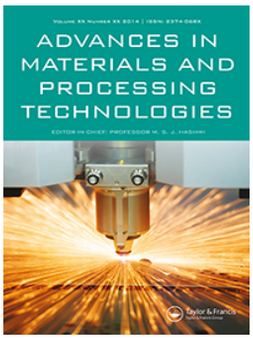

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Preparation and characterisation of pure and Ni doped ZnO nanorods

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ABSTRACT

One-dimensional pure and Ni-doped zinc oxide nanorods (NRs) were prepared by chemical bath technique. Some physical properties like optical, morphological and structural were examined for prepared NRs. The result of X-ray diffraction XRD was exposed that the crystal structure was hexagonal for both pure and Ni-doped NRs where there is no change in the crystal system but some small shifting in diffraction angle appeared. The chemical composition and the presence of Ni atoms in the ZnO were approved by EDX test. Additionally, morphology investigation of the scanning electron microscopy (SEM) is conducted and showed that the shape of prepared materials was NRs. A red shift in the absorption spectrum and band gap happened after doping with Ni where the energy gap dropped from 3.72 for ZnO to 3.5 eV for ZnO:Ni.

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KEYWORDS
ZnO; doping; ZnO:Ni; optical properties; structural properties

1. Introduction

Because of the one-of-a-kind physicochemical characteristics they possess, materials on the nanoscale have recently been the primary focus of attention among researchers. ZnO belongs to the class of II–IV semiconductors and has a large bandgap of 3.34 eV. Due to its unique conductivity, photocatalytic activity, piezoelectricity, and pyroelectricity, zinc oxide has shown to be a viable material for use in sensor, photovoltaic, and solar cell applications [1–7].

ZnO has an exciton binding energy that is quite high (60 meV), making it a suitable material for the development of optical devices that are based on excitonic activities. ZnO

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nanostructures can have their characteristics altered by doping with transition metal ions, which results in the introduction of inherent donor defects [8].

Due to the intriguing combination of charges and spin degrees of freedom, weak magnetic semiconductor materials (DMSs) have garnered a lot of devotion as a hopeful functional materials. DMSs are created when rare earth or transition metals ions substitute a significant number of the intuitive ions in the lattice of semiconductor. Such functional materials form the basis of spin electronics (spintronics), a real-world technology [9].

Doping will cause the Zn ions that are found in the lattice of ZnO to be substituted by metals ions, which will result in an increase in the amount of free electrons. The oxide semiconductor's electronic characteristics are consequently improved as a result of this [10].

Ni possesses a number of useful qualities, including resistance to corrosion, room-temperature ferromagnetic, optical characteristics, and the ability to conduct heat and electricity. In addition, the ion radius of nickel is less than that of zinc (0.69 compared to 0.74 A^{o}), which means that in the compound ZnO, the zinc ions can be easily replaced by nickel ions. At present time, the majority of the scientific study groups have decided to use Ni as the doping element for ZnO [11–16].

Therefore, several approaches such as thermal decomposition method, co-precipitation method, hydrothermal method, chemical bath deposition, sol–gel process, pulsed-laser deposition and solvothermal were used to synthesise Ni-doped ZnO nanorods (NRs) [17–24].

In this work, the ZnO NRs and ZnO that had been doped with nickel were manufactured utilising the chemical bath approach. Studies were conducted on the structural, morphological and optical aspects of ZnO NRs that had been doped with Ni.

1.1. Synthesis of pure ZnO NRs

ZnO NRs synthesis was formed by chemical bath technique. An aqueous solution holding 0.005 M zinc nitrate hexahydrate (Zn (NO3)2.6H2O) and 0.005 M of hexamine ((CH2)6N4) was put on hot plate at 90°C for 4 h. White precipitate was formed at the glass backer indicating the formation of ZnO. The precipitates were collected and washed with distilled water for two periods of time and washed with methanol once and dried in oven at 80°C for 5 h.

1.2. Synthesis of Ni-doped ZnO NRs

ZnO:Ni NRs synthesis was formed by chemical bath technique. An aqueous solution containing 0.005 M zinc nitrate hexahydrate (Zn (NO3)2.6H2O) mixed with 3% elemental nickel (Ni) and 0.005 M of hexamine ((CH2)6N4) was put on hot plate at 90°C for 4 h. White precipitates were formed at the glass backer indicating the formation of doped ZnO. The precipitates were collected and washed with distilled water twice and washed with methanol once and dried in oven at 80°C for 5 h. Figure 1 displays the preparation and testing procedure of NRs.

