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Electrical and Magnetic Properties of Nanostructured NiO Thin Films Prepared by Spray Pyrolysis Method

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ABSTRACT

In this work, nickel oxide thin films was fabricated on glass substrate at different temperature by spray pyrolysis technique. The NiO layers were obtained with different molar concentrations. The NiO thin films were crystallized with a cubic structure that can be related to obtaining peaks in the XRD diffraction of NiO thin films. The optical transmission of the deposited films was measured in the range of (300–900nm) by using an ultraviolet-visible spectrophotometer (LAMBDA 25). The electrical conductivity σ was measured by four point methods. This study shows that the NiO thin films have a good electrical conductivity. The NiO thin films have different electrical conductivity values. The pure NiO thin films prepared with a molar concentration C= 0.1mol/l at a temperature of T=360°C has the best electrical conductivity of σ= 11.24 $(\Omega.cm)^{-1}$. The NiO:8Li thin films prepared with a molar concentration C=1mol/l at a temperature of T= 420°C has the best electrical conductivity of σ= 100 $(\Omega.cm)^{-1}$.

Keywords: Nickel Oxide; Thin Films; Spray Pyrolysis Method; Magnetic Properties; Electrical Properties

Introduction

In the latest research, the nickel oxide NiO was found in the cubic structure with a lattice parameter (a= 0.4186 nm) [1]. NiO is forming of nickel metal and oxygen element, it is a p-type of semiconducting nature. NiO was used in a variety of technology such as optoelectronic devices and gas sensing [2,3] due to having a good structure crystallinity, good electrical conductivity and high transparency in the visible region. The optical band gap of NiO thin films varied between 3.6 to 4 eV [4]. However, the NiO thin films can be used in various applications due to the simplicity of synthesis such as solar cells [5], chemical sensors [6], photo detectors [7], electro chromic minors [8], organic light-emitting diodes [9], UV detectors [10], vans parent diodes [11], and defrosting windows [12]. Table 1 shows the physical and chemical properties of NiO material, it is found that the NiO has a high solubility in water with a refractive index of 2.18. The NiO as a thin film was studied on verities of substrates with chemical and physical methods; it was used to improve the structural optical and electrical properties. The pulsed laser deposition [13], chemical vapor deposition [14], electrochemical deposition [15], abeam evaporation [16], anodic deposition [17], electroless bath deposition [18] sputtering [19], chemical vapor deposition [20] and spray pyrolysis techniques [21-24], are used to prepare the NiO thin films, the spray techniques also were favorites with comparing by others methods due to the simple deposition and best cost. The mean objective of this research is to study the electrical and magnetic properties of NiO thin films based on past research. In this work we have proposed a review of original research to nanostructured NiO prepared by spray techniques.

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Table1: Summary of the basic physical and chemical properties of NiO material.

Property	Value
Appearance	Green crystalline solid
Molecular mass	74.69 g/mol
Density (N)(cm³)	6.67 g/cm3
Lattice parameter (a)	0.4186 nm
Stable Phase at 300 K	3.1-4.3 Ev
Conductivity σ $(\Omega cm)^{-1}$	1.5×10^{-3}
Melting Point	1995°C
Refractive Index	2.18
Band Gap Energy (Eg)	3.6-4.0 Ev
Solubility in water µ $(cm^2/V.s)$	0.1-1
A	4.75 A°
B	11.77 A°
C	8.44A°
B	93° 36′

Information of Nickel Types

In the deposition of NiO thin films by using the spray techniques with NiO solution, it is prepared by various methods and protocol as shown in the following steps:

Nio Thin Film Deposition from Nickel Chloride Solutions

The NiO thin films prepared by using chloride nickel can be dissolved in various solvents such as water, ethanol and methanol solution. However in the preparation of NiO solution from water solvent, when dissolving the nickel chloride dehydrate $(NiCl_2, 2H_2O)$ in water (H_2O) , before using and deposit NiO thin films into substrates which heating the final solutions at 50°C than add drops of HCl to the solution for stabilization. Menaka and Umadevi [25] they discussed that process decomposition of nickel chloride to nickel oxide in the presence of water, according to the following equation (Table 2) [26]:

$$NiCl_2 + 2H_2O \rightarrow 2HCL + Ni(OH)_2$$

$$NiCl_2 + 2H_2O \rightarrow 2HCl + NiO + H_2O$$

Table 2: information of Nickel types.

