[1]Hiba Saad Rasheed

[2]Jameel M. Dhabab

[3]Mustafa Zaien Mohammed

[4]Nadir Fadhil Habubi

[5]Ibrahim Ramadhan Agool

[6]Sami Salman Chiad

Physical Characterization of sprayed nanostructured Fe2O3 thin films with Tin-doped Prepared by Spray Pyrolysis Method

Journal of Electrical Systems

Abstract: - The Spray Pyrolysis Method (SPM) was utilized to make thin films of nanostructured Fe2O3 and nanostructured Tin-doped Fe2O3 with a volumetric concentration of 0.01%. (2 and 4. percent). The strongest peak, as determined by X-ray diffraction, corresponds to the (200). The average particle size values in the AFM imaging for the deposited films decreased from 58.46 nm to 31.13 nm, revealing a smooth surface morphology. The average roughness was also observed to drop from 9.29 nm to 4.68 nm. Roughness ratings range from 16.70 nm to 3.66 nm. The strain decreases from 26.64 to 23.68. We determined optical characteristics such as transmittance and optical constants using a UV-Visible spectrophotometer. For Tin Undoped Fe2O3 and 3 percent Sn doping, the optical transmittance is outstanding, with 80 and 75 percent in the visible zone. It was also discovered that as the concentration of Tin dopant was raised, the absorption coefficient increased. The Fe2O3 bandgap was reduced from 2.71 eV for Fe2O3 to 2.54 eV for Fe2O3: 4 % Sn film.

Keywords: Fe2O3, Sn, thin films, XRD, AFM, Optical Properties, bandgap.

I. Introduction

The transition metal Fe_2O_3 has a band gap of 2.2 eV, making it crucial. Due to its beneficial inherent physical and chemical characteristics, including cheap cost, stability under natural conditions, and kindness to the environment are all attractive qualities. [1], it has attracted a lot of interest. Photoelectrodes, gas sensing, catalysts, and medical sectors all use (Fe_2O_3). Iron oxide is hence materials that have the most promise for various optical applications and technologies, such as telecommunication, electrochromic applications, and magnetic devices. [3]. Microelectronic devices also use thin layers of Fe_2O_3 as a dielectric material [4-6]. Hematite, a stable form of iron oxide, can be utilized in photoelectrodes, photovoltaic applications and devices, solar energy conversion, magnetic and nonlinear optical devices, sensors, and other objects [7-9]. Researchers prepare hematite nanostructures using a variety of methods to study the impact of these methods on sensing [10-17]. Chemical deposition [18], sol-gel [19, 20], and PLD [21] are only a few of the Fe_2O_3 depositing methods that have been studied. CVD [22], thermal evaporation method [23], DC reactive magnetron sputtering [24], and SPM [25-29] are some of the techniques

[1] Dept. Physics College of Education, Mustansiriyah University Baghdad, Iraq
hibasaad@uomustansiriyah.edu.iq

[2]Dept. Physics Alnukhba University College Baghdad, Iraq
j.mousa@alnukhba.edu.iq

[3]Dept. Physics College of Education for Pure science University of Anbar Anbar, Iraq
eps.mustafaz.mohamad@uoanbar.edu.iq

[4]Dept. Engineering of Refrigeration and Air Conditioning Technologies Alnukhba University College Baghdad, Iraq

n.fadhil@alnukhba.edu.iq
[5]Bilad Alrafidain University College Diyala, Iraq
dr.agool@bauc14.edu.iq

[6]Dept. Physics College of Education, Mustansiriyah University Baghdad, Iraq
dr.sami@uomustansiriyah.edu.iq

used. Because of its simplicity, ease, and low cost, this work seeks to investigate various physical properties of nanostructured undoped Fe_2O_3 and Fe_2O_3: Sn films deposited using the Spray Pyrolysis Method.

II. EXPERIMENTAL

The Spray Pyrolysis Method was used to make undoped Fe_2O_3 and Fe_2O_3: Sn thin films. The initial stock solution was made using Fe chloride in deionized water at a concentration of 0.1 M. $SnCl_2$ was added to a stock solution of H_2O (0.1) M, and a few drops of acetic acid were added to make a transparent solution that was agitated for 14 minutes. Tin had a volumetric ratio of (2, 4) percent, and the substrate temperature was 400 degrees Celsius. The layers were placed onto glass substrates that had previously been chemically and ultrasonically cleaned. To optimise the deposition, the following parameters were used: 0.2 ml/spray spray rate, 28 cm base to injector distance, 10 sec of spraying duration per cycle, 2 min between sprays, and carrier gas (filtered air) at a pressure of 10^5Nm^{-2}. The thickness was determined to be roughly 310 nm using the gravimetric method. An X-ray diffractometer (Shimadzu, model:) was used to examine film structure that were deposited. X–ray diffractometer (XRD) with monochromatic CuK radiation was applied to specify the composition of the structure. The surfaces of the films were studied using AFM (AA 3000 Scanning Probe Microscope). The optical properties of Fe_2O_3 and Fe_2O_3: Sn films were carried out with a double beam spectrophotometer UV-Vis-NIR Shimadzu corporation.

