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Electrical and photoresponse properties of Al/graphene oxide doped NiO nanocomposite/p-Si/Al photodiodes

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The electrical and photoconducting properties of Al/graphene oxide doped NiO nanocomposite/p-Si/Al photodiodes with various graphene oxide contents were investigated by using current–voltage, transient photocurrent, photocapacitance and photoconductance measurements at various illumination intensities in the range of 10–100 mW/cm^2. Graphene oxide doped NiO nanocomposite thin films were prepared by sol–gel spin method. Experimental results indicate that the reverse current of the photodiodes increases with the increasing illumination intensity. The value of transient photocurrent, photocapacitance and photoconductance measured as a function of time increases after illuminating and returns to original value after turning off the illumination. In addition, the frequency-dependent capacitance and conductance measurements was performed to indicate the existence of interface states. The obtained results suggest that the fabricated diode can be used as a photodiode in optoelectronic applications.

1. Introduction

Nanocomposites are developed for superior device performance. In solar energy harvest and conversion, nanocomposites are utilized to overcome limits of single materials in solar spectrum response, transport of electrons or holes, and reaction of electrons or holes with chemicals [1]. Nanocomposites demonstrate better light harvesting and activity compared to their individual components by effectively suppressing the electron hole recombination [2]. The orientation and arrangement of asymmetric nanoparticles, thermal property mismatch at the interface, interface density per unit volume of nanocomposite, and polydispersity of nanoparticles significanlty affect the effective thermal conductivity of nanocomposites.

Metal oxide semiconductors are promising materials for electronic and optoelectronic applications. One of them is nickel oxide, NiO with a wide band gap of 3.6–4.0 eV [3]. It is interesting material due to its low material cost, promising ion storage, optical properties. Also, it can be producted using various methods [4].

On the other hand, in recent years, the graphene is functional and advanced material since 2004 [5] because ti exhibited high electrical and thermal conductivity, and excellent optical properties [6–8]. In present study, our aim is to prepare NiO based photodiodes. For this, we can evaluate that the photocondting properties of NiO can be improved by doping of graphene oxide into NiO. Thus, in present study, we prepared graphene oxide doped NiO/p-Si heterojuncton photodiodes. It is well known that photodiodes are the most versalite semiconductor optoelectronic devices used for direct detection of light in the ultraviolet visible and infrared spectral regions, and of soft x-rays and charged particles. Also, they are also suitable for detection of gamma rays and neutrons [9]. Photodiodes operate by absorption of charged particles or photons and generate a flow of current in an external circuit, proportional to the incident power. A photodiode transforms light into current and is designed to operate in reverse bias and has a depleted semiconductor region with a high electric field that serves to separate photo-generated electron–hole pairs, most of which contribute to a photocurrent. The separated electrons and holes must diffuse in different directions to avoid electron–hole recombination. The charge separation is usually driven by a potential difference induced by band bending at an interface in the semiconductor [10–12].

The aim of this study is to investigate electrical and photoconductivity properties of Al/graphene oxide doped NiO nanocomposite/p-Si/Al photodiodes with various graphene oxide contents. These properties of the photodiodes were analyzed by using current–voltage (I–V) and capacitance/conductance-voltage (C/G–V) measurements.

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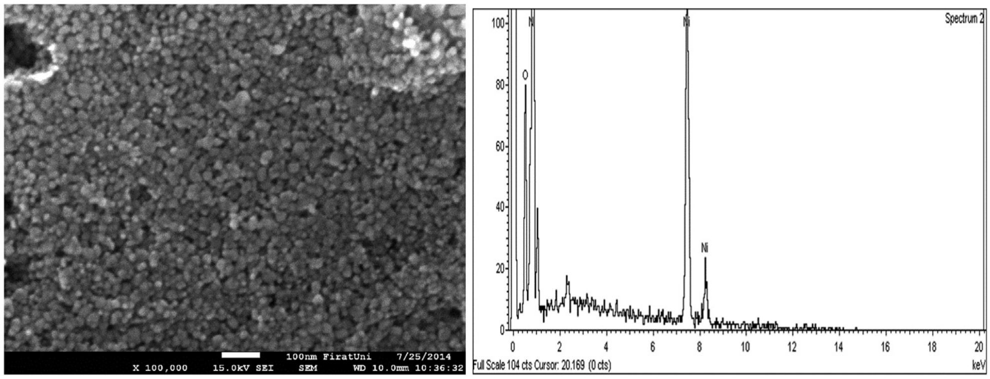

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Fig. 1. SEM image and EDS spectra of the GO doped NiO samples.

