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A study of the rectifying behaviour of aniline green-based Schottky diode

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ABSTRACT

An Al/aniline green (AG)/Ga_2Te_3 device was fabricated and the current–voltage (*I–V*), capacitance–voltage (*C–V*) and capacitance–frequency (*C–f*) characteristics of the device have been investigated at room temperature. The values of the ideality factor, series resistance and barrier height obtained from Cheung and Norde methods were compared, and it was seen that there was an agreement with each other. It was seen that the forward bias current–voltage characteristics at sufficiently large voltages has shown the effect of the series resistance. In addition, it was seen from the *C–f* characteristics that the values of capacitance have been decreased towards to the high frequencies. The higher values of capacitance at low frequencies were attributed to the excess capacitance resulting from the interface states in equilibrium with the Ga_2Te_3 that can follow the ac signal.

1. Introduction

Recently, a great deal of interest has been focused on semiconducting III–VI chalcogenides compounds. This interest has arisen partly because of their anisotropic physical properties and possible devices applications. There are various compositions in a gallium–tellurium system, in literature, such as GaTe, Ga_2Te_3 and Ga_3Te_4 [1–4]. Among those Ga_2Te_3 (or Gallium sesquitelluride) is of interest because although it crystallizes in the zinc-blend structure, the presence of stoichiometric cation vacancies in one-third of the lattice sites [5]. The bonding is tetrahedral, and the compound has very large concentration of vacancies. The presence of the gallium vacancies in the Ga_2Te_3 lattice makes it an interesting material for fabricating devices. According to the optical absorption the band gap of the crystal has been found 1.08 eV [6]. Fig. 1 depicts the crystal structure of the Ga_2Te_3.

In addition, in the last few decades the organic semiconductors and organic–inorganic semiconductor interfaces have been a subject of intensive research. Due to their stability and barrier height enhancement properties, non-polymeric or polymeric semiconducting organic compounds have been employed particularly in electronic devices. Semiconducting organic materials can be used at different in condensed matter physics applications, such as organic light emitting diodes, organic field effect transistors, Schottky diode, photovoltaic (PV) and solar cells, organic spintronics and so on [7–11]. Among those, aniline green (AG) is considered a good candidate for organic semiconductor device fabrication such as Schottky device and solar cell. Because, it offers a possibility of low-cost and large-area devices. Aniline green with molecular formula $C_{23}H_{25}ClN_2$ (4-[(4-dimethylaminophenyl)-phenylmethyl]-*N*,*N*-dimethyl-aniline) used in this study is a typical aromatic azo compound. The molecular structure of the aniline green is given in Fig. 2. The structure of azo dyes has attracted considerable attentions recently due to their wide applicability in the light-induced photo isomerization process, and their potential usage for the reversible optical data storage [12].

Although, the various experimental works have been studied on Ga_2Te_3 crystals, there is no work dealing with organic/Ga_2Te_3 structures. The aim of this study is to fabricate an Al/AG/Ga_2Te_3 structure and to study some junction parameters of the structure by the electrical measurements such as; current–voltage (*I–V*), capacitance–voltage (*C–V*) and capacitance–frequency (*C–f*).

2. Experimental procedure

The crystal with (1 1 0) orientation and about 400 μm thickness was used for fabricating the device. The surfaces of the crystal were mirror-like and no further polishing procedure was necessary. Before metallization, the Ga_2Te_3 crystal was cleaned in acetone and

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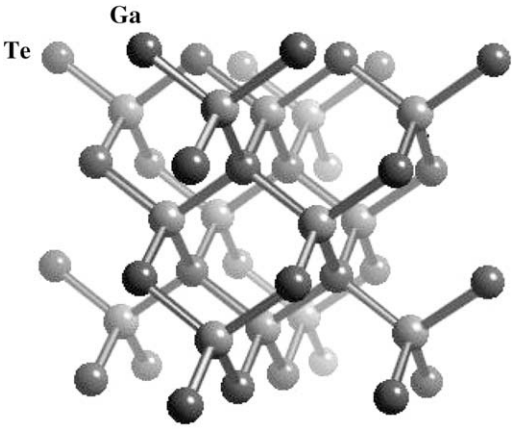

Fig. 1. The crystal structure of Ga_2Te_3 semiconductor.

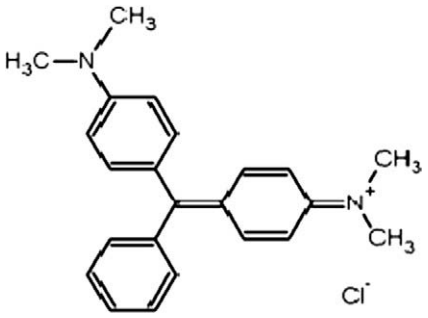

Fig. 2. Chemical structure of aniline green (AG).

