Current Applied Physics 10 (2010) 687–692

Contents lists available at ScienceDirect

Current Applied Physics

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

Influence of rapid thermal annealing on electrical and structural properties of double metal structure Au/Ni/n-InP (1 1 1) diodes

M. Bhaskar Reddy, V. Janardhanam, A. Ashok Kumar, V. Rajagopal Reddy *, P. Narasimha Reddy

Department of Physics, Sri Venkateswara University, Tirupati 517 502, India

ARTICLE INFO

Article history:
Received 12 May 2009
Received in revised form 26 July 2009
Accepted 1 September 2009
Available online 6 September 2009

PACS:
61.05.cp
68.37.Ps
73.30.+y
73.40.Kp
85.30.Hi
85.30.Kk

Keywords:
Indium phosphide
Ni/Au Schottky contacts
Electrical and structural properties
Auger electron spectroscopy
X-ray diffraction
Surface morphology

ABSTRACT

The effect of rapid thermal annealing on the electrical and structural properties of Ni/Au Schottky contacts on n-InP have been investigated by current–voltage (*I–V*), capacitance–voltage (*C–V*), auger electron spectroscopy (AES) and X-ray diffraction (XRD) techniques. The Au/Ni/n-InP Schottky contacts are rapid thermally annealed in the temperature range of 200–500 °C for a duration of 1 min. The Schottky barrier height of as-deposited Ni/Au Schottky contact has been found to be 0.50 eV (*I–V*) and 0.86 eV (*C–V*), respectively. It has been found that the Schottky barrier height decreased with increasing annealing temperature as compared to as-deposited sample. The barrier height values obtained are 0.43 eV (*I–V*), 0.72 eV (*C–V*) for the samples annealed at 200 °C, 0.45 eV (*I–V*) and 0.73 eV (*C–V*) for those at 400 °C. Further increase in annealing temperature to 500 °C the barrier height slightly increased to 0.46 eV (*I–V*) and 0.78 eV (*C–V*) compared to the values obtained for the samples annealed at 200 °C and 400 °C. AES and XRD studies showed the formation of indium phases at the Ni/Au and InP interface and may be the reason for the increase in barrier height. The AFM results showed that there is no significant degradation in the surface morphology (rms roughness of 1.56 nm) of the contact even after annealing at 500 °C.

1. Introduction

Among III–V compound semiconductors, indium phosphide (InP) is useful material for studying mechanisms responsible for Schottky barrier formation. Metal–semiconductor (M–S) structures play an important role in devices based on the III–V compound semiconductors in the form of Schottky barrier diodes or ohmic contacts [1–4]. Metal films deposition on InP substrates has received much attention for many years because of interest to develop fabrication technology for high-speed devices. Schottky barrier contacts based on n-InP are of considerable interest on account of their potential applications in solar cells, microwave FETs and high-speed charge-coupled devices. The choice of InP as substrate for these devices stems from the fact that it has an optimum bandgap required for photovoltaic energy conversion and large charge carrier mobility required for high-speed devices [5–9].

Normally InP Schottky diode shows low barrier heights than desirable due to many reasons. One reason may be the out-diffusion of InP atoms into the adjoining metal films leaving vacancies or more complex defects within the band gap which can pin the Fermi level [10–14]. Another possibility is that the chemical reaction and/or out-diffusion occurring at the metal-InP interface produce interfacial layers, which contribute to the barrier by local charge redistribution and/or effective work function change at the interface [15–20]. The low barrier height in InP Schottky contacts may increase the leakage currents and the device performance is degraded.

Many researchers have studied the electrical and structural properties of Schottky contacts on n-InP [21–25]. Eftekhari [21] investigated the effect of rapid thermal annealing on the electrical properties of Ni and Pd contacts on n-InP. Results showed that annealing the contacts at 450 °C for 100 s has little effect on their electrical parameters and the contacts annealed at 600 °C showed some degradation. Miyazaki et al. [22] investigated Ni/Al Schottky contacts on n-type InP and reported that the barrier height was enhanced after rapid thermal annealing. Chen and Chou [23] studied the hydrogen sensing performance of Pd/n-InP Schottky diodes and found that the changes in the Schottky barrier height and ideality factor are increased with the increase of hydrogen concentration.

