Journal of Materials Chemistry C

PAPER

Cite this: J. Mater. Chem. C, 2014, 2, 2387

Fabrication of an efficient GLAD-assisted p-NiO nanorod/n-ZnO thin film heterojunction UV photodiode

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Received 14th October 2013
Accepted 7th January 2014

DOI: 10.1039/c3tc32030h

www.rsc.org/MaterialsC

The glancing angle deposition (GLAD) configuration in RF magnetron sputtering has been utilized to deposit p-type NiO nanorods, which are integrated with n-type ZnO thin film to realize a high performance p–n heterojunction diode for the efficient detection of UV photoradiation. The fabricated nano p-NiO/n-ZnO heterojunction shows excellent rectifying characteristics (rectification ratio $\sim 4 \times 10^3$) with a very low reverse saturation current ($\sim 10^{-10}$ A). The heterojunction photodiode exhibits a high current gain (3.71×10^3), high photoresponsivity (3.24×10^5 A W^{-1}), with a relatively fast response (~200 ms) and recovery speed (~25 ms) towards a very low UV intensity of 0.62 μW cm^{-2} ($\lambda = 300$ nm). Recombination tunneling and space-charge limited current are the probable conduction mechanisms at low and high applied voltages respectively for the fabricated heterojunction diode. The observed high response speed and excellent responsivity of the diode towards deep-UV ($\lambda = 300$ nm) radiation might lead to potential military applications such as missile tracking, in addition to optical communications.

A. Introduction

Ultraviolet (UV) photodetectors based on wide band-gap (WBG) ($E_g > 3.0$ eV) semiconductors are gaining tremendous research interest due to the high quantum efficiency, enhanced photocurrent gain and large UV/visible rejection ratio in comparison to narrow band-gap semiconductor-based UV photodetectors such as Si ($E_g = 1.12$ eV), which exhibits a wide photoresponse spectrum covering both the UV and visible region and hence gives low sensitivity.[1–4] Nanostructures of wide band-gap semiconductors such as nanorods or nanoneedles are considered to be promising for the development of UV photodetectors as they provide a large surface to volume ratio and are known to have a high internal photoconductivity gain due to the surface enhanced electron–hole separation efficiency.[5] Therefore, research is continuing worldwide to improve the response characteristics of WBG semiconductor-based UV photodetectors.[6–8] Amongst the different materials studied thus far, zinc oxide (ZnO) is a widely used n-type semiconductor for the fabrication of UV photodetectors for advanced optoelectronic device applications due to its wide band gap ($E_g = 3.37$ eV), large exciton binding energy (60 meV) and strong cohesive energy (1.89 eV).[9–11] NiO is another WBG semiconductor with $E_g \sim 4.0$ eV and enhanced optoelectronic properties, exhibiting potential applications in nanoscale electronics and optoelectronic devices, such as field effect transistors, biosensors and photodiodes.[12,13] The p–n junction-based photodiodes are of specific importance in comparison to semiconductor detectors for UV detection applications due to their fast response and recovery speeds.

Most of the efforts for the development of heterojunction UV photodiodes are directed towards the synthesis of nanomaterials of WBG semiconductors (p-type as well as n-type) by chemical routes, which suffer from the problems of low photosensitivity due to imperfections of the junction interface and poor crystallinity, which thus limits their application in the realization of practical device fabrication.[14–18] The p–n junctions based on ZnO nanoparticle films fabricated by a chemical route have been reported, but rectifying characteristics were not successfully achieved because of the indefinable junction areas.[14] Chen *et al.*, in another report, fabricated heterojunctions comprised of ZnO nanowire with GaN for the detection of UV radiation, but obtained a high reverse leakage current (3.8×10^{-6} A) with poor photosensitivity (~12).[16] Some reports are available in the literature on heterojunction photodiodes comprised of n-ZnO with p-NiO.[19–21] However, the obtained results are not encouraging for device applications. Hence, achieving a nanomaterial-based p–n junction with a low leakage current and low imperfections of the junction interface is still a challenge. On the contrary, nanostructures fabricated by physical deposition techniques such as RF sputtering is a potential way to resolve the problems encountered in the heterojunction diodes prepared using chemical routes. Surprisingly, no reports have described the preparation of heterojunctions of nanostructured NiO and ZnO using a reproducible physical route, and the exploitation of their

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