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The effect of hydrostatic pressure on the electrical characterization of Au/*n*-InP Schottky diodes

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ABSTRACT

The effect of hydrostatic pressure on the interface state density and Schottky barrier diode parameters such as ideality factor and barrier height obtained from the current–voltage (I–V) characteristics of Au/*n*-InP Schottky diodes was studied. It is shown that the ideality factor and the barrier height values of Au/*n*-InP diodes are in the range 2.36–1.93 and 0.546–0.579 eV for the 0.0–5.0 kbar pressure interval at room temperature, respectively. We have seen that the barrier height for Au/*n*-InP Schottky diodes has a linear pressure coefficient of 6.87 meV/kbar (=68.7 meV/GPa), approximately equal to that found for the band gap of InP. This means that the Fermi level is a reference level which is pinned to the conduction band minimum as a function of pressure. On the other hand, the interface state density decreases with increasing hydrostatic pressure due to the rectifying properties of the diode.

1. Introduction

Schottky barrier diodes (SBDs) have been widely studied in terms of material and device physics, design and fabrication technology and applications for decades. The most characteristic parameter of these diodes is their barrier height (Φ_b); that is, the energy separation between the Fermi level and the edge of the majority carrier band right at the interface [1–3]. However, a serious limitation of InP SBDs is the low Φ_b and large leakage currents which may be due to Fermi level pinning [4]. So, the low-Φ_b Schottky diodes of *n*-InP seem to be a good candidate for the application of zero-bias Schottky detector diodes [4–6].

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In a metal/semiconductor system, the Fermi level within the semiconductor band gap determines the formation of Φ_b, and thus the exact position of the Fermi level depends on the details of the interface [7–9]. On the other hand, the Φ_b of metal/semiconductor contacts is almost independent of the metal work function. Such a behavior indicates that some mechanisms must be responsible for the Fermi level pinning, such as metal-induced gap states (MIGSs) and defect models [10,11]. Thus, it has been shown that the investigation of the temperature dependence of Φ_b is very helpful for understanding the problem of Fermi level pinning. Corresponding to this, Kumar et al. [12] showed that the zero-bias Schottky barrier height decreases with decreasing temperature. However, the flat-band barrier height is almost independent of the temperature in Au/*n*-Si Schottky diodes. These results have been interpreted by using the models of Fermi level pinning.

Recently, hydrostatic pressure as well as the temperature dependence of SBDs has been investigated in order to study the optical and electrical properties and Schottky barrier formation. It is well known that these properties are sensitive to the application of external pressure and to the variations in temperature as well as non-idealities such as the interface state, interface oxide layer, interface fixed charges, interface traps and series resistance [13–15]. So, in recent years, hydrostatic pressure has been used as a tool for studying the optical and electronic properties of semiconductors and SBDs. The experimental evidence shows that pressure or stress plays a very important role in the transport properties in semiconductor materials [16]. The well-known effects are the energy band gap variation with hydrostatic pressure, the stress-induced piezoelectric field in III–V compound semiconductors, and the change of the band edge curvature and the band edge splitting with uniaxial pressure [17]. In this connection, it has been shown that Φ_b decreases under compressive stress parallel to the interface and increases under tensile stress due to the change in band gap caused by stress [18]. Additionally, Cankaya and Abay [13] showed that Φ_b, the ideality factor (n) and the series resistance (R_S) of Cd/*p*-GaTe SBDs decrease with an increase in the hydrostatic pressure. In contrast, Sonmezoglu et al. [19] showed that the values of Φ_b and n of Cd/*n*-GaAS SBDs increase with increasing hydrostatic pressure. So, it can be said from the experimental results on ideal Schottky diodes that the Fermi level is pinned relative to the valence band or conduction band edge at the interface to explain both the temperature and applied pressure dependence of Φ_b. Considering the Fermi level pinning and interface properties of metal/semiconductor systems, it would be interesting to study the hydrostatic pressure effect on the Au/*n*-InP SBD parameters such as Φ_b, and also interface state density (N_{SS}), and this paper presents our important results on them by using current–voltage (I–V) measurements.

2. Experimental method

The *n*-type InP wafer (Si-doped) used was (100) oriented with a free carrier concentration of $(2.90 \pm 0.05) \times 10^{15}$ cm^{-3} at room temperature. The wafer was degreased consecutively in trichloroethylene, acetone and methanol for 3 min. The degreased wafer was etched with H_2SO_4:H_2O_2:H_2O (5:1:1) for 1 min to remove surface damage and undesirable impurities. Indium was evaporated on the backside of the *n*-InP to provide the ohmic contact and the *n*-InP/In structure was annealed at 350 °C for 2 min in a N_2 atmosphere. Schottky contacts were formed on the front face of the *n*-InP as dots with a diameter of about 1 mm by evaporation of Au.

The pressure was created by a piston and cylinder-type chamber apparatus and a special transformer oil was used to transmit the pressure. The Au/*n*-InP Schottky diode was located in the pressure cell by using a specially designed sample holder and the I–V measurements in the hydrostatic pressure range of 0 to 5 kbar were made by electrical connections from the cell to the diode. The I–V characteristics of the Au/*n*-InP Schottky diodes with pressure and without pressure were obtained using an HP 4140B picoammeter in complete darkness and at room temperature.

3. Results and discussion

For SBDs, the thermionic emission theory predicts that the I–V characteristics are given as follows [20–22]:

$$I = I_S \left(\frac{qV}{nkT}\right)\left[1 - \exp\left(-\frac{qV}{kT}\right)\right]. \quad (1)$$