III. RESULTS AND DISCUSSIONS

XRD patterns of Fe_2O_3 and Fe_2O_3: Sn thin films produced by SPM are shown in Fig. 1. All of the patterns had diffraction peaks around (228.41o, 33.10, 56.32, and 64.27), which correspond to the (111), (200), (211), and (321) favored directions. These findings match the card number 42-1340 (JCPDS) [30,31].

Using Scherer formula given in Eq. 1, the grain size (D) of Fe_2O_3 thin films was estimated [32-34]:

$$D = \frac{0.9\lambda}{\beta cos\theta} \qquad (1)$$

Where λ is the x-ray wavelength, θ is Bragg's angle,and k=0.9. *D* for Undoped Fe_2O_3 particle is (13.01- 14.63) nm with Fe_2O_3: 4% Sn [35-36]

The dislocation density (δ) is gained by [37-39]:

$$\delta = \frac{1}{D^2} \qquad (2)$$

Table 1. It is seen that δ suffer a diminution from 58.89 to 46.72 [40, 41].

The strain (ε) was offered via Eq. 3 [42-44]:

$$\varepsilon = \frac{\beta cos\theta}{4} \qquad (3)$$

Table 1. It depicted that ε reduces from 26.64 to 23.68 [45, 46]. Structural parameters S_{para} are offered in Fig. 2.

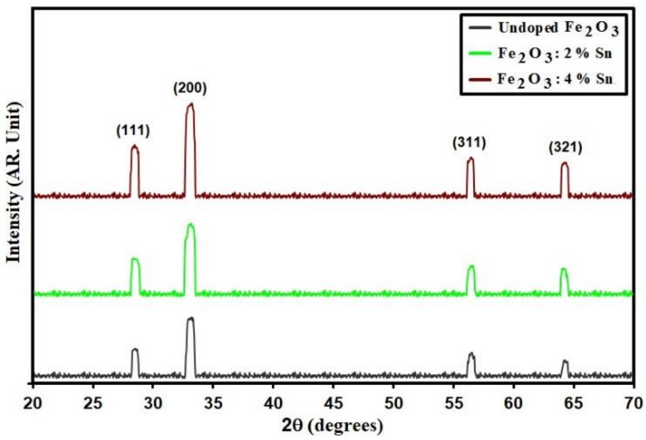

Fig.1. XRD styles of grown films.

The surface abrasiveness and root-mean-square of the planned films are examined using AFM images. Crystallites with regular sizes and dense packing are visible in Fig. 3's AFM scans. The average particle size P_{av} was of (87.5), (49.7), and (41.6) nm for the required films. According to AFM, undoped NiO and NiO: Sb films have surface roughness (Ra) and root mean square roughness (Rms) in the (10.71-5.26) nm range (8.76-3.32). The decrease in R_a is due to the more extensive grain production [35-37]. Figure 3 displays R_a and Rms. Table 2 shows the R_a and Rms with Antimony content.

TABLE 1. *D*, E_g *and Spara of grown films.*

Sample	**2 q (º)**	**(hkl) Plane**	**β (º)**	**E_g (eV)**	**Grain size (nm)**	**dislocation density (δ) (× 10^{14}) (lines/m^2)**	**strain (ε) (× 10^{-4})**
Fe_2O_3	28.41	200	0.63	2.71	13.01	58.89	26.64
Fe_2O_3: 2% Sn	28.38	200	0.6	2.62	13.66	53.59	25.37
Fe_2O_3: 4% Sn	28.35	200	0.56	2.54	14.63	46.72	2.68

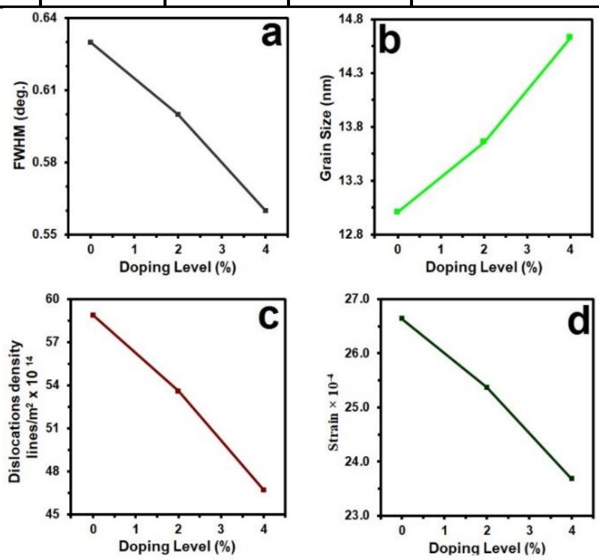

Fig.2. S_{para} of the grown films.

