Optical Properties of (CuFe$_{(1-x)}$ Cr$_x$O$_4$) Nanostructures Prepared by Chemical Deposition Method

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ABSTRACT

Thin films of (CuFe$_{(1-x)}$ Cr$_x$O$_4$) with weight ratios (x = 0, 0.2, 0.4, 0.6, 0.8, 1) were prepared using the chemical deposition method on glass bases with dimensions x 1cm (1cm) at (700°C) temperature. Studying the optical properties of the prepared films includes recording the absorbance spectrum and the optical energy gap for the wavelength range (300-900 nm). Moreover, studying the optical constants is represented by the extinction coefficient, the refractive index, and the real and imaginary part of the dielectric constant as a function of wavelength. The optical properties show the appearance of a peak, an absorbance at a wavelength of 370 nm when adding a chromium ion as a substitute for the iron ion. The intensity of this peak increases directly with the increase in the percentage of chromium in the sample. It was also observed that the energy gap decreases significantly to 3eV. There is a slight increase in the value of the optical energy gap to 3.1eV when the percentage increases to x=0.8 due to decrease in size.

Keywords- Nano ferrite, Optical properties of Nanoferrite, Nanoferrite prepared by chemical deposition method.

I.   INTRODUCTION

Recently, the study of nanoferrites has received wide interest among researchers, because of their unique properties and a wide range of applications. These studies have dealt with various properties, including structural, electrical, and magnetic properties, as well as the optical ones. Nuclear ferrites show a significant effect on the physical, electrical and magnetic properties due to the large surface-to-volume ratio of the particles. Interest in nanoscale ferrite has emerged in the field of science and technology in recent years because it possesses various properties that make it suitable for many applications [1]. Ferrites are used in the cores of high-frequency transformers, antenna bars, and choke coils [2,3]. In nanoelectronic devices, integrated circuits, and magnetic resonance imaging (MRI) [4]. Ferrites have the general formula (MFe2O4), where M represents one of the divalent metallic elements such as (Zn+2, Cu+2, Fe+2, Mg+2……). Ferrites are classified according to their composition into three types: Garnet Ferrite, Hexagonal Ferrite and Spinal Ferrite [5].

Table of Raw Materials Used to Prepare Samples

Company	Country product	Purity	M.W	Chemical Formula	Materials
CDH	India	98%	404.00	Fe(NO$_3$)$_3$ 9(H$_2$O)	Iron (III) nitrate
CDH	India	97%	241.60	Cu(NO$_3$)$_2$.3H$_2$O	Copper (II) nitrate
CDH	India	97%	400.21	Cr(NO$_3$)$_3$.9H$_2$O	Chromium (III) nitrate
Reagent world	U.S.A.	98%	40	NaOH	Sodium hydroxide

II. METHODOLOGY

Samples of the ferrite nanocomposite with the chemical formula ($CuFe_{(1-x)} Cr_xO_4$) were prepared using chemical deposition technology in which the materials shown in the table below are used.

Iron nitrate, copper nitrate, and chromium nitrate were dissolved, each according to the proportions calculated and shown in the table below.

Table of materials weights used to prepare samples

X	1	0.8	0.6	0.4	0.2	.00
Iron nitrate	0	8.08	16.16	24.24	32.32	40.4
Copper nitrate	24.1	24.1	24.1	24.1	24.1	24.1
Chromium nitrate	40.021	32.021	24.021	16.0084	8.0042	0

To thoroughly and uniformly dissolve the material in (100 ml) of distilled water, swirl it with a stirrer magnetic mixer at a temperature of (60 C) for half an hour. Then, using a magnetic mixer, all of the sample solutions are combined in a glass beaker and heated to (60 C) for 30 minutes. The second step included dissolving 40 grammes of NaOH in 200 millilitres of distilled water in a glass beaker over the course of 15 minutes while stirring constantly with a magnetic mixer and maintaining a temperature of 60 degrees Celsius. Sodium hydroxide solution (NaOH) is most useful as a pH indicator and catalyst for precipitation of materials. In the third step, a magnetic mixer is used to thoroughly combine all the solutions in a glass beaker at room temperature (60 C) for half an hour. Finally, we continue mixing the sodium hydroxide solution at (60 C) and progressively distil the solution using a burette. The pH of a solution of sodium hydroxide is measured by subjecting it to a distillation process.

