Materials Science in Semiconductor Processing 30 (2015) 420–428

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

Effect of copper phthalocyanine (CuPc) interlayer on the electrical characteristics of Au/n-GaN Schottky rectifier

I. Jyothi [a], V. Janardhanam [a], Yi-Rang Lim [a], V. Rajagopal Reddy [b], Kwang-Soon Ahn [c,*], Chel-Jong Choi [a,*]

[a] School of Semiconductor and Chemical Engineering, Semiconductor Physics Research Center (SPRC), Chonbuk National University, Jeonju 561-756, Republic of Korea
[b] Department of Physics, Sri Venkateswara University, Tirupati 517502, India
[c] School of Chemical Engineering, Yeungnam University, Gyeongsan 712-749, Republic of Korea

ARTICLE INFO

Available online 14 November 2014

Keywords:
GaN
Schottky contact
CuPc
Interface state density

ABSTRACT

Electrical properties of Au/n-GaN Schottky rectifier with copper pthalocyanine (CuPc) interlayer were investigated using current–voltage (*I–V*), capacitance–voltage (*C–V*) and conductance–voltage (*G–V*) characteristics. The barrier height obtained for the Au/CuPc/n-GaN Schottky diode was higher than that of the Au/n-GaN Schottky diode. This could be associated with the presence of the CuPc interlayer influencing the space-charge region of the Au/n-GaN structure. The Au/CuPc/n-GaN Schottky structure exhibits higher ideality factor, indicating the higher interface inhomogeneity in Au/CuPc/n-GaN as compared to Au/n-GaN Schottky structure. The density of interface states was extracted using *I–V*, *C–V*, and *G–V* characteristics. The results showed that the introduction of CuPc interlayer facilitated the reduction of interface state density (N_{SS}) of Au Schottky contact to n-GaN. Particularly, the N_{SS} obtained from frequency-dependent *C–V* characteristics was lower than that determined from forward *I–V* characteristics, which could be attributed to the inhomogeneous distribution of N_{SS} at Schottky interface.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

The significant progress being made in growing high-quality GaN makes it attractive for applications in high-temperature, high-frequency, and high-power devices as well as in short-wavelength optoelectronic devices [1,2]. In order to realize such novel devices, it is important to clarify the electrical properties and to elucidate the nature of the transport that occurs at metal/GaN Schottky interfaces. Specifically, metal–semiconductor contacts play an important role in the performance of these devices [3]. In particular, due to the technological importance of Schottky contacts, a full understanding of their electrical characteristics is of great interest. Generally, it is well known that the electrical characteristics of Schottky contacts are primarily controlled by their interfacial layer. The interfacial layer, which comprises the interface between the metal and semiconductor, exhibits rectification behavior in which the values of the barrier height and ideality factor are greater than conventional metal/semiconductor structures [4]. This behavior can be attributed to the space-charge region of the semiconductor, which is influenced by the interlayer in the metal/semiconductor structure.

Recently, organic/inorganic semiconductor devices fabricated from organic compounds grown on inorganic semiconductor substrates have been extensively investigated by many researchers for their potential use in electronic and optoelectronic technologies [5–10]. In particular, organic interlayers can act as a physical barrier between metal and inorganic semiconductor substrates, thereby preventing the

* Corresponding authors.
E-mail addresses: kstheory@ynu.ac.kr (K.-S. Ahn), cjchoi@chonbuk.ac.kr (C.-J. Choi).

http://dx.doi.org/10.1016/j.mssp.2014.10.047
1369-8001/© 2014 Elsevier Ltd. All rights reserved.

metal from directly coming into contact with the inorganic semiconductor's surface. Furthermore, despite the abrupt and unreactive appearance of organic–inorganic interfaces, organic interlayer can significantly modify interface states [11,12]. In other words, organic interlayers have functional variety and flexibility that can be used to effectively control the electronic properties of both an inorganic semiconductor and a metal, which will ultimately contribute to increased device performance. Despite the prominent features of organic interlayers, reports on the implementation of such organic interlayers on GaN-based Schottky contacts are scarce. Kim et al. [13] fabricated and characterized a heavily Si-doped GaN/PEDOT:PSS/Au structure with and without poly(3,4-ethylene-dioxythiophene):beta-1,3-glucan (PEDOT nanoparticle) in a PEDOT:PSS layer. They showed that while the ideality factor of the structure without PEDOT nanoparticles in a PEDOT:PSS layer is 12.9, the ideality factor decreased dramatically to 1.9 after insertion of PEDOT nanoparticles in the PEDOT:PSS layer. Such a change in the ideality factor of a structure indicates that the current transport mechanism is a combination of diffusion-limited and space-charge-limited transport induced by the PEDOT nanoparticle interface layer. In this work, a thin CuPc film, which has been considered as one of the valuable organic semiconductors due to its chemical and thermal stability, and its tendency to form highly ordered layers for the enhancement of device performance [14,15], was used as organic interlayer in the fabrication of Au/n-GaN Schottky rectifiers. Very recently, we reported on the forward conduction mechanism and series resistance of Au/n-GaN Schottky diode with CuPc interlayer using *I–V* and *C–V*, and *G–V* characteristics [16]. As a continuation of our previous work, the electrical properties of Au/CuPc/n-GaN Schottky diodes are directly compared with those of Au/n-GaN Schottky diodes along with an attempt made to discuss the interface inhomogeneity of the studied diodes in present work. Furthermore, it is shown that the introduction of the CuPc interlayer reduced the interface state density, leading to an increase of the barrier height.

