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Synthesis & Characterization of Structural and Optical Properties of $CoFe_2O_4$ Thin Films

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Abstract

Cobalt ferrite ($CoFe_2O_4$) thin films have been deposited on quartz substrates by chemical spray pyrolysis technique at different substrate temperature of 350 ^{0}C and 375 ^{0}C. The deposited films were annealed at 900 ^{0}Cfor 5 h. The effects of substrate temperature on the structural and optical properties were studied. The thin films were characterized by X-ray diffraction (XRD), and UV-visible spectroscopic.TheXRD patterns showed that the $CoFe_2O_4$ are oriented along (311) plane, which enhances peak intensity with respect to the substrate temperature. The analysis of XRD pattern revealed the formation of single phase cubic spinel structure. The Raman spectroscopy confirmed the formation of cubic spinel crystal structure of the thin films. The optical properties of the films were studied by absorbance spectrum in the range of 300 nm to 800 nm. UV- Visible absorbance spectroscopy showed the band gap variation from 3.45 eV to 2.01 eV with the increases of substrate temperature.

Keywords; Spray pyrolysis, Cobalt ferrite, substrate temperature, UV-Vis

Introduction

Thin films of spinel ferrites have been studied for their excellent electric and magnetic properties. Among these spinel ferrites, cobalt ferrite ($CoFe_2O_4$) thin films have proven their candidature for numerous applications in magnetic recording, microelectro-mechanical system devices, etc. due to its high Curie temperature, high saturation magnetization, and high coercivity [1-4]. The cobalt ferrite follows an inverse spinel structure with a general formula for the ion distribution $A^{3+}[B^{2+}B^{3+}]O_4^{2-}$. In this structure, half of Fe^{3+} cations are occupied in tetrahedral (A) sites, while the remaining half of the Fe^{3+} cations along with divalent Co^{2+} cations are occupied in octahedral [B] lattice sites [5-8]. Cobalt ferrite thin films are very promising materials for magnetic recording and thin film device applications because they exhibit high crystalline anisotropy energy, good chemical stability and mechanical wear [9-10]. The excellent magnetic properties of the cobalt ferrite are known to be mainly attributed to the Co ions in a spinel lattice.There had been different methods, namely pulsed laser deposition (PLD), sputtering, sol–gel method, spray pyrolysis, and molecular beam epitaxial, for the growth of cobalt ferrite thin films.Keeping drawbacks of physical methods in mind, recently, several chemical methods are used for the preparation of ferrite thin films [11-12]. On the other hand, chemical methods are simple, economical and convenient for the deposition of metallic thin films. The different preparative parameters are easily controllable

In this paper, we report the deposition of $CoFe_2O_4$ thin films by usingspray pyrolysis technique at different substrate temperatures and their structural and optical properties were investigated as function of annealing temperature.

Experimental

Thecobalt ferrite ($CoFe_2O_4$) thin film was deposited on to preheated glass substrate using spray pyrolysis technique. The solutions were prepared by using mixture of $Co(NO_3)_2.6H_2O$

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(cobalt nitrate hexahydrate) of 0.08 M and $Fe(NO_3)_3.9H_2O$ (ferric nitrate nonahydrate) of 0.08 M in separately dissolve in double distiled water. The final solutions were prepared by mixing two initial solutions in 1: 2 volumetric proportion. The $CoFe_2O_4$ thin film was prepared by spraying solution on to preheated glass substrate. The glass substrate was cleanedwith an ultrasonification for 30 min in distiled water before film deposition. Then after cleaning glass substrate was mounted on to surface hot plate and set the substrate temperature to 350 and 375°C. The temperature controller was used to control the temperature within ± 10 °C through a thermo couple connected to the surface of a hot plate. The set other preparative parameter such as spray rate 5ml/min. the solution of total quantity 30 ml. The parameters of nozzle to substrate distance 28.5 cm were kept constant and freshly prepared solution was atomized in air pressure 0.25 MPa using a step by step film rgowth. Compressed air was used as a carrier gas to atomize the spray. The atomized droplets were transferred on to the heated glass substrate for 10second intermittently. The deposited thin films (350 and 375 °C) at annealed 900 °C for 5 h.

Characterizations

The deposited thin film was characterized by X-ray diffraction (XRD) analysis (BRUKERD8 Advance) with Cu-Kα radiation. The optical property of the thin film was measured, using the instrument UV-VIS Spectrophotometer Perkin Elmer Lamda 950.

Results and Discussion

X-ray diffraction

Fig. 1 shows the X-ray diffraction (XRD) pattern of $NiFe_2O_4$ thin film deposited at different substrate temperature 350 and 375°C. The X-ray diffraction patterns with 2θ ranging from 20° to 80° indicate the formation of cubic spinel ferrite with most intense peak (311). This shows typical of inverse spinel ferrite structure [12].

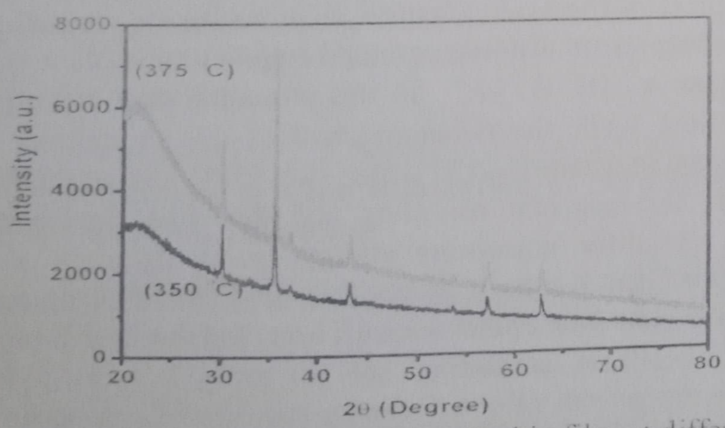

Fig.1. X-ray diffraction of $CoFe_2O_4$ thin film at different substrate temperature.

