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Poly(ethylene glycol dimethacrylate-co-1-vinyl-1,2,4-triazole/ carbon nanotube, single-walled)/*n*-GaAs Diode Formed by Surface Polymerization

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Poly(ethylene glycol dimethacrylate-co-1-vinyl-1,2,4-triazole/carbon nanotube, single-walled)/*n*-GaAs ([P(EGDMA-VTAZ)-CNSW]/*n*-GaAs) diode was fabricated by using surface polymerization method. Electrical properties were carried out at several temperatures. Dark current mechanisms were investigated by using current–voltage (*I*–*V*) measurements. It was shown that the fabricated structure exhibited rectification behaviour that makes it a good candidate for electronic device applications.

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1. Introduction

The Schottky barrier diodes are widely investigated due to their technological importance in electronic industry. They play an important role in many applications, such as solar cells, photodetectors, metal-based transistors, MESFETs, etc. [1–3]. Gallium arsenide (GaAs) is one of the most useful III–V semiconductors due to its direct band-gap photon absorption and has been intensively investigated in recent years. Especially, GaAs based devices have attracted great interest for high speed electronic and optoelectronic applications [3–7]. In recent years, some investigations have been focused on organic–inorganic junctions because of their promising electrical and optical properties for new electronic devices [8–10].

In the present paper, ([P(EGDMA-VTAZ)-CNSW]/*n*-GaAs) structure has been fabricated using surface polymerization [11] and electrical properties of the device has been reported. Current–voltage (*I*–*V*) characteristics are analyzed at a temperature range between 100 K and 360 K and several parameters are investigated depending on temperature. In addition, capacitance–voltage (*C*–*V*) measurement of the structure is carried out at room temperature. It is shown that the fabricated structure by surface polymerization technique exhibits rectification behaviour that makes it a good candidate for electronic device applications.

2. Experimental

Ethylene glycol dimethacrylate (EGDMA) was obtained from Merck (Darmstadt, Germany); we purified it by passing it through active alumina and stored it at 48 °C until use. 1-Vinyl-1,2,4-triazole (VTAZ) (Aldrich, Steinheim, Germany) was distilled in vacuum (74–768 °C, 10 mm Hg). 2,20-Azobisisobutyronitrile (AIBN) was obtained from Fluka A.G. (Buchs, Switzerland). In carbon nanotube single-walled (CNSW), powdered cylinder cores, composition was used: carbon $>$ 90%, assay $\geq$ 77% (carbon as SWCNT), diameter 0.7–1.1 nm, as properties obtained from Aldrich (USA). All other reagents of analytical grade were used without further purification.

n-type GaAs wafer used for the fabrication of the [P(EGDMA-VTAZ)-CNSW]/*n*-GaAs structure has (100) orientation, 400 μm thickness and 508 mm diameter. Before making contacts the wafer was chemically cleaned using RCA cleaning procedure (i.e. 10 min boiling in $H_2SO_4+H_2O_2$ followed by a 10 min $HCl+H_2O_2+6H_2O$ at 60 °C). It was immersed in diluted 20% HF for 60 s. The wafer was rinsed in deionized water of resistivity 18 MΩ cm with ultrasonic cleaning in each step. After that, the sample was dried in the high-purity nitrogen stream and inserted into the deposition chamber. Au (88%) and Ge (12%) were used for ohmic contact [1, 12]. The ohmic contact with a thickness of ≈1875 Å was made by evaporating 99.995% purity Au metal and germanium on the back of the surface wafer in a thermal evaporator unit at 10^{-6} Torr. Then it was annealed at 450 °C for 5 min in flowing N_2 in a quartz tube furnace. The top ohmic contact on the P(EGDMA-VTAZ)-CNSW was formed by silver contact paste.

The *I*–*V* measurements were performed at various temperatures using a Keithley 6517A electrometer/voltage source (USA) and *C*–*V* measurements were carried out at room temperature with a TEGAM 3550 LCR Meter (USA). All measurements were controlled by a computer via an IEEE-488 standard interface so that the data collecting, processing and plotting could be accomplished automatically.

