Uttaranchal Journal of Applied and Life Sciences
U. J. App. Life. Sci. Vol: 3 (1): 110-121 Dec 2022

A Brief Review on UV-Visible Spectroscopy of Nanostructured Ferrite Materials

Utkarsh Rawat, AsmitaSemwal, Asmita Negi, Reena Dhyani*, andPankaj Singh Rawat
School of Applied and Life Sciencesdedw, Uttaranchal University, Dehradun, 248007,
***Corresponding author**: reenadhyani16@gmail.com

Received: (12 Oct 2022) Revised: (26 Dec 2022) Accepted: (28 Dec 2022)

Abstract: With the growing technology of semiconducting materials, it is essential to understand the photonic properties of materials. Optical absorption measurements of materials are widely used to evaluate the parameters such as the absorption coefficient, band gap energy, and lifetime of excited state, etc.UV-Visible spectroscopy is the tool to analysethe optical behaviour of materials. Ferritesare both thermally and chemically stable ferrimagnetic materials which consisting of the properties of semiconducting materials that have been used for numerous electronic applications. Optical behaviour of ferrites refers to the study of their interaction with light and extracting information about band gap, refractive index, absorption coefficient, etc.From the absorption spectra of ferrites it was confirmed that they can absorb considerable amount of UV and visible lightdue to which it recivedenormous interest from researchers to apply as a photocatalyst in organic/inorganic dye degradation, pollutant removal from wastewater, etc.This review provides an overview of UV-Visible spectra of ferritesalongwiththe qualitative and quantitative analysis of commonly used ferrites in photocatalytic activity.

Keywords: Spectroscopy; Semiconductor;Photocatalyst; Refractive Index; Band gap energy.

Introduction:

The optical properties of semiconducting materials received considerable attention owing to their tremendous applications in optical sensors and laser devices [1].It was noticed thatmany physical and chemical characteristics of the materials shows size dependency [2]. At nanoscale, measurement of the nanoparticle is comparable to the Bohr radius. The size dependent band gap in nanostructured semiconducting materialsis the consequence of phenomenon of “Quantum confinement”[3]. Aextraordinary growth has been found in the research field of nano-structured

materials. Each materials have their own benefits as well as limitations [4]. In the thrust of suitable material for specific application the multidisciplinary research area opens a new direction of modern research.Amidst of various nanostructured materials “Ferrite nanoparticles” gained uttermost importance due to easy functionalization and distinguish feature which can be utilized in different biomedical applications like magnetic resonance imaging,drug delivery, diagnosis, and radiotherapy [5-7].Besides medical application these ferrimagnetic nanoparticles are desirable in photocatalyst, electromagnetic shielding, magnetostrictive sensors, gas sensors, electronic devices, information storage,etc [7-10]. The chemical formula for spinel ferrites is MFe_2O_4, where M represents a metallic alloy cations.The oxygen ions in spinal ferrites are closely attached within face centered cubic structure and forms two type of interstitial sites, namely tetrahedral (A) and octahedral (B) sites. The arrangement of metal subatomic particles in the structure of ferrites results either normal or inverse spinel structure. All divalent metal ions(M^{2+}) in normal spinel are occupy at A sitesand all trivalent Fe^{3+} ions occupy at B sites. On other side if trivalent ions equally occupy at A and B sites and all divalent ions (M^{2+}) take up at ‘A’ sitesit leads to inverse spinel structure. Ferritenanoparticles consists of excellent magnetic properties along with novel electrical and optical properties which differ remarkably from bulk crystals.

Since their discovery, there has been an exponential increase of interest in ferrites, which is still growing. It still requires many engineering challenges to be addressed. The progressive use of more sophisticated and advanced instruments with high precision is utilized to characterizeboth thechemical and physical properties of materials at the nanoscale [10, 11].The motive of the on goingreview is to explore all optical properties related absorption spectra and band gap of ferrite nanoparticles under UV-Visible spectroscopy.

