Spinel zinc ferrite nanoparticles: an active nanocatalyst for microwave irradiated solvent free synthesis of chalcones

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Abstract
A profoundly effective magnetically recoverable nano zinc ferrite nanocatalyst was fabricated by means of sol-gel auto ignition strategy. The synthesized nanocatalyst has been completely portrayed by standard techniques for structural, morphological, compositional, surface, magnetic, dielectric, optical and photoluminescence properties individually. The x-ray diffraction pattern affirmed the arrangement of cubic spinel structure with an average crystallite size of 21 nm. FE-SEM images uncovered the circular morphology with nanometric average grain measure (37 nm). The surface area, pore volume and pore radius was observed to be 39.812 m² g⁻¹, 3.41 cc g⁻¹ and 1.34 nm individually from BET analysis. VSM investigation demonstrated the superparamagnetic nature of the prepared sample with moderate magnetization value and negligible coercivity. The optical band gap deduced from UV–vis spectra was observed to be 2.098 eV. Every one of these properties of zinc nanoferrite makes them brilliant contender for microwave radiation absorption. Further, a proficient and versatile microwave irradiated solvent free synthesis of chalcone derivatives has been developed using prepared zinc nano ferrite catalyst. The remarkable highlights of this new protocol are solvent free reaction, economical cheapness, eco-friendliness, high yields, reduced reaction times and easy recovery and reuse of zinc ferrite nanocatalyst.

1. Introduction

Magnetic nanoparticles have increased significant enthusiasm for different areas, for example, ferrofluids, magnetic drug transportation, magnetic separations, magnetic data storage devices, magnetic resonance imaging (MRI), and magnetic fluid hyperthermia treatment for malignant growth [1–8]. Magnetic nanoparticles are alluring catalyst since they can be isolated from the response medium by applying an outside magnetic attractive field. Magnetic partition is a charming option in contrast to filtration or centrifugation as it keeps the loss of catalyst and upgrades reusability, rendering the catalyst cost-adequacy and is promising for modern applications [9–11]. Unmistakably, the advancement of attractive nanoparticles with tunable reactant movement is of incredible essentialness for both scholarly community and industry [12–14].

The cubic spinel ferrites represents to a critical class of magnetic metal oxide materials. Among ferrite materials, nano zinc ferrite is imperative for its potential use in data recording media, adsorption, sensors and attractive innovations, and has great photo induced catalytic reactant properties, low saturation magnetization, high resistivity and uniform and reproducible qualities [15–17]. Microwave absorption performance of zinc ferrite nanoparticles has been accounted for and discovered much preferred and more secure over Fe₃O₄, which is a sort of famous hyperthermia operator in malignancy considers [18–20]. Literature survey uncovered that few endeavors have been made to fabricate nano size zinc ferrite and to study its potential reactant application in organic transformations [21–23].
In the previous couple of years, exceptionally proficient couplings catalyzed by different nano attractive catalyst have been depicted \cite{24-27}. Hu et al reported that such a coupling can likewise be catalyzed by Fe$_3$O$_4$ \cite{28}. Unfortunately, Fe$_3$O$_4$ nanoparticles are normally temperamental and the coagulation of the nanoparticles amid the response is regularly unavoidable. Blended metal oxide nanoparticles (MMONs) have accumulated significantly more consideration as of late and are effectively sought after in the improvement of present day modern organic synthesis and greener response conventions viably \cite{29-35}. Catalytic processes dependent on such blended metal oxide nanocatalyst are less complex, financially effective and all the more naturally well disposed; establishing ‘green science approach’ that produces just the most attractive items with a greatest yield \cite{36}. These MMONs have developed as manageable options in contrast to customary materials, as vigorous, high surface area heterogeneous catalyst, prudent and cheap. These nano-sized particles increment the uncovered surface region of the dynamic segment of the catalyst, consequently improving the contact among reactants and the catalyst significantly and imitating the homogeneous catalyst. Their insolubility in response solvents renders them effectively detachable from the response blend, which thus makes the item separation arrange easy. Outprisingly, the MMONs are better as far as their catalytic movement than the individual metal oxides in different responses as a result of their improved surface area \cite{37-41}. Consequently, in perspective on present day catalytic science, MMONs represents a standout amongst the most vital and generally utilized materials in catalysis science.