TABLE 2. PAFM of grown films.

Samples	**Pav nm**	**R_a (nm)**	**Rms (nm)**
Fe_2O_3	58.46	9.29	6.78
Fe_2O_3: 2% Sn	36.23	7.94	4.85
Fe_2O_3: 4% Sn	31.13	4.68	3.80

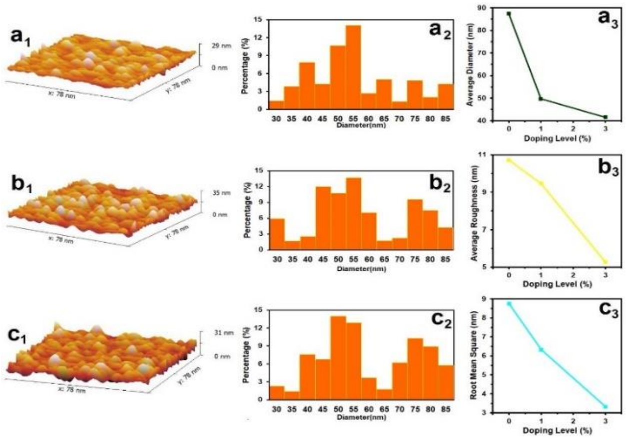

Fig. 3.AFM images, granularly distributed and diversity of P_{AFM}.

The optical transmission (T) spectra of Fe_2O_3 and Tin doped Fe_2O_3 are offered in Figure 3. For wavelengths of 750 nm, the undoped Fe_2O_3 and Fe_2O_3: Sn films show strong transmission (average > 70%), which is one of the requirements for optoelectronic devices, particularly for solar cell window layers [49, 50].

The transmission and reflectance spectra, as well as the film thickness(t), were used to calculate the absorption coefficient (α). [51-53]:

$$\alpha = (2.303\times A)/t \quad (4)$$

It was observed that α increased as the content of Tin increased. A considerable increase in the transitions from the bonding molecular orbit to the nonbonding molecular orbit may be the cause of the significant rise in the absorption coefficient at higher energy [54, 55].

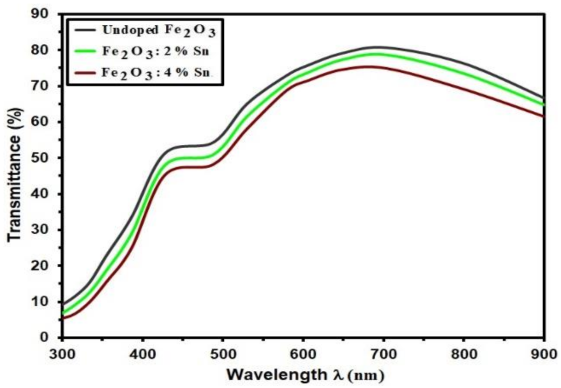

Fig. 4 Transmittance of the deposited Undoped Fe_2O_3 and Fe_2O_3: Sn thin films versus wavelength.

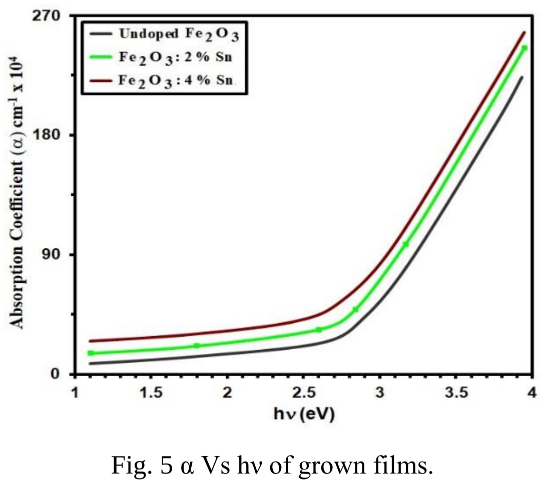

Fig. 5 α Vs hν of grown films.

The optical band gap (E_g) is measured using Tauc 's equations [56-58]:

$$(\alpha h\nu) = A\left(h\nu - E_g\right)^{\frac{1}{2}} \qquad (5)$$

Plots were obtained using A as the constant and $(h\nu)^2$ vs. photon energy ($h\nu$) is demonstrated in Fig. 6, the E_g values for Undoped Fe_2O_3, Fe_2O_3: Sn were quite near to each other. E_g was reduced from 2.71 eV for Fe_2O_3 to 2.54 eV for Fe_2O_3: 4 % Sn film [59, 60].