Determination of Optical Parameters viaUV-Visible Spectroscopy:

UV-Visible spectroscopy refers to soaking up, reflection, or conveyance spectra. The basic principle of UV-Visible spectroscopy is related to interaction of thespecimen with photons of UV-Visible radiation. The transmitted radiation depends upon the amount of radiation absorbed by the molecules of the sample [12]. Absorption of photons takes place only at specific energy which is a measure of the materials optical band gap .The band gap of semiconducting material can be described in two types, a direct band gap or an indirect band gap [13]. A photocatylyst with a maximum band gap of about 3.1 eV is required to absorb visible light

energy.Materials exhibiting characteristic absorption bands in visible region are the potential materials for optical applications [14].

The optical parameters such as band gap (E_g), absorption index (k) and refractive index (n) has a important role in the research of optical materials. These can be evaluated from absorption spectra of the samples[15].An American physicist Jan Tauc [16] introduced the concept of the Tauc model for the characterization of crystalline materials. Taucgave a standard empirical formullafor determining the band gap of semiconducting materials as a function of incident photon energy [17].The Tauc relation to evaluate the optical bandgap (E_g)is shown below :

$$(F(R)\ h\nu)^{m} = A\ (h\nu - E_g) \qquad (1)$$

F(R) is Kubelka–Munk function and the value of 'm' denotes the nature of the transition. The value of m = 2, 1/2, represents the indirect and direct allowed transition with respect to each other . The values 3/2, and 3 show aindirect and direct forbidden transition, respectively.

The formulas to calculate the refractive index (n) and absorption index(k)[18] are given as below:

$$k(\lambda) = \frac{-2\sin(\theta(\lambda))\sqrt{R(\lambda)}}{1+R(\lambda)-2\cos(\theta(\lambda))\sqrt{R(\lambda)}} \qquad (2)$$

$$n(\lambda) = \frac{1-R(\lambda)}{1+R(\lambda)-2\cos(\theta(\lambda))\sqrt{R(\lambda)}} \qquad (3)$$

where R , λ, and θ are reflectance, wavelength of incident photon, phase shift angle of the sample respectively.

Optical Properties of Nanostructured Ferrites:

The ultraviolet and visible region falls in the range of wavelength 190-380 nm and 380-800nmrespectivelyof the electromagnetic radiation. Band gap of the energy of nanostrucred materials is affected by several factors including crystal symmetry, crystal structure,induced lattice strain, quantum effects of the particles sizes,carrier attentiveness, existence of the dirty particles, surface roughness, etc[18]. The optical properties of the materials are fragile to their particle size. Therefore, it is necessary to understand the impact of crystallite size on optoelectronic applicatrions of the material. When the particle size isdecreses, band gap energy increses and hence, absorption is shifted to lower wavelength. This can be attributed to quantum confinement effect ofnanoparticles and the induced defects in the energy levels [19, 20].In the case of bulk sample, the formation of energy bands are owing to contribution of each energy levels due to hug e presence of atoms . At the nanoscale, as the size of the particle is reduced, the

amount of overlapping orbitals or energy levels reduces, and the band width gets narrower. It increases the band gap between the valence band and the conduction band.Hence, the energy band gap of a nanoparticle is greaterin comparison to the corresponding bulk particle [21]. The band gap region is forgotten for the movement of electrons.The larger the forbidden region , the bigger will be thebarrier on the movement of electrons . Hence the nanoparticleelectrical conductivity gets reduced .

A wide range of semiconducting band gap with ability of absorbing the visible lightoffers an advantage of enhanced photocatalytic activity of ferrites. Some of commonly used ferrites with important highlights and corresponding band gap are summarized in Table1.