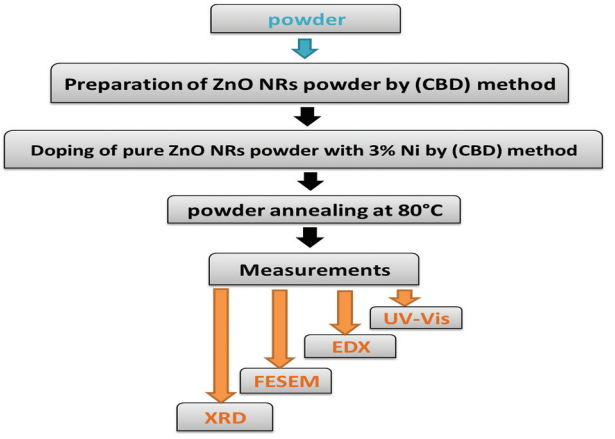

Figure 1. The preparation and testing procedure of NRs.

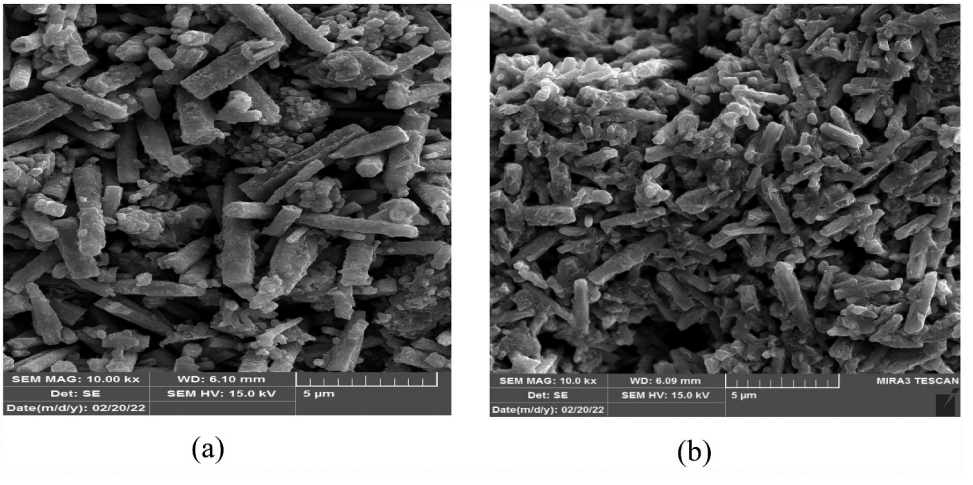

Figure 2. FESEM micrographs of (a) ZnO:Ni and (b) ZnO NRs.

2. Results and discussion

Figure 2 shows the morphology and size of ZnO and ZnO:Ni NRs. It can be seen that both types of NRs are same in the shape and size. The diameter of rods is in nanoscale and their lengths are in microscale. Good yield was obtained and most rods are identical with high homogeneity.

In order to confirm the formation of nickel-doped zinc oxide NRs, EDX analysis was performed. As can be seen in Figure 3, EDX was used to perform an investigation of the chemical composition of both pure and Ni-doped ZnO NRs. EDX examination substantiates the hypothesis that there is nickel present in the ZnO system, and the wt% is almost identical to that which was utilised in experimental production.

The X-ray diffracted patterns of pure ZnO and 3% nickel-doped ZnO are presented in Figure 4. The XRD patterns that were obtained demonstrate that the samples are

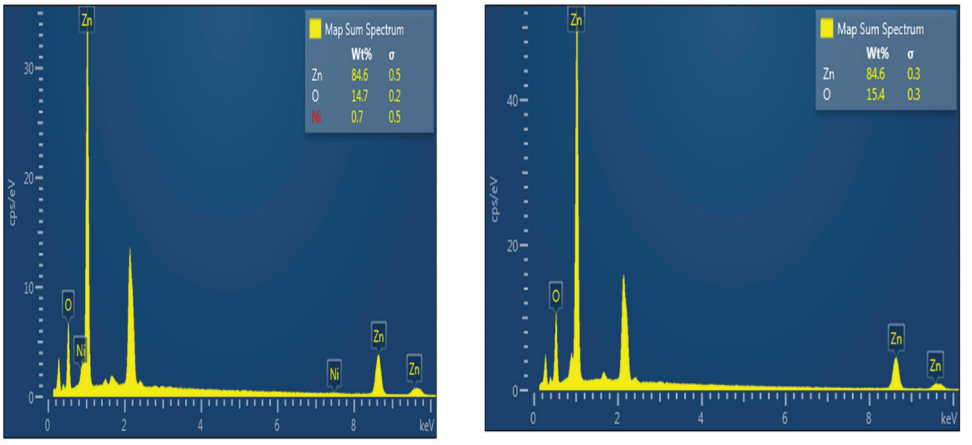

Figure 3. EDX spectra of (a) ZnO:Ni and (b) ZnO NRs.