The Claisen—Schmidt condensation reaction of a nucleophilic ketone benefactor to an electrophilic aldehyde acceptor is one of the vital strategies for development of carbon—carbon bonding, yielding a conjugated enone as the last item and comprises huge significance in manufactured science \cite{42}. In the Claisen—Schmidt condensation reaction, the response of benzaldehydes with acetophenones to frame chalcones (1, 3-diarylpropenones) pulled in the most consideration on account of various pharmacological applications, for example, anticancer \cite{43}, anti-inflammatory \cite{44}, and against hypertensive medications \cite{45}. Since the improvement of Claisen—Schmidt condensation reaction during the 1970s, the responses catalyzed by solid base or Lewis acids is a critical instrument for developing chalcones \cite{46}.

Notwithstanding, the utilization of these homogeneous catalyst requires balance of the base or corrosive and partition from the reaction mixture, prompting loss of catalyst, decrease of the item yields, inconceivability to reuse, and various environmental issues \cite{47}. One approach to conquer these issues is to utilize a heterogeneous catalyst rather than the homogeneous one. Heterogeneous catalysts are simple of giving, straightforward workup and regenerability \cite{48}. Numerous heterogeneous catalyst have been created to advance Claisen—Schmidt response, for example, the SO$_3$H-functionalized ionic fluids \cite{49}, L-proline—Cysteine conjugate on functionalized Au nanoparticles and reproduced hydrotalcite \cite{50, 51}. Among these, numerous zeolite based catalyst has been accounted for as heterogeneous catalyst for the blend of chalcone and its subsides. As of late, mesoporous silica changed by useful gatherings, for example, amine and sulfonic corrosive have been shown to be another sort of aldo condensation catalysts \cite{52, 53}. These silica-based catalysts have substantial explicit surface area and standard pore structures, and the useful gatherings altered on silica drastically increment the movement. Notwithstanding, the union technique of these functionalized mesoporous silica catalyst is impressively confused and their reactant effectivenss is still low. As of late, Garcia and colleagues have detailed that Cu, Fe and Al based MOFs are viable and reusable heterogeneous catalyst for the carbon—carbon bond development of Claisen—Schmidt condensation reaction \cite{54}. It is notable that the recyclability is an imperative factor for the nanocatalyst in handy applications. Nonetheless, for this novel heterogeneous catalyst, just as for ordinary heterogeneous catalyst frameworks, it was hard to totally separate and reuse the catalyst from the response arrangement, making their mechanical applications costly. Fei Ke et al reported MOF-based attractive core—shell heterogeneous catalysts, Fe$_3$O$_4$@MIL-100(Fe), it required extreme response condition, long response time and costly dissolvable \cite{55}.

Zinc ferrite magnetic nanocatalyst not just show high effectiveness and selectivity towards the dissolvable free microwave irradiated synthesis of chalcones by means of Claisen—Schmidt condensation reaction (scheme 2), yet in addition can be isolated and recuperated productively from the reactive solution by essentially applying outer attractive magnetic fields. A maintainable and ‘greener’ strategy would concentrate on negligible to no utilization of solvents, decrease of different squanders, utilization of encompassing conditions just as shortening of response time, and growing increasingly easy methods for product and detachment, cleaning, reusability of catalyst and so on.

In the literature, there are some reports available regarding the synthesis of chalcones using the nanocatalyst. Some of them are dealt with the spinel ferrite nanocatalyst but the systematic studies related to the physicochemical characterizations and catalytic efficiency with recyclability are lacking. Thus, it is aimed to undertake the systematic investigations related to the physicochemical and catalytic evaluation of novel zinc ferrite nanoparticles with size of few nanometer and high surface area. From our progressive research movement on the uses of magnetic nanomaterials \cite{36}, we report here the novel combination of ZnFe$_2$O$_4$ magnetic nanoparticles by sol-gel auto burning reaction assisted by utilizing glycine as green fuel with average particle size.
of 21 nm and their catalytic application in organic synthesis as profoundly effective adaptable recyclable catalyst in dissolvable free microwave synthesis of Chalcones by means of Claisen—Schmidt condensation reaction (scheme 1). The prepared chalcones are characterized by their physical constant, FTIR, NMR and mass spectral data. These spectral data exactly match with their spectral data reported in earlier published literature. The novelty of the present work lies in the applicability of zinc ferrite nanocatalyst having size of few nanometers and elevated surface area which enables the active solvent free synthesis of chalcone derivatives with maximum yield.