Table 1. Important Highlights of Optical Properties of Recently Reported Nanostructured Ferrites:

S. No.	Ferrites	Important Highlights	Ref.
1.	$CuFe_2O_4$, $Cu_{0.5}Co_{0.5}Fe_2O_4$ and $CoFe_2O_4$ respectively	• Synthesis route: Sol-gel auto combustion method. • Optical energy bandgap (eV): 1.58, 1.18 and 1.01 eV respectively. • Crystallite size (nm): 25, 34 and 38 nm respectively. The strong absorption was found in the rangeof500–600 nm for all samples.	[21]
2.	$Co_{0.5}Zn_{0.5}Fe_2O_4$	• Synthesis route: Co-precipitation method • Surfactant used: Ethanol, Polyethylene glycol (PEG), Acetic acid and Cetyl trimethylammonium bromide (CTAB). • Optical energy bandgap (eV) : 1.99-2.06 • Crystallite size (nm): 11.7 - 53.3 • It was observed that in the visible region all synthesized samples showed two disctint absorption edges at wavelength 550 nm and 700 nm.	[22]
3.	MFe_2O_4 (M = Cu, Zn, Ni and Co)	• Synthesis route: Sol-gel process. • Optical energy bandgap (eV) :1.26–2.08 • Crystallite size (nm): 15–30 • For all samples an absorption edge were observed around 730 nm which promised illustrate them suitable	[23]

		for visible light photocatalysis.	
4.	$Co_xMg_{1-x}Fe_2O_4$ (x= 0.0, 0.1, 0.3, 0.5, 0.7, 0.9 and 1.0)	• Synthesis route: Sol-gel combustion method • Optical energy bandgap (eV) : 2.09 -1.42 eV • Crystallite size (nm): 34-48 nm • A strong dependence on cation content,morphology,and crystalline sizewa seen at the determined optical band gaps from UV/Vis DRS measurements.	[24]
5.	$Mn_{0.5}Zn_{0.5}Fe_2O_4$	• Synthesis route: Co-precipitation method • Optical energy bandgap (eV) : 3.47 eV • Crystallite size (nm): 28 nm • UV-Vis spectroscopy measurement showed in the visible range around 346nm an absorption peak was seen.	[25]
6.	$NiFe_{2-x}Nd_xO_4$ (x= 0.0, 1.0, 1.5 and 2.0)	• Synthesis route: Co-precipitation method • Optical energy bandgap (eV) : 3.31-1.76eV • Crystallite size: 19-24nm • The enhanced photo-activity were observed with the addition of Nd^{+3} in nickel ferrite can be shown upward to the decrease of band gap by substitution.	[26]
7.	$Zn_{1-x}Ni_xFe_2O_4$ (x=0.0,0.25,0.45,0.65, and 0.85)	• Synthesis route: Sol-gel combustion method • Optical energy bandgap (eV) : 1.85-1.95 eV • Crystallite size (nm): 18-30nm • As Ni content increases the band gap also varies linearly.	[27]
8.	$Mn_{1-x}Zn_xFe_2O_4$ (x=0.00, 0.20, 0.40, 0.60, 0.80, 1.00)	• Synthesis route: Chemical co-precipitation method • Optical energy bandgap (eV) : 2.26-2.63 eV • Crystallite size (nm):10-20nm • For all samples the higher absorbance was seen in the ultraviolet (UV)area .	[28]
9.	$Co_{0.5}Zn_{0.5}R_xFe_{2-x}O_4$ (R= Ce, Dy, x=0.00, 0.01, 0.03 and 0.05)	• Synthesis route: Hydrothermal method • Optical energy bandgap (eV) : 0.25-0.77 eV • Crystallite size (nm): 7-12nm • The band gap value for Co0.5Zn0.5DyxFe2-xO4 NPs upon increasing concetration of x become quite narrow.	[29]
10.		• Synthesis route: Sol-gel combustion method	[30]

