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The Electrical and Optical Properties of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ Lithium Doped Nanoparticle Prepared by Coprecipitation Method

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Abstract

In this study, nano ferrite materials were produced to replace costive industrial materials [1]. Ferrite nanoparticles are the interesting material due to their rich and unique physical and chemical properties. They find applications in catalysis, bio-processing, medicine, magnetic recording, adsorption, devices etc. Using co-participation method, five nano ferrite samples $Zn_{0.5}Mg_{0.5-x}Li_{2x}Fe_2O_4$ (x = 0.00, 0.10, 0.20, 0.30 and 0.40) were prepared. The electrical and optical properties of the $Zn_{0.5}Mg_{0.5-x}Li_{2x}Fe_2O_4$ samples were studied using the Ultraviolet-visible (UV-Vis) spectroscopy. The results verified that the formation of the absorption coefficient of the five samples of $Zn_{0.5}Mg_{0.5-x}Li_{2x}Fe_2O_4$ increased with the increase of Lithium (Li_{2x}). The energy band gap of the $Zn_{0.5}Mg_{0.5-x}Li_{2x}Fe_2O_4$ samples ranged from 3.28 to 3.12 eV [1]. The extinction coefficient (K) for five samples of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ increased with the increase of Lithium (Li_{2x}) at 338 nm from 0.074 to 0.207. The high magnitude of optical conductivity is (1.34×10^{12} sec^{-1}) and the maximum value of electrical conductivity is 42 $(\Omega \cdot cm)^{-1}$. This may due to the electrical and optical properties of lithium.

Keywords

$Zn_{0.5}Mg_{0.5-x}Li_{2x}Fe_2O_4$, Nano Ferrites, UV.vis, Co-Precipitation, Electrical Properties, Optical Properties

1. Introduction

Particles in the size range of approximately 1 - 100 nm can display novel optical,

electric, magnetic properties because of quantum confinement and surface effects that may find many important technological applications [2] [3] [4]. Nanotechnology is well-known as a very important key technology in science. In the field of material science, Ferrites are well-known magnetic nanomaterial's intensively studied as a recording media due to their superior physical properties [5] [6] [7]. These properties make ferrites an ideal candidate for technical applications such as magnetic resonance imaging enhancement, catalysis, sensors and pigments [8]. Spinel nano ferrites (AB_2O_4) are materials of today's research due to their amazing structural, dielectric, electrical and magnetic properties [9]. Such properties are dependent on the nature of cations, their charges and their distribution among tetrahedral (A) and octahedral (B) sites [10]. Various physical and chemical methods of preparation have been developed to achieve nano-sized ferrite particles such as sol-gel [11], chemical co-precipitation [12], hydrothermal [13], and chemical combustion route [14]. Among them, the chemical co-precipitation method seems to be the most convenient method for the synthesis of Zn-Co-Mg ferrites. It is very simple and has better control over the crystalline size and other properties of the materials [15]. In this work, $Zn_{0.5}Mg_{0.5-x}Li_{2x}Fe_2O_4$ nano ferrite where (x = 0.1, 0.2, 0.3, 0.4 and 0.5) was synthesized using co-precipitation methods. Ultraviolet-visible spectrometer (UV) was used to study the optical, electric and magnetic properties of nanoparticles [16].

2. Materials and Methods

$Zn_{0.5}Mg_{0.5-x}Li_{2x}Fe_2O_4$ nanoparticles samples (x = 0.00, 0.10, 0.20, 0.30 and 0.40) were studied by the co-precipitation method [1]. The raw stoichiometric materials are $FeCl_3$, $MgCl_2{\cdot}6H_2O$, $LiCl{\cdot}H_2O$, $ZnCl_2$ with high pure, NaOH was used to found the required solutions with required molarities. Firstly, the solution of $MgCl_2{\cdot}6H_2O$ 0.2 M (25 ml), $ZnCl_2$ and $FeCl_3$ 0.4 M (25 ml) were mixed, next, slowly added to NaOH solution with stirring to obtain a mixture of pH 11 - 12. The colloid solution was kept in a water bath at 80˚C for 1 hrs to the removal of $NaCl_2$ and H_2O from the powder. The produced powder was washed by deionized water until the filtrate had a pH 7. Then the samples were dried and grinned to absolute powder and annealed to 450˚C for 6 hrs in temperature-controlled muffle furnace Vulcan A-550 at a heating rate 10˚C/min. The absorption of a solution with different concentrations was calculated using UV min 1240 spectrometer Shimadzu.

3. Results and Discussion

UV-VIS absorbance behaviour of curves was found to be the same for five samples of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$; as shown in **Figure 1**. The figure shows the relation between absorbance and wavelengths for five samples of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$. It depicts the rapid increase of the absorption at wavelengths 340 nm. It indicated an Lithium index (Li_{2x}) in the absorbance value, as the absorbance value increases with the increase of Lithium index (Li_{2x}).

Absorption coefficient **(α):** It describes how much light of a given color is absorbed by a material of a given thickness. The absorption coefficient (α) of the five prepared samples ($Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$) was found using the following relation:

$$\alpha = \frac{2.303xA}{t}$$

where (A) is the absorbance and (t) is the optical length in the samples. **Figure 2** shows that the $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ plot of (α) with wavelength (λ) was the top among the five samples. The highest value of (α) for all samples was in the U.V region (340 nm). This means that the transition must be corresponding to a direct electronic transition, and the properties of this state are important since they are responsible for electrical conduction. Also, this figure shows that the value of (α) for the five samples increases with the increase of the Lithium index (Li_{2x}), which explains that lithium has a high absorbency [17] [18].

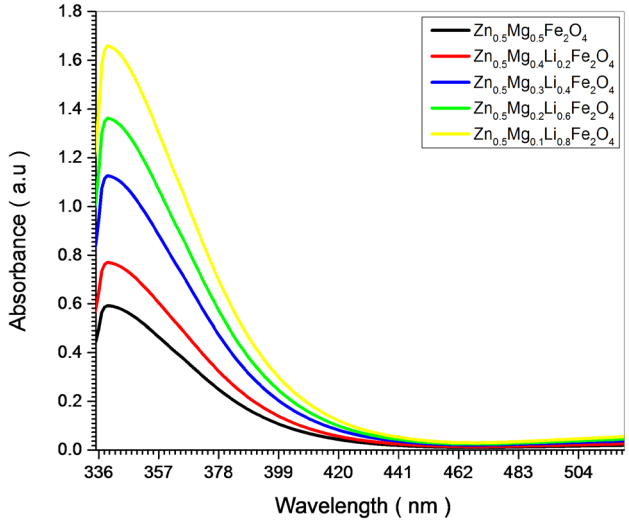

Figure 1. The relation between absorbance and wavelengths of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ samples.

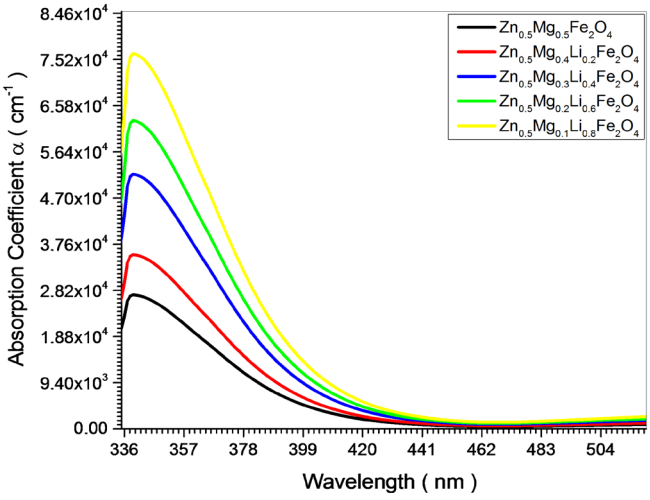

Figure 2. The relationship between absorption coefficient (α) and wavelengths of $ZnLi_{2x}Mg_{0.5}xFe_2O_4$ samples.

***Extinction coefficient* (*K*):** It is a measure of light lost due to scattering and absorption per unit volume. Extinction coefficient (K) was calculated using the relation The variation at the (K) values as a function of (λ) for five samples of ($Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$) is shown in **Figure 3**, where it is observed that the spectrum shape of (K) as the same shape of (α). The Extinction coefficient (K) for five samples of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ in **Figure 3** indicated that the value of (K) at the wavelength depends on the samples treatment method, where the value of (K) at 338 nm for $Zn_{0.5}Mg_{0.5}Fe_2O_4$ sample equals 0.074 while it was 0.207 for the other sample ($Zn_{0.5}Li_{0.1}Mg_{0.8}Fe_2O_4$) at the same wavelength. The Extinction coefficient (k) increased with the increase of Lithium index (Li_{2x}) in the $Zn_{0.5}Li_{0.2x}Mg_{0.5-x}Fe_2O_4$ samples.

***The optical energy gap* (E_g):** It is the threshold for photons to be absorbed. The optical energy gap (E_g) has been calculated by the relation $(\alpha h\upsilon)^2 = C(h\upsilon - E_g)$ where (C) is constant. By plotting $(\alpha h\upsilon)^2$ vs photon energy ($h\upsilon$), as shown in **Figure 4** for the five prepared samples and by extrapolating the straight thin portion of the curve to intercept the energy axis, the value of the energy gap has been calculated. In this figure, the value of (E_g) for $Zn_{0.5}Mg_{0.5}Fe_2O_4$ sample was (3.282) eV while it was (3.121) eV for the $Zn_{0.5}Li_{0.8}Mg_{0.1}Fe_2O_4$ sample. The decrease of (E_g) seemed to be associated with the Lithium index (Li_{2x}) for ($Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$) samples as it was observed that the E_g value has decreased with the increase of Lithium index (Li_{2x}) confirming that it is the reason for the bandgap shifts [1] [19] [20].

***The refractive index* (*n*):** It is a dimensionless number that describes how fast light travels through the material. The refractive index (n) is the ratio between the speed of light in a vacuum to its speed in a material which does not absorb this light. The value of n was calculated using the equation Where (R) is the reflectivity. The variation of (n) vs (λ) for the five samples is shown in **Figure 5**. The figure depicts the relationship of the five prepared samples by $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ refractive index (n) spectra. The maximum value of (n) is (2.159) for all samples

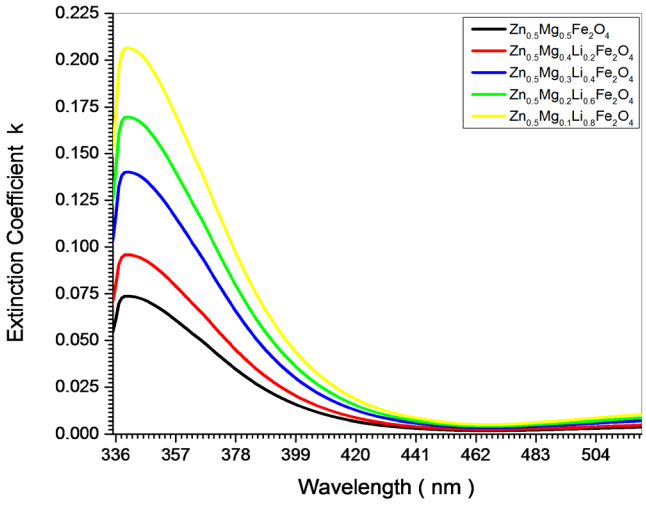

Figure 3. The relationship between extinction coefficient (k) and wavelengths of $Zn_{0.5}Li_{2x}Mg_{0.5}xFe_2O_4$ samples.

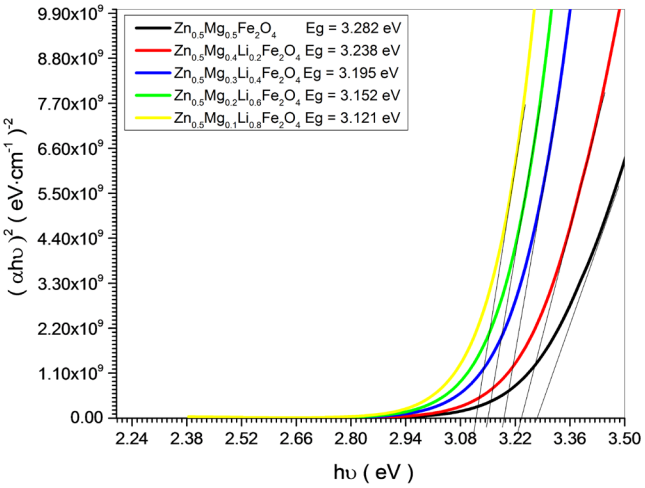

Figure 4. The optical energy bandgap of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ samples.

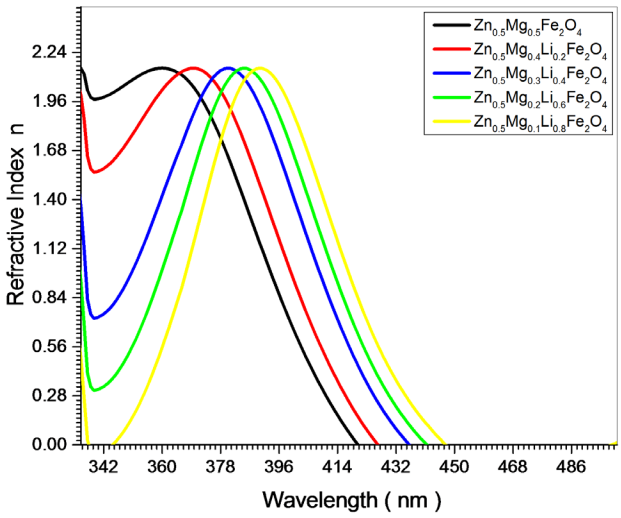

Figure 5. The relationship between refractive index and wavelengths of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ samples.

at the different wavelength which is agreement with (redshift when the Lithium index (Li_{2x}) increased for all samples of ($Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$).

Real dielectric constant **(ε_1):** Figure 6 shows the variation of the real dielectric constant (ε_1) with the wavelength of five samples prepared by $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ form, which was calculated using the equation $\varepsilon_1 = n^2 - k^2$; where the real the dielectric (ε_1) is the normal dielectric constant. From Figure 6; the Real Dielectric Constant (ε_1) increased in the region (340 to 432) nm for all samples of ($Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$), where the absorption of the samples at these wavelengths is small, but the polarization was high. The (ε_1) reported a maximum value of (4.63) at a wavelength near 360 nm and 390 nm wavelength for the samples ($Zn_{0.5}Mg_{0.5}Fe_2O_4$) and ($Zn_{0.5}Li_{0.8}Mg_{0.1}Fe_2O_4$), respectively. The effect of treatment by $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ on the (ε_1) was redshift when the Lithium index (Li_{2x}) increased for all samples of ($Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$).

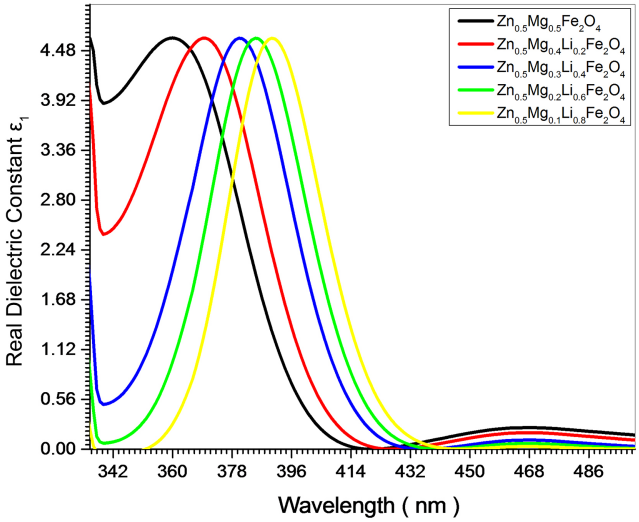

Figure 6. The relationship between real dielectric constant and wavelengths of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ samples.

The imaginary dielectric constant **(ε_2):** The imaginary dielectric constant (ε_2) vs (λ) was shown in **Figure 7**. This value was calculated using the equation ε_2 = 2 nK, where (ε_2) represents the absorption associated with free carriers. As shown in **Figure 7**; the shape of (ε_2) is as the same as (ε_1). This means that the refractive index was dominated in this behaviour. The maximum values of (ε_2) are different according to the treatment operation, so, while the maximum value of (ε_1) was (4.63) for ($Zn_{0.5}Mg_{0.5}Fe_2O_4$) sample at wavelength near 360 nm, the value of (ε_2) for this sample was (0.29) at the same wavelength. Similarly, the maximum value of (ε_1) was (4.63) for the ($Zn_{0.5}Li_{0.8}Mg_{0.1}Fe_2O_4$) sample at wavelength 390 nm, the value of (ε_2) was (0.34) at the same wavelength. This behaviour may be related to the different absorption mechanisms for the free carriers.

Electrical and optical conductivity**:** The optical conductivity is a measure of the frequency response of material when irradiated with light which is determined using the following relation,

$$\delta_{opt} = \frac{\alpha nc}{4\pi} \tag{1}$$

where (c) is the light velocity. The electrical conductivity can be estimated using the equation

$$\delta_{ele} = \frac{2\lambda\delta_{opt}}{\alpha} \tag{2}$$

The high magnitude of optical conductivity (1.34×10^{12} sec^{-1}) following relation confirms the presence of very high photo-response of the five samples prepared by $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ form. The increased optical conductivity at high photon energies is due to the high absorbance of the five samples prepared by $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ form and may be due to electron excitation by photon energy as it is shown in **Figure 8** and **Figure 9**. The maximum value of electrical conductivity is 42 $(\Omega\cdot cm)^{-1}$ [21] [22] [23] [24] [25].

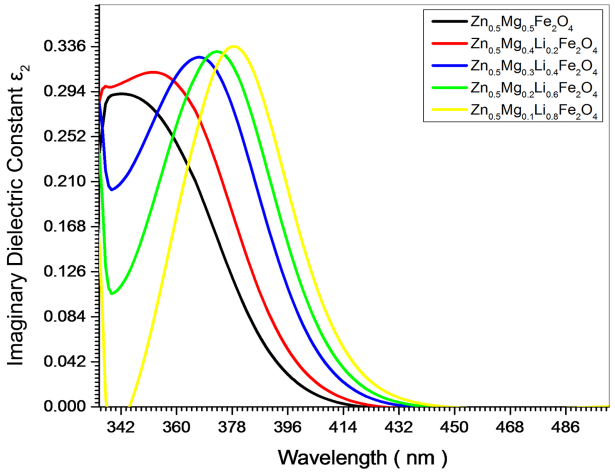

Figure 7. The relationship between imaginary dielectric constant and wavelengths of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ samples.

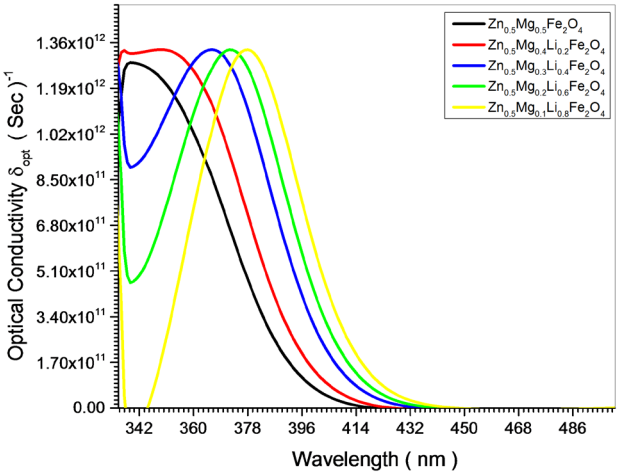

Figure 8. The relationship between optical conductivity and wavelengths of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ sample.

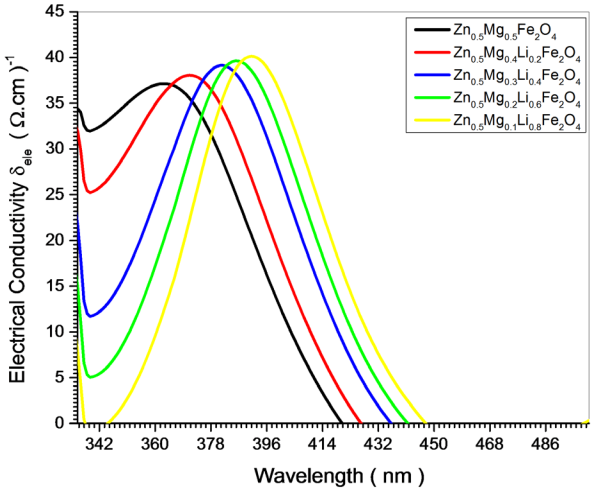

Figure 9. The relationship between electrical conductivity and wavelengths of $Zn_{0.5}Li_{2x}Mg_{0.5-x}Fe_2O_4$ samples.

4. Conclusion

Nanocrystalline, $Zn_{0.5}Mg_{0.5-x}Li_{2x}Fe_2O_4$ nano ferrites (x = 0.00, 0.10, 0.20, 0.30 and 0.40) samples are successfully prepared by co-precipitation approach. UV-visible spectroscopy showed that the bandgap energy of the samples was computed to be 3.28, 3.24, 3.19, 3.15 and 3.12 eV, for Li^{1+} concentration increased for the samples, respectively and the physical properties are increased with the lithium concentration and correspond to the Mirghni *et al.* study. This study was limited to the preparation and study of the composition and photometric properties. It is also recommended to study the rest of the physical and chemical properties to classify these materials and determine their applications.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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