We get a clear solution at a pH level we choose after distillation. A paper filter is subsequently used to purify the solution. In addition, it is rinsed many times with distilled water to remove any nitrates that were not already dissolved. After that, the substance is calcined and dried in an oven at (100 °C) to produce a powder. The system (Cu-Fe-Cr-O) is dry and free of moisture, a limited number of drops of the binder (poly vinyl alcohol) are added. The powder is placed in a mold (stainless steal) with a diameter of (10mm). The sample thickness is approximately (2mm - 3mm), samples are compressed using a hydraulic press with a range of up to (10ton), as the samples were compressed at a pressure of (5ton). Next, samples are sintered at a temperature of (700°C) for a period of (4hours), hence the samples are left in the oven to refrigerate until the next day because exposing samples directly to air causes them to crack. The goal of the sintering process is to transform the samples from brittle to cohesive and strong.

III. RESULTS AND DISCUSSIONS

4-1 Absorption spectrum

The absorption spectra of CuFe(1-x)CrxO4 samples prepared at different x values are shown in Figure 1. It can be noticed that the absorbance spectrum of pure copper ferrite (x = 0). The absorbance decreases with an increase in wavelength, the absorption edge is located at approximately 300 nm. as only photons that have an energy greater than the energy gap (with a wavelength less than the absorption edge) can Generation of electron-gap pairs through the process of electrical-optical conduction. It can be observed that an absorption peak appears at a wavelength of (370 nm) when a chromium ion is added as a substitute for the iron ion, and the intensity of this peak increases directly with the increase in the percentage of chromium in the sample. Chromium ferrite compounds can They exhibit interesting absorption properties in the ultraviolet-visible spectrum when suspended in water. The specific appearance of the absorption bands depends on the crystal structure, composition and oxidation states of the chromium and iron ions in the compound. Chromium ferrite compounds are often dark in color due to their mixed metal-oxide nature, and may appear Absorption bands in both the UV and visible regions of the spectrum. Chromium compounds may exhibit absorption bands in the UV region due to electronic transitions of metal ions. These bands are usually broad and can arise from bond-to-metal charge transfer transitions and d-d transitions for the chromium ion the trio [6][7].
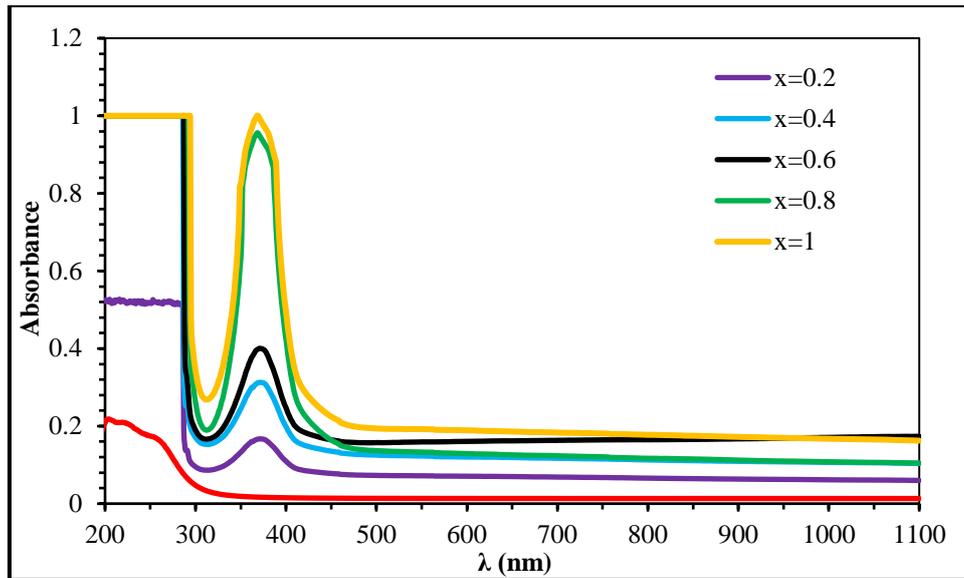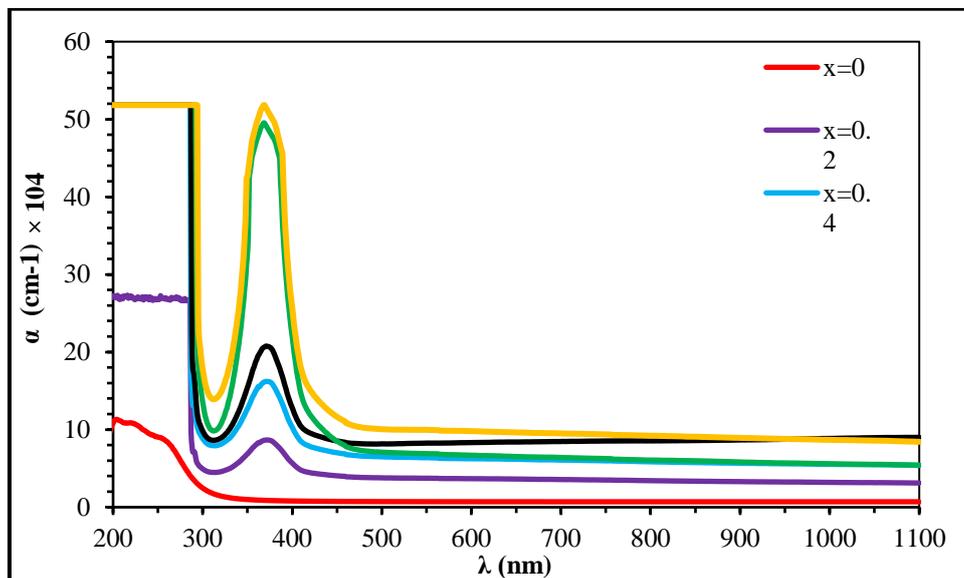
The absorption coefficient (α) of CuFe(1-x)CrxO4 samples at different x values was calculated using the relationship[8]:

$$\alpha = 2303 \, \frac{A}{t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where (A) is the absorbance and (t) is the thickness of the thin film.

As shown in Figure 2, the prepared samples have an absorption coefficient greater than 104 cm-1, especially in the ultraviolet region, which indicates the direct-permissible electronic transfer.

4.2 Optical bandgap

The optical energy gap (Egopt) of CuFe(1-x)CrxO4 samples at different x values was calculated using the relationship[9]:

$$\alpha h\upsilon = A(h\upsilon - Eg)r \dots\dots \dots\dots\dots\dots\dots (2)$$

whereas

α: absorption coefficient (cm-1), A: absorbency of the material, and h: Planck's constant

The energy gap is extracted by plotting the relationship between $(\alpha h\upsilon)2$ versus the photon energy $h\upsilon$, as shown in Figure 3. The energy gap is found from the intersection of the tangent of the curve with the x-axis. It is noted from the figure that the optical energy gap is approximately 4.2 eV at x=0. The energy gap decreases to 3 eV upon doping with chromium, and this effect is linked to the appearance of a new transition band in the electronic structure of the material. Impurity atoms partially replace the original atoms in the crystal lattice, leading to changes in the properties of the material. When chromium is doped into copper ferrite, additional energy levels and electrons interact with the original energy levels of the host material. These interactions can lead to changes in the electronic band structure. Specifically, the