	$MnCe_xFe_{2-x}O_4$ (x=0.03,0.05,0.07 and 0.09)	• Optical energy bandgap (eV) : 2.3-2.8eV • Crystallite size (nm): 15-18nm • The alternative of cerium (Ce) ion in $MnFe_2O_4$ results to shiftingof the wavelengthin direction to the visible light.	
11.	$Cd_xZn_{1-x}Fe_2O_4$ (*x*=0.0, 0.3, 0.7, and 1.0)	• Synthesis route: Chemical co-precipitation method • Optical energy bandgap (eV): 1.46-1.95eV • Crystallite size (nm): 30-55nm • With the increase in cadmium concentration the absorption band slightly shifted . It was observed that with the decerase in Cd concentration the enrgy band gap also decreases .	[31]

From table 1 it can concluded that band gap of ferrites lie in the range of 2-3 eV which shows them effective under visible light. Hence it may be concluded that ferrites are capable for photocatalytic conversion of visible light energy for use in reduction and oxidation processes .Besides, ferrites get control of separation and can be used again as they can be parted away magnetically[22]. Photocatalyst areused in many ways including the removal of contaminants from air and water ,smell control, germs inactivation, the inactivation of cancer cells, and etc[32,33]. Using this technology for the whitewash of potentially poisonous and harmful compounds from the environment has generated a great interest in the last decade. With this background, the newly developments on photocatalytic presentation of spinel ferrites (MFe_2O_4) are extensively checked out in the field of photocatalytic degradation oftoxic pollutants [34]. It is generally with respect to their biocompatibility, restrictnessof precursors, easy synthesis and magnetic property. Some recently reported photocatalytic activity of ferrites are concluded in table 2 given below .

Table 2. Recently Reported Photo-catalytic Application of Ferrites for Dye Degradation:

S. No.	Ferrites (Photocatalyst)	Dye	Important Highlights	Ref
1.	$Co_xMg_{1-x}Fe_2O_4$ (x=0.0, 0.1, 0.3, 0.5, 0.7, 0.9 and1)	MB	• Irradiation source : Sunlight and Visible light • Best photocatalyst under:	[24]

	(sol-gel combustion method)		• Sunlight: $MgFe_2O_4$ Degradation efficiency: 82%, Exposure time : 4 h • Visible light: $Co_{0.1}Mg_{0.9}Fe_2O_4$ Degradation efficiency: 79%, Exposure time : 4 h	
2.	$NiFe_{2-x}Nd_xO_4$ (x= 0.0, 1.0, 1.5 and 2.0)	RB MB Rh-B MR MO	• Irradiation source : Visible light • Sample x=1.5 shows maximum degradation of98%,93%,91%,96%, and 94% of MB, MO, BG, and MR respectively	[26]
3.	MFe_2O_4, M= Co, Ni, Cu, and Zn (Co-precipitation method)	• MB • MO • BG • MR)	• Irradiation source : Sunlight • $NiFe_2O_4$ showedmaximum degradation of 89%, 92%, 93%, and 78% of MB, MO, BG, and MR respectively	[35]
4.	$ZnFe_2O_4$ (Co-precipitation method)	• MB	• Irradiation source : Sunlight • Degradation efficiency: 99% • Exposure time : 2 h	[36]
5.	$CoFe_2O_4$ (Synthesized via bimetal-organic frameworks template)	(BP-A)	• Irradiation source : Sunlight • Degradation efficiency: 80.3% • Exposure time : 40min	[37]
6.	$NiFe_2O_4$ (Co-precipitation method)	IV	• Irradiation source: Sunlight • Degradation efficiency: 99% • Exposure time : 2 h	[38]
7.	$Co_{0.25}Zn_{0.75}Fe_2O_4$ (Co-precipitation method)	RA	• Irradiation source: UV irradiation • Degradation efficiency: 90% • Exposure time : 3 h	[39]
8.	$Mg_{0.5}Zn_{0.5}FeMnO_4$ (sol-gel method)	RB21	• Irradiation source : Visible light • Degradation efficiency: 96% • Exposure time : 30 Min	[40]