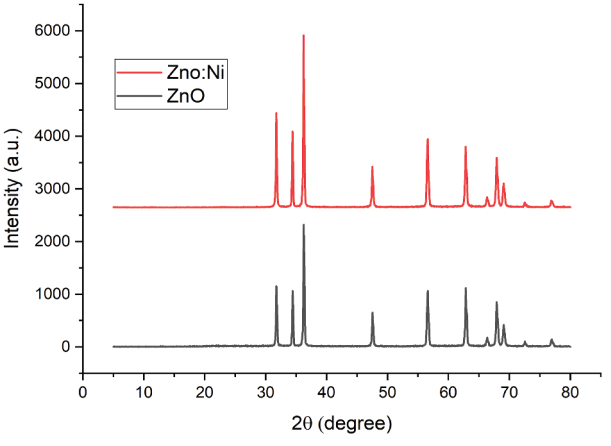

Figure 4. XRD patterns of ZnO and ZnO:Ni NRs.

composed of zinc oxide in a hexagonal arrangement. On the other hand, after doping, the intensity of the ZnO diffraction peaks begins to rise. Because there are no other diffraction patterns that follow on following Ni, this suggests that the dopant has been completely dispersed throughout the material [25]. When compared to ZnO, Ni-doped ZnO exhibits a very minor shift towards a lower angle in its diffraction peaks. It is possible that this is because of doping with Ni atoms [17,26]. Crystallite sizes for all the prepared samples were calculated using Scherrer equation and found to be equal to 18 nm for pure ZnO and 14 nm for Ni-doped ZnO. Tables 1 and 2 show the diffraction angles, inter-atomic distance and corresponding miller indices for ZnO and ZnO:Ni, respectively.

UV-Vis spectroscopy had been applied to obtain the absorbance spectra and calculated the energy gap of pure and Ni-doped ZnO NRs at regions of wavelengths (250–1000) nm. Figure 5 shows the absorption spectra of ZnO and ZnO:Ni. From the figure, it

Table 1. Diffraction angles, inter atomic distance and corresponding miller indices for ZnO.

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing [Å]	Matched by
31.7893	1142.14	0.2400	2.81265	100
34.4509	1027.71	0.2400	2.60120	101
36.2713	2312.71	0.1920	2.47471	002
47.5295	650.19	0.3360	1.91150	102
56.5677	1015.26	0.2880	1.62565	110
62.8320	1069.00	0.1920	1.47780	103
66.3279	151.07	0.2400	1.40813	200
67.9067	817.34	0.2880	1.37918	112
69.0721	391.09	0.2400	1.35873	201
72.5220	76.63	0.1440	1.30236	004
76.9497	130.53	0.2400	1.23808	202

Table 2. Diffraction angles, inter atomic distance and corresponding miller indices for ZnO:Ni.

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing [Å]	Matched by
31.7758	1759.40	0.1920	2.81382	100
34.4234	1477.73	0.2400	2.60322	101
36.2459	3254.68	0.2400	2.47639	002
47.5079	750.74	0.2880	1.91231	102
56.5554	1250.01	0.3840	1.62598	110
62.8101	1161.27	0.1920	1.47826	103
66.3224	163.98	0.1920	1.40823	200
67.8929	858.77	0.2400	1.37943	112
69.0438	395.91	0.2880	1.35922	201
72.5170	82.22	0.1440	1.30244	004
76.8998	121.67	0.2880	1.23876	202

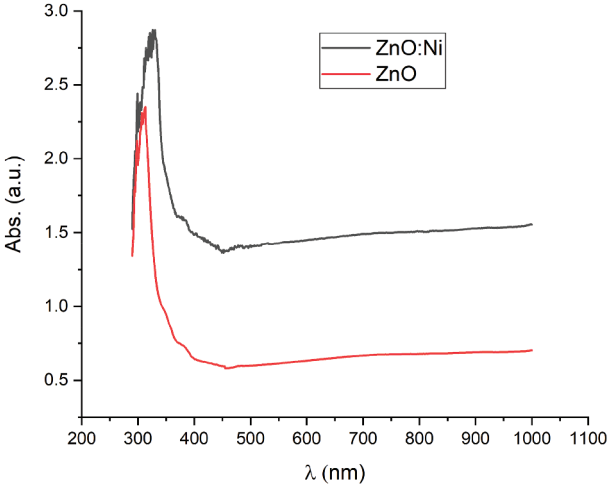

Figure 5. Absorption spectra of ZnO and ZnO:Ni NRs.

can be seen that the absorption peak of ZnO was located at 310 nm; after doping in the case of ZnO:Ni, this peak faced a red shift towards the higher wavelengths and located at 340 nm.