* Corresponding author.
E-mail address: reddy_vrg@rediffmail.com (V. Rajagopal Reddy).

1567-1739/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.cap.2009.09.001

Huang and co-workers [24] fabricated a high performance double metal structure using Pt and Al as Schottky contacts to n-InP and reported an effective barrier height of 0.74 eV. Cetin and Ayyildiz [25] fabricated Au, Al and Cu/n-InP Schottky diodes on chemically cleaned and air-exposed n-InP surfaces and studied the influence of air-grown oxide on electrical performance. They observed Schottky barrier height enhancement for the air-grown oxide Schottky barrier diode than the Schottky barrier diode without oxide layer. In the present work, we have investigated the effect of rapid thermal annealing on the electrical and structural properties of Ni/Au Schottky contacts on n-InP (1 1 1).

2. Experimental details

The samples used for this study are LEC grown undoped n-InP (1 1 1) (Crystal Specialities International, Tokyo) with carrier concentration of 3.8–4.5 × 10^{15} cm^{-3}. The samples are initially degreased with organic solvents like trichloroethylene, acetone and methanol by means of ultrasonic agitation in sequence for 5 min each to remove contaminants, rinsed in deionised water and dried in N_2 flow. The samples are then etched with HF (49%) and H_2O (1:10) to remove the native oxides from the substrate. The samples are loaded into electron beam evaporation system and ohmic contacts using indium of thickness 500 Å are formed on the rough side of the InP wafer prior to Schottky diode fabrication at a pressure of 7 × 10^{-6} mbar. The samples are then annealed at 350 °C for 1 min in N_2 atmosphere. Ni/Au (30 nm/30 nm) Schottky contacts are fabricated on n-InP using stainless steel circular mask of diameter of 0.7 mm on the polished side using electron beam evaporation system at a pressure of 5 × 10^{-6} mbar. The Ni/Au Schottky contacts are rapid thermal annealed at temperatures 200 °C, 300 °C, 400 °C and 500 °C for duration of 1 min in N_2 flow. The current–voltage (*I–V*) and capacitance–voltage (*C–V*) characteristics are measured using DLS-83D spectrometer. Auger electron spectroscopy ((AES: VG: Microlab 350) and X-ray diffraction studies (Siefert XRD PW 3710) (using Cu kα radiation) have been made to characterize the interfacial reactions between the metal and InP layers. The surface morphology of the contacts is obtained using atomic force microscopy (AFM).

3. Results and discussion

The electrical properties of the Ni/Au Schottky contacts on n-InP have been evaluated by using current–voltage (*I–V*) and capacitance–voltage (*C–V*) measurements at room temperature. Fig. 1 shows the *I–V* characteristics of the Au/Ni/n-InP Schottky contacts as a function of annealing temperature.

The *I–V* characteristics of Schottky contacts on semiconductors ($\leqslant 10^{18}$ cm^{-3}) can be explained generally using the *I–V* equation based on a TE mode. However, if we consider the presence of a high density of defects near InP surface ($N_{defect} > 10^{19}$ cm^{-3}), tunneling transport at the Au/Ni/InP interface should be also considered [26–28]. Thus, in our calculation, the *I–V* relations based on TFE as well as TE conduction modes were used to describe the Schottky barrier behaviors of the Ni/Au contacts to n-InP (5 × 10^{15} cm^{-3}). The *I–V* equations of the TE and TFE modes can be given as below [29]

$$I = AA^{**}T^2 \exp\left(-\frac{q\Phi_b}{kT}\right)\left[\exp\left(\frac{qV}{nkT}\right) - 1\right] \text{for TE conduction} \tag{1}$$

$$I = I_0 \exp\left[\frac{qV}{E_{00}\coth(E_{00}/kT)}\right] \text{ for TFE conduction} \tag{2}$$

