Thin Solid Films 531 (2013) 436–441

Contents lists available at SciVerse ScienceDirect

Thin Solid Films

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

Current–voltage–temperature characteristics of Au/*p*-InP Schottky barrier diode

Demet Korucu [a,*], Songül Duman [b]

[a] Department of Material Science and Engineering, Faculty of Engineering, Hakkari University, 30000, Hakkari, Turkey
[b] Department of Physics, Faculty of Sciences, Atatürk University, 25240, Erzurum, Turkey

ARTICLE INFO

Article history:
Received 19 May 2012
Received in revised form 5 November 2012
Accepted 16 January 2013
Available online 31 January 2013

Keywords:
Semiconductors
Phosphors
Nanofabrication
Electronic properties
Photolithography
Schottky barrier height

ABSTRACT

In order to evaluate current conduction mechanism in the Au/*p*-InP Schottky barrier diode (SBD), some electrical parameters such as the barrier height (Φ_{bo}) and ideality factor (n) have been obtained from the forward bias current–voltage (I–V) characteristics. The I–V measurements show that n is close to unity at room temperature, indicating that the main mechanism of current flow through the SBD is thermionic emission (TE).On the other hand, the particular contact fabrication process produces a relatively high value of barrier height (0.78 eV) at room temperature. The variation of Φ_{bo} with temperature has been obtained as 4×10^{-4} eV K^{-1}, which is close to the temperature coefficient of the band-gap of InP. It has been found that Φ_{bo} and n values of the SBD are temperature dependent below room temperature by using TE theory. Φ_{bo} increases and n decreases with increasing temperature. The assumption of a double Gaussian distribution of the Schottky barrier height has been applied due to barrier inhomogeneities that prevail at the metal–semiconductor interface giving mean barrier heights of 0.98 and 0.84 eV and standard deviations of 88 and 53 mV for 80–180 K and 180–320 K temperature regions, respectively. The values of mean barrier height and Richardson constant (A^*) using the modified Richardson $\ln(I_0/T^2)-(q^2\sigma_s^2/2k^2T^2)$ plot have been found as 1.00 eV, 77.52 A/cm^2 K^2 for 80–180 K and 0.83 eV, 56.76 A/cm^2 K^2 for 180–320 K, respectively. A^*values are in close agreement with the value of 60 A/cm^2 K^2 known for p-type InP.

1. Introduction

A metal–semiconductor (MS) contact is one of the most widely used rectifying contact type in the electronics industry [1]. Indium phosphide (InP) is a semiconductor compound which is utilized in optoelectronic and electronic applications such as high-speed optoelectronic devices operating at the communications wavelength of 1.55 μm [2] and high power microwave devices [3–5]. The electron mobility of InP is high, thereby leading to interesting prospects for fast integrated circuits. This semiconductor compound can also be used for diode lasers and photodetectors [6]. It has a direct band gap of 1.35 eV [7], which is quite optimum for a solar photovoltaic energy conversion system [4]. The formation of high quality Schottky barrier diodes (SBDs) is required for the development of advanced device technologies [4]. The SBDs formed through deposition of several metals on chemically etched *n*- and *p*-type InP have been investigated by various researchers [8–11]. Analysis of the current–voltage (I–V) characteristics of the SBDs only at room temperature does not give detailed information about their conduction process or the nature of barrier formation at the MS interface [12–16]. The I–V characteristics of the MS contacts usually deviate from the ideal thermionic emission (TE) current model [17].

The decrease in barrier height (Φ_{bo}) at low temperatures, in fact, leads to nonlinearity in the activation energy ($\ln(I_0/T^2)$ vs $1/kT$) plot; I_0 and T being the saturation currents at zero-bias and diode temperature in Kelvin, respectively. Inhomogeneities may play an important role and have to be taken into account in the evaluation of experimental I–V characteristics [18]. The nature and origin of the decrease in the Φ_{bo} and increase in ideality factor (n) with decreasing temperature and all of the electrical anomalies in the SBDs may be attributed to the presence of Schottky barrier height (SBH) inhomogeneity [15–17,19]. The high values of n can be attributed to the presence of a wide distribution of low-SBH patches caused by laterally inhomogeneous barrier [14,20].