Molecule	Molecule formula	Molar mass	Aspect	Density	Solubility in water (mg/l)
Nickel Chloride	$Cl_2H_{12}NiO_6$	237.69 g/mol	Green crystalline solid.	1.92 g/cm³	254010^3 (20 °C)
Nickel Acetate	$C_4H_6NiO_4$	176.78 g·mol⁻¹	Green crystalline solid.	1.798 g/cm³	Easily soluble in cold water, hot water
Nickel Nitrate	$Ni(NO_3)_2 . 2H_2O$	290.08 g/mol	Green crystalline solid.	3.55 g/cm³	6.42×10^5 at 20°C

NiO Thin Film Deposition from Nickel Nitrate Solutions

NiO solution can be prepared by using nitrate Nickel with various solvents such as water, ethanol and methanol. However, in the preparation of NiO solution from water solvent, when introduce of nickel nitrate dehydrate $(Ni(NO_3)_2 .2H_2O)$ in a volume equal to wither solvent (H_2O) (Table 2) [27]:

$$NiO(NO_3)_2 + 2NH_4OH \rightarrow Ni(OH_2) + 2NH_4NO_3$$

$$2Ni(OH)_2 \rightarrow 2NiO + H_2O$$

NiO Thin Film Deposition from Nickel Acetate Solutions

NiO solution can be prepared by using acetate Nickel with various solvents such as water, ethanol and methanol. However, in the preparation of NiO solution from water solvent, when introduce nickel acetate dehydrate $(Ni(CH_3COO)_2 - 4H2O)$ in a volume equal to wither solvent (H_2O) · $(Ni(CH3COO)_2 - 4H_2O)$ are monoclinic with space group P21/c the unit cell off dimension(see Table 2) [28]:

$$Ni(CH_3COO)_2 .4H_2O + CH_3 - OH = Ni(OH) + 2CH_3COOCH + 4H_2O$$

Electrical Properties of NiO Thin Films

The electronic band of the nickel oxygen are expressed as:

Ni: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^8$

O: $1s^2 2s^2 2p^4$

NiO is a native p-type semiconducting material [29].

The electrical conductivity of NiO films has a string depended on the microstructure defect existing in NiO crystallites, such as nickel vacancies and interstitial.

Furthermore, the microstructure and composition, as well as the deposition conditions and environment, are the main factor affecting the electrical properties of NiO thin films [30].

They found that the electrical conductivity of NiO is strongly related to the formation of microstructure defect inside the NiO crystallites, such as nickel vacancies and interstitial oxygen, it was related the decreasing in carrier concentration and mobility, which as a p-type semiconductor, in which vacancies occur in caption sites, from each caption vacancy, two electron holes are formed.

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1. The existing in NiO films are electron holes, which are responsible for the electrical conductivity of the undoped nickel oxide.
2. The resistivity is inverse proportional to the product of the carrier concentration with their mobility.
3. The decrease in resistivity can be explained by the improved stoichiometry of the film.

The four-points probe method was used to determine the electrical conductivity of $Ni_{1-x}Zn_xO$ thin films, it is based on measuring the sheet resistance of the films as expressed by [23,31,32]:

$$R_{sh} = \frac{\pi}{1n(2)} \cdot \frac{V}{1}$$

where I is the applied currant = 1 nA and V is the measurement voltage. However, the electrical conductivity σ is also determined by the following equation:

$$\sigma = \frac{1}{d.R_{sh}}$$

Alver, et al. [33], investigated the synthesis and characterization of born-doped NiO thin films produced by spray pyrolysis. Obtained an electrical resistivity in the range of 0 to 19 Ω.m, they found the resistivity of Boron doped NiO films with doping by annealing temperature is smeller then without, when they introduced Boron atoms in the ZnO matrix the decrease in resistivity might be mainly due to the substitution of B3+ with Ni2+ in the lattices, which provides more free electrons for the conduction mechanism. Similar results are obtained with [34] (Table 3).