The energy band gap, Eg, of each sample that was synthesised is determined by applying the tauc relation. Figure 6 reveals the energy gap of prepared NRs where the bang gap for pure ZnO was equal to 3.7 eV and for ZnO:Ni it was equal to 3.5 eV, which

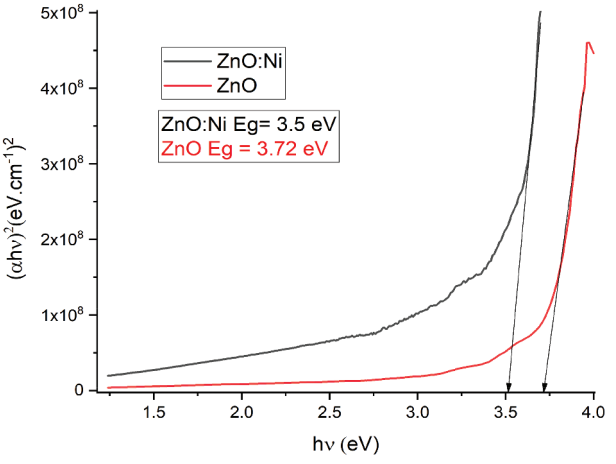

Figure 6. Energy band gaps of ZnO and ZnO:Ni NRs.

means there is a red shift to lower energy because presenting Ni atoms in the ZnO [27–31].

3. Conclusions

In conclusion, we have investigated the influence that the Ni doping on the structural, morphological and optical properties of Ni-doped ZnO NRs that were generated using the chemical bath approach. The structure investigation revealed that the as-prepared ZnO before and after doping have a single-crystalline Wurtzite Hexagonal structure, and the NRs did not contain any other secondary phases. Absorption spectra measurements confirmed that both the ZnO and ZnO:Ni NRs show a strong UV absorption peaks. The FESEM result concludes that ZnO and ZnO:Ni are rod-shaped particles. The energy gap showed a reduction after doping.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

[1] Baron AS, Mohammed KA, Abood MM. The role of Ag layer in the optical properties of CdS thin film. Chalcogenide Lett. 2021;18(10):585–588.
[2] Xu CX, Sun XW, Zhang XH, et al. Photoluminescent properties of copper-doped zinc oxide nanowires. Nanotechnology. 2004;15(7):856.

