Superlattices and Microstructures 48 (2010) 330–342

Contents lists available at ScienceDirect

Superlattices and Microstructures

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

Analysis of current–voltage–temperature (I–V–T) and capacitance–voltage–temperature (C–V–T) characteristics of Ni/Au Schottky contacts on n-type InP

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ARTICLE INFO

Article history:
Received 16 April 2010
Received in revised form
27 May 2010
Accepted 23 June 2010
Available online 31 July 2010

Keywords:
Schottky contacts
I–V–T and C–V–T characteristics
Gaussian distribution
Barrier height

ABSTRACT

The current–voltage (I–V) and capacitance–voltage (C–V) characteristics of Ni/Au/n-InP (111) Schottky contacts have been studied in the temperature range 210–420 K in steps of 30 K. The forward I–V characteristics are analyzed on the basis of thermionic emission (TE) theory assuming a Gaussian distribution of the barrier heights (BHs). The estimated Schottky barrier height (SBH) of an Ni/Au Schottky contact is in the region of 0.38 eV (I–V), 0.93 eV (C–V) at 210 K and 0.70 eV (I–V), 0.73 eV (C–V) at 420 K, respectively. The calculated ideality factor of an Ni/Au Schottky barrier diode (SBD) varies from 3.25 at 210 K to 1.99 at 420 K. It has been observed that the ideality factor decreases while the zero-bias BH increases with increasing temperature. This behavior has been interpreted by the assumption of a Gaussian distribution of BHs due to barrier inhomogeneities that prevail at the metal–semiconductor interface. The zero-bias BH Φ_{bo} versus $1/2kT$ plot has been drawn to obtain evidence of the Gaussian distribution of the BHs. The mean value of Φ_{bo} obtained is 1.01 eV, with standard deviation $\sigma_o = 155$ meV. From the modified Richardson plot, the mean BH Φ_{bo} is 0.97 eV and the Richardson constant (A^{**}) is 4.507 A cm^{-2} K^{-2}, which is close to the theoretical value of 9.4 A cm^{-2} K^{-2}. The discrepancy between SBHs obtained from the I–V and C–V measurements is also explained. The experimentally observed E_0 value of 5.235 meV agrees very well with the theoretically calculated value of $E_{00} = 5.801$ meV.

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doi:10.1016/j.spmi.2010.06.019

1. Introduction

Metal–semiconductor (MS) structures are important research tools in the characterization of new semiconductor materials. The fabrication of these structures plays an important role in developing some useful devices such as microwave field-effect transistors, radio frequency detectors, photo transistors and space solar cells [1–7]. Metal film deposition on InP substrates has received much attention for the fabrication of opto-electronic devices used in modern high-speed optical communication systems due to its direct transition band gap and high electron mobility [1,4,8–11]. The current–voltage (I–V) and capacitance–voltage (C–V) characteristics of the metal–semiconductor contacts usually deviate from the ideal thermionic emission (TE) current model [12–15]. The analysis of I–V characteristics of the Schottky contacts obtained at room temperature does not give detailed information about the charge transport process and the nature of the barrier height (BH) formed at the metal–semiconductor interface. The temperature-dependent electrical characteristics of the Schottky contacts provide the information regarding the charge transport process through MS contacts and also give a better picture of the conduction mechanisms [16–19]. However, a complete description of the charge carrier transport through an MS contact is still a challenging problem. The analysis of the I–V characteristics of the Schottky contacts based on TE theory usually reveals an abnormal decrease in the BH and increase in the ideality factor with decrease in temperature [17,20–24]. The decrease in BH at low temperature leads to nonlinearity in the activation energy ($\ln(I_o/T^2)$ versus $(1/T)$) plot. On the other hand, it has been assumed that the BH is inhomogeneous in the MS interface. The interface may contain patches with low BH. Moreover, if the patch area is small (less than or comparable to the depletion layer), the pinch-off effect will be taken into account, i.e. the effective reduction of the BHs between the patch and the surrounding area is smaller than its original drop in the metal–semiconductor interface.

The temperature-dependent characteristics of Schottky contacts in n-type InP have been reported by many researchers [25–30]. Cimilli et al. [25] investigated Au/n-InP/In Schottky barrier diodes, and reported that the BH varied from 0.557 eV to 0.615 eV and the ideality factor from 1.002 to 1.087. Cetin et al. [26] studied the temperature dependence of the electrical characteristics of Au/InP Schottky barrier diodes. They observed that the ideality factor decreased while the BH increased with increase of temperature. Janardhanam et al. [27] investigated the electrical transport characteristics of ruthenium/n-InP Schottky diodes by current–voltage–temperature (I–V–T) measurements. They reported that the BH varied from 0.39 eV (at 200 K) to 0.60 eV (at 400 K) and the ideality factor from 4.2 (at 200 K) to 2.5 (at 400 K). Bhaskar Reddy et al. [28] studied the current–voltage–temperature (I–V–T) characteristics of Pd/Au Schottky contacts on n-InP and found that the barrier parameters vary significantly with temperature. Ashok et al. [29] investigated Pd/Pt Schottky contacts on n-InP(100) in a wide temperature range (230–410 K), and found a decrease of BH and increase of ideality factor with decreasing temperature. Recently, Cimilli et al. [30] evaluated the temperature-dependent current–voltage characteristics of an Ag/n-InP Schottky diode with inhomogeneous Schottky barrier height (SBH) in the temperature range 30–320 K. They concluded that the BH and ideality factor varied from 0.20 eV and 3.89 at 70 K to 0.61 eV and 1.18 at 320 K. In this work, the transition metal Ni was selected as the first layer because it has a high metal work function and relatively high reactivity with InP. In the present work, we have investigated the current–voltage (I–V) and capacitance–voltage (C–V) measurements of nickel/gold Schottky contacts on n-InP (Ni/Au/n-InP) over the temperature range 210–420 K. The resultant temperature-dependent Schottky contacts have been explained on the basis of the existence of a Gaussian distribution of the BHs around a mean value due to BH inhomogeneities at the MS interface.

2. Experimental details

The samples used in this study were undoped one-side-polished n-type InP (111) having carrier concentration of $\sim$4.9–5.0 $\times$ 10^{15} cm^{-3}. The wafer was degreased successively in warm trichloroethylene, acetone, and methanol for 5 min each and then rinsed in deionized (DI) water. The wafer was dried in high-purity argon gas. The samples were then etched with HF (49%):H_2O (1:10)