Table 3: Electrical conductivity values of NiO thin films deposited at different conditions.

S.N.	Condition	Electrical conductivity $(\Omega.cm)^{-1}$	Ref
Li-NiO	420°C	σ= 8	[35]
NiO-Ag	400°C Ni : 42.13 % atomic Ag: 11.06 % atomic O: 47.13 % atomic P : 5.10^{-4} mbar	σ= 0.0073	[36]
NiO-B	NiO:97 % B:3% 400°C C = 0.1 M	σ= 2.8	[37]
NiO	C = 0.5 M T=500°C	σ= 0.56 σ=11.59	[38]
NiO-Li	NiO = 98 % Li = 2 %	σ= 0.47	[34]
NiO:8Li	C = 1 M T = 600°C	σ= 0.3	[39]
NiO:8Li	C = 1 M T = 400-430°C	σ= 10^2	[40]
NiO	C = 0.2 M T = 470°C	σ= 2.3 10^{-5}	[41]
NiO	C = 0.1 M T = 360°C	σ= 11.24	[42]
$Ni_{1-x}Zn_xO$	T = 480°C C = 0.05 M X = 0.06	σ= 0.014	[32]
$Ni_{1-x}Zn_xO$	T = 480°C C = 0.05 M X = 0.88	σ= 9.5	[23]
NiS	T = 573°C C = 0.01 M	σ= 4.29 10^5	[24]
NiS	T = 300°C C = 0.07 M	σ= 7.91 10^4	[31]
NiO	T = 460°C C = 0.2 M	σ= 4.34	[43]
$NiO_{1-x}Zn_X$	T = 623°K C = 0.1 M X = 0.05	σ= 10^{-9}	[44]
NiO-Cu	T = 1737°F Cu = 16.17 at%	σ= 0.1	[45]
$(NiO)_{1-x}(ZnO)_x$	T = 400°C C = 0.05 M X = 0.25	σ= 10^{-9}	[46]

Magnetic Properties of NiO Thin Films

The change of crystal structure with temperature actually is associated with the magnetic properties of nickel oxide. The Neel temperature (TN) defends as the temperature at which ant ferromagnetism changes to paramagnetism. Nickel oxide is ant ferromagnetic at room temperature, and paramagnetic above (TN= 250°C).

Each magnetic unit cell contains four chemical unit cells. Above the Neel temperature, the spin ordering disappears and spin becomes random [35-60].

Conclusion

Nickel oxide (NiO) has attracted a great deal of attention due to its wide direct band gap of (3.6-4.2 eV), which exhibits p-type conductivity. Stoichio metric NiO is an insulator with a resistivity of the order of 1013Ω.cm at room temperature. NiO is one of the most important oxide materials due to its excellent chemical stability and durability, low toxicity, large span optical density, low cost and good thermal stabilityand high stability that are similar to ZnO. NiO can be used in various potential applications such as solar cells due to the p-type semiconducting, transparent diodes, transparent transistors, displays and defrosting windows because their transparency can be used for the UV photo detectors and touch screens due to the good responsively. NiO can be produced by several techniques such as reactive evaporation, molecular beam epitaxy (MBE), magnetron sputtering technique, pulsed laser deposition (PLD), spray pyrolysis, sol–gel process, chemical vapor deposition, and electrochemical deposition. This study shows that the NiO thin films have a good electrical conductivity. The NiO thin films have different electrical conductivity values. The pure NiO thin films prepared with a molar concentration C= 0.1mol/l at a temperature of T=360°C has the best electrical conductivity of σ= 11.24 $(\Omega.cm)^{-1}$. The NiO:8Li thin films prepared with a molar concentration C=1mol/l at a temperature of T= 420°C has the best electrical conductivity of σ= 100 $(\Omega.cm)^{-1}$.