(MB- Methylene blue, RhB- Rhodamine-B, MO- Methyl orange, MR- Methyl red, BG-Bromo green, IV- Irgalite violet, Bisphenol-A (BP-A), Reactive Blue 21 (RB21), RA- Red Amaranth)

Conclusions: In the present review article a brief background information about UV-Vis spectroscopy with important highlights of optical properties of some commonly used ferrites and their recent advantages in photocatalytic application are discussed.It included the current progresses in the scientific and technological charchetristicsof ferrite, which are emerging due to their excellent optical properties.From published articles it was concluded that method of synthesis has a remarkable impact on the constructional parameters of ferrites such as particle size, surface area,and crystallinity that affect the optical properties and hence, the entire process of photocatalysis.Hence, an excellent photocatalytic activity of ferrites can be achieved by selecting an appropriate method of synthesiswhich are crucial for fundamental, and application viewpoint.

References:

1. Bigdeli, A., Ghasemi, F., Golmohammadi, H., Abbasi-Moayed, S., Nejad, M. A. F., Fahimi-Kashani, N., andHormozi-Nezhad, M. R. (2017). Nanoparticle-based optical sensor arrays. *Nanoscale*, *9*(43), 16546-16563.
2. Adekoya, J. A., Ogunniran, K. O., Siyanbola, T. O., Dare, E. O., andRevaprasadu, N. (2018). Band structure, morphology, functionality, and size-dependent properties of metal nanoparticles. *Noble and Precious Metals—Properties, Nanoscale Effects and Applications; Seehra, M., Bristow, AD, Eds*, 15-42.
3. Edvinsson, T. (2018). Optical quantum confinement and photocatalytic properties in two, one and zero-dimensional nanostructures. *R. Soc. Open Sci. 5*(9), 180387.
4. Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T., and Hui, D. (2018). Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. *Comps. Part B: Eng.*, *143*, 172-196.
5. Kefeni, K. K., Msagati, T. A., Nkambule, T. T., and Mamba, B. B. (2020). Spinel ferrite nanoparticles and nanocomposites for biomedical applications and their toxicity. *Mater.Sci. Eng. : C*, *107*, 110314.
6. Rawat, P. S., Srivastava, R. C., Dixit, G., Joshi, G. C., andAsokan, K. (2019). Facile synthesis and temperature dependent dielectric properties of $MnFe_2O_4$ nanoparticles. *AIP Conf. Proceed.* (Vol. 2115, No. 1, p. 030104). AIP Pub. LLC.

7. Narita, F., Wang, Z., Kurita, H., Li, Z., Shi, Y., Jia, Y., andSoutis, C. (2021). A review of piezoelectric and magnetostrictive biosensor materials for detection of COVID-19 and other viruses. *Adv. Mater.*, *33*(1), 2005448.
8. Zhang, J., Liu, X., Neri, G., and Pinna, N. (2016). Nanostructured materials for room-temperature gas sensors. *Adv. Mater.*, *28*(5), 795-831.
9. González, M., Pozuelo, J., andBaselga, J. (2018). Electromagnetic shielding materials in GHz range. *The Chem.l Rec.*, *18*(7-8), 1000-1009.
10. Zhang, S., Li, L., and Kumar, A. (2008). *Materials characterization techniques*. CRC press.
11. Mourdikoudis, S., Pallares, R. M., and Thanh, N. T. (2018). Characterization techniques for nanoparticles: comparison and complementarity upon studying nanoparticle properties. *Nanoscale*, *10*(27), 12871-12934.
12. Titus, D., Samuel, E. J. J., andRoopan, S. M. (2019). Nanoparticle characterization techniques. In *Green synthesis, characterization and applications of nanoparticles* (pp. 303-319). Elsevier.
13. Clark, B. J., Frost, T., and Russell, M. A. (Eds.). (1993). *UV Spectroscopy: Techniques, instrumentation and data handling* (Vol. 4). Springer Science and Business Media.
14. De Kersauson, M., Jakomin, R., El Kurdi, M., Beaudoin, G., Zerounian, N., Aniel, F., andBoucaud, P. (2010). Direct and indirect band gap room temperature electroluminescence of Ge diodes. *J. App. Phy.*, *108*(2), 023105.
15. Casbeer, E., Sharma, V. K., and Li, X. Z. (2012). Synthesis and photocatalytic activity of ferrites under visible light: a review. *Sep. Purif. Technol.*, *87*, 1-14.
16. Tauc, J. (1968). Optical properties and electronic structure of amorphous Ge and Si. *Mater. Res. Bulletin*, *3*(1), 37-46.
17. Dhyani, R., Srivastava, R. C., Rawat, P. S., and Dixit, G. (2022). Structural and elastic properties of tetragonal nano-structured copper ferrite. *Int. J. Mater. Res.*, *113*(10), 884-892.
18. Kavak, H., Eker, S., and Mamedov, A. (2004). Harmonic oscillator model and determination of optical parameters. *J. Quant. Spectrosc. Radiat. Transf.*, *86*(2), 223-229.

