Abstract

Au and Ti/Au layers were deposited on n-GaN. The samples were annealed at 400, 700 and 900 °C for 10 min in vacuum. The contacts were rectifying up to 700 °C and the highest Schottky barrier height of 1.07 eV was obtained for an Au single layer by current–voltage measurements. A binary phase of Au_2Ga was identified at the interface of the n-GaN/Ti/Au contact after annealing at 900 °C. The formation of Ti_2N and TiN (twin) phases epitaxially grown on GaN was also observed in the same contact as well as some gold diffusion into the topmost region of the GaN epilayer.

Keywords: GaN; Thin films; Electron microscopy; Solid phase reaction; Electrical properties

1. Introduction

Gallium nitride-based wide bandgap semiconductors find increasing applications in optoelectronic (LEDs, lasers, detectors) and microelectronic (high-temperature, high-power and high-frequency transistors) devices. However, the performance of GaN-based devices is limited by several materials and engineering problems, including the difficulty in making low-resistance, thermally stable ohmic contacts, especially to n-type GaN. Two models—low Schottky barrier or tunnelling contact—have been proposed to explain the ohmic behaviour of metal contacts to n-type III-nitrides [1,2]. On the other hand it is relatively easy to make a Schottky contact at room temperature, but making a rectifying contact, which can withstand high temperature operation is also a scientific challenge. New phases are often formed at the metal/nitride interface, and these can change the electrical properties of the contact [2,3]. Many different metal layer schemes have been investigated. Some of the most successful contact structures contain Ti and Au [1,2,4,5].

The microstructure and electrical properties of metal contacts to n-GaN layers grown by MOCVD onto sapphire substrates are the subjects of the present paper. One of the best ways to learn the microstructural properties of the annealed contact layers is transmission electron microscopy (TEM), which was applied for the present study, as the main characterisation tool.

2. Experimental

A 15.2 μm thick GaN layers were epitaxially grown on *c*-plane Al_2O_3 by MOCVD. The GaN layers contained two sublayers, a 10.5 μm thick undoped layer using a process leading to material with an ultra low dislocation density ($8 \times 10^7\,cm^{-2}$) [6] and a 4.7 μm thick Si-doped GaN top layer with a Hall free electron concentration of $2.5 \times 10^{18}\,cm^{-3}$ and a sheet resistance of $20\,\Omega_{sq}$. Au (120 nm) and Ti (40 nm)/Au (120 nm) contact metallisations were deposited by thermal evaporation. The samples were annealed in vacuum at three different temperatures: 400, 700 and 900 °C for 10 min, respectively.

The metallised samples were patterned using photolithography and lift-off techniques to define contacts for electrical characterisation. Current–voltage (*I–V*)

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0042-207X/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.vacuum.2007.11.005

measurements were performed on the as-deposited layers and after each annealing step between a large (about $0.5\,cm^2$) pad and small contacts with different areas in the range of $0.01–1\,mm^2$ by a Keithley 236 series Source Measure Unit at room temperature in dark, for monitoring the annealing effect on the electrical properties of metal contacts to n-GaN. The Schottky barrier height was evaluated according to the thermionic emission theory by the method of Cheung and Cheung [7] using the effective Richardson constant value of $24.6\,A\,cm^{-2}\,K^{-2}$ [8].

The special geometry of contacts mentioned above was necessary to avoid the influence of ohmic contacts during annealing. The proposed geometry makes possible to use the studied metallisation for ohmic contacts as well. The main point is that "ohmic" contact with low resistance is formed by using a much larger contact area than that used for the other (Schottky) contact. Such a geometry makes possible to evaluate or estimate the Schottky barrier height of the contacts in most cases. The current flows through two Schottky (or ohmic) contacts with different areas connected back to back, and through the GaN layer. If the Schottky barrier height is less than 0.3–0.4 eV (depending on the series resistance [9]), the contact usually exhibits linear or near linear *I–V* characteristics at room temperature and at low current levels indicating ohmic behaviour [9,10]. An example is presented in Fig. 1 for the Au/Ti/n-GaN contacts annealed at 700 °C with an area of $1\,mm^2$. In this case the current is limited by the resistance of the GaN layer and of the spreading resistance of contact areas. However, decreasing the area of the smaller contact and/or the temperature, in many cases such a situation can be reached, when the current is limited mainly by the Schottky barrier of the smaller contact for both forward and reverse directions, as presented in Fig. 1 for the Au/Ti/n-GaN contacts annealed at 700 °C with an area of $0.01\,mm^2$. For this contact area rectifying *I–V* behaviour is obtained, and the evaluation of Schottky barrier height is possible. (The actual Schottky barrier height is 0.43 eV.)