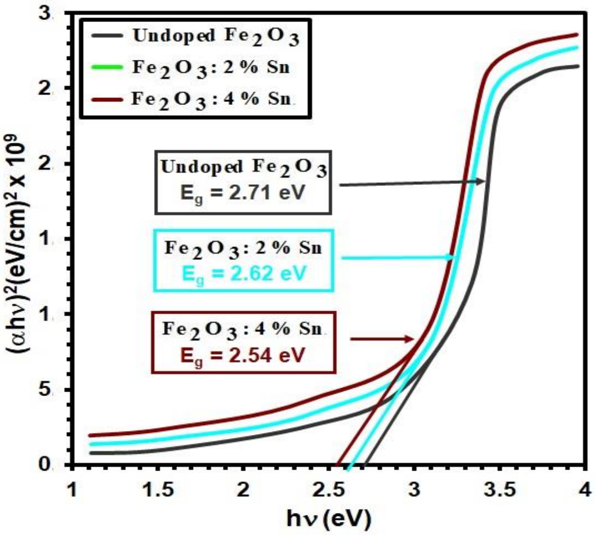

Fig. 6 Direct bandgap of grown films.

The extinction coefficient (k) using the following relation [61-63]:

$$k = \frac{\alpha\lambda}{4\pi} \text{ ----- } (7)$$

Where λ is the wavelength, Figure 7 shows the fluctuation in K via wavelength when the concentration of tin dopant is increased [64, 66].

The refractive index (n) is obtained from the reflectance (R) data via the relation [67-69]:

$$n = \left(\frac{1+R}{1-R}\right) + \sqrt{\frac{4R}{(1-R)^2} - k^2} \text{ ----- } (8)$$

As seen in Fig. (8), n is affected by the concentration of the Tin dopant, with an increase in Tin dopant causing a drop in its value, which may be linked to an increase in film compactness [70, 71].

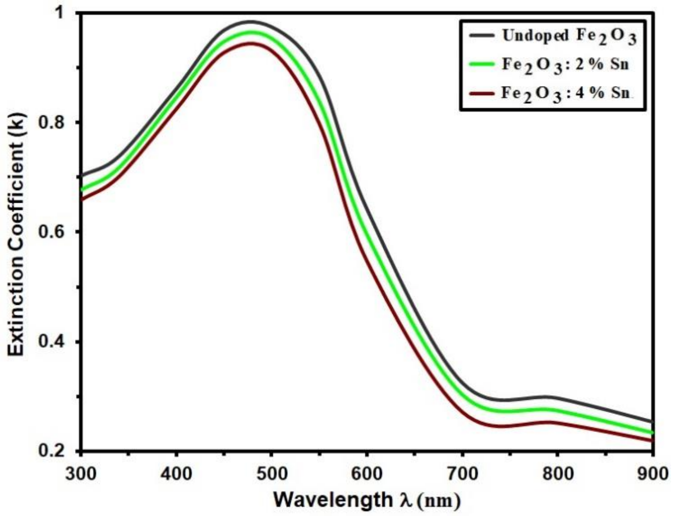

Fig. 7 k of the intended films.

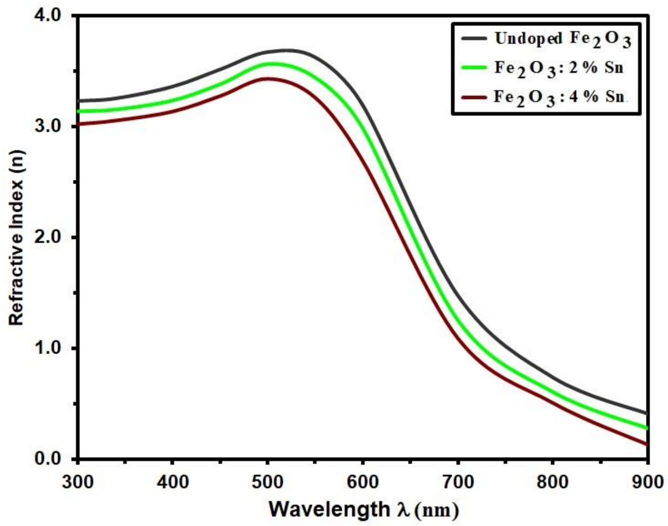

Fig. 8 n of the intended films.

IV. CONCLUSION

Spray Pyrolysis Method was used to grow undoped Fe_2O_3 films doped with Tin. The shape of Fe_2O_3 thin films changed dramatically as the Tin dopant was increased from 0% to 4%. According to X-ray diffraction, the optimal orientation (200) for Undoped Fe_2O_3 films at 4 percent Sn corresponds to the peak of greatest intensity. With Fe_2O_3: 4 % Sn, the grain size for undoped Fe_2O_3 particles is around (13.01- 14.63) nm, but the strain increased from 26.64 to 23.68. With Undoped Fe_2O_3 and Fe_2O_3: 4 % Sn nm, P_{av} was in the area of 58.46 nm to 31.13 nm, respectively. The transmittance spectra are set by UV-Visible spectrophotometer. With increasing Tin doping, the optical energy gap dropped to 2.54 eV for the Fe_2O_3: 4 % Sn film, but the absorption coefficient increased. The optical constants were also calculated.