[3] Abdulameera ZT, Alrubaieb AJ, Alshamartic HA, et al. Optical properties of ZnO nanorods and ZnO/CdZnS thin films. Chalcogenide Lett. 2022 July;19(7):457–462.
[4] Wang ZL, Song JH. Piezoelectric nanogenerators based on zinc oxide nanowire arrays. Science. 2006;312(5771):242.
[5] Huang GJ, Wang JB, Zhong XL, et al. Synthesis, structure, and room-temperature ferromagnetism of Ni-doped ZnO nanoparticles. J Mater Sci. 2007;42(15):6464–6468.
[6] Chen Y, Ding MH, Sun S. Preparation and characterization of ZnO nanoparticles supported on amorphous SiO_2. Nanomaterials. 2017;7(8):217.
[7] Thyab RM, Mohammed KA. Preparation and characterization of ZnO: co nanoparticles as DSSC photocathode. AIP Conf Proc. 2022 January;2386(1):030028. AIP Publishing LLC.
[8] Kumari P, Misra KP, Chattopadhyay S, et al. A brief review on transition metal ion doped ZnO nanoparticles and its optoelectronic applications. Mater Today Proc. 2021;43:3297–3302.
[9] Cong CJ, Hong JH, Liu QY, et al. Synthesis, structure and ferromagnetic properties of Ni-doped ZnO nanoparticles. Solid State Commun. 2006;138(10–11):511–515.
[10] Elhamdi I, Souissi H, Taktak O, et al. Experimental and modeling study of ZnO: ni nanoparticles for near-infrared light emitting diodes. RSC Adv. 2022;12(21):13074–13086.
[11] Zhao J, Wang L, Yan X, et al. Structure and photocatalytic activity of Ni-doped ZnO nanorods. Mater Res Bull. 2011;46(8):1207–1210.
[12] Amari R, Benrezgua E, Deghfel B, et al. Ni doping effect on the electronic, structural and optical properties of ZnO nanoparticles prepared by Co-precipitation route. Opt Mater. 2022;128:112398.
[13] Rostamzadeh D, Sadeghi S. Ni doped zinc oxide nanoparticles supported bentonite clay for photocatalytic degradation of anionic and cationic synthetic dyes in water treatment. J Photochem Photobiol A. 2022;431:113947.
[14] Abbasi F, Zahedi F, Hasan Yousefi M. Fabricating and investigating high photoresponse UV photodetector based on Ni-doped ZnO nanostructures. Opt Commun. 2021;482:126565.
[15] Hammouche J, Daoudi K, Columbus S, et al. Structural and morphological optimization of Ni doped ZnO decorated silicon nanowires for photocatalytic degradation of methylene blue. Inorg Chem Commun. 2021;131:108763.
[16] Zheng JH, Song JL, Zhao Z, et al. Optical and magnetic properties of Nd-doped ZnO nanoparticles. Cryst Res Technol. 2012;47(7):713–718.
[17] Saravanan R, Santhi K, Sivakumar N, et al. Synthesis and characterization of ZnO and Ni doped ZnO nanorods by thermal decomposition method for spintronics application. Mater Charact. 2012;67:10–16.
[18] Raja K, Ramesh PS, Geetha D. Synthesis, structural and optical properties of ZnO and Ni-doped ZnO hexagonal nanorods by Co-precipitation method. Spectrochim Acta A Mol Biomol Spectrosc. 2014;120:19–24.
[19] Cheng C, Xu G, Zhang H, et al. Hydrothermal synthesis Ni-doped ZnO nanorods with room-temperature ferromagnetism. Mater Lett. 2008;62(10–11):1617–1620.
[20] Nadeem MS, Munawar T, Mukhtar F, et al. Hydrothermally derived co, Ni co-doped ZnO nanorods; structural, optical, and morphological study. Opt Mater. 2021;111:110606.
[21] Chu YL, Young SJ, Ji LW, et al. Synthesis of Ni-doped ZnO nanorod arrays by chemical bath deposition and their application to nanogenerators. Energies. 2020;13(11):2731.
[22] Ismail AS, Mamat MH, Malek MF, et al. Structural, optical, and electrical properties of Ni-doped ZnO nanorod arrays prepared via sonicated sol-gel immersion method. AIP Conf Proc. 2018 May;1963(1):020029. AIP Publishing LLC.
[23] Cheng Z, Zhou S, Chen T, et al. Acetic acid gas sensors based on Ni2+ doped ZnO nanorods prepared by using the solvothermal method. J Semicond. 2012;33(11):112003..
[24] Liu X, Lin F, Sun L, et al. Doping concentration dependence of room-temperature ferromagnetism for Ni-doped ZnO thin films prepared by pulsed-laser deposition. Appl Phys Lett. 2006;88(6):062508..

[25] Shanmugam N, Thirumal V, Kannadasan N, et al. Influence of Cerium and Nickel Co-Doping on ZnO Nanostructures for Electrochemical Behavior of H2O2 Sensing Applications. Sustainability. 2022;14(10):6353.
[26] Saleem S, Jameel MH, Akhtar N, et al. Modification in structural, optical, morphological, and electrical properties of zinc oxide (ZnO) nanoparticles (NPs) by metal (Ni, Co) dopants for electronic device applications. Arabian J Chem. 2022;15(1):103518.
[27] Shkir M, Palanivel B, Khan A, et al. Enhanced photocatalytic activities of facile auto-combustion synthesized ZnO nanoparticles for wastewater treatment: an impact of Ni doping. Chemosphere. 2022;291:132687.
[28] Shivaraj B, Prabhakara MC, Naik HB, et al. Optical, bio-sensing, and antibacterial studies on Ni-doped ZnO nanorods, fabricated by chemical co-precipitation method. Inorg Chem Commun. 2021;134:109049.
[29] Salah HY, Mahmoud KR, Ismail W, et al. Influence of Nickel Concentration on the Microstructure, Optical, Electrical, and Photoelectrochemical Properties of ZnO Nanorods Synthesized by Hydrothermal Method. J Electron Mater. 2022;51(2):910–920.
[30] Ikram M, Haider A, Bibi ST, et al. Synthesis of Al/starch co-doped in CaO nanoparticles for enhanced catalytic and antimicrobial activities: experimental and DFT approaches. RSC Adv. 2022;12(50):32142–32155.
[31] Moeen S, Ikram M, Haider A, et al. Comparative Study of Sonophotocatalytic, Photocatalytic, and Catalytic Activities of Magnesium and Chitosan-Doped Tin Oxide Quantum Dots. ACS Omega. 2022;7(50):46428–46439.