Microstructural, functional group and electrical properties of nano-structured ITO-NiO layer via sol-gel process

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Abstract
In the present work, pure nano-crystalline nickel oxide (NiO) thin films were deposited on ITO glass substrates by employing sol-gel spin coating process. The microstructural, functional and electrical properties have been studied. The X-Ray diffraction (XRD) patterns revealed that the synthesized films are polycrystalline nature and corresponding to the cubic crystal structure with predominant orientation along (200) plane. The Fourier transform infrared spectroscopy (FTIR) analyses confirm the formation of NiO nanoparticles The electrical characterization shows that the NiO film are p-type conductivity. However, resistivity and carrier mobility of the NiO films were also measured.
Key words: Microstructural, functional group, electrical, sol-gel, ITO-NiO films
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1. Introduction:

Nickel oxide (NiO) is one of few p-type metal oxide semiconductors that received extensive attention for decades due to its specific physical and chemical properties such as highest exciton binding energy (110 meV), wide direct band gap (4.0 eV), low materials cost, excellent chemical and thermal stability [1-3]. NiO films have been an advantageous candidate to be used in a diverse potential application such as magnetic material, transparent electronics, heterojunction solar cells, smart windows, and gas sensors, etc… [4-9]. Currently, a variety of deposition techniques are available for the production of NiO thin films including, thermal oxidation, electron beam evaporation, pulsed laser deposition, spray pyrolysis, and sol-gel, etc… [10-14]. Compared to other techniques, the sol-gel spin coating process can be considered as simple and cost-effective methods involve low deposition temperature, good control over the coating process and large deposition area [14].In this paper, pure nanocrystalline NiO filmswere synthesized via sol-gel spin coating process on ITO glass substrates. The structural, functional group and electricalproperties of the prepared samples has been discussed.

2. Materials and preparation

In this work, Pure NiO thin films were synthesized using the sol-gel spin coating technique on to ITO glass substrate. Nickel (II) acetate tetrahydrate [Ni $(OCOCH_3)_2{\cdot}4H_2O$] (98%, Sigma Aldrich) was used as a starting material. 2-Methoxethanol

[$C_3H_8O_2$] (99.8%, Sigma Aldrich) and Monoethanolamine [C_2H_7NO, MEA] (99%, Sigma Aldrich) were used as solvent, and stabilizer, respectively. For the preparation of the pure NiO precursor solution, nickel (II) acetate was initially added in 2- Methoxethanol to obtain a final concentration of 0.5 M. The solution was stirred slowly for 1 hr at 60°C using magnetic stirrer. At that moment a few drops of MEA was added to achieve a transparent and homogeneous green solution. Before deposition process, the ITO glass substrates were successively cleaned with acetone, ethanol, and deionized water for 15 min. the obtained mixture solution was dropped on glass substrates using spin coater device with the rotation rate fixed at 3000 rpm for 30 s. The as-deposited NiO films were dried at 100°C for about 5 min to remove organic contaminations. The last process was repeated four times, to get the desired film thickness. Finally, all deposited films were annealed at 480 °C in air for 2 h.

3. Characterization methods

The structural properties of all prepared films were investigated using X-ray diffraction (BRUKER-AXS type D8) equipped with X'Pert High Score under Cu Kα radiation source (λ=1.5406Å) operating at 40 kV and 30 mA in the range of the diffraction angles (2θ) between 20° and 80°. The functional group of the synthesized films were characterized using Fourier transformed infrared spectroscopy (FTIR -Perkin Elmer Spectrum 1000) in the range of 400-4000 cm^{-1}. The electrical properties were examined by using (Ecopia HMS-5000) Hall Effect measurements at room temperature.

4. Results and discussion

4.1. Structural properties

The X-ray diffraction pattern of NiO films synthesized using sol-gel spin coating process and annealed at 480°C is shown in Fig. 1. The prepared films exhibited three prominent diffraction peaks located at 2θ = 37.38°, 43.30°, and 62.80°, which corresponding to the (111), (200) and (220) planes respectively.XRD analysis indicates that the deposited films of the face-centered cubic of NiO phase and excellently coincides with the standard NiO of : ICDD No:04–08350[14]. From the XRD patterns, it is observed that all the films are polycrystalline and the intensity of (200) diffraction peak was observed higher compared with other peaks indicating the preferred orientation.Notably, in figure 1, the existence of other diffraction peaks which referred to ITO substrate.

The average crystallite size G was calculated from Debye-Scherrer formula [14]:

$$G = \frac{0.9\lambda}{\beta \cos\theta} \quad (1)$$

Where β is the full width at half-maximum (FWHM) of the most intense diffraction peak, λ is the X-ray wavelength (1.54056 Å) and θ is the Bragg angle at (200) peak.