The intensity of these planes increases with an increase in substrate temperature [15]. The XRD pattern shows the reflections corresponding to (220), (311), (400), (411), (422), (511) and (440) which are allowed peaks of the cubic spinel structure. The matching of observed and standard '*d*' value has been made using JCPDS card No.08-0234which is conform that cubic spinel structure. The crystallite size was calculated from the most intense peak (311) using full width half maxima value (FWHM) by Debye –Scherrer formula [13].

$$D = \frac{0}{\beta c} (1)$$

where D is the crystallite size, λ the wavelength of X-ray (1.5406 Å), β is full-width at half-maxima in radian, and θ is the angle of diffraction. The crystallite size found to be 22 to 27 nm for cobalt ferrite thin film. The Lattice constant, X-ray density and crystallite size are tabulated in table 1 with different substrate temparature [14]. The increase inlattice parameter with saubstrate temperaturemay be due to the strain developed in the films and varying crystalline size.

Optical properties

The optical properties of cobalt ferrite (deposited at different temperature and annealed) thin films on quartzsubstrate were studied using UV-vis spectrophotometer. **Fig 2(a)** shows that, the absorption spectra of nanocrystalline$CoFe_2O_4$ ferrite thin films were recorded at room temperature in the wavelength range of 400-1000 nm by substracting the absorbance of the glass substrate.

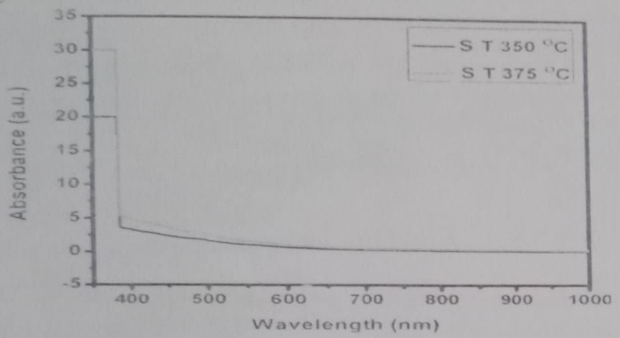

Fig. 2(a) UV-Visible absorbance spectraofcobalt ferrite thin film (350 °C and 375 °C).

Optical absorbance increases with increase in substrate temperature from 350 °C to 375°C until a value of 90% for the films annealing at 900°C for 5 h, because of structural homogeneity, crystallinity and the thickness of films. The values of the band gap of the films have been determined from transmission spectra by using the following relation applicable to near edge optical absorption of semiconductors [15].

$$\alpha = \frac{A(h\nu - E_g)^{n/2}}{h\nu} \quad (2)$$

where, α is the absorption coefficient,A is a constant independent of hν,hν is the photon energy in eV, E_g is the band gap and n is a number equal to 1 for direct band gap and 4 for the indirect gap $CoFe_2O_4$ thin film [16]. The band gap energy of$CoFe_2O_4$ thin films has been determined by Tauc plot based on the above formula as shown in **Fig.2 (b).**

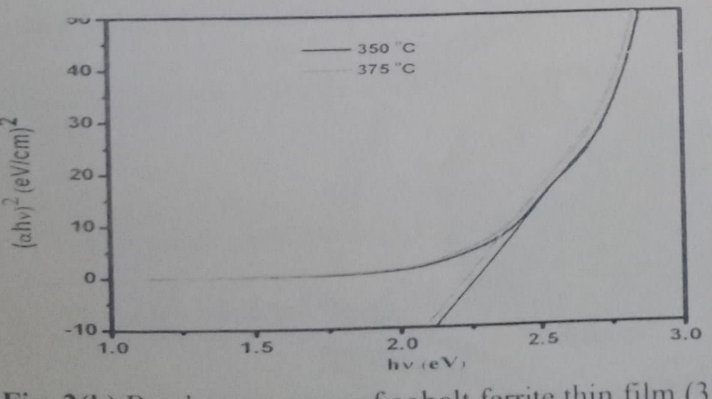

Fig. 2(b). Band gap energy of cobalt ferrite thin film (350 °C and 375 °C).

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ical band gaps are found to be 3.45 eV to 2.01 eVfor the films as-deposited 350 and temperature respectively. The energy band gap $CoFe_2O_4$thin films tends to decrease substrate temperature is increased due to increased crystallite size of the films. The es thickness of thin films at increases substrate temperatures (375 °C) may be due to ition of the solution and previous to the substrate causing in Ferric less amount of reaching to glass substrates. The result decreases in thickness of the films at higher ture.

sion

oalt ferrite thin films have been successfully deposited on quartz substrates by using yrolysis technique. The process of deposited at different temperature and annealing in has been found to change the crystallinity of films from oriented nanocrystalline cubic tructure for XRD analysis. The energy band gap decreases from 3.45 eV to 2.01 eV as-deposited $CoFe_2O_4$ thin films. Together with the substrate temperature, the spray is method becomes a convenient method for preparation of cobalt ferrite thin films.

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