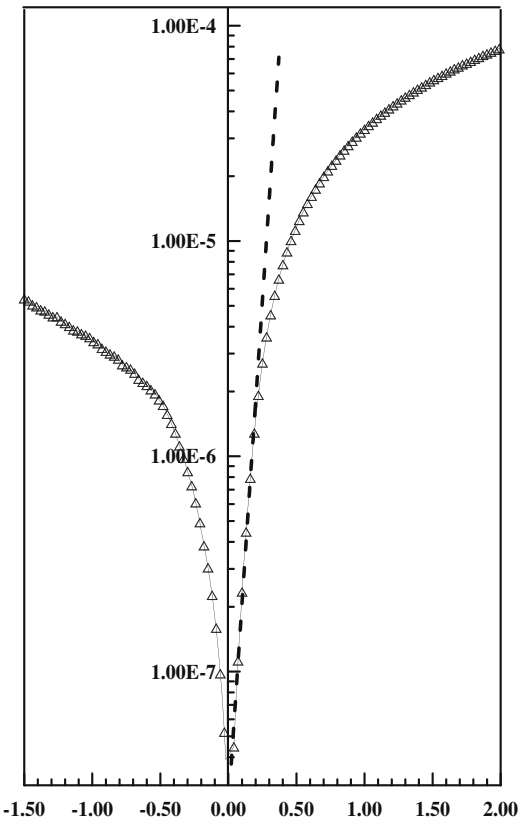

Fig. 3. The current–voltage characteristics of the Al/AG/Ga_2Te_3 device.

methanol for 10 min each with ultrasonic agitation to degrease and to remove gross contamination. Finally, it was rinsed in de-ionized water for 30 s and was dried in N_2 atmosphere, and then the ohmic contact was made by evaporating In on the back of the substrate at 10^{-5} torr, and then was annealed at 200 °C for 3 min in N_2 atmosphere. AG organic layer was directly formed by adding 6 μL of the aniline green organic compound solution (wt 0.2% in methanol) on the front surface of the crystal, and evaporated by itself for drying of solvent in N_2 atmosphere for 1 h. The thickness of the AG film was calculated as 780 nm from the high frequency *C–V* characteristics. Then, to perform the electrical measurements Al was evaporated on the AG at 10^{-5} torr (diode area = 7.85×10^{-3} cm^2). In this way the Al/AG/Ga_2Te_3/In structure was obtained. The *I–V* and *C–V–f* measurements of this structure were performed with KEITLEY 487 Picoammeter/Voltage Source and HP 4192A (5 Hz–13 MHz) LF IMPEDENCE ANALYZER, respectively.

3. Results and discussion

Room temperature *I–V* measurement of the Al/AG/Ga_2Te_3 is shown in Fig. 3. It shows a rectifying behaviour: The forward current increases exponentially with voltage, but the reverse bias current presents a poor saturation for low reverse applied voltages and increases slowly. The current through a Schottky diode according to thermionic emission theory (TE) is given by [13,14]

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

with

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

where I_0 is the saturation current, q is the electronic charge, V is the junction voltage, n is the diode ideality factor, k is the Boltzmann constant, T is the temperature, A is the diode area, A^* is the effective Richardson constant and Φ_b is the barrier height. The diode ideality factor (n) and the reverse bias saturation current (I_0) are determined [13,14] from the slope and the intercept of semi-logarithmic forward bias *I–V* plot for $V > 3kT/q$ using Eqs. (1) and (2) and the n and the Φ_b were given by

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

and

$$\Phi_b = (kT/q)\ln\left(AA^*T^2/I_0\right), \tag{4}$$

respectively. The value of ideality factor is equal unity for an ideal Schottky contact. However, the higher value of the ideality factor may be greater unity due to the presence of interface states between the metal and the semiconductor since an interfacial film of atomic dimensions always exists between a metal and semiconductor [15].

The values of the n and Φ_b obtained from *I–V* characteristics in Fig. 3 by using Eqs. (3) and (4) are 1.79 and 0.67 eV, respectively. The high values in the ideality factor are caused possibly by various effects such as inhomogeneities of organic film thickness, nonuniformity of the interfacial charges and the effect of the series resistance (R_s). The series resistance is an important parameter affects the electrical characteristics of the rectifying contacts. The R_s is influenced by the presence of the interface layer between the organic layer and the semiconductor and leads to non-ideal forward bias current–voltage (*I–V*). Usually, the forward bias current–voltage (*I–V*) characteristics are linear in the semi-logarithmic scale at low voltages but deviate considerably from linearity due to effect