References

1. V Verma, M Katiyar (2013) Effect of the deposition parameters on the structural and magnetic properties of pulsed laser ablated NiO thin films. Thin Solid Films 527: 369-376.
2. S C Chen, T Y Kuo, Y C Lin, H C Lin (2011) Preparation and properties of p-type transparent conductive Cu-doped NiO films. Thin Solid Films 519(15): 4944-4947.
3. R Sharma, A D Acharya, S B Shrivastava, M M Patidar, M Gangrade, et al. (2016) Studies on the structure optical and electrical properties of Zn-doped NiO thin films grown by spray pyrolysis. Optik 127(11): 4661-4668.
4. S Benramache, M Aouassa, (2016) Journal of Chemistry and Materials Research 5(6): 119.
5. S Dendouga, S Benramache, S Lakel (2016) Journal of Chemistry and Materials Research 5(4): 78.
6. D Dini, Y Halpin, J G Vos, E A (2015) The influence of the preparation method of NiOx photocathodes on the efficiency of p-type dye-sensitized solar cells. Gibson, Coordination Chemistry Reviews 304-305: 179-201.
7. G F Cai, C D Gu, J Zhang, P C Liu, X L Wang, et al. (2013) Dual electrochromic film based on WO3/polyaniline core/shell nanowire array. Electrochimica Acta 87: 341-347.
8. A C Nwanya, S U I Offiah, C Amaechi, S Agbo, S C Ezugwu, et al. (2015) Electrochromic and electrochemical supercapacitive properties of room temperature PVP capped Ni (OH) 2/NiO thin films. Electrochimica Acta 171: 128-141.
9. R Romero, F Martin, J R Ramos-Barrado, D Leinen (2010) Synthesis and characterization of nanostructured nickel oxide thin films prepared with chemical spray pyrolysis. Thin Solid Films 518(16): 4499-4502.
10. T Chtouki, L Soumahoro, B Kulyk, H Bougharraf, B Kabouchi (2017) Optik 128: 8.
11. R J Deokate, R S Kalubarme, C J Park, CD Lokhande (2017) Simple Synthesis of NiCo2O4 thin films using Spray Pyrolysis for electrochemical supercapacitor application: A Novel approach Lokhande 224: 378-385.
12. Y Yu, X Li, Z Shen, X Zhang, P Liu, et al. (2017) Restrain recombination by spraying pyrolysis TiO2 on NiO film for quinoxaline-based p-type dye-sensitized solar cells. Journal of Colloid and Interface Science 490: 380-390.
13. S U Offiah, M O Nwodo, A C Nwanya, S C Ezugwu, S N Agbo, (2014) Optik 125: 2905.
14. S C Chen, T Y Kuo, Y C Lin, S W Hsu, H C Lin (2013) Effect of palladium content on microstructures, electrical and optical properties of NiO films by rf sputtering. Thin Solid Films 549: 50-53.
15. X H Xia, J P Tu, J Zhang, X L Wang, W K Zhang, et al. (2008) Morphology effect on the electrochromic and electrochemical performances of NiO thin films. Electrochimica Acta 53(18): 5721-5724.
16. I Castro-Hurtado, J Herrán, G G Mandayo, E Castaño (2011) Studies of influence of structural properties and thickness of NiO thin films on formaldehyde detection. Thin Solid Films 520(3): 947-952.
17. C Zaouche, Y Aoun, S Benramache, A Gahtar (2019) Synthesis and Characterization of Deposited NiO Thin Films by Spray Pyrolysis Technique. Scientific Bulletin of valahia University materials and mechanics 17(17): 27-32.
18. A Diha, S Benramache, B Benhaoua (2018) Transparent nanostructured Co doped NiO thin films deposited by sol–gel technique. Optik 172: 832-839.
19. SA Mahmoud, S Alshomer, MA Tarawnh (2011) Structural and Optical Dispersion Characterisation of Sprayed Nickel Oxide Thin Films. Journal of Modern Physics 2(10): 1178-1186.
20. S Benramache, Y Aoun, S Lakel, H Mourghade, R Gacem, et al. (2018) Effect of Annealing Temperature on Structural, Optical and Electrical Properties of ZnO Thin Films Prepared by Sol-Gel Method. Journal of Nano- and Electronic Physics 10(6): 6032.
21. V Panneerselvam, K K Chinnakutti, S T Salammal, A K Soman, Parasuraman K, et al. (2018) Role of copper/vanadium on the optoelectronic properties of reactive RF magnetron sputtered NiO thin films. Applied Nanoscience 8: 1299-1312.
22. D K Pathak, A Chaudhary, S Mishra, P Yogi, S K Saxena, et al. (2019) Precursor concentration dependent hydrothermal NiO nanopetals: Tuning morphology for efficient applications. Superlattices and Microstructures 125: 138-143.
23. R Sharma, A D Acharya, S Moghe, S B Shrivastava, M Gangrade, et al. (2014) Effect of cobalt doping on microstructural and optical properties of nickel oxide thin films. Materials Science in Semiconductor Processing 23: 42-49.
24. CC Wua, CF Yang (2015) Effect of annealing temperature on the characteristics of the modified spray deposited Li-doped NiO films and their applications in transparent heterojunction diode. Solar Energy Materials and Solar Cells 132: 492-498.
25. J Al Boukhari, L Zeidan, A Khalaf, R Awad (2019) Synthesis, characterization, optical and magnetic properties of pure and Mn, Fe and Zn doped NiO nanoparticles. Chemical Physics 516: 116-124.
26. C Zaouche, A Gahtar, S Benramache, Y Derouiche, M Kharroubi, et al. (2022) The determination of urbach energy and optical gap energy by many methods for Zn doped NiO thin films fabricant semiconductor by spray pyrolysis. Digest Journal of Nanomaterials and Biostructures 17(4): 1453-1461.
27. N N Ge, C H Gong, X C Yuan, H Z Zeng, X H Wei (2018) Effect of Mn doping on electroforming and threshold voltages of bipolar resistive switching in Al/Mn : NiO/ITO. RSC Advances 8: 29499-299504.