2.1. Poly(ethylene glycol dimethacrylate-co-1-vinyl-1,2,4-triazole/carbon nanotube, single-walled)/n-GaAs diode structure

The feed composition menu for the preparation of the poly(ethylene glycol dimethacrylate-co-1-vinyl-1,2,4-triazole/carbon nanotube, single-walled)/*n*-GaAs diode

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is shown in Table I. About 2.0 mL of each solution, consisting of toluene, EGDMA, VTAZ, AIBN, and CNSW, were used to prepare the [P(EGDMA-VTAZ)-CNSW]/n-GaAs diode structure. The mixture was degassed for 90 min by nitrogen purging prior to the addition of the initiator, AIBN. Then the polymerization was conducted for 4 h at 25 °C under stirring and nitrogen atmosphere. After 4 h, the solution was transferred into a known area (1 cm^2) — surface of n-GaAs and the polymerization was continued for 24 h at 70 °C in an oven. The thickness of the films was 200 μm.

TABLE I

Feed composition used for the polymerization.

EGDMA	VTAZ	AIBN	Toluen	CNSW
2.0 mL	1.0 mL	50 mg	2.0 mL	30 mg

3. Results and discussion

The current–voltage (I–V) characteristics for the Schottky diode [3] are as follows:

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

where I is the current flowing, n is the ideality factor, q is the electron charge, V is the bias voltage, T is the temperature in K, I_0 is the saturation current that can be extracted from the extrapolation of the linear portion of plot to the y-axis and is given by

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

where A is diode area, A^* is the Richardson constant which is 8.16 A/(cm^2 K^2) for n-GaAs [13], φ_{b} is the Schottky barrier height. From Eqs. (1) and (2), the ideality factor (n) and barrier height (φ_{b}) can be calculated from the following relations:

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

$$\varphi_{\mathrm{b}} = \frac{kT}{q}\ln\left(\frac{AA^*T^2}{I_0}\right). \tag{4}$$

Figure 1 shows the semilogarithmic forward and reverse current–voltage characteristics of the [P(EGDMA-VTAZ)-CNSW]/n-GaAs structure in the temperature range of 100–360 K. It is obvious from the figure that the structure demonstrates good diode characteristics and rectifying properties with rectification coefficient 363.

The ideality factor and barrier height values are obtained from the intercept and slope of the linear portion of the forward-bias ln(I) versus V plot at each temperature. As can be seen from Fig. 2, the obtained values of n and φ_{b} for the structure are strong functions of temperature and they decrease from 9.04 to 2.76 and increase from 0.286 eV to 0.861 eV with increasing temperature from 100 K to 360 K, respectively. The large ideality factor values may be attributed to the presence of a native oxide layer, inhomogeneities of P(EGDMA-VTAZ)-CNSW film thickness and series resistance [3, 5, 12].

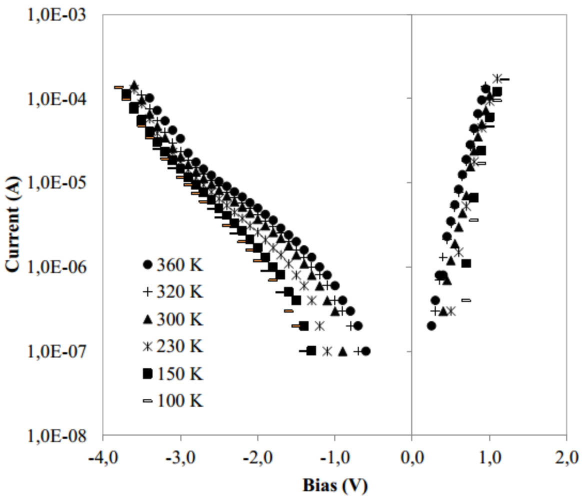

Fig. 1. Forward and reverse I–V characteristics of the [P(EGDMA-VTAZ)-CNSW]/n-GaAs structure at several temperatures.

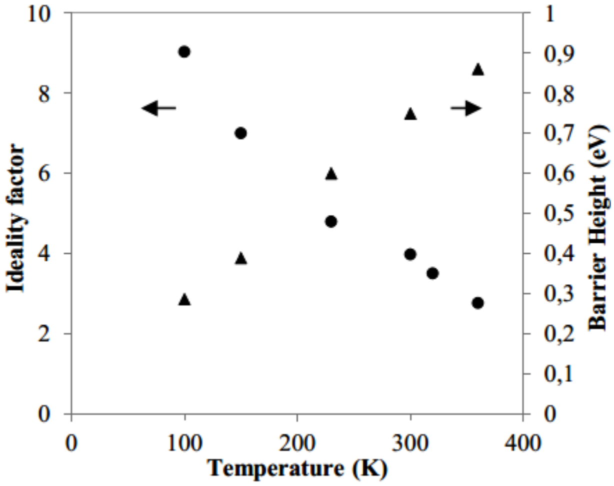

Fig. 2. Temperature dependence of the ideality factor and barrier height for the [P(EGDMA-VTAZ)-CNSW]/n-GaAs structure.