19. Banerjee, R., Jayakrishnan, R., and Ayyub, P. (2000). Effect of the size-induced structural transformation on the band gap in CdS nanoparticles. *J. Phys.: Cond. Matter*, *12*(50), 10647.
20. Sattler, K. (2002). The energy gap of clusters, nanoparticles, and quantum dots. In *Handbook of Thin Films* (pp. 61-97). Academic Press.
21. Dhyani, R., Srivastava, R. C., and Dixit, G. (2022). Study of Magnetic and Temperature-Dependent Dielectric Properties of Co-$CuFe_2O_4$Nanoferrites. *J. Elect. Maters*, *51*(10), 5492-5507.
22. El Foulani, A. H., Aamouche, A., Mohseni, F., Amaral, J. S., Tobaldi, D. M., andPullar, R. C. (2019). Effect of surfactants on the optical and magnetic properties of cobalt-zinc ferrite $Co_{0.5}Zn_{0.5}Fe_2O_4$. *J. f Alloys Comp.*, *774*, 1250-1259.
23. Sharma, R., Bansal, S., and Singhal, S. (2015). Tailoring the photo-Fenton activity of spinel ferrites (MFe_2O_4) by incorporating different cations (M= Cu, Zn, Ni and Co) in the structure. *Rsc Advances*, *5*(8), 6006-6018
24. Dojcinovic, M. P., Vasiljevic, Z. Z., Pavlovic, V. P., Barisic, D., Pajic, D., Tadic, N. B., and Nikolic, M. V. (2021). Mixed Mg–Co spinel ferrites: structure, morphology, magnetic and photocatalytic properties. *J. Alloys. Compd.*, *855*, 157429.
25. DebnathDebnath, S., and Das, R. (2020). Study of the optical properties of Zn doped Mn spinel ferrite nanocrystals shows multiple emission peaks in the visible range–a promising soft ferrite nanomaterial for deep blue LED. *J. Molecular Struct.*, *1199*, 127044.
26. Harish, K. N., Bhojya Naik, H. S., Prashanth Kumar, P. N., and Viswanath, R. (2013). Optical and photocatalytic properties of solar light active Nd-substituted Ni ferrite catalysts: for environmental protection. *ACS Sustainable Chem. Eng.*, *1*(9), 1143-1153.
27. Verma, R., Mazaleyrat, F., Deshpande, U. P., and Kane, S. N. (2020). Ni addition induced modification of structural, magnetic properties and bandgap of Ni-Zn nano ferrites. *Mater. Today: Proceed.*, *32*, 329-333.
28. Patade, S. R., Andhare, D. D., Kharat, P. B., Humbe, A. V., and Jadhav, K. M. (2020). Impact of crystallites on enhancement of bandgap of $Mn_{1-x}Zn_xFe_2O_4$ ($1 \geq x \geq 0$) nanospinels. *Chem. Phys. Letters*, *745*, 137240.