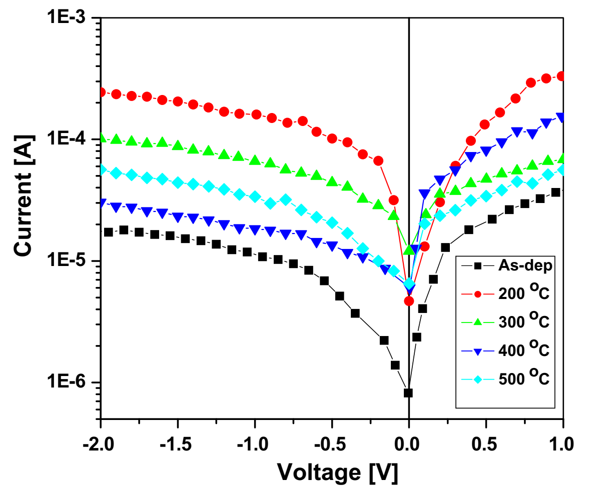

Fig. 1. Typical *I–V* Characteristics of Ni/Au Schottky contacts to n-InP as a function of annealing temperature.

$$I_0 = \frac{AA^{**}T\sqrt{\Pi E_{00} q(\Phi_b - V - \xi)}}{k\cosh(E_{00}/kT)} \times \exp\left[-\frac{q\xi}{kT} - \frac{q}{E_{00}\coth(E_{00}/kT)}(\Phi_b - \xi)\right] \tag{3}$$

$$E_{00} = \frac{qh}{4\Pi}\sqrt{\frac{N_d}{\varepsilon_s m^*}} \tag{4}$$

where A^{**} is the Richardson constant, *A* the effective area of the Schottky diode, *k* the Boltzmann constant, *h* the Planck constant, m^* the effective mass of the semiconductor, *T* the temperature, N_d the carrier concentration, *n* the ideality factor, Φ_b the barrier height, E_{00} the tunneling parameter, ε_s the dielectric constant of the semiconductor, and ξ the energy band bending of $E_C - E_F = kT/q\ln(N_C/N_d)$.

For the TFE mode, (calculated using Eqs. (2)–(4)), the Schottky barrier height and the tunneling parameter of the as-deposited sample are determined to be 0.56 eV and 1.30 meV, respectively. For the contacts annealed at 200 °C, 300 °C, 400 °C and 500 °C, the Schottky barrier height (Φ_b) and tunneling parameters (E_{00}) are found to be 0.52 eV, 0.51 eV, 0.54 eV, 0.53 eV and 1.16 meV, 1.12 meV, 1.11 meV and 1.10 meV, respectively. The ideality factors of the Schottky contacts are determined using [$n = E_{00}/kT \coth(E_{00}/kT)$]. The ideality factor is obtained as 1.3 and 1.1 for the as-deposited contact and 500 °C, respectively.

For the TE mode, the Schottky barrier heights (SBH) calculated using Eq. (1) is 0.50 eV for the as-deposited contact, 0.43 eV for 200 °C, 0.42 eV for 300 °C, 0.45 eV for 400 °C and 0.46 eV for 500 °C annealed contacts. The values of ideality factor for as-deposited and 200 °C annealed samples of Ni/Au Schottky diodes are found to be 1.5 and 2.7, respectively. However, the ideality factor of Ni/Au Schottky contact is reduced to 1.2 after annealing at 500 °C. The results of the TE and TFE calculations are summarized in Table 1. The values of *n* are fairly similar to those obtained by the TE calculations, indicating that our calculation is valid.

To compare the effective Schottky barrier height of contacts, the Norde method is also employed [30] since high series resistance can hinder an accurate evaluation of barrier height from the standard ln *I* versus *V* plot. According to Norde method, a function *F*(*V*) is plotted against *V*. Function *F*(*V*) can be expressed as

$$F(V) = \frac{V}{2} - \frac{kT}{q}\ln\left[\frac{I(V)}{AA^{**}T^2}\right] \tag{5}$$