Benha Journal of Applied Sciences (BJAS) **print: ISSN 2356–9751**
Vol. (7) Issue (12) (2022), (143-148) **online: ISSN 2356–976x**
http://bjas.bu.edu.eg

Fabrication, study, and optical properties of zinc ferrite using combustion method and glycine

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Abstract

Zinc ferrite nanoparticles were synthesized using zinc nitrate, ferric nitrate, and glycine via the combustion method. The synthesized zinc ferrite nanoparticles were obtained after the calcination at 400 ° C for 1 h. The obtained zinc ferrite nanoparticles are characterized using various techniques. The reflectance and optical properties were investigated using diffuse reflectance spectroscopy. The band gap and color analysis of the obtained zinc ferrite nanoparticles were exanimated.

Keywords: Zinc ferrite, Combustion, Glycine fuel, and band gap.

1. Introduction

Nowadays nanomaterials attracted attentions due to their unique physical properties such as electrical conductivity, optical band gap, refractive index, magnetic properties and superior mechanical properties like hardness [1]. Among of them zinc ferrite nanoparticle is a cubic spinel ferrite materials which having a general formula MFe_2O_4 (where, M = divalent metal ion such as $Co^{2+,}$ $Ni^{2+,}$ $Zn^{2+,}$ Mn^{2+} etc.) and consisting of oxygen atoms form face-centered cubic (FCC), while Zn and Fe occupy tetrahedral and octahedral sites, respectively. The properties, shape, size and purity of zinc ferrite nanoparticles changes according to the experimental condition, calcination temperature and preparation method [2, 3].

There are various synthesis methods for preparing $ZnFe_2O4$ nanoparticles such as combustion[4-7], co-precipitation, thermal decomposition, sol-gel [8, 9], ball milling, hydrothermal/ solvothermal, microemulsion method, green and ceramic route techniques [2, 10-16]. Among of these synthesis methods we have used combustion method in this work which fasting the rate of reaction, chemical homogenecity, giving highly crystalline nanoparticles and saving energy and time [17]. Zinc ferrite ($ZnFe_2O_4$) nanostructure has been interested due to their various and distinctive applications in gas sensor [18], magnetic behavior, electrical properties, semiconductor photocatalysis (it has a narrow band gab of about 1.9 eV and has ability to absorb visible light) antimicrobial activity [19, 20], superacation batteries [21], hydrogen sensor, drug delivery [22] and water treatment [23].

Zinc ferrite nanoparticles have attracted attention due to their wide range applications and useful properties which include distinctive chemical and physical properties such as enhanced saturation magnetization, high electrical resistivity, low electrical losses and very good chemical stability [24], excellent magnetic permeability, high electronic conductivity, low band gap energy (~1.9 eV), non-toxicity, low cost of production [25], large volume, long life span, easily prepared, reusable, easily separated from the solution when applying an external magnetic field [26]. In this paper zinc ferrite nanoparticles have been prepared by combustion method. The synthesized material was characterized by using X-ray diffraction (XRD), FT-IR, diffuse reflectance spectroscopy DRS.

2.Experimental

3. Materials and reagents:

All Chemical used in this work were purchased and used as received without any further purification. Zinc nitrate hexahydrate ($Zn(NO_3)_2.6H_2O$). Ferric nitrate Nonahydrate ($Fe(NO_3)_3.9H_2O$) were purchased from Qualikems. Glycine ($C_2H_5NO_2$) was purchased from El Nasr Pharmaceutical Chemical Company.

4.Preparation of zinc ferrite nanoparticles via combustion method:

0.01 mole of zinc nitrate and 0.02 mole of ferric nitrate were dissolved in 20 ml distilled water. The solution was mixed with calculated amount of fuel (Glycine) with stirring for 6 minutes without heating. The mixture was ignited on hot plat producing an orange ash powder. The synthesized ash calcined at 400°C for 1 hour to remove the residual organic material and get pure zinc ferrite nanoparticles. Figure 1 displayed the flowchart for the preparation of zinc ferrite using auto-combustion method.

