Radiation Measurements 71 (2014) 402–406

Contents lists available at ScienceDirect

Radiation Measurements

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

Effect of gamma radiation on the electrical properties of Polyaniline/silicon carbide heterojunctions

Jorlandio F. Felix [a,*], Diego L. da Cunha [b], Mohsin Aziz [c], Eronides F. da Silva Jr. [b,e], David Taylor [c], Mohamed Henini [c], Walter M. de Azevedo [b,d]

[a] Departamento de Física, Universidade Federal de Viçosa, Av. P H Rolfs, s/n, Campus Universitário, Viçosa, MG 36570-900, Brazil
[b] Pós-Graduação em Ciência de Materiais, Universidade Federal de Pernambuco, Av. Professor Luiz Freire 1235, Recife, PE 50670-901, Brazil
[c] School of Physics and Astronomy, Nottingham Nanotechnology and Nanoscience Center, University of Nottingham, Nottingham NG7 2RD, United Kingdom
[d] Departamento de Química Fundamental, Universidade Federal de Pernambuco, Av. Professor Moraes Rego, 1235, Cidade Universitária, 50670-901 Recife, PE, Brazil
[e] Departamento de Física, Universidade Federal de Pernambuco, Av. Professor Moraes Rego, 1235, 50670-901 Recife, PE, Brazil

HIGHLIGHTS

- We demonstrate the fabrication of PANI/p-SiC devices with good electrical properties.
- The electrical characteristics of the devices present good reproducibility.
- We show that the PANI/p-SiC devices are good candidates for gamma irradiation sensors.

ARTICLE INFO

Article history:
Available online 29 May 2014

Keywords:
Polyaniline
Silicon carbide
Heterojunction
Gamma radiation
Sensor

ABSTRACT

Polyaniline thin films have been deposited by a very simple technique on p-type Silicon Carbide (SiC) substrates to fabricate heterojunctions devices with good electrical properties. In this work two heterojunctions devices of Polyaniline (PANI) on p-type 4H–SiC and 6H–SiC substrates were electrically characterized using current- voltage (I-V) in the temperature range 20–430 K Capacitance–frequency (C-f) measurements. Furthermore, impedance and capacitance measurements are carried out to study the effect of gamma irradiation on these devices. Additionally, we demonstrate not only the ease of fabrication of PANI/p-SiC heterostructures, but also we show strong indication that these heterostructures have potential applications as sensors of gamma irradiation.

1. Introduction

Conducting Polymers (Shirakawa et al., 1977; Huang et al., 1986; Forrest, 2004) have attracted significant interest in the last few years due to the fact that they could be used as active materials in low cost electronic and optoelectronic devices (Dimitrakopoulos and Malenfant, 2002). Amongst all the conducting polymers, polyaniline (PANI) materials (Gospodinova and Terlemezyan, 1998; Nicolas-Debarnot and Poncin-Epaillard, 2003) are the most promising due to their exceptional electrical properties, ease of synthesis, good environmental stability, and doping capability with protonic acids. Consequently, these classes of polymers have been employed to fabricate devices with applications in the electronic industry (Posudievsky et al., 2008; Bangar et al., 2010; Park et al., 2010; Chambers et al., 2009; Wang et al., 2010; Bhandari et al., 2010; Laranjeira et al., 2002a,b). On the other hand, silicon carbide (SiC) is a well-known material for its extraordinary mechanical and physical properties such as hardness, abrasive wear resistance, chemically inert, high thermal conductivity (Harris, 1985), and high breakdown electric fields (>10^6V/cm) (Harris, 1985; Wright and Horsfall, 2007). SiC is a wide band gap semiconductor; 4H–SiC and 6H–SiC have energy gaps of 3.03 eV and 3.26 eV, respectively. Laranjeira et al. (2003) reported that the optical characteristics of PANI is also strongly affected by the interaction with gamma radiation, leading to an optical dosimeter for ionizing radiation based on the color change of this polymer. They also studied Polyaniline/silicon heterojunction diodes for gamma radiation detection (Laranjeira et al. 2002a,b; Lima Pacheco et al., 2003; Azevedo et al., 1999). In this work, we prsent the characterization of the PANI/SiC heterojunctions and analyze their performance as a function of the gamma radiation

* Corresponding author. Tel.: +55 31 3899 3486; fax: +55 31 3899 2483.
E-mail addresses: jorlandio@ufv.br, jorlandiof@gmail.com (J.F. Felix).

http://dx.doi.org/10.1016/j.radmeas.2014.05.014
1350-4487/

dose. Additionally, we demonstrate for the first time not only the ease of fabrication of PANI/p-SiC heterostructures, but also we present strong indication that these kinds of heterojunctions have potential applications as sensors of gamma irradiation.

2. Experimental procedure

In this work, we used p-type SiC–4H and SiC–6H wafers (Si terminated) purchased from Cree Research Corporation. These substrates have a 4.9 μm epitaxial layer with a doping level of $10^{16}cm^{-3}$. The total wafer thickness was 421 μm for 4H–SiC and 382 μm for 6H–SiC. Details of the PANI film preparation technique have been reported elsewhere (Felix et al., 2011). In brief, after cleaning the substrates by RCA process, a large area backside electrical contact was deposited by thermal evaporation of 99.9% pure Al (thickness of 200 nm) and Ni (thickness of 50 nm). Subsequent to the backside electrical deposition, the substrates were annealed in vacuum (10^{-6} Torr) for 5 min at 800 °C. After this procedure, a thin film of polyaniline (thickness of 200 nm) was deposited by spin coating on the epitaxial layer. Electrical Ohmic contacts of 180 nm of Au (99.9%), with area of 0.0020 cm^2, were deposited on the polyaniline thin film by thermal evaporation. Finally, the devices were encapsulated in TO5 holders. Fig. 1 shows a schematic diagram and the packaged devices. The current–voltage (I-V) characteristics were measured in the temperature range of 20–430 K with intervals of 40 K using a current source measurement unit (Keithley 236) and a closed-loop helium cryostat (Janis CCS-450). The capacitance and impedance measurements were performed by using the HP 4284A precision LCR system (DC signal of 500 mV and the frequency of the AC signal varied from 100 Hz to 1 MHz). To investigate the effect of radiation on the PANI/SiC heterojunctions, the devices were irradiated in a ^{60}Co Gamma-cell (dose rate of 5.143 kGy/h).

3. Results and discussion

Dark I-V characteristics as a function of temperature were measured on both PANI/p-6H–SiC and PANI/p-4H–SiC heterojunctions, as shown in Fig. 2(a) and 2(b). It is worth pointing out that the I–V characteristics were measured in the temperature range of 20–430 K at 40 K intervals; however, in the interest of clarity, only some representative curves are shown. In these Figures, it can be seen that the reverse currents as function of temperature for PANI/p-6H–SiC heterojunctions is higher than those of PANI/p-4H–SiC heterojunctions. This behaviour can be explained by using the characteristics parameters of the devices, such as, ideality factor and barrier high, which will be discussed later.

The room temperature rectification ratio at ±1 V was about 10^3 and 10^5 for PANI/p-6H–SiC and PANI/p-4H–SiC, respectively. Such values are in the range of the highest values reported in the literature for rectifier devices based on organic/inorganic hybrid heterojunctions (Roman et al., 1999, Liem et al., 2010). The devices were modeled as Schottky diodes with series resistance. The I-V characteristic, including series resistance, is expressed by the following relation (Schroder, 1998):

$$I = I_0\left(\exp\left(\frac{q(V-IR_s)}{nkT}\right)-1\right) \quad \text{and} \quad I_0 = AA^*T^2\exp\left(-\frac{q\phi_{Bo}}{kT}\right) \tag{1}$$

In the above equations, I_0 is the saturation current, A^* is the effective Richardson's constant, A is the effective diode area, k is the

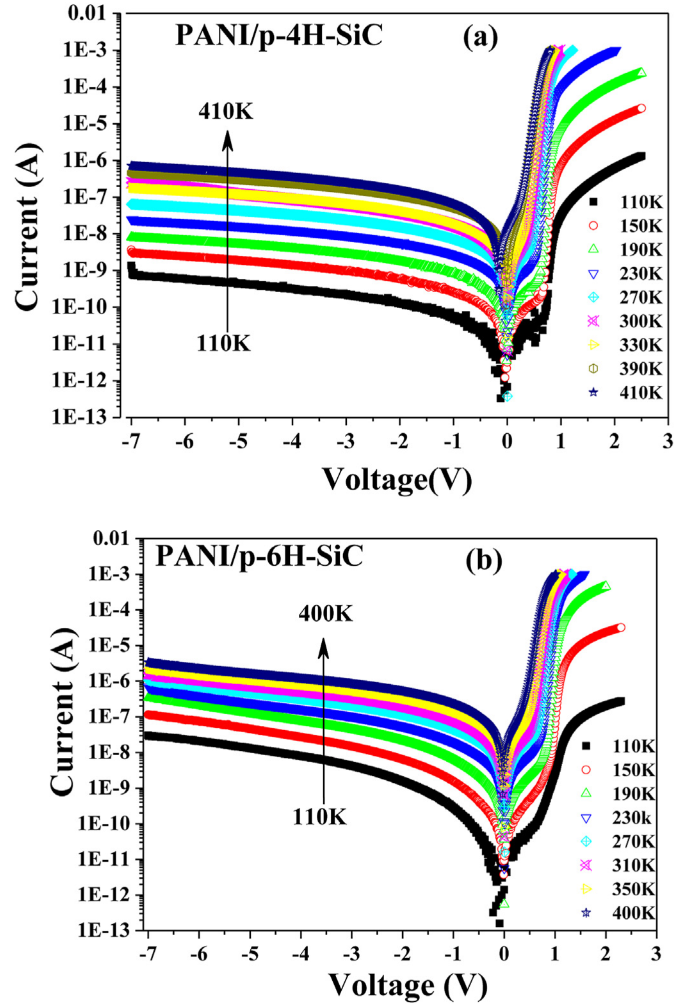

Fig. 2. Semi-logarithmic plots of dark I–V characteristics of (a) PANI/p-4H–SiC heterojunction and (b) PANI/p-6H–SiC heterojunction in the temperature range of 110–410 K at 40 K intervals.

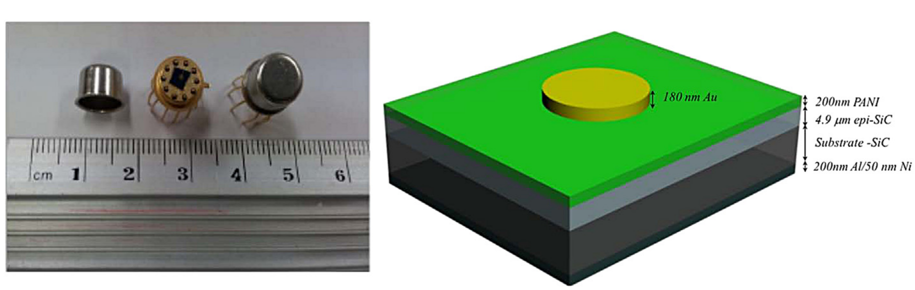

Fig. 1. Final aspect of the devices mounted on a TO5 holder (left). A schematic representation of the Au/PANI/p-SiC/Al/Ni (right).