DOI: 10.26717/BJSTR.2023.52.008258

28. JY Zhang, W W Li, R L Z Hoye, J L MacManus-Driscoll, M Budde, et al. (2018) Electronic and transport properties of Li-doped NiO epitaxial thin films. Thin Solid Films 6: 2275-2282.

29. YAK Reddy, B Ajitha, PS Reddy, MSP Reddy, JH Lee (2014) Effect of substrate temperature on structural, optical and electrical properties of sputtered NiO-Ag nanocrystalline thin films. Electronic Materials Letters 10: 907-913.

30. U Alver, H Yaykaşlı, S Kerli (2013) Synthesis and characterization of boron-doped NiO thin films produced by spray pyrolysis. A Tanriverdi, International Journal of Minerals, Metallurgy, and Materials 20: 1097-1101.

31. AA Yadav, UJ Chavan (2016) Influence of substrate temperature on electrochemical supercapacitive performance of spray deposited nickel oxide thin films. Journal of Electroanalytical Chemistry 782: 36-42.

32. V Gowthami, M Meenakshi, P Perumal, R Sivakuma, C Sanjeeviraja (2014) Materials Science in Semiconductor Processing 27: 1042-1049.

33. R Sharma, A D Acharya, S Moghe, SB Shrivastava, M Gangrade, et al. (2014) Effect of cobalt doping on microstructural and optical properties of nickel oxide thin films. Materials Science in Semiconductor Processing 23: 42-49.

34. CC Wua, CF Yang (2015) Effect of annealing temperature on the characteristics of the modified spray deposited Li-doped NiO films and their applications in transparent heterojunction diode. Solar Energy Materials and Solar Cells 132: 492-498.

35. X Yi, W Wenzhong, Q Yitai, Y Li, C Zhiwen (1996) Deposition and microstructural characterization of NiO thin films by a spray pyrolysis method. Journal of Crystal Growth 167(3-4): 656-659.

36. A Hakim, J Hossain, KA Khan (2009) Temperature effect on the electrical properties of undoped NiO thin films. Renewable Energy 34(12): 2625-2629.

37. P Nazari, S Gharibzadeh, F Ansari, B AbdollahiNejand, M Eskandari, et al. (2017) Materials Letters 190: 40.

38. R J Deokate, RS Kalubarme, CJ Park, CD Lokhande, (2017) ElectrochimicaActa 244: 378.

39. R Sharma, AD Acharya, SB Shrivastava, T Shripathi, V Ganesan (2014) Preparation and characterization of transparent NiO thin films deposited by spray pyrolysis technique. Optik 125(22): 6751-6756.

