

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 $C= 0.1\text{mol/l}$ at a temperature of $T=360^\circ\text{C}$ has the best electrical conductivity of $\sigma= 11.24 (\Omega.\text{cm})^{-1}$. The NiO:8Li thin films prepared with a molar concentration $C=1\text{mol/l}$ at a temperature of $T= 420^\circ\text{C}$ has the best electrical conductivity of $\sigma= 100 (\Omega.\text{cm})^{-1}$.

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 ($a= 0.4186 \text{ nm}$) [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], vana 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.

Table 1: Summary of the basic physical and chemical properties of NiO material.

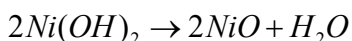
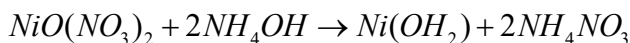
Property	Value
Appearance	Green crystalline solid
Molecular mass	74.69 g/mol
Density (N)(cm ³)	6.67 g/cm ³
Lattice parameter (a)	0.4186 nm
Stable Phase at 300 K	3.1-4.3 Ev
Conductivity σ (Ωcm) ⁻¹	1.5×10 ⁻³
Melting Point	1995°C
Refractive Index	2.18
Band Gap Energy (Eg)	3.6-4.0 Ev
Solubility in water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

Table 2: information of Nickel types.

Molecule	Molecule formula	Molar mass	Aspect	Density	Solubility in water (mg/l)
Nickel Chloride	Cl ₂ H ₁₂ NiO ₆	237.69 g/mol	Green crystalline solid.	1.92 g/cm ³	254010 ³ (20 °C)
Nickel Acetate	C ₄ H ₆ NiO ₄	176.78 g mol ⁻¹	Green crystalline solid.	1.798 g/cm ³	Easily soluble in cold water, hot water
Nickel Nitrate	Ni (NO ₃) ₂ · 2H ₂ O	290.08 g/mol	Green crystalline solid.	3.55 g/cm ³	6.42 ×10 ⁵ at 20°C

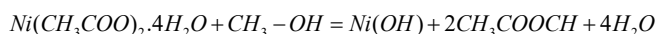
NiO Thin Film Deposition from Nickel Nitrate Solutions

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 ($Ni(NO_3)_2 \cdot 2H_2O$) in a volume equal to wither solvent (H_2O) (Table 2) [27]:



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 ($Ni(CH_3COO)_2 \cdot 4H_2O$) in a volume equal to wither solvent (H_2O) · ($Ni(CH_3COO)_2 \cdot 4H_2O$) are monoclinic with space group P21/c the unit cell off dimension(see Table 2) [28]:

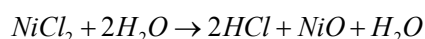
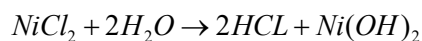


Information of Nickel Types

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:

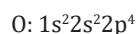
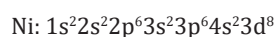
NiO Thin Film Deposition from Nickel Chloride Solutions

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 ($NiCl_2 \cdot 2H_2O$) 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]:



Electrical Properties of NiO Thin Films

The electronic band of the nickel oxygen are expressed as:



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.

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]:

$$R_{sh} = \frac{\pi}{ln(2)} \cdot \frac{V}{I}$$

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

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

Alver, et al. [33], investigated the synthesis and characterization of boron-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 smaller than 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 (Ω.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 _x O	T = 480°C C = 0.05 M X = 0.06	σ= 0.014	[32]
Ni _{1-x} Zn _x O	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) depends as the temperature at which antiferromagnetism changes to paramagnetism. Nickel oxide is antiferromagnetic 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. Stoichiometric 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 stability and 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 responsiveness. 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 $C = 0.1 \text{ mol/l}$ at a temperature of $T = 360^\circ\text{C}$ has the best electrical conductivity of $\sigma = 11.24 (\Omega \cdot \text{cm})^{-1}$. The NiO:8Li thin films prepared with a molar concentration $C = 1 \text{ mol/l}$ at a temperature of $T = 420^\circ\text{C}$ has the best electrical conductivity of $\sigma = 100 (\Omega \cdot \text{cm})^{-1}$.

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