Electron transparent, cross sectional samples for TEM analysis were prepared using our standard procedure [11]. This includes cutting the wafers, embedding each piece into a special Ti-holder, mechanical grinding and polishing, followed by 10 keV Ar^+ ion milling (reduced to 3 keV at the end of the process). The microstructure of annealed samples was investigated in a Philips CM 20 TEM operating at 200 kV. Energy dispersive X-ray spectroscopy (EDS) analysis was conducted using a Noran microprobe attached to the TEM. High resolution transmission electron micrographs (HRTEM) were taken in a JEOL 3010 microscope operating at 300 kV. X-ray diffraction (XRD) data were collected using a Philips PW 1050 diffractometer.

3. Results

3.1. Electrical behaviour

Electrical characterisation of both Au and Ti/Au contacts was conducted using *I–V* measurements. The typical semilogarithmic *I–V* characteristics obtained for the studied Au/Ti/n-GaN and Au/n-GaN contacts with an area of $0.01\,mm^2$ as a function of annealing temperature are presented in Figs. 2 and 3, respectively. The character of room temperature *I–V* characteristics, the evaluated

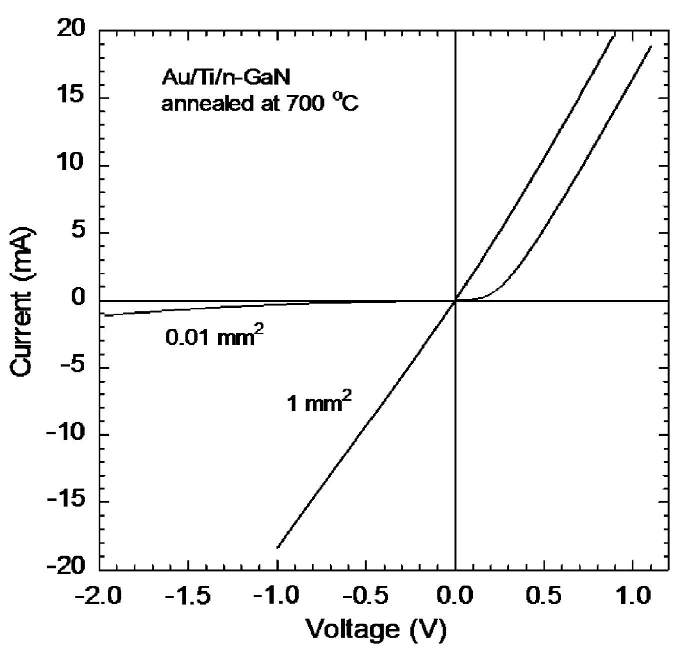

Fig. 1. Typical current–voltage characteristics of Au/Ti/n-GaN contacts annealed at 700 °C with area of 100 μm × 100 μm and 1 mm × 1 mm measured at room temperature. Note that the larger contact yields "ohmic" behaviour with near linear characteristics, while the smaller one exhibits rectifying behaviour [9,10].

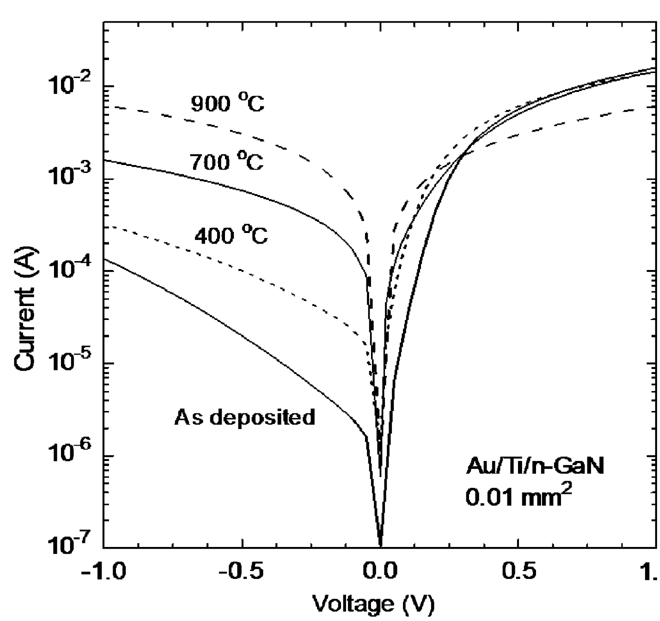

Fig. 2. Typical current–voltage characteristics of Au/Ti/n-GaN contacts with an area of 1 mm × 1 mm as a function of annealing temperature (measured at room temperature).