ACKNOWLEDGMENT

Alnukhba University College and Mustansiriyah University (www.mustansiriyah.edu.iq) supported this effort.

REFERENCES

[1] J. J. Wu, Y. L. Lee, H. H. Chiang, D. K. P. Wong, "Growth and magnetic properties of oriented alpha-Fe_2O_3 nanorods", *J. Phys. Chem.* B110 (2006): 18108.

[2] M. Catti, G. Valerio, "Theoretical study of electronic, magnetic, and structural properties of α-Fe_2O_3", *Phys. Rev. B* 51 (1995): 7441.

[3] S. Mallesh, D. Narsimulu, K. H. Kim, "High coercivity in α- Fe_2O_3 nanostructures synthesized by surfactant-free microwave-assisted solvothermal method", Physics Letters A 384 (1), (2020): 126038.

[4] E. L. Miller, D. Paluselli, B. Marsen, R. E. Rocheleau, "Low-temperature reactively sputtered iron oxide for thin film devices", Thin Solid Films 466 (2004): 307.

[5] A. S. Hassanien, A. A. Akl, Optical characteristics of iron oxide thin films prepared by spray pyrolysis technique at different substrate temperatures", Applied Physics A (2018): 124:752.

[6] Y. J. Park, K. M. A. Sobahan, C. K. Hwangbo, "Optical and structural properties of Fe_2O_3thin films prepared by ion-beam assisted deposition", Surf. Coat. Technol. 203, 2646 (2009)

[7] B. Ouertani, J. Ouerfelli, M. Saadoun, H. Ezzaouia, B. Bessaïs, "Characterisation of iron oxide thin films prepared from spray pyrolysis of iron trichloride-based aqueous solution", Thin Solid Films 516 (2008): 8584–8586.

[8] N. Shreelekha, S.D. Khatavkar, Sartale, "α- Fe_2O_3 thin films by liquid phase deposition: low-cost option for supercapacitor", J. Solid State Electrochem. 21(2017): 2555–2566.

[9] M. A. Gondal, M.N. Sayeed, A. Alarfaj, "Activity comparison of Fe_2O_3, NiO, WO_3, TiO_2 semiconductor catalysts in phenol degradation by laser enhanced photo-catalytic process", Chem. Phys. Lett. 445 (2007): 325.

[10] V. Balouria, A. Kumar, S. Samanta, A. Singh, A. Debnath, A. Mahajan, R. Bedi, D. Aswal, S. Gupta, "Nano-crystalline Fe_2O_3 thin films for ppm level detection of H_2S", Sensors and Actuators B: Chemical 181 (2013): 471-478.

[11] D. Bandgar, S. Navale, G. Khuspe, S. Pawar, R. Mulik, V. Patil, "Novel route for fabrication of nanostructured α- Fe_2O_3 gas sensor", Materials Science in Semiconductor Processing 17 (2014): 67-73.

[12] D. Bandgar, S. Navale, A. Mane, S. Gupta, D. Aswal, V. Patil, "Ammonia sensing properties of polyaniline/α- Fe_2O_3 hybrid nanocomposites", Synthetic Metals 204 (2015): 1-9.

[13] Q. Hao, L. Li, X. Yin, S. Liu, Q. Li, T. Wang, "Anomalous conductivity-type transition sensing behaviors of n-type porous α- Fe_2O_3 nanostructures toward H_2S", Materials Science and Engineering: B 176 (2011): 600-605.

[14] L. Huo, Q. Li, H. Zhao, L. Yu, S. Gao, J. Zhao, Sol–gel route to pseudocubic shaped α- Fe_2O_3 alcohol sensor: preparation and characterization", Sensors and Actuators B: Chemical 107 (2005): 915-920.

[15] E. Lee, G. Jang, C. Kim, D. Yoon, Fabrication and gas sensing properties of α- Fe_2O_3 thin film prepared by plasma enhanced chemical vapor deposition (PECVD)", Sensors and Actuators B: Chemical 77 (2001): 221-227.

[16] S. Wang, L. Wang, T. Yang, X. Liu, J. Zhang, B. Zhu, S., Zhang W. Huang, S. Wu, "Porous α- Fe_2O_3 hollow microspheres and their application for acetone sensor", Journal of Solid State Chemistry 183 (2010): 2869-2876.

[17] S. Wang, W. Wang, W. Wang, Z. Jiao, J. Liu, Y. Qian, Characterization and gas-sensing properties of nanocrystalline iron(III) oxide films prepared by ultrasonic spray pyrolysis on silicon", Sensors and Actuators B: Chemical 69 (2000): 22-27.

[18] S. Mathur, V. Sivakov, H. Shen, S. Barth, C. Cavelius, A. Nilsson, P. Kuhn, "Nanostructured films of iron, tin and titanium oxides by chemical vapor deposition", Thin Solid Films 502 (2006) 88-93.