5.Characterization:

The obtained sample was identified by using powder x-ray diffraction (model; SIEMENS D5000**)**. The functional groups characterized by FTIR (Model Cary 630 spectrometer) for the as prepared and the calcined powder sample. Reflectance of the obtained sample was studied using Jasco-V670 spectrophotometer and integrating sphere calibrated with barium sulfate as white standard. The CIE-Lab colorimetric method was used for determination of color parameters[27]. CIE LCH is a second method for calculation the color axes. The chroma parameter (C^*) calculated from $C^* = \sqrt{(a^*)^2 + (b^*)^2}$ and the hue angle h^* is determined from $h^* = \tan^{-1}(b^*/a^*)$. Type equation here.The solar

reflectance (SR) is investigated by the following formula (1).

$$SR=\int_{\lambda_1}^{\lambda_2} R(\lambda)I(\lambda)d\lambda \Big/ \int_{\lambda_1}^{\lambda_2} I(\lambda)d\lambda \qquad (1)$$

Where, R (λ) is the experiment reflectance, and I(λ) is the standard solar spectrum. The solar reflectance was determined by Japanese Industrial Standards Association (JIS) standard k5602-2008[28, 29].

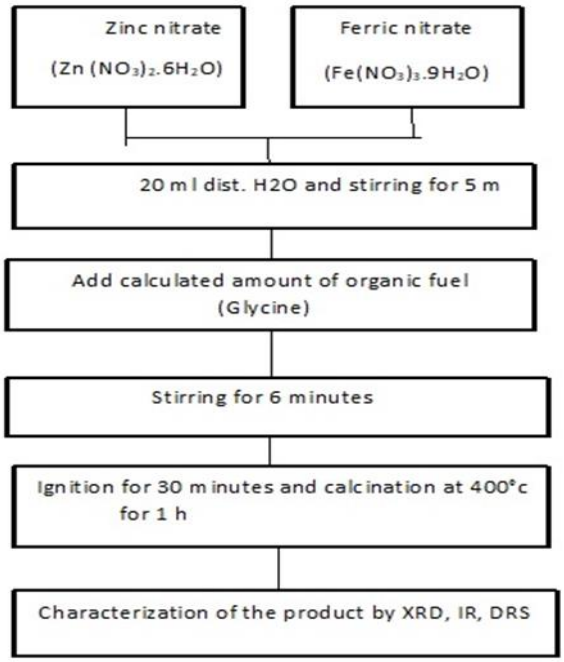

Fig. (1) Flowchart for the preparation of zinc ferrite using auto-combustion method

6. Results and Discussion:

X-ray diffraction (XRD):

Figure (2) displays the XRD patterns of zinc ferrite after calcination at 400°C for 1 h. the XRD patterns appeared the presence of the sharp lines of zinc ferrite without any impurities. The crystal size (S) of the calcined sample determined using Scherrer formula in the light of the following formula (2).

$$S = 0.9\lambda/Z_{1/2} \qquad (2)$$

Where, Θ is the diffraction angle, λ is the wavelength (0.15406 nm for Cu Kα) and Z is the x-ray full width at half-maximum height (FWHM) of the diffraction peak. The average crystalline size is calculated from the x-ray diffraction lines is 37.33nm.

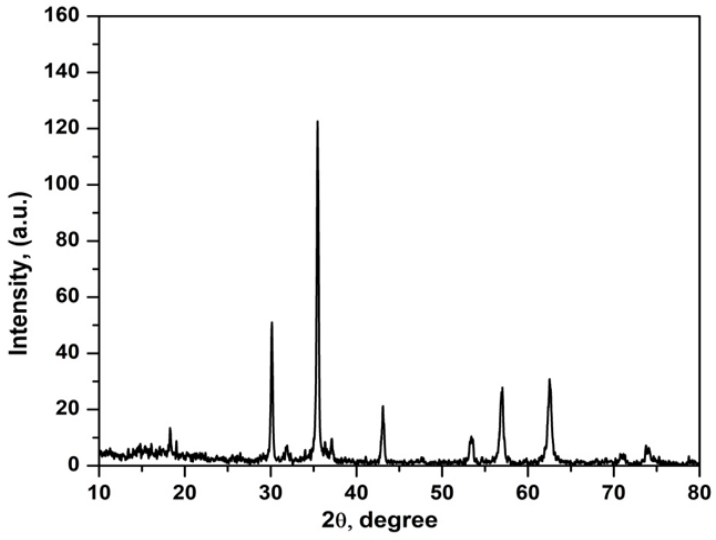

Fig. (2) The XRD of the synthesized zinc ferrite after calcination at 400°C/1 h.