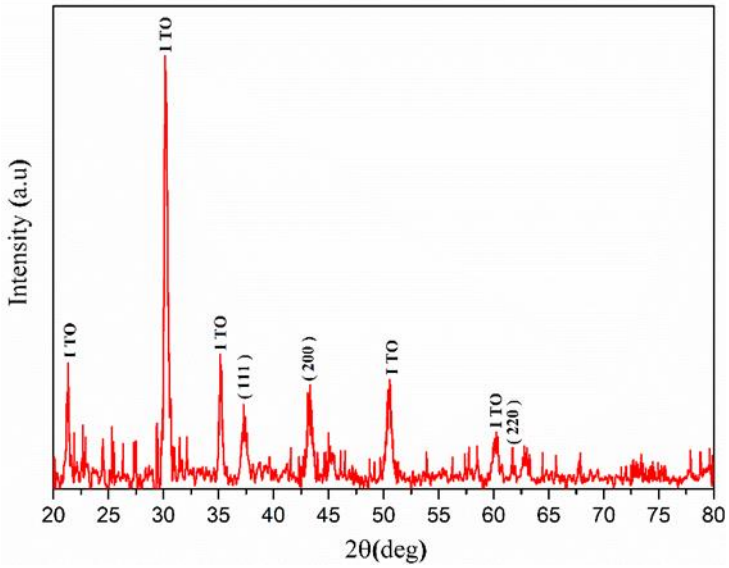

Fig.1: X-ray patterns of pure NiO/ITO thin film

The calculated crystallite sizes of undoped NiO sample were equal to 18.09 nm. this result confirmed the production of nanomaterial.

4.2. Functional group analysis

In order to confirm and identify the functional groups of the prepared NiO/ITO material, Fourier transform infrared spectroscopy (FTIR) were investigated in this work. FTIR spectrum of pure NiO thin film were recorded in the range of 4000 to 400 cm^{-1}at RT. the result is presented in Fig. 2.As indicated in the NiO spectrum, a different absorption bands located at 491,563, and 759cm^{-1} correspond to Ni-O stretching vibration bonds as reported in the literature [15-17].The absorption band located at 993 cm^{-1}corresponds to metal-oxygen bond [18]. Other absorption bands may be related to the O–H stretching vibrations ,CH_2 vibrations mode and C=H stretching vibrations mode.

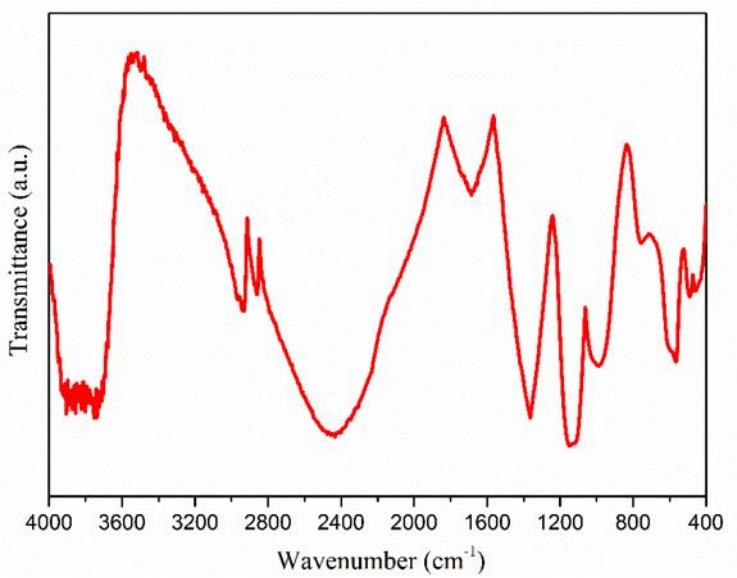

Fig.2: FT-IR spectraum of of pure NiO/ITO thin film

4.3. Electrical properties

The electrical property of deposited films was achieved by using Ecopia HMS-5000 Hall Effect measurements at room temperature. The resistivity, mobility, and sheet resistance values obtained for NiO films are; 222×10^{-3} Ω, 21.858(cm^2 V^{-1} s^{-1}), and 222.49(Ω/square) respectively. The resistivity of NiO is highly correlated to the presence of microstructural defects in NiO crystallites, such as nickel vacancies and interstitials [19-23].

5. Conclusion

Nano-crystalline ITO-NiO thin films were successfully deposited by using sol-gel spin coating process on ITO glass substrates. X-ray diffraction study indicates that film have a FCC crystal structure with preferential plan (200).XRD pattern imply that the prepared film has good quality and crystallinity. The grain size of NiO grains is found to be equal to 18.09 nm. The Fourier transform infrared spectroscopy (FTIR) analyses confirm the formation of NiO nanoparticles. The electrical parameter such as the resistivity, the sheet resistance and carrier mobility of the NiO films were determined.

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