[19] K.-R. Lee et al, "Effects of Spin Speed on the Photoelectrochemical Properties of Fe_2O_3Thin Films", Int. J. Electrochem. Sci. 9 (2014): 7680-7692.

[20] C.D. Park, D. Magana, A. E. Stiegman, "High-Quality Fe and γ- Fe_2O_3 Magnetic Thin Films from an Epoxide-Catalyzed Sol−Gel Process", Chem. Mater. 19 (2007): 677-683.

[21] X.W. Li, A. Gupta, G. Xiao, G. Q. Gong, "Transport and magnetic properties of epitaxial andpolycrystalline magnetite thin films", J. Appl. Phys. 83 (1998): 7049-7051.

[22] E. L. Miller, D. Paluselli, B. Marsen, R. E. Rocheleau, "Development of reactively sputtered metal oxide films for hydrogen-producing hybrid multijunction photoelectrodes", Solar Energy Mater. And Solar Cells. 88 (2005): 131-144.

[23] A. Z. Moshfegh, R. Azimirad, O. Akhavan, "Optical properties and surface morphology of evaporated$(WO3)_{1-x}$–($Fe_2O_3)_x$ thin films", Thin Solid Films. 484 (2005) 124-131.

[24] J. A. Glasscock, P. R. F. Barnes, I. C. Plumb, N. Savvides, "Enhancement of photoelectron chemical hydrogen production from hematite thin films by the introduction of Ti and Si", J. Phys. Chem. C 111 (2007): 16477-16488.

[25] N. Khademi, M. M. Bagheri-Mohagheghi, The Structural, "Thermoelectric and Optical Properties of SnO_2-F Fe_2O_3: Bi Thin Films Deposited by Spray Prolysis Technique", Thermal Energy and Power Engineering. 2 (2013): 89-93.

[26] R. S. Ali, M. K. Mohammed, A. A. Khadayeir, Z. M. Abood, N. F. Habubi, S. S. Chiad, "Structural and Optical Characterization of Sprayed nanostructured Indium Doped Fe_2O_3Thin Films", Journal of Physics: Conference Series, 1664(1), 2020,012016.

[27] N. N. Jandow, N. F. Habubi, S. S. chiad, I. A. Al-Baidhany and M. A. Qaeed, "Annealing Effects on Band Tail Width, Urbach Energy and Optical Parameters of Fe_2O_3:Ni Thin Films Prepared by Chemical Spray Pyrolysis Technique", International Journal of Nanoelectronics and Materials, Malaysia, 12 (1) (2019): 1-10.

[28]- H. K. Essa, A. A. Khadayeir, H. T. Salloom, N. F. Habubi, S. S. Chiad, "Physical Properties of Nanostructured Fe_2O_3Thin films-Effect of Cobalt Doping Deposited by CSP", Journal of Physics: Conference Seriesthis link is disabled 1999(1) (2021): 012062.

[29] N. Y. Ahmed, B. A. Bader, M. Y. Slewa, N. F. Habubi, S. S. Chiad, "Effect of boron on structural, optical characterization of nanostructured Fe_2O_3 thin films", NeuroQuantology, 18 (6) (2020): 55-60.

[30] A. A. Al-Ghamdi, S. A. Ansari, M. A. Ahmed, F. El-Tantawy, S. H. Kim, "Physical characterization of sprayed nanostructured Fe_2O_3 thin films with tin-doped prepared by spray pyrolysis method", Journal of Nanomaterials, (2013): 1-9.

[31] A. Rani, N. Singh, S. K. Tripathi, R. Shanker, "Influence of tin doping on the optical and electrical properties of Fe_2O_3 thin films synthesized by sol-gel method", Journal of Materials Science: Materials in Electronics, 27(8) (2016): 8502-8508.

[32] S. S. Chiad and T. H. Mubarak, "The Effect of Ti on Physical Properties of Fe_2O_3 Thin Films for Gas Sensor Applications", International Journal of Nanoelectronics and Materials, 13(2) (2020): 221-232.

[33] M. S. Othman, K. A. Mishjil, H. G. Rashid, S. S. Chiad, N. F. Habubi, I. A. Al-Baidhany, "Comparison of the structure, electronic, and optical behaviors of tin-doped CdO alloys and thin films", Journal of Materials Science: Materials in Electronics 31(11) (2020): 9037-9043.

[34] N. N. Jandow, M. S. Othman, N. F. Habubi, S. S. Chiad, K. A. Mishjil, I. A. Al-Baidhany, "Theoretical and experimental investigation of structural and optical properties of lithium doped cadmium oxide thin films", Materials Research Express 6(11) (2020).

[35] W. Tawfik, A. A. Al-Ghamdi, F. El-Tantawy, "Effect of Sn doping on structural and optical properties of Fe_2O_3 nanostructured thin films prepared by spray pyrolysis technique" Applied Physics A, 122(8) (2016): 1-9.