40. K Sajilal, A M E Raj (2016) Effect of thickness on physico-chemical properties of p-NiO (bunsenite) thin films prepared by the chemical spray pyrolysis (CSP) technique. Optik 127(3): 1442-1449.

41. RSharma, AD Acharya, SB Shrivastava, MM Patidar, M Gangrade, et al. (2016) Studies on the structure optical and electrical properties of Zn-doped NiO thin films grown by spray pyrolysis. Optik 127(11): 4661-4668.

42. T Chtouki, L Soumahoro, B Kulyk, H Bougharraf, B Kabouchi, et al. (2017) Optik 128: 8.

43. R Romero, F Martin, JR Ramos-Barrado, D Leinen (2010) Synthesis and characterization of nanostructured nickel oxide thin films prepared with chemical spray pyrolysis. Thin Solid Films 518(16): 4499-4502.

44. A A Akl, S A Mahmoud (2018) Effect of growth temperatures on the surface morphology, optical analysis, dielectric constants, electric susceptibility, Urbach and bandgap energy of sprayed NiO thin films. Optik 172: 783-793.

45. I Manouchehri, S A O AlShiaa, D Mehrparparvar, M I Hamil, R Moradian (2016) Optical properties of zinc doped NiO thin films deposited by RF magnetron sputtering. Optik 127: 9400-9406.

46. P Baraskar, R J Choudhary, P Kumar Sen, P Sen (2019) Dispersive optical nonlinearities and optical path length compensation in NiO/Al doped NiO bilayer thin film. Optical Materials 96: 109278.

47. I S Yahia, G F Salem, JavedIqbal, F Yakuphanoglu, Physica B (2017) Condensed Matter 511: 54.

48. N Zhou, Y Cheng, B Huang, X Liao (2019) Physica B: Condensed Matter 557: 6.

49. J Yang, B Wang, Y Zhang, X Ding, J Zhang (2018) Low-temperature combustion synthesis and UV treatment processed p-type Li:NiOx active semiconductors for high-performance electronics. Journal of Materials Chemistry C 6: 12584-12591.

50. S Benramache, B Benhaoua, N Khechai, F Chabane, Matériaux (2012) Elaboration and characterisation of ZnO thin films. Techniques 100(6-7): 573-580.

51. C Zaouche, L Dahbi, S Benramache, A Harouache, Y Derouiche, et al. (2023) Study the effect of Ni doping on structural, optical and electrical properties of . Zn1-xNixO thin films deposited by spray pyrolysis technique Journal of Ovonic Research 19(2): 197-205.

52. A Gahtar, A Benali, S Benramache, C Zaouche (2022) Effect of annealing time on the structural, morphological, optical and electrical properties of NiS thin filmsChalcogenide Letters 19(2): 103-116.

53. P Puspharajah, S Radhakrishna, A K Arof (1997) Transparent conducting lithium-doped nickel oxide thin films by spray pyrolysis technique. Journal of Materials Science 32: 3001-3006.

54. S Benramache, M Aouassa, (2016) Journal of Chemistry and Materials Research 5: 119.

55. S C Chen, T Y Kuo, Y C Lin, H C Lin (2011) Preparation and properties of p-type transparent conductive Cu-doped NiO films. Thin Solid Films 519(15): 4944-4947.

56. L Herissi, L Hadjeris, M S Aida, J Bougdira (2016) Properties of (NiO)1-x(ZnO)x thin films deposited by spray pyrolysis. Thin Solid Films 605: 116-120.

57. S M H Al-Jawad, A F S Al-Shareefi , A K Jurdan, (2011) Iraqi journal of Applied physics 7: 11.

58. S A Gahtar, S Benramache, C Zaouche, A Boukacham, A Sayah, (2020) ADVANCES IN MATERIALS SCIENCE 20(3): 36.

59. Y Wang, J Ghanbaja, P Boulet, D Horwat, J F Pierson (2019) Growth, interfacial microstructure and optical properties of NiO thin films with various types of texture. ActaMaterialia 164: 648-653.

60. M Predanocy, I Hotový, M Čaplovičová (2017) Structural, optical and electrical properties of sputtered NiO thin films for gas detection. Applied Surface Science 395: 208-213.

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