introduction of chromium can create new energy states within the band gap, closer to the valence or conduction bands. These new transitions could involve absorbing light at lower energies than the original energy gap allowed. The specific effects of doping depend on the impurity concentration, crystal structure, and interactions between the added atoms and the host [10]. This phenomenon is significant in many technological applications, such as optoelectronics and photovoltaics, where tuning the optical properties of materials is crucial. There is no change in the energy gap when the ratio is increased to 0.6, but a slight increase occurs to 3.1 eV when the ratio x = 0.8 and x = 1 due to the decrease in crystalline size, as revealed by electron microscope examinations. This leads to the phenomenon of quantum confinement of nanomaterials.
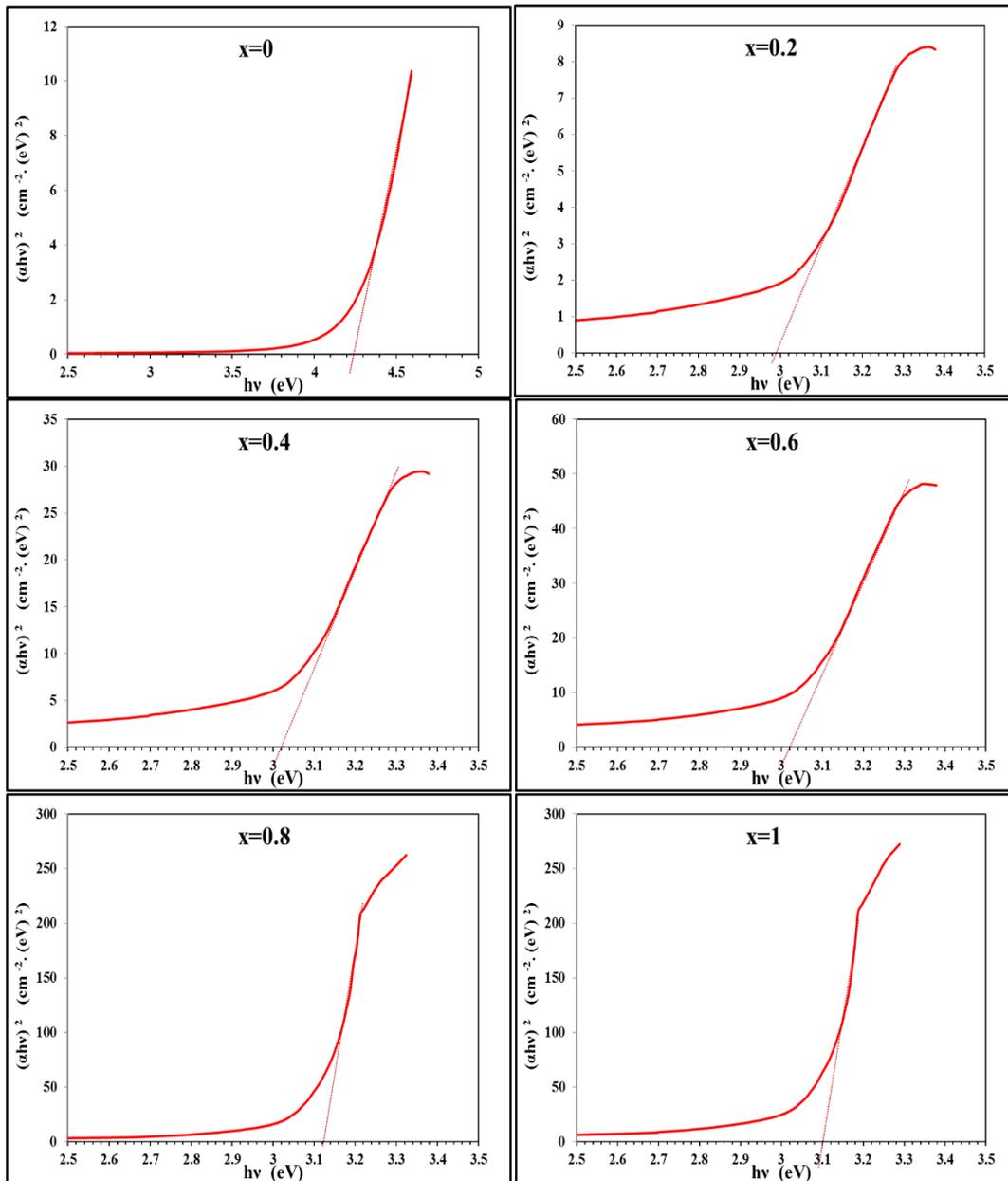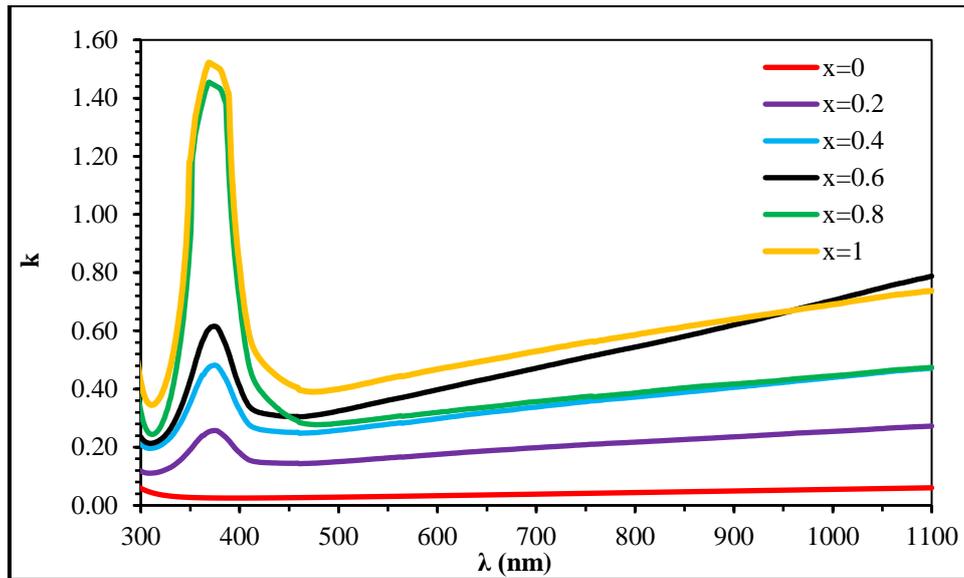

4.3 Extinction Coefficient

Figure 4 shows the variation of the extinction coefficient (k) with wavelength for CuFe(1-x) CrxO4 samples at different values of x, which was found using equation [11]:

$$K = \frac{\alpha\lambda}{4\pi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where α is the absorption coefficient and λ is the wavelength

The extinction coefficient directly depends on the absorption coefficient so it has the same behavior.

4.4 Refractive Index

Figure 5 shows the change of refractive index with wavelength for CuFe(1-x)CrxO4 samples at different x values, which was calculated using equation [12]. $n = [(\frac{1+R}{1-R})^2 - (k+1)]^{0.5} + (\frac{1+R}{1-R})$ **………………… (4)** .

That figure shows the refractive index values range between 1.4 and 2.6. In general, an increase is noticed in the refractive index by increasing the percentage of replacement with chromium ions instead of iron ions. The specific refractive index of semi-crystalline materials is affected by factors such as the composition of the material, which is represented by the percentage of substitution in CuFe(1-x) CrxO4 samples. In addition, its dependence is shown on the arrangement of atoms or molecules in the sample and the degree of crystallinity. Also, the presence of pores in the sample and the increase in crystalline boundaries lead to more scattering of light. [10].
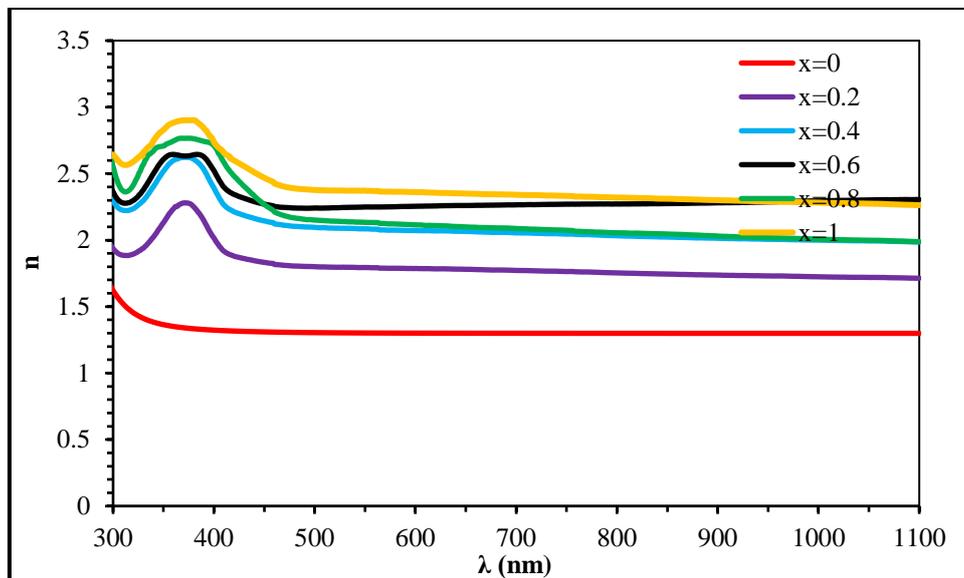
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