[36] S. H. Ali, H. A. Khalaf, H. H. Abbas "Physical Characterization of Sprayed Nanostructured Fe_2O_3 Thin Films with Tin-doped Prepared by Spray Pyrolysis Method" Materials Today: Proceedings, 38(2) (2021): 485-491.

[37] A. A. Khadayeir, E. S. Hassan, T. H. Mubarak, S. S. Chiad, N. F. Habubi, M.O. Dawood, , I. A. Al-Baidhany, "The effect of substrate temperature on the physical properties of copper oxide films", Journal of Physics: Conference Series, 1294 (2) (2019): 022009.

[38] E. H. Hadi, D. A. Sabur, S. S. Chiad, N. F. Habubi, K. H. Abass, "Physical properties of nanostruc tured li-doped zro_2 thin films", Journal of Green Engineering, 10(10) (2020): 8390-8400.

[39] A. J., Ghazai O. M. Abdulmunem, K. Y. Qader, S.S. Chiad, N. F. Habubi, "Investigation of some physical properties of Mn doped ZnS nano thin films", AIP Conference Proceedings 2213 (1) (2020): 020101.

[40] D. Sharma, A. Datta, M. Sharma, A. Rani, "Synthesis and characterization of Sn-doped α-Fe_2O_3 nanorods by spray pyrolysis method", Journal of Experimental Nanoscience, 11(2) (2016): 142-154.

[41] S. S. Chiad, "Optical Characterization of NiO Doped Fe_2O_3 thin Films Prepared by Spray Pyrolysis Method", International Letters of Chemistry, Physics and Astronomy, 45 (2015): 50-58

[42] E. S. Hassan, K. Y. Qader, E. H. Hadi, S. S. Chiad, N. F. Habubi, K. H. Abass, "Sensitivity of nanostructured mn-doped cobalt oxide films for gas sensor application", Nano Biomedicine and Engineering, 12(3) (2020): 205-213.

[43] M. D. Sakhil, Z. M. Shaban, K. S. Sharba, N. F. Habub, K. H. Abass, S. S. Chiad, A. S. Alkelaby, "Influence mgo dopant on structural and optical properties of nanostructured cuo thin films", NeuroQuantology, 18 (5) (2020): 56-61.

[44] S. S. Chiad, H. A. Noor, O. M. Abdulmunem, N. F. Habubi, M. Jadan, J. S. Addasi, "Optical and structural performance of nanostructured Te thin films by (CSP) with various thicknesses", Journal of Ovonic Research, 16 (1) (2020): 35-40.

[45] J. Gu, G. Shao, J. Cao, Q. Zhang, G. Han, "Synthesis and optical properties of Sn-doped α- Fe_2O_3 thin films prepared by spray pyrolysis", Journal of Nanomaterials, (2016): 1-9.

[46] R. Hussain, M. U. Khandaker, K. Asaduzzaman, "Physical characterization of sprayed nanostructured Fe_2O_3 thin films with tin-doped prepared by spray pyrolysis method", Results in Physics, 12, (2019):1186-1192.

[47] L. Zhang, J. Zhang, "Enhanced visible light photocatalytic activity of Sn-doped hematite nanorods by hydrothermal synthesis", Journal of Physics and Chemistry of Solids, 142 (2020): 109466.

[48] H. M. Ali, M. J. Jawad, H. A. Majeed, "Physical characterization of sprayed nanostructured Fe_2O_3 thin films with Tin-doped prepared by spray pyrolysis method" Journal of Materials Science: Materials in Electronics, 31(3) (2020): 2099-2109.

[49] J. S. Corneille, J.-W. He, D. W. Goodman "Preparation and characterization of ultra-thin iron oxide films on a Mo (100) surface", Surface Science 338(1) (1995): 211-224.

[50] J. Krysa, M. Zlamal, S. Kment and Z. Hubicka, "Photo-Electrochemical Properties of WO3 and α-Fe_2O_3 Thin Films", The Italian Association of Chemical Engineering, 41 (2014): pp.379-484.

[51] H. T. Salloom, E. H. Hadi, N. F. Habubi, S. S. Chiad, M. Jadan, J. S. Addasi, "Characterization of silver content upon properties of nanostructured nickel oxide thin films", Digest Journal of Nanomaterials and Biostructures 15(4) (2020): 1189-1195.

[52] H. A. Hussin, R. S. Al-Hasnawy, R. I. Jasim, N. F. Habubi, S. S. Chiad, "Optical and structural properties of nanostructured CuO thin films doped by Mn", Journal of Green Engineering, 10(9) (2020) 7018-7028.

[53] S. S. Chiad, A. S. Alkelaby, K. S. Sharba, "Optical Conduct of Nanostructure Co_3O_4 rich Highly Doping Co3O4: Zn alloys", Journal of Global Pharma Technology, 11(7) (2020):662-665.