In the present study, the I–V characteristics of Au/*p*-InP have been investigated over the temperature range of 80–320 K by steps of 20 K. As the temperature is decreased, n values increase and Φ_{bo} values decrease. In addition, significant deviation from linearity in the Richardson plots with decreasing temperature for the SBD has been observed. These anomalies have been explained by TE mechanism by assuming the coexistence of double Gaussian distribution (GD) of SBHs and by quantum mechanical tunneling including the thermionic field emission (TFE).

2. Experimental procedure

The Au/*p*-InP SBDs were fabricated using p-type single crystal InP wafer with <100> surface orientation, having 350 μm thickness, 2″ diameter and 4–8$\times10^{17}$ cm^{-3} carrier concentration (given by the

* Corresponding author: Tel.: +90 438 212 12 12; fax: +90 438 212 12 11.
E-mail addresses: dkorucu@yahoo.com (D. Korucu), sduman@atauni.edu.tr (S. Duman).

0040-6090/$ – see front matter
http://dx.doi.org/10.1016/j.tsf.2013.01.079

manufacturer). Before the SBD fabrication process, InP wafer was degreased for 5 min in organic solvent of trichloroethylene ($CHClCCl_2$), acetone (CH_3COCH_3) and methyl alcohol (CH_3OH), etched in a sequence of sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2), 20% hydrofluoric acid (HF), a solution of nitric acid ($6HNO_3$):1HF:35H_2O. Preceding each cleaning step, the wafer was rinsed thoroughly in de-ionized water with resistivity of 18 MΩ cm.

Ohmic contact on the back surface of p-InP was formed by vapor deposition of high purity (99.999%) Al at a low pressure about 1.33×10^{-4} Pa through a thermal evaporation system. After the Al deposition, the sample was annealed at 400 °C for a few minutes for the formation of ohmicity. The Schottky contacts were formed by conventional photolithography process onto the front surface through a photomask of Au dots with diameters ranging from 20 μm to 200 μm. Positive photoresist (AZ5214) was spread on InP wafers at a fixed rotational speed 5000 rpm for 30 s and InP wafer was baked 110 °C for 60 s. Depending on viscosity of the resist, a certain thickness of film remains on the substrate. Ultraviolet (UV) light was used to cure the resist into the desired structural pattern using a photo mask for 90 s. The exposed resist pattern was then developed in MF-701 developer solution for 60 s, with the UV light exposed regions dissolving in the solvent. Photoresist was removed by dipping in acetone for 3 min and dried with N_2, but the results represented in this paper are for the diode (200 μm) having the area of 3.14×10^{-4} cm^2. Wire bonding to Au dots of contacts on ceramic supports was carried out with a TBI HB16 Wire Bonder System. The special sample structures displayed with material microscopy are shown in Fig 1.

3. Results and discussion

The current through a uniform metal–semiconductor interface due to TE can be expressed as [1]

$$I = I_0\left[\exp\left(\frac{qV}{nkT}\right)-1\right] \tag{1}$$

where I_0 is the saturation current defined by

$$I_0 = AA^*T^2\exp\left(-\frac{q\Phi_{b0}}{kT}\right) \tag{2}$$

where V, A, A^*, T, k, q, Φ_{b0} and n are the forward-bias voltage, effective diode area, effective Richardson constant for p-type InP, temperature in Kelvin, Boltzmann constant, electronic charge and the zero bias SBH and ideality factor, respectively. From Eq. (1), n can be written as

$$n = \frac{q}{kT}\left(\frac{dV}{d(\ln I)}\right) \tag{3}$$

n is introduced to take the deviation of the experimental I–V results from the ideal thermionic model into account or to include the contributions of other current transport mechanisms. It should be $n=1$ for an ideal contact.

Fig. 2 shows the I–V characteristics of Au/p-InP SBD in the temperature range of 80–320 K by steps of 20 K.

