



## Physical Properties of Chemically Grown Nanocrystalline Nickel Oxide Thin Films

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### Abstract

Recently transparent conducting oxide thin films like nickel oxide are attracting more attention because of their importance in several scientific and technological applications. Nanostructured thin film of nickel oxide were successfully deposited onto glass substrates at 573 K by chemical spray technique using nickel chloride as starting solution. The structural and surface morphological studies were carried out using X-ray diffractometry (XRD) and scanning electron microscopy (SEM). The structural study revealed that NiO thin films are nanocrystalline in nature with hexagonal lattice. The optical characterization shows that the band gap of the spray deposited NiO thin film is 3.3eV.

**Keywords:** Thin films; Nanostructures; Electrical properties; Optical properties.

### Introduction

The study of structural, electrical and optical properties of thin films is very important for many applications, including interference devices, such as antireflection coatings, laser mirrors and monochromatic filters, as well as optoelectronics, integrated optics, solar power engineering, microelectronics and optical sensor technology etc. Nickel oxide (NiO) is a versatile wide band gap semiconductor material. At present, transparent conducting oxide films, such as indium oxide, tin oxide and zinc oxide, are routinely used as transparent electrodes and window coatings for opto-electronic devices [1, 2]. These films are of n-type. However p-type conducting films are required in optical window devices where hole injection is required. NiO is a p-type semiconductor with a band gap ranging from 3.6 eV to 4.0 eV with cubic rock salt crystal structure [3, 4]. It offers promising candidature for many application such as electrocatalysis [5], positive electrode in batteries [6], fuel cell [7], electrochromic devices [8], solar thermal absorber [9], catalyst for oxygen evolution [10] and photo electrolysis [11]. Several physical and chemical methods, such as sputtering [12], pulsed laser deposition [13], chemical bath deposition [12, 14] and sol-gel [15] have been used to obtain nickel oxide thin films. All these methods offer different advantages depending on the application of interest and many efforts have been conducted to obtain films with the desirable physical and/or chemical properties. Among these different methods spray pyrolysis method is relatively simple and economic and its potential application for large area deposition make it very attractive, for mass production processes.



In the present work, chemical spray pyrolysis method was utilized for the deposition of nanocrystalline NiO thin films onto glass substrates. The various deposition parameters were optimized to get good quality NiO thin films. The structural and morphological characterizations were carried out using X-ray diffraction (XRD) and Scanning electron microscopy (SEM). The optical and electrical properties were studied by using optical absorption, electrical resistivity and thermo-emf measurement techniques.

### Experimental Details

All the compounds used for preparation of NiO films were brought into their ionic form by using fresh doubly distilled water. To obtain NiO thin film nickel chloride solution of 0.15M was used. Before deposition the substrates were boiled in the concentrate chromic acid (0.5M) for 1 hour and then kept in it for next 48 hours. The substrates were then washed with double distilled water. The spray deposition method involves the decomposition of an aqueous solution of nickel chloride. The 0.15M nickel chloride solution was sprayed using compressed air as a carrier gas onto hot glass substrates kept at  $573 \pm 5\text{K}$  temperature. Several trials were conducted to optimize the different deposition parameters such as substrate temperature, spray rate, concentrations of cationic and anionic sources etc. The optimized deposition temperature was found to be  $\approx 573\text{ K}$ . The films deposited below this temperature were discontinuous and less adhesive. The optimized spray rate was found to be  $6\text{ mL min}^{-1}$ . The films deposited above this spray rate are discontinuous with cracks which may be due to incomplete thermal decomposition. However, films deposited at low spray rate are discontinuous due to insufficient quantity of sprayed solution.

The average thickness of the as deposited NiO thin film was measured by the gravimetric method. The structural studies were carried out using Philips PW 1710 diffractometer with  $\text{Cu-K}\alpha$  radiation of wavelength  $1.5405\text{ \AA}$ . The optical characteristics were studied using UV-VIS-NIR spectrophotometer (Hitachi-330), to find band gap energy of NiO thin films. The surface morphological studies were carried out using scanning electron microscope (JSM 6100). The dc two-point probe method of dark electrical resistivity was used to study the variation of resistivity with temperature.

### Results and discussion

#### Structural Analysis

X-ray diffraction patterns of the spray deposited NiO thin films at  $573\text{ K}$  were recorded by varying diffraction angle ( $2\theta$ ) from  $20$  to  $80$  degree. Figure 1 shows the XRD pattern of NiO thin film. The pattern shows well defined (1 1 1), (2 0 0) and (2 2 0) peaks due to cubic lattice.

#### Morphology

The two-dimensional high magnification surface morphology of NiO thin film was carried out using Scanning electron microscope. Figure 2 shows, SEM image of NiO thin film. The film surface shows

random distribution NiO material with porous morphology. The agglomeration of material observed at several places makes surface porous.

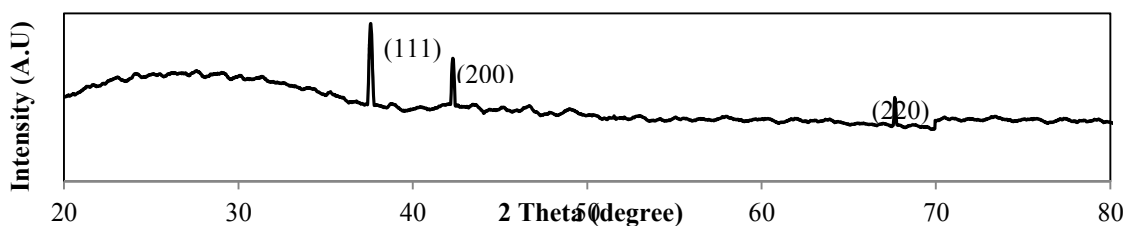


Figure 1. XRD pattern of spray deposited NiO thin film.