2. Experimental details

For the synthesis of the nickel oxide material, we used the nickel acetate precursor. Firstly, the nominal value of its was dissolved in methanol solution under stirring. The dissolution process of the nickel acetate was completed after 10 min and then, NaOH was added to this solution and solution was stirred for 2 h at 60 °C. The obtained solution was centrifuged for 10 min to collect preciapates. The preciapates were washed in methanol for three times and were dried and then, the preciapate powders were calcinated at 400 °C for 1 h. The NiO material was charactrizaed by the scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and UV-VIS and FTIR spectroscopy techniques. The graphene oxide was prepared by Hummers method [13]. The graphene oxide doped NiO composites were prepared for various molar ratios of GO:NiO = 0, 0.01 and 0.03. The prepared composites were coated on the p-Si having Al ohmic contact using the drop coating method. After coating procedure, the films were dried at 50 °C for 10 min. Then, the top contacts were prepared for the diodes. For this, Al metal was used to prepare top contact of the diodes. Al metal was evaporated by thermal evaporation system in the form of circles. The diode contact ares was found to be 3.14×10^{-2} cm^2. I–V measurements of Al/graphene oxide doped NiO nanocomposite/p-Si/Al photodiodes were carried out using a Keithley 4200 semiconductor characterization system in dark and illumination intensity range of 10–100 mW/cm^2 using a solar simulator. The intensity of the light was measured by solar power meter (Model TM-206). The C–V and G–V measurements were performed with Keithley 4200 semiconductor characterization system in a wide frequency range.

3. Results and discussion

3.1. Current–voltage characteristics of GO doped NiO/p-Si diodes

The structural and elemental analysis of the synthesized NiO sample were performed using SEM microscope and X-ray energy dispersive analysis (EDS). The SEM image of the NiO sample is shown in Fig. 1(a). It is seen that the NiO sample is formed from the nanoparticles and the grain size was found to be about 20–30 nm. The particle size distribution of NiO particles is almost homogeneous. The elemental analysis spectra of the NiO is shown in Fig. 1(b). In EDS specrtra of the NiO sample, Ni and O elements are observed. This confirm the chemical composition of the NiO. The SEM images of GO doped NiO samples are shown in Fig. 2 (a–b). As seen in Fig. 2 (a–b), the NiO nanoparticles are covered by GO particles. The coverage of GO on NiO particles change the distribution of particles in GO doped NiO nanocomposites. This distribution has a significant effect on the photoresponse properties of GO doped NiO/p-Si heterojunction diodes. It will be discussed in following section in detail.

The current–voltage (I–V) measurements have been used to extract the electrical parameters of Schottky diode. The electrical

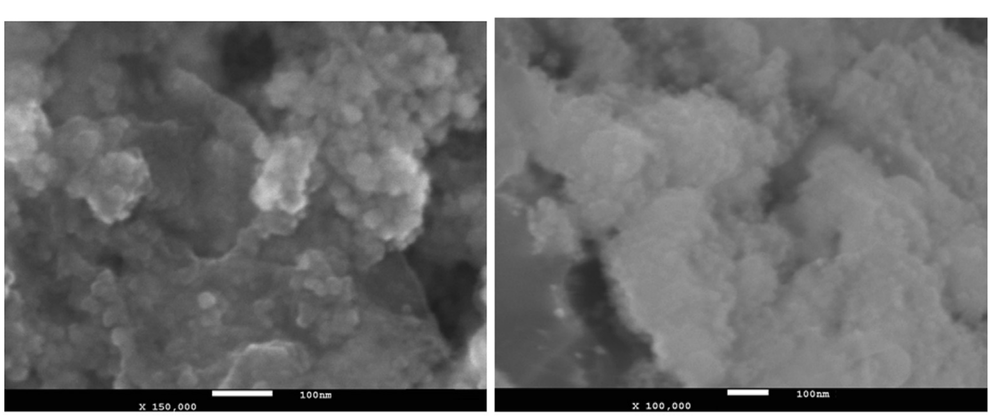

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Fig. 2. SEM images of the GO doped NiO samples.