FT-IR analysis

The FT-IR spectra of the synthesized zinc ferrite sample as prepared and after calcination at 400°C for 1 h are shown in Figure 3 (a and b). The absorption peaks at 3423 -3414 cm^{-1} and 1624-1630 cm^{-1} are indexed to the stretching and bending vibration modes of the hydroxide groups of adsorbed water on the surface of the prepared zinc ferrite nanoparticles. The characteristic absorption peaks at 522-541 and 422-442 cm^{-1} are indicated to the stretching and bending vibration mode of zinc ferrite nanoparticles.

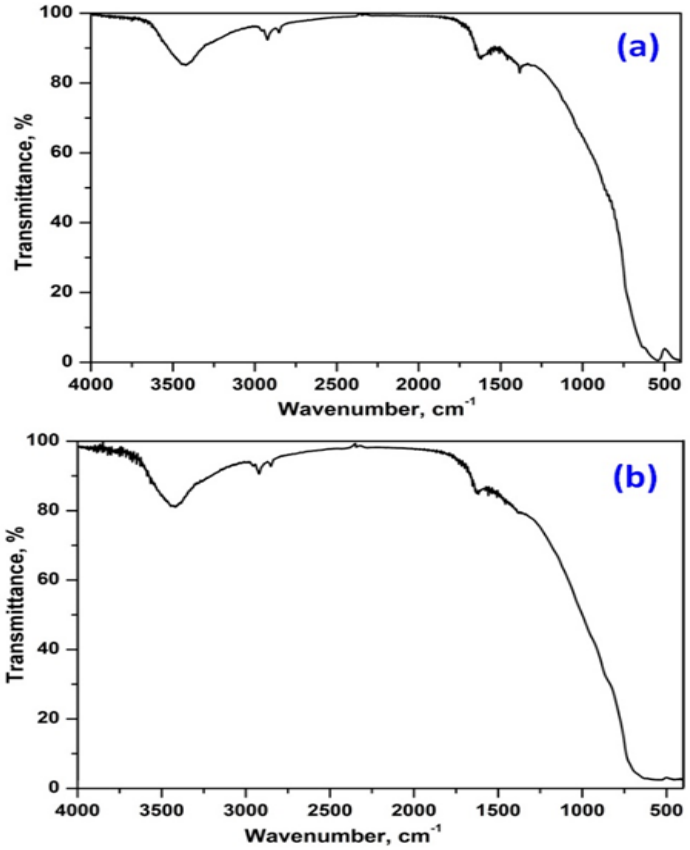

Fig. (3) FTIR of the synthesized zinc ferrite after ignition at 250ºC (b) and calcination at 400°C/ h (a).

Optical studies:

The sample investigated using UV-Vis and NIR diffuse reflectance and absorbance spectra of the calcined zinc ferrite as shown in Figures 4 and 5. Spectra show the reflectance edge between 250- 2500 nm for the synthesized zinc ferrite (ZF sample) as shown in Figure 4.

The absorption coefficients (α) extracted from the experiment reflectance data using Kubelka Munk function as given by equation No (3)[29].

$$F(R) = (K - M) = \alpha = (1 - R)^2/2R \qquad (\mathbf{3})$$

Where, R is the experiment reflectance, F(R) is K-M function, α is absorption coefficients. Absorbance spectra of the obtained zinc ferrite (ZF sample) show the broad absorption band between 500-750 nm as shown in Figure 5. The band gap of the obtained zinc ferrite can be determined by using the equation No. (4)[27].

$$(F(R)h\upsilon)^H = A(h\upsilon - E_g) \qquad (\mathbf{4})$$

Where R is the experiment reflectance sample and H value is equal to 1/2 or two (indirect and direct allowed electronic transitions). Using equation (4), the indirect and direct band gaps of the fabricated sample extracted from the relation between $[f(R)h\upsilon]^H$ and [hυ] (H = ½ and 2 for indirect and direct transitions, respectively) as shown in Figure 6(a and b). The band gap value of the obtained zinc ferrite after calcination at 400 º C (ZF sample) calculated from Tauc formula to be 1.8 eV and 1.47 eV from direct and indirect band gap, respectively.