29. Almessiere, M. A., Korkmaz, A. D., Slimani, Y., Nawaz, M., Ali, S., and Baykal, A. (2019). Magneto-optical properties of rare earth metals substituted Co-Zn spinel nanoferrites. *Ceram. Int.*, *45*(3), 3449-3458
30. Meena, S., Anantharaju, K. S., Vidya, Y. S., Renuka, L., Uma, B., Sharma, S. C., and More, S. S. (2021). Enhanced sunlight driven photocatalytic activity and electrochemical sensing properties of Ce-doped $MnFe_2O_4$ nano magnetic ferrites. *Ceram. Int.*, *47*(10), 14760-14774.
31. Harish, K. N., Naik, H. B., and Viswanath, R. (2012). Synthesis, enhanced optical and photocatalytic study of Cd–Zn ferrites under sunlight. *Cat. Sci. Tech.*, *2*(5), 1033-1039.
32. Jarusheh, H. S., Yusuf, A., Banat, F., Haija, M. A., and Palmisano, G. (2022). Integrated photocatalytic technologies in water treatment using ferrites nanoparticles. *J. Env. Chem. Eng.*, 108204.
33. Harish, K. N., Naik, H. B., and Viswanath, R. (2012). Synthesis, enhanced optical and photocatalytic study of Cd–Zn ferrites under sunlight. *Cataly. Sci. Tech.*, *2*(5), 1033-1039.
34. Sharma, R., Thakur, P., Kumar, M., Sharma, P., and Sharma, V. (2018). Nanomaterials for high frequency device and photocatalytic applications: Mg-Zn-Ni ferrites. *J. Alloys Compd.*, *746*, 532-539.
35. Gupta, N. K., Ghaffari, Y., Kim, S., Bae, J., Kim, K. S., and Saifuddin, M. (2020). Photocatalytic degradation of organic pollutants over MFe_2O_4 (M= Co, Ni, Cu, Zn) nanoparticles at neutral pH. *Sci. Reports*, *10*(1), 1-11.
36. Yadav, N. G., Chaudhary, L. S., Sakhare, P. A., Dongale, T. D., Patil, P. S., and Sheikh, A. D. (2018). Impact of collected sunlight on ZnFe2O4 nanoparticles for photocatalytic application. *J. Colloid Int.Sci.*, *527*, 289-297.
37. Yang, S., Qiu, X., Jin, P., Dzakpasu, M., Wang, X. C., Zhang, Q., and Wu, K. (2018). MOF-templated synthesis of $CoFe_2O_4$ nanocrystals and its coupling with peroxymonosulfate for degradation of bisphenol A. *Chem. Eng. J.l*, *353*, 329-339.
38. VijayVijay, S., Balakrishnan, R. M., Rene, E. R., and Priyanka, U. (2019). Photocatalytic degradation of Irgalite violet dye using nickel ferrite nanoparticles. *J. Water Supply: Res. Tech.-Aqua*, *68*(8), 666-674.

39. López, J., Ortíz, A. A., Muñoz-Muñoz, F., Dominguez, D., de León, J. D., Galindo, J. E., and Soto–Herrera, G. (2021). Magnetic nanostructured based on cobalt–Zinc Ferrites designed for photocatalytic dye degradation. *J. Phys. Chem. Solids*, *150*, 109869.

40. Moradnia, F., Fardood, S. T., Ramazani, A., Min, B. K., Joo, S. W., and Varma, R. S. (2021). Magnetic $Mg_{0.5}Zn_{0.5}FeMnO_4$ nanoparticles: green sol-gel synthesis, characterization, and photocatalytic applications. *J. Cleaner Prod.*, *288*, 125632.