Using the TE [1,21] for Au/p-InP SBDs, the experimental values of Φ_{b0} and n were determined from the current axis intercept and the slope of the linear region of the forward bias ln$I$–V characteristics at each temperature. The variation of Φ_{b0} and n with temperature has been given in Fig. 3. This figure shows that Φ_{b0} decreases and n increases with decreasing temperature ($n=2.15$, $\Phi_{b0}=0.42$ eV at 80 K and $n=1.06$ and $\Phi_{b0}=0.79$ eV at 320 K). n is very close to unity because of the homogeneity of the interface structure at 300 K. The BH value of 0.78 eV is in agreement with the value of 0.79 eV obtained from the I–V characteristics for Au/p-InP diodes by Newman et al. [22] at 300 K. Asubay et al. [23] have obtained a BH value of 0.72 eV for Au/p-InP at 300 K.

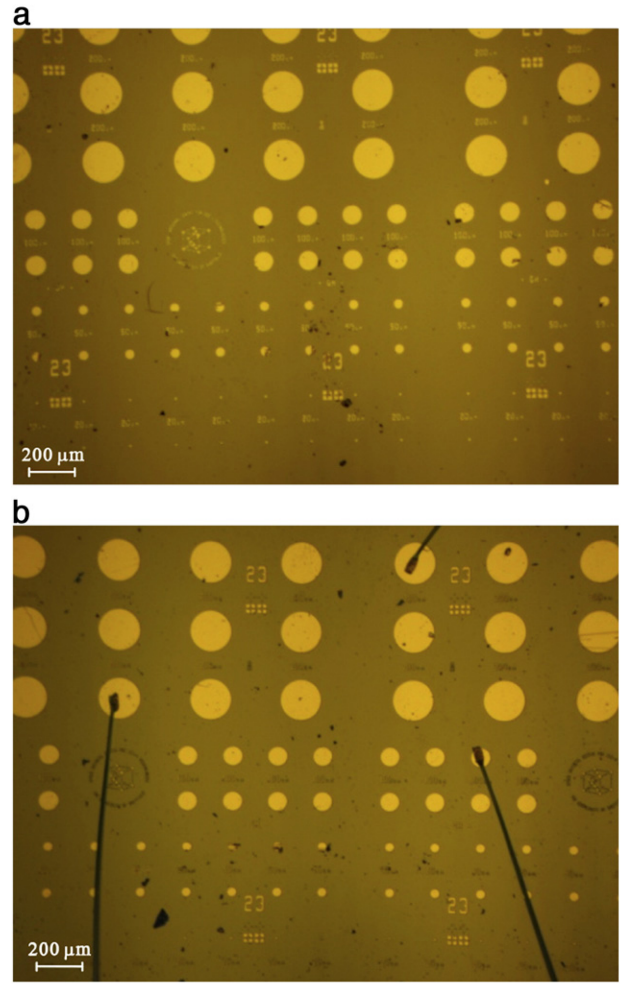

Fig. 1. (a) The special sample structures displayed with material microscopy. (b) Wire bonding to Au dots of contacts.

The high values of n show that there is a deviation from the TE theory for the current mechanism. The increase in n with decreasing temperature is known as the T_0 effect [24]. T_0 effect is advanced for explaining the variation of n with temperature. It has been shown that the T_0 effect can also be connected either with the lateral inhomogeneity of the BH or with the role of the recombination and tunneling current components

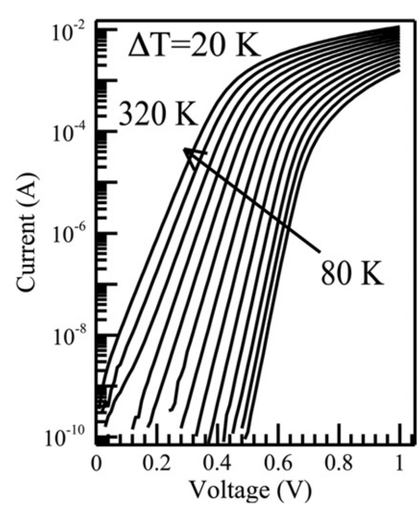

Fig. 2. The forward-bias current–voltage characteristics of Au/p-InP SBD in the temperature range of 80–320 K.