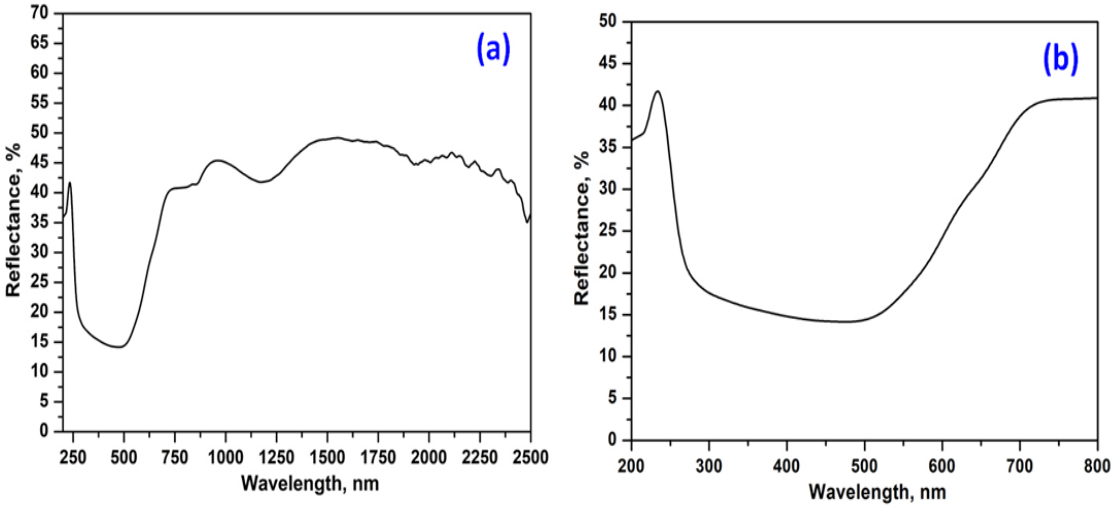

Fig. (4) UV-vis-NIR reflectance of the synthesized zinc ferrite nanoparticles after calcination at 400°C.

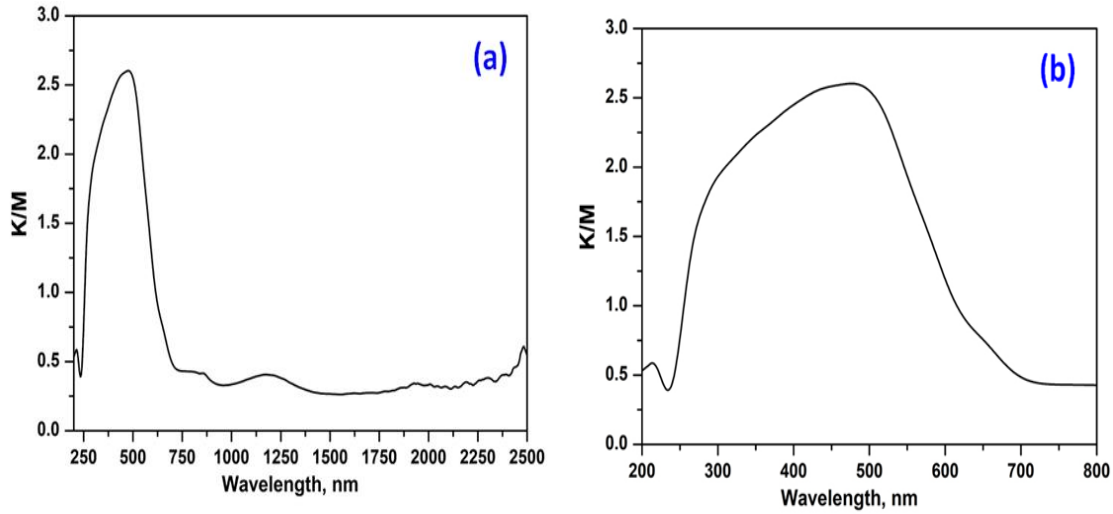

Fig. (5) UV-vis-NIR reflectance of the synthesized zinc ferrite nanoparticles after calcination at 400°C.