2. Experimental

2.1. Preparation of zinc ferrite nanoparticles (catalyst)

2.1.1. Materials and methods

The nanostructured zinc ferrite specimen was fabricated by sol-gel auto burning strategy by utilization of glycine as a green fuel. AR grade synthetic compounds, for example, zinc nitrate (Zn(NO_3)_2 \cdot 6H_2O), ferric nitrate (Fe(NO_3)_3 \cdot 9H_2O) and glycine (C_2H_5NO_2) were utilized for the synthesis procedure. The metal nitrate to fuel proportion was taken as 1:4.4. Alkaline solution of ammonia was added to keep up the pH of the nitrate solution at \( \approx 7 \) (scheme 2). The as-synthesized powder was sintered in the air atmosphere at 600°C for 4 h and afterward utilized for further examinations. The point by point flowchart of fabrication of zinc ferrite nanoparticles by sol-gel auto ignition technique with combination pictures is appeared in figure 1.

2.2. Selection of Fuel for Sol-gel auto combustion method

Formation of nanoferrite phase by sol-gel auto ignition is a non conventional methodology in which fuel or chelating authority expect a basic employment by giving required vitality for the start reaction. Regularly, the energies are common blends having great warmth of ignition rate. Stoichiometry and crystallite size can be compelled by assurance of real fuel in sol-gel auto consuming, which thus impacts the physical and dependent properties of spinel ferrites. Sol-gel auto ignition methodology is a low temperature amalgamation procedure that offers an intriguing technique by methods for a high exothermic redox reaction to make oxides. In this present work, we used glycine as fuel, first amino acid, condition all around arranged green substance having negative warmth of start about \(-2.98 \text{ kcal g}^{-1}\) and citric acid \(-2.76 \text{ kcal g}^{-1}\) [57].

2.3. Characterizations of zinc ferrite nanoparticles (catalyst)

The thermal, structural, optical, surface morphology, magnetic and dielectric properties examination of prepared zinc ferrite nanocrystalline material were made by various standard portrayals procedures. The thermal stability of prepare specimen was studied by the Thermal Gravimetric and Differential Thermal Analysis (TG-DTA). For structural examination, the prepared specimen was portrayed by x-ray diffraction (XRD) procedure by Bruker–D-8-Advance model. The XRD patterns were recorded at room temperature in the 20 scope of 20° to 80° utilizing Cu-Kα radiation (\( \lambda = 1.54 \text{ Å} \)). Morphology and the compositional investigation of the prepared sample was examined by utilizing field emission scanning electron microscope (FE-SEM) JEOL-JSM 840 model.
at working voltage of 20 kV joined with EDX machine. Brunauer–Emmett–Teller (Quantachrome Instruments v 5.2) examination was utilized to decide the pore span and the particular surfaces territory of the zinc ferrite nanoparticles [58]. The arrangement of spinel structure were recognized by utilizing Fourier Transform Infrared Spectroscopy (FTIR) (Bruker Germany, Vertex 70 show) in the scope of 400 cm$^{-1}$ to 4000 cm$^{-1}$. Magnetic properties of the prepared specimen were considered by vibrating test magnetometer (Lakeshore VSM 7410) at room temperature. The dielectric constant ($\varepsilon'$) was estimated at room temperature in the recurrence scope of 100 Hz to 50 KHz utilizing (WAYNE KERR 6500B) accuracy impedance analyzer. Optical investigations of prepared zinc ferrite nanoparticles were contemplated by account the range in the UV–vis locale (250–700 nm) utilizing UV–vis spectrometer (Avaspec-ULSi2048L) with resolution of 0.05 nm. The photoluminescence (PL) properties were considered by Fluoromax-4CP-0975D-1512-FM in the wavelength extends of 490–800 nm.

