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Trap assisted space charge conduction in p-NiO/n-ZnO heterojunction diode

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ABSTRACT

The development of short-wavelength p–n junction is essentially important for the realization of transparent electronics for next-generation optoelectronic devices. In the present work, a p–n heterojunction diode based on p-NiO/n-ZnO has been prepared under the optimised growth conditions exhibiting improved electrical and junction parameters. The fabricated heterojunction gives typical current–voltage (I–V) characteristics with good rectifying behaviour (rectification ratio $\approx 10^4$ at 2 V). The temperature dependent current–voltage characteristics of heterojunction diode have been studied and origin of conduction mechanism is identified. The space-charge limited conduction with exponential trap distribution having deep level trap is found to be the dominant conduction mechanism in the fabricated p–n heterojunction diode. The conduction and valence band discontinuities for NiO/ZnO heterostructure have been determined from the capacitance–voltage (C–V) measurements.

1. Introduction

p–n junctions are the necessary building blocks for many optoelectronic device applications such as rectifying diodes, transistors, photodetectors, solid state lasers, light emitting diodes etc. [1–5]. Transparent oxide wide band gap (WBG) semiconductor junctions offer distinct advantages including excellent stability in harsh environments and their ability to efficiently combine the good electrical conductivity with high optical transmission for short wavelength electronic devices. Zinc oxide (ZnO) has been considered a promising oxide semiconductor for advanced optoelectronic device applications due to wide band gap (3.37 eV), large exciton binding energy (60 meV) and a strong cohesive energy (1.89 eV) [6]. ZnO is a naturally occurring n-type semiconductor which can be made to have p-type conductivity when deposited under special conditions or doped with certain impurities. However, reliability and reproducibility of p-type ZnO thin film is a major concern due to high ionization energy of acceptor impurities, low solubility of dopants, and self-compensation effect [7]. Alternatively, p–n heterojunction devices combining n-type ZnO with different p-type materials including GaN, NiO, Si, doped and intrinsic Cu based compounds have been studied [8–9]. Heterojunctions of p-GaN/n-ZnO and related structures have been widely reported as p-type GaN has the same wurtzite structure and nearly identical lattice constants as that of ZnO [8–9]. However, high resistivity, low mobility, and complex fabrication processing of p-type GaN block further industrial application [10]. Therefore efforts are going on continuously worldwide towards the search of p-type WBG material having excellent electrical and optical properties.

Nickel oxide (NiO) is a p-type direct band-gap semiconductor having wide band-gap energy varying from 3.4 to 4.0 eV with a small electron affinity of 1.8 eV [11]. NiO is also a promising candidate for transparent conducting oxide (TCO) applications as its electrical conductivity can be tuned combining with the high optical transparency [12]. Furthermore, NiO can be easily deposited using various techniques including rf sputtering, electron beam evaporation, pulse laser deposition, spray pyrolysis, chemical solution deposition etc. Amongst them rf sputtering is the most preferred deposition technique for device fabrication due to better control over stoichiometry, defect profile and excellent uniformity over large area of the deposited thin films [13]. The p-type NiO (p-NiO) thin film can be easily integrated with n-type ZnO (n-ZnO) film for the realization of a p–n heterojunction. Few reports are available on the fabrication of NiO/ZnO p–n heterojunctions [14,15]. However, the crucial junction parameters like rectification ratio and ideality factor are found to be inferior and show poor reproducibility due to difficulty in controlling the crystallite size and film uniformity resulting in poor electrical and optical properties [14–16].

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