2. Experimental details

Si-doped n-GaN films with a thickness of 2 μm were grown on C-plane Al_2O_3 substrates by metal organic chemical vapor deposition (MOCVD). During GaN growth, the flow rates of trimethlylgallium (TMGa), ammonia (NH_3), and silane (SiH_4) were 160 μmol/min, 4 l/min, and 4 nmol/min, respectively. The carrier concentration and mobility of n-GaN layer obtained by Hall measurements performed at room temperature with a magnetic field of 0.5 T were 4.1×10^{17} cm^{-3} and 220 cm^2/V s, respectively. The n-GaN wafers were first ultrasonically degreased with warm trichloroethylene followed by acetone and methanol for 5 min each. Next, wafers were dipped into boiling aqua-regia [HNO_3:HCl=1:3] for 10 min to remove native oxide, and then rinsed in deionized water. The atomic force microscope (AFM) examination (inset of Fig. 1) of the cleaned GaN film showed the smooth surface with a root-mean-square (RMS) roughness of 0.21 nm, of which value was acceptable for device fabrication. For forming Ohmic contacts, 25 nm-thick Ti and 100 nm-thick Al films were sequentially deposited on a portion of the sample defined by photolithography using electron beam evaporation, followed by N_2 ambient annealing at 650 °C for 3 min. X-ray photoemission spectroscopy (XPS) analysis revealed that Ga3*d* spectra (Fig. 1) taken from the cleaned GaN surface before and after annealing at 650 °C for 3 min under N_2 ambient were almost identical, implying that the modification of chemical property of GaN surface caused by thermal treatment required for Ohmic contact was negligible. Next, 15-nm-thick CuPc films were deposited by thermal evaporation of powdered CuPc. Finally, circular Schottky electrodes of diameter 200 μm were fabricated by evaporation of Au (30 nm) on top of the CuPc film using electron beam evaporation. Au was chosen as Schottky metal owing to its high work function, good electrical conductivity, and pronounced resistance to oxidation. For comparison purposes, the conventional Au/n-GaN Schottky diode was fabricated under similar conditions. In particular, to avoid poor adhesion of Au on n-GaN film caused by surface contamination layer (may be gallium oxides or gallium oxynitrides which often remains even after cleaning GaN surface), prior to the Au deposition, the samples were dipped in buffered oxide etch, followed by rinsing in deionized water and immediately loaded in the electron beam evaporator. The *I–V* and *C–V* characteristics of the Au/n-GaN Schottky contacts with and without CuPc interlayers were performed at room temperature using a precision semiconductor parameter analyzer (Agilent 4155C) and a precision *LCR* meter (Agilent 4284A), respectively.

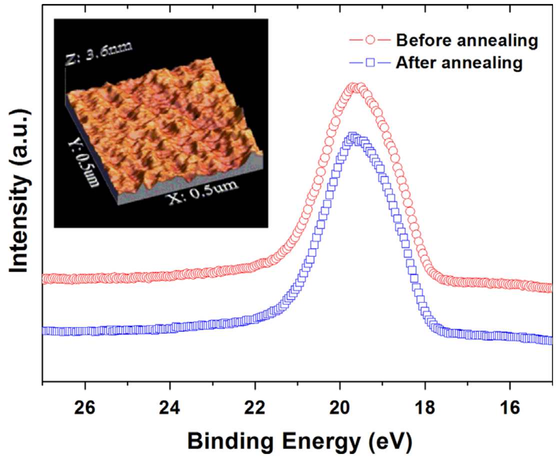

Fig. 1. XPS Ga3*d* spectra taken from the GaN substrate surface before and after annealing at 650 °C in N_2 ambient for 3 min. Inset shows the surface morphology of the GaN surface after the cleaning process.

3. Results and discussion

The experimental semi-logarithmic *I–V* characteristics of Au/n-GaN Schottky diodes with and without CuPc interlayer are shown in Fig. 2. It is clear that both devices exhibited good rectifying properties with weak voltage dependence of the reverse bias current and an exponential increase of the forward bias current, which are characteristic properties of the rectifying interface. However, the forward bias *I–V* characteristics of Au/n-GaN Schottky diodes with and without CuPc interlayer deviated considerably from linearity due to the effect of series resistance. In fact, the

Download English Version:

https://daneshyari.com/en/article/729230

Download Persian Version:

https://daneshyari.com/article/729230

Daneshyari.com