Figure 3 also shows temperature dependence of reverse current at different biases. It is seen from the figure that the reverse current is poorly dependent on temperature, indicating that tunneling mechanism dominates the current flow.

Capacitance–voltage (C–V) measurement is one of the fundamental electrical measurement techniques used to investigate the properties of the Schottky barrier structure [11]. Figure 4 shows $1/C^2$ dependence on V taken at temperature $T = 300$ K and frequency $f = 1$ MHz.

The C–V dependence can be interpreted by the law

$$\frac{1}{C^2} = \frac{2\left(V_{\mathrm{R}}+V_{\mathrm{B}}\right)}{q\varepsilon_{\mathrm{s}}N_{\mathrm{d}}A^2}, \tag{5}$$

where A is the device area, V_{R} is the reverse bias voltage, V_{B} is the built in potential at zero bias and is determined from the extrapolation of the $1/C^2$ plot to the V-axis,

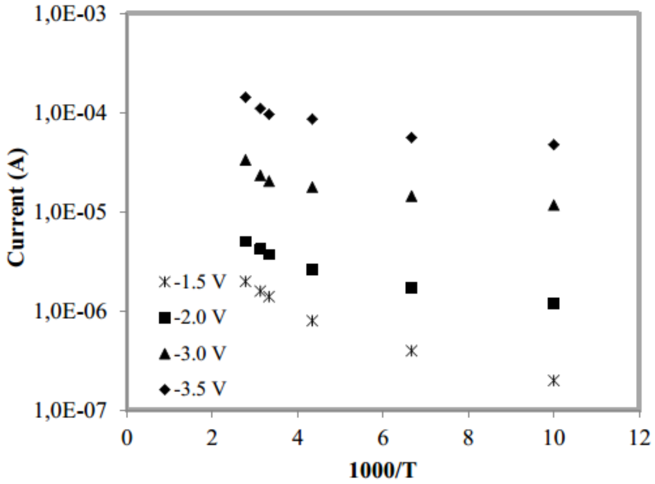

Fig. 3. Reverse current as a function of reciprocal temperature at different reverse biases.

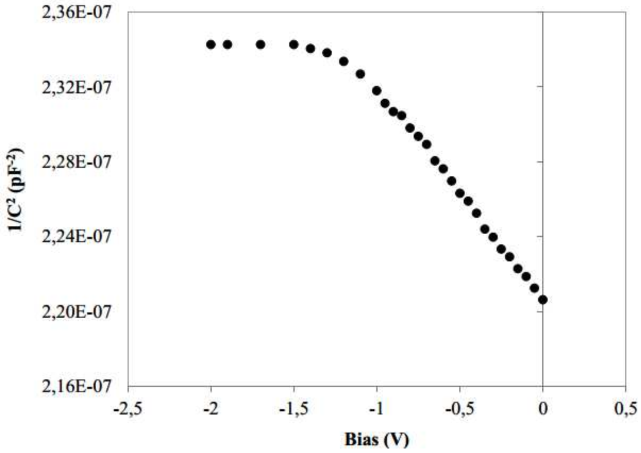

Fig. 4. C–V characteristics of the [P(EGDMA-VTAZ)-CNSW]/n-GaAs structure at room temperature at $f = 1$ MHz.

ε_s is the dielectric constant of the GaAs and N_d is the doping concentration. The gradient of the C^{-2}–V curve leads to a carrier concentration in the GaAs of $N_d = 1.5 \times 10^{16}$ cm^{-3}.

4. Conclusion

Poly(ethylene glycol dimethacrylate-co-1-vinyl-1,2,4-triazole/carbon nanotube, single-walled)/n-GaAs diode has been fabricated using surface polymerization and electrical properties of the device has been investigated. Current–voltage (I–V) characteristics are analyzed at various temperatures. Capacitance–voltage (C–V) measurement of the structure is carried out at room temperature. Barrier height of the structure was obtained from I–V measurements. It is shown that the fabricated structure by surface polymerization technique exhibits rectification behaviour that makes it a good candidate for electronic device applications.

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