2.4. Preparation of chalcone

2.4.1. Materials and methods

All required chemicals were purchased from Merck and S D fine-chem limited Mumbai and used as received without further purification. Microwave reactions were performed in domestic microwave oven (LG), with power output from 0 to 300 W. Purity of compounds were checked by thin layer chromatography (TLC) on Aluchrosep Silica Gel 60/UV$_{254}$, pre-coated sheets, melting points of synthesized compounds were determined in open glass capillaries on TANCO® melting point apparatus. The $^1$H and $^{13}$C NMR spectra were run on a BRUKER AVANCE II 400 NMR spectrometer operating at 400 MHz, using detoured chloroform (CDCl$_3$) and DMSO-$d_6$ as solvent and TMS as internal standard. The mass spectrum was obtained on WATERS, Q-TOF
MICROGMASS (ESI-MS) spectrometer. All compounds were known, and obtained physical and spectroscopic data were compared with literature data.

2.5. General procedure for synthesis of chalcone derivatives
Equimolar amounts of substituted aromatic aldehydes (1 mmole), substituted acetophenone (1 mmole) and ZnFe₂O₄ (5 moles %, 12 mg) was taken and homogenized in a mortar and moved into a funnel shaped jar. Then the mixture containing conical flask was illuminated under 160 W microwave irradiation power for 1–3 min in domestic microwave oven. The advancement of the reaction was observed by TLC (n-hexane: ethyl acetate, 7:1) after every 30 s. Subsequent to cooling reaction mixture to room temperature ethyl acetate (15 ml) was added and catalyst was isolated by external magnet. After isolation of catalyst solvent was concentrated under reduced pressure and the product was recrystallized from ethanol.

3. Results and discussion
3.1. TGA-DTA
Thermal examination of as readied zinc ferrite nanoparticles was done to explore the development of the spinel ferrite stage. It is recorded in the temperature scope of 30°C – 800°C in nitrogen environment at a warming rate of 5°C min⁻¹. The TGA-DTA plot for zinc ferrite nanoparticles as readied powder is appeared in figure 2. The nearness of exothermic tops at 368°C in DTA bend demonstrates the response of glycine with nitrates, disintegration of glycine and the expulsion of nitrates pursued by arrangement of ferrite stage. It is seen from gelation strategy that above 350°C the organics are evacuated totally. The TGA bend displayed the absolute weight reduction of 6%. Also, it is seen from TGA bend that there is no noteworthy weight reduction after temperature 575°C which can be ascribed to ferrite stage development. Accordingly, we have picked the temperature 600°C as a sintering temperature for prepared zinc ferrite nanoparticles.

3.2. X-ray diffraction (XRD)
The room temperature (300K) x-ray diffraction pattern (XRD) of ZnFe₂O₄ nanoparticles prepared by sol-gel auto ignition strategy is appeared in figure 3. It is seen from figure 3 that the XRD pattern demonstrates reflections listed as (220), (311), (222), (400), (422), (511) and (440). The nearness of the considerable number of reflections peaks in the XRD pattern demonstrates the development of single phase cubic spinel structure. Every one of these peaks in the XRD pattern is sharp and extreme. The observed reflections consummately coordinated with those reported in literature of zinc ferrite nanoparticles [59]. The XRD pattern does not demonstrate any extra peak other than referenced above shows the high immaculateness of prepared sample.

Utilizing the estimations of Bragg’s angle (2θ) and interplanar spacing (d), the estimations of lattice parameter was determined utilizing the accompanying connection,
The obtained value of lattice constant is given in table 1.

The crystallite size estimation was calculated from the most intense peak i.e. (311) presented in the XRD patterns using the outstanding Debye–Scherrer’s formula [60].

\[ t = \frac{0.9\lambda}{\beta \cos \theta} \text{ nm} \]  

The acquired estimation of crystallite size is given in table 1, which demonstrates the nanocrystalline nature of the prepared zