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Microelectronic properties of organic Schottky diodes based on MgPc for solar cell applications

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ABSTRACT

The magnesium phthalocyanine (MgPc) based Schottky diodes are fabricated using four inorganic semiconductors (*n*-GaAs, *n*-Si, *p*-InP, *p*-Si)by the spin-coating process at 2000 rpm for 1 min. Their microelectronic and photoelectrical parameters are investigated from the current-voltage I–V characteristics measurements at room temperature in dark and under light. The ln I–V plots, Cheung and Norde methods are used to extract the MgPc based Schottky diodes parameters in dark, including ideality factor (n), barrier height (Φ_b), series resistance (R_s) and the obtained values are compared. The MgPc/n-Si showed excellent *n* of 1.1 which is very closer to ideal Schottky diode behavior, high Φ_b of 0.98 eV and low series resistance of 237.77 Ω in contrast MgPc/p-Si showed non-ideal Schottky diode behavior with n of 2.42 and high series resistance of $1.92 \times 10^3\ \Omega$. The MgPc/p-InP exhibited photovoltaic behavior with excellent J_{SC} of 3.11×10^3 mA/cm^2 and a photosensitivity of 30.46. The I–V forward bias in log scale have been investigated to survey the dominated conduction mechanism. This study reviews thecrucial effect of (p and n) type conductivity substrates on the electrical parameters of organic MgPc Schottky diodes for the use in such organic photovoltaic applications.

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1. Introduction

Nowadays, metal phthalocyanine (MPc's) organic materials take large interest in the development of microelectronic technology; particularly for their efficient use in various optoelectronic and electrochromic device [1,2]. Due to their electrical and optical properties, the small size molecule organic MPc semiconductors are subject of interest [3,4]. It is reported that MPc demonstrated a high thermal and chemical stability [4,5]. For their appropriate characteristics the organic semiconductor used as active components in electronic devices mainly for their easy process in low cost and large area device characterization [2]. Specifically, magnesium phthalocyanine (MgPc) is good candidate because it shows a high photoconductivity and large value of photo-absorption coefficient of $2 \times 10^5\ cm^{-1}$[6].

In the last decades, many works focused on the investigation and development of fabrication methods and the characterization of Schottky diode devices by using MPc's organic materials. Schottky diodes are the bases of large diodes and number of compound semiconductor electronic devices, such as microwave diodes, field-effect transistors and solar cells [7,8]. The fast response, low threshold voltage and simple fabrication technology are among of the best advantages of such diodes [9,10]. Up to our knowledge, rare works reported on the magnesium phthalocyanine Schottky device characteristics and no reports on the effect of material substrate and conductivity type of substrate on the electronic properties of organic MPc devices are prior mentioned.

In the current paper, we investigate the electrical and photoelectrical behavior of MgPc Schottky diodes deposited on different substrate materials (*n*-GaAs, *n*-Si, *p*-InP and *p*-Si). For this aim, MgPc diodes are fabricated by spin coating on *n*-GaAs, *n*-Si, *p*-InP, *p*-Si substrates separately with back side of Au-Ge, Au, Au-Zn and Al respectively. These back contacts such as Ag for MgPc/n-GaAs/Au-Ge, MgPc/n-Si/Au and MgPc/p-InP/Au-Zn and Au for MgPc/p-Si/Al are respectively evaporated on organic films as displayed on Fig. 1. The electrical properties of the device are analyzed using its current-voltage (I–V) data in dark and light using a solar simulator with AM1.5 filter. Furthermore, the effect of material and conductivity type of substrate is evidenced, emphasized and discussed.

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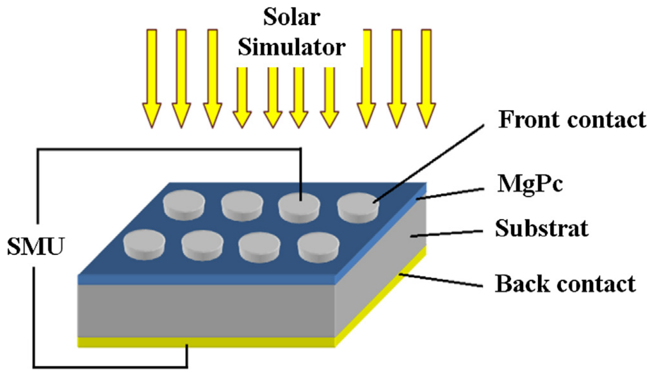

Fig. 1. The cross sectional of MgPc Schottky diode.

2. Experimental details

In order to fabricate the MgPc Schottky diodes, we use the following process: four types of substrates are selected for comparative study, *p*-Si and *n*-Si substrate with (1 0 0) crystal orientation, 1–10 ohm.cm of resistivity and 380 μm, 280 μm of thickness respectively, *p*-InP substrate with (1 0 0) crystal orientation, 1.36×10^{-1}–1.63×10^{-1} ohm.cm of resistivity and 350 μm of thickness and *n*-GaAs substrate with (1 1 1) crystal orientation, 1.7×10^{-3}–2.37×10^{-3} ohm.cm of resistivity and 350 μm of thickness. Firstly, we rinse the substrates in $5H_2SO_4 + H_2O_2 + H_2O$ solution for 60 s to eliminate surface damage layer and organic contamination and then in H_2O + HCl solution. The substrates are then rinsed in dionized water and finally dried by nitrogen (N_2). For each sample 0.02 g of MgPc supplied by Sigma–Aldrich are dissolved in 25 ml of chloroform; the blue solutions are poured on each substrate and the films are produced by spin-coating process utilizing a spin coating system (spin coat G3P-8) at 2000 rpm for 1 min and dried at 115 °C for 3 min. In the aim to obtain a suitable film the process is repeated 2 times for each sample. The front and back contact Al/Au-Zn, Au/Al, Ag/Au-Ge and Ag/Au are respectively formed on MgPc/n-Si, MgPc/p-Si, MgPc/n-GaAs and MgPc/p-InP. The front contacts are made by evaporating the used metals in these samples as dots on MgPc thin film trough shadow mask, after that the back contacts metals are formed on the entire surface of each sample. All evaporations are carried out using the NVBJ-300 NANOVAK® vacuum thermal evaporation system at pressure of 3×10^{-6} Torr. The current-voltage I-V measurement MgPc Schottky diode is performed from −1.0 to +1.0 V bias voltages in dark and under light source of 100 mW by using Keithely 2400 sourcemeter.

3. Results and discussion

3.1. Extraction of schottky diode parameters under dark conditions

The study of the current-voltage I–V characteristics gives the significant information about Schottky diode behavior; here Fig. 2 shows the semi-logarithmic reverse and forward bias of the experimental I–V of the MgPc Schottky diodes in dark.

The experimental I–V characteristic is analyzed by using the thermionic emission (TE) theory given by [7]:

$$I = I_0 \exp\left[\frac{q(V - IR_s)}{nkT}\right] \quad (1)$$

I and V are the measured current and voltage of Schottky diode; I_0 is the saturation current given by [11]:

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

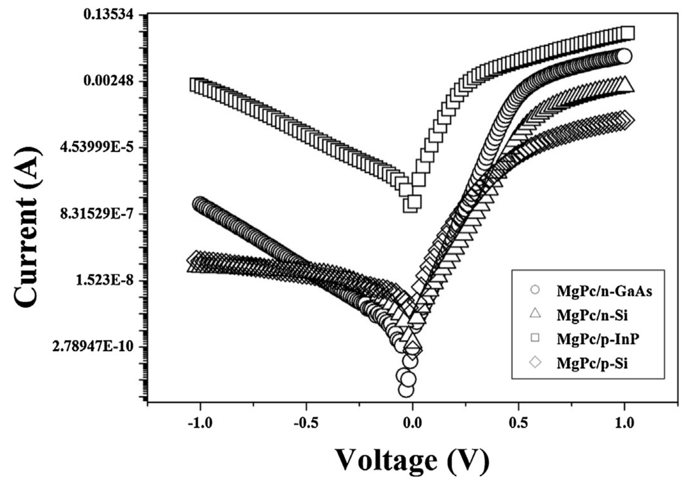

Fig. 2. Current-voltage (semilog scale) characteristic plots of MgPc/n-GasAs, MgPc/n-Si, MgPc/p-InP and MgPc/p-Si organic Schottky diode at room temperature.

A is the effective diode area, A^* is the Richardson constant which equal: 110 [12], 32 [13], 8.16 [14] and 60 $A/cm^2 K^2$ [15] for *n*-Si, *p*-Si, *n*-GaAs and *p*-In Prespectively, T is the temperature in Kelvin, q is the electron charge, n is ideality factor, Φ_b is the zero-bias Schottky barrier height which can calculate by using the following equation:

$$\Phi_b = \frac{kT}{q} \ln\left(\frac{AA^*T^2}{I_0}\right) \quad (3)$$

The equation of I–V for Schottky diode based on the TE theory shows that the plot of current versus voltage is linear; from this plot we extract the value of I_0 from the y-axis intercept and we introduce it in the Eq. (3) to calculate Φ_b. The *n* represent the ideality factor which is greater than the unity and shown the deviation between the experimental I–V characteristics of the Schottky diode and the ideal TE theory where $n = 1$; this n can be calculated by using the following equation [16]:

$$n = \frac{q}{kT} \frac{dV}{d(\ln I)} \quad (4)$$

where k is Boltzmann constant, T is the absolute temperature (300 K) and q is the electron charge. The parameter n is equal to unity in the ideal diode case but for our devices it is greater than 1 due to interface density and series resistance. By using the Eq. (4), we determine the ideality factor of MgPc Schottky diodes from the slope of the linear part of the bias forward ln I–V. The ideality factor n is very important parameter that decide the amount of contribution of tunneling on the recombination process and the change of performance of the device [17], and also high values of n can be attributed to the presence of the interfacial this layer, a wide distribution of the low-Schottky barrier height (SBH) patches (or barrier inhomogeneities), series resistance and therefore, to the bias voltage dependence of SBH [7].

Table 1
The electrical parameters of MgPc organic diodes under dark calculated with different methods.

Schottky diode structure	dV/dlnI		Cheung's method		Norde method	
	n	R_s (Ω)	R_s (Ω)	Φ_b (eV)	R_s (Ω)	Φ_b (eV)
Ag/MgPc/n-GaAs/Au-Ge	3.29	32.89	34.01	0.54	28.66	0.54
Ag/MgPc/p-InP/Au-Zn	8.87	3.36	3.36	0.47	3.73	0.49
Ag/MgPc/n-Si/Au	1.10	237.77	237.77	0.98	252.46	0.78
Au/MgPc/p-Si/Al	2.42	1920.29	1922.29	0.73	1936.19	0.76

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