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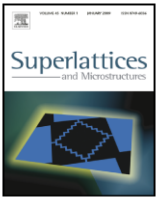

Hydrostatic pressure effect on the electrical properties of Al/conducting polymer (P3DMTPT)/p-Si/Al structure

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ABSTRACT

Al/P3DMTPT/p-Si/Al structure has been obtained by the evaporation of the polymer P3DMTPT on the front surface of a p-type silicon substrate. The current–voltage characteristic (I–V) of the structure has been measured under hydrostatic pressure at room temperature. Al/P3DMTPT/p-Si/Al structure demonstrates clearly rectifying behaviour by I–V curves under hydrostatic pressure. The barrier height and ideality factor from I–V characteristics varies from 3.8 to 2.03 and 0.63 to 0.72 eV at 0.0–6.0 kbar pressure, respectively. The barrier height for Al/P3DMTPT/p-Si/Al Schottky diodes has a linear pressure coefficient of $\alpha = 16.3$ meV/kbar (=163 meV/GPa). The energy distribution of the interface state density determined from I–V characteristics ranges from 1.46×10^{12} cm^{-2} eV^{-1} in $(0.58 - E_V)$ eV to 2.14×10^{12} cm^{-2} eV^{-1} in $(0.44 - E_V)$ eV and 4.84×10^{11} cm^{-2} eV^{-1} in $(0.64 - E_V)$ eV to 1.27×10^{12} cm^{-2} eV^{-1} in $(0.44 - E_V)$ eV for 0 and 6 kbar, respectively. The interface state density decreases with increasing hydrostatic pressure due to the rectifying properties of the diode.

1. Introduction

Conductor polymers are molecular analogs of inorganic semiconductors and metals [1] such as polypyrrole, polyaniline, polythiophene, and other conjugated polymers. Polythiophene (PT) and its derivatives, e.g., poly [3-(2,5-dimethyl-4-tienyl) phenyl thiophene] (P3DMTPT), are the most challenging class of conjugated polymers and can be used as electrical conductors, non-linear optical devices, sensors, batteries, organic transistors, and electrochromic devices because of their

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environmental and thermal stability [2–6]. Owing to the technological importance of contacts in the electronics industry, many experimental and theoretical efforts have been devoted to contact properties of polymer/inorganic semiconductor and metal/semiconductor polymer contacts [7–9]. Experimental studies are focused on the preparation, barrier height (Φ_b), and ideality factor (n) of polymer/inorganic semiconductor structures, changing with ageing time and temperature [10–13]. In Refs. [14,15], it has been shown that Φ_b increases and n decreases with increasing temperature. This shows that the current transport across the conducting polymer/semiconductor interface is a temperature activated process at the metal/semiconductor interface [16].

Hydrostatic pressure and temperature dependence of Schottky barrier diodes (SBDs) have been investigated to understand their optical and electrical properties and barrier formation. It is assumed that the Φ_b is determined by metal induced defect states which pin the Fermi level. In addition, Brillson et al. [17] suggests that an interface dipole contributes significantly to the effective barrier height. Peanasky and Drickamer [18] have showed that a pressure of barrier height decouples the measurements of the conduction band minimum movement from the valence band maximum and creates a second frame of reference for interpreting the energy band movement with pressure. Corresponding to this, Cankaya et al. [19] have found that the barrier height of Au/n-GaAs SBDs increases with increasing hydrostatic pressure with a linear pressure coefficient of 11.21 MeV/kbar. On the other hand, it has been concluded that the interface states in the organic/inorganic semiconductor structures play an important role in the determination of the characteristic parameters of the devices. In Refs. [7,12,20], the non-ideal behaviour of diodes with an ideality factor greater than unity has been ascribed to the interface states together with the series resistance and interfacial layer. It has also been shown that the interface state charges depend on the annealing temperature in the Ni/n-LEC GaAs SBDs [21]. Thus, the positive equilibrium interface state charges are concluded to be responsible for the actual equilibrium barrier height in that study. In particular, the interface state density (N_{SS}) decreases with the increase of energy from the edge of the valence band [7,13,14] and temperature and hydrostatic pressure seriously affect the (N_{SS}) in the metal–semiconductor contacts [22]. Considering the Fermi level pinning and interface properties of metal/conducting polymer/semiconductor systems, it would be interesting to study the hydrostatic pressure effect on the Al/conducting polymer (P3DMTPT)/p-Si/Al SBD parameters such as Φ_b, n and also N_{SS}. This paper present our important results on them by using I–V measurements.

2. Experimental method

In this study, to fabricate a Schottky diode with polymer interface, a p-type silicon wafer with (100) orientation, 400 μm thickness and 1 Ω cm resistivity was used. The wafer was chemically cleaned by boiling first in $NH_4OH + H_2O_2 + 6H_2O$ for 10 min then in $HCl + H_2O_2 + 6H_2O$ at 60 °C for 10 min. The ohmic contact was made by the evaporation of Al with high purity at the back face of the Si wafer. This was followed by a temperature treatment at 580 °C for 3 min in N_2 atmosphere. During this process, to remove the native oxide layer formed on the front face, the sample was kept in HF:H_2O (1:10) solution for 30 s and finally the wafer was rinsed in de-ionized water for 30 s, then was dried. 30 μg P3DMTPT was dissolved in 1 μl N-methyl-2-pyrrolidone (NMP). Silicon wafers were cut into rectangles and placed individually into a spin coater and the polymer solution was dropped on the front surface of the p-type silicon substrate by pipette. The metal–organic polymer film was formed by spinning wafers for 3 min at a maximum angular velocity of 1500 rpm reached within 11 s and then the solvent was allowed to evaporate at room temperature.

We have used chemically synthesized poly-[3-(2,5-dimethyl-4-tienyl)phenyl thiophene. For the synthesis, 3-(2,5-dimethyl-4-tienyl) phenyl thiophene] (1.1×10^{-3} mol, 0.297 g) was dissolved in 50 mL $CHCl_3$. The polymerization was initiated by the dropwise addition of (2.77×10^{-3} mol, 0.45 g) ferric (III) chloride as oxidizing agent under constant stirring at 25 °C. At the end of polymerization, the precipitated polymer was filtered and washed with $CHCl_3$ until the filtrate was colorless. Finally, the polymer was dried at 50 °C for 24 h under vacuum environment. The poly-[3-(2,5-dimethyl-4-tienyl)phenyl thiophene is called P3DMTPT. The molecular structure of P3DMTPT is given in Fig. 1. FTIR spectra of the polymers were recorded on a Perkin-Elmer model spectrometer (Beaconsfield, Buckinghamshire, UK). The FTIR spectra and characteristic peak values of P3DMTPT are presented in