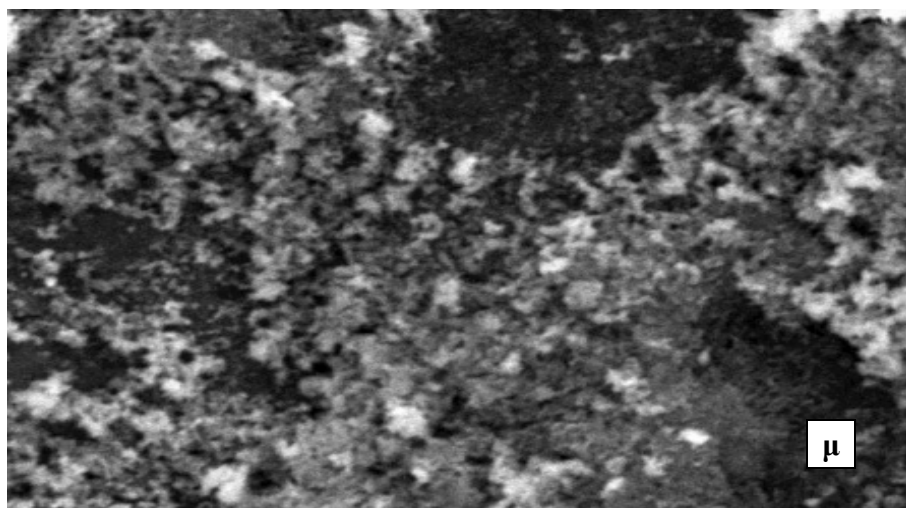


Figure 2. SEM image of spray deposited NiO thin film.

### Optical Analysis

An important technique for estimation of the band gap energy of a semiconductor is the measurement of optical absorption. The photons with energies greater than the band gap energy are absorbed while photons with energies less than the band gap are transmitted. The absorption spectrum of the NiO thin film is shown in Figure 3.

In order to confirm the nature of optical transition (direct or indirect), the optical data was analyzed using the classical relation,

$$\alpha = \frac{A(h\nu - E_g)^n}{h\nu} \quad (1)$$

where  $h\nu$  is the photon energy,  $E_g$  is the band gap energy,  $A$  and  $n$  are constants. For allowed direct transitions  $n = 1/2$  for allowed indirect transitions  $n = 2$ .

The plots of  $(\alpha h\nu)^2$  versus  $h\nu$  is shown in Figure 4. Since the variation of  $(\alpha h\nu)^2$  with  $h\nu$  for NiO thin film is a straight line it indicates that the involved transition is direct one. Band gap energy,  $E_g$  was determined by extrapolating the straight line portion to the energy axis for zero absorption coefficient ( $\alpha$ ). The value of  $E_g$  for as deposited film was found 3.3 eV.

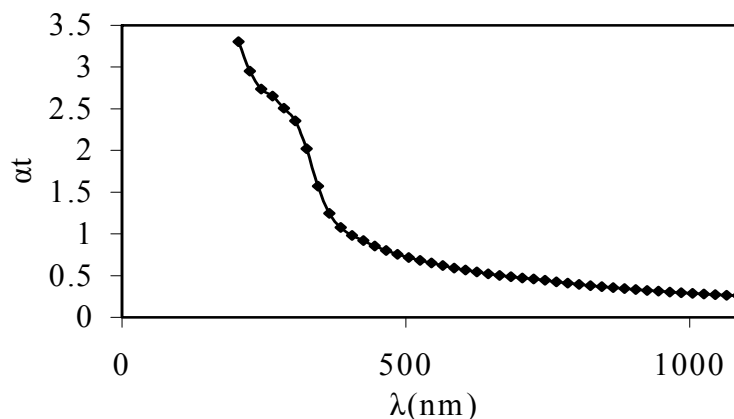


Figure 3. Variation of optical absorption vs. wavelength for spray deposited NiO thin film.

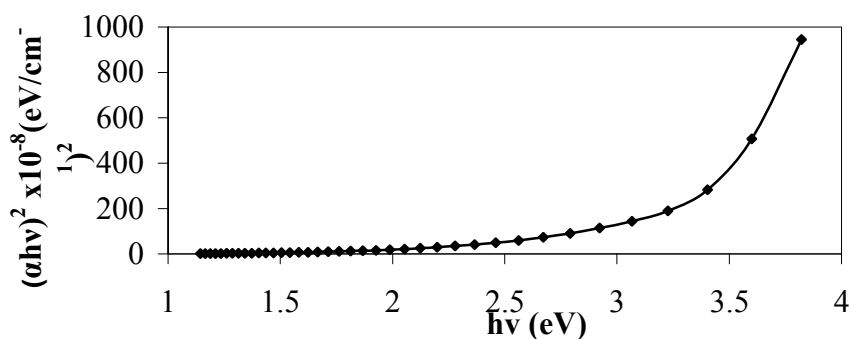


Figure4. Plot of  $(\alpha h\nu)^2$  versus  $h\nu$  for spray deposited NiO thin film.

## Conclusions

In the present paper, physical properties of nanostructured nickel oxide thin films deposited by chemical spray pyrolysis technique have been reported. Nickel oxide films are nanocrystalline in nature with cubic phase. The electrical characterization shows, that nickel oxide films are semiconducting in nature with n-type conductivity. The optical studies confirmed that spray deposited NiO exhibits 3.3eV band gap energy.

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