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Ga doping improved electrical properties in p-Si/n-ZnO heterojunction diodes

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Abstract
Doping of metal ions in the ZnO nanomaterials have attained much research interest for increasing the optical and electrical properties in various applications. Here, we report Ga doped ZnO nanoparticles obtained using the phytochemicals assisted hydrothermal synthetic strategy. The phytochemicals in the extract of the neem (*Azadirachta indica*) leaves were utilized as both reactant and agglomeration preventing agent. The structural studies indicated the Ga doping introduced decrease in the interplanner distance of the Zn–O lattice. The electron microscopic images revealed the consistency of the interconnected particles morphology for the Ga doping in ZnO nanoparticles. The emission spectrum indicated the electron rich Ga^{3+} ions induced fermi energy level shift towards the conduction band in accordance to the B–M effect. Further, we had fabricated p-Si/n-$Zn_{1-x}Ga_xO$ heterojunction diode structures using the Ga doped ZnO nanomaterials. The electrical studies of the diodes were indicated the enhanced charge conduction for Ga doping.

1 Introduction

The ZnO nanostructures either grown or deposited on the surfaces of p-type substrates such as p-Si [1], p-CuO [2, 3], p-NiO [4], p-CuI [5], resulting the effective p–n heterojunction diodes have been identified as a potential devices for the applications like photodetectors, sensors, solar cells, piezo-phototronics, photocatalytic electrodes and other optoelectronic applications [1–7]. Further, doping process [6] and thermal treatments [7] were conducted in the materials to improve the performance of the diodes. However, the major problem in the n-ZnO nanostructures are the low charge carrier concentration and the formation of high energy barrier height. These parameters results in poor charge carrier conduction in the diodes. Moreover, the low-cost viable techniques of producing the diode structures could enhance the feasibility for low cost high efficient devices.

Doping of elements in ZnO nanomaterials are being in practice for effective alteration in the charge carrier concentration and thus enhances the device efficiency as reported [8–11]. Importantly group III elements such as Ru [8], Sm [9], Gd [10], In [11] and Ga [6], are found to be the promising dopants for enhancing the performance of the devices. Especially, the Ga doping had studied for improving the electrical conductivity properties of ZnO [6]. The covalent bond length of Zn-O is 1.97 Å, whereas the bond length of the suggested dopants are 2.7 Å, 1.92 Å and 2.1 Å respectively for Al–O, Ga–O and In–O. Since the Ga–O and Zn–O bond lengths are almost equal, the Ga doping in ZnO results in a smaller amount of alteration in the ZnO lattice [6].

Even though various synthesis strategies are in practice for producing the ZnO nanomaterials, green synthesis using the natural sources is a clean methodology, toxic-free and low cost production technique [12]. Green synthesis of ZnO nanostructures is highly recommended nowadays since this methodology does not require any sophisticated equipment and toxic chemical reagents. Moreover the green synthesis strategy generally uses plant parts like leaf, root, stem, fruits, etc., which are abundant in nature. The extract obtained from the parts of the plants having the phytochemicals are used as redox agents for ZnO synthesis. The reduction/oxidation

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