[54] M. J. Jawad, H. M. Ali, , H. A. Majeed, "Effect of Sn doping on the physical properties of sprayed nanostructured Fe_2O_3 thin films prepared by spray pyrolysis method", Materials Research Express, 7(8) (2020): 086432.

[55] S. Balamurugan, R. Sivakumar, S. Ramesh, "Physical Characterization of Sprayed Nanostructured Fe_2O_3 Thin Films with Tin-doped Prepared by Spray Pyrolysis Method", Journal of Electronic Materials, 48(8) (2019): 4872-4879.

[56] A. A. Khadayeir, R. I. Jasim, S. H. Jumaah, N. F. Habubi, S. S. Chiad, "Influence of Substrate Temperature on Physical Properties of Nanostructured ZnS Thin Films", Journal of Physics: Conference Series1664(1) (2020).

[57] R. S. Ali, N. A. H. Al Aaraji, E. H. Hadi, K. H Abass, N. F. Habubi, S. S Chiad, "Effect of Lithium on Structural and Optical Properties of anostructured CuS Thin", Journal of Nanostructuresthis link is disabled 10(4) (2020) 810–816.

[58] A S. Al Rawas, M. Y. Slewa, B. A. Bader, N. F. Habubi, S. S. Chiad, "Physical characterization of nickel doped nanostructured TiO_2 thin films", Journal of Green Engineering10 (9) (2020) 7141-7153.

[59] S. Kumar, M. Tomar, "Structural, optical and magnetic properties of Fe_2O_3 nanoparticles doped with transition metal ions", Materials Research Express, 4(10) (2017): 105008.

[60] M. Bilal, R. Ahmad, A. Rehman, M. Rafique, "Tin doped iron oxide thin films prepared by spray pyrolysis technique", Journal of Materials Science: Materials in Electronics, 27(1) (2016): 862-868.

[61] E. S. Hassan, T. H. Mubarak, S. S. Chiad, N. F. Habubi, A. A. Khadayeir, M. O. Dawood, I. A. Al-Baidhany, "Physical Properties of indium doped Cadmium sulfide thin films prepared by (SPT)", Journal of Physics: Conference Series, 1294(2) (2019).

[62] S. S. Chiad, N. F. Habubi, W. H. Abass, M. H. Abdul-Allah, "Effect of thickness on the optical and dispersion parameters of $Cd_{0.4}Se_{0.6}$ thin films", Journal of Optoelectronics and Advanced Materials, 18(9-10) (2016): 822-826,.

[63] M. O. Dawood, S. S. Chiad, A. J. Ghazai, N. F. Habubi, O. M. Abdulmunem, "Effect of Li doping on structure and optical properties of NiO nano thin-films by SPT", AIP Conference Proceedings 2213 (2020) 020102.

[64] A. B. F. Martinson, M. J. DeVries, J. A. Libera, S. T. Christensen, J. T. Hupp, M. J. Pellin, and J. W. Elam, "Atomic Layer Deposition of Fe_2O_3Using Ferrocene and Ozone", The Journal of Physical Chemistry, C, 115 (2011): 4333–4339.

[65] R. M. Cornell, U. Schwertmann, "The Iron Oxides: Structure, Properties, Reactions, Occurrences and Uses", second ed. Wiley-VCH, Weinheim, (2003).

[66] A. A. Khadayeir, E. S. Hassan, S. S. Chiad, N. F. Habubi, K. H. Abass, M. H. Rahid, T. H Mubarak, M. O. Dawod, I. A. Al-Baidhany Structural and Optical Properties of Boron Doped Cadmium Oxide", Journal of Physics: Conference Series 1234 (1) (2019): 012014.

[67] H. T. Salloom, R. I. Jasim, N. F. Habubi, S. S. Chiad, M. Jadan, J. S. Addasi, "Gas sensor using gold doped copper oxide nanostructured thin films as modified cladding fiber", Chinese Physics Bthis link is disabled,30(6) (2021): 068505.

[68] K. Y. Qader, R. A. Ghazi, A. M. Jabbar, K. H. Abass, S.S Chiad., "Reduce of energy gap of CuO nano structure film by Ag doping", Journal of Green Engineering, 10(10) (2020): 7387-7398.

[69] S. Wang, W. Wang, W. Wang, Z. Jiao, J. Liu, Y. Qian, "Characterization and gas-sensing properties of nanocrystalline iron (III) oxide films prepared by ultrasonic spray pyrolysis on silicon. Sensors and Actuators B: Chemical 69 (2000): 22-27.

[70] E. Lee, G. Jang, C. Kim, D. Yoon, "Fabrication and gas sensing properties of α- Fe_2O_3 thin film prepared by plasma enhanced chemical vapor deposition (PECVD)", Sensors and Actuators B: Chemical 77 (2001): 221-227.