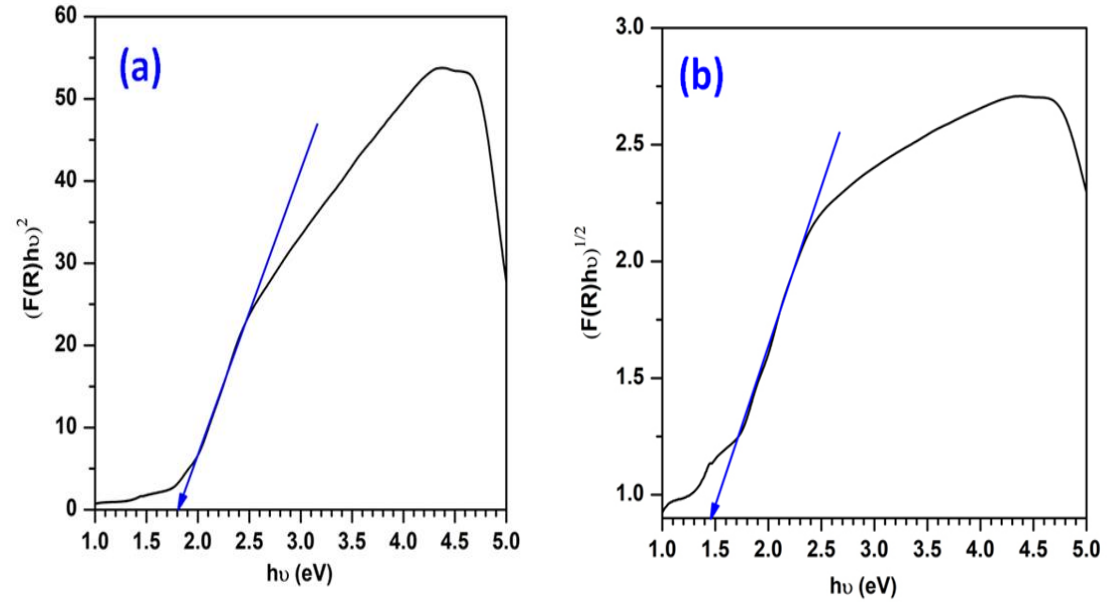

Fig. (6) The direct and indirect band gap of the synthesized zinc ferrite nanoparticles (ZF sample)

The colorimetric methods were used for determination of color parameters according to the CIE-lab and CIE-LCH analysis methods. The values of L/a/b/c/H calculated to be 56.66/12.17/10.21/15.88/39.99/40 for ZF sample. For the calculated data, the color of the synthesized zinc ferrite gives radish color[30].

Light and solar reflectance of the synthesized sample determined by using IISK5602: 2008 and JISA5759: 2008 methods according to the eq. No. (1). The value of light and solar reflectance using JISA5759: 2008 determined to be 19.24% and 32.4% Also, the solar reflectance determined in the UV-Visible, near infrared and total solar reflectance using IISK5602: 2008 method to be 24. 27%, 44.06% and 32.82% respectively[28].

7.Conclusion

Zinc ferrite nanoparticles were prepared from zinc nitrate, ferric nitrate and glycine fuel using combustion method. Zinc ferrite nanoparticles (ZF sample) were obtained after the calcination at 400°c for 1 h. The obtained zinc ferrite nanoparticles were characterized using various techniques such as x-ray power diffraction XRD, Fourier transform infrared analysis FTIR and diffuse reflectance spectroscopy. The average crystallite size of calcined ZF was determined to be 37.33 nm. The direct and indirect band gap of the synthesized zinc ferrite nanoparticles are determined to be 1.8 eV and 1.47 eV, respectively. UV-Vis-NIR diffuse reflectance spectra of the ZF sample show a reflectance edge between 500-750 nm. The solar reflectance determined in the UV-Visible, Near Infrared and total solar reflectance using IISK5602: 2008 method to be 24.27%, 44.06% and 32.82%, respectively. According to the color analysis methods, the color of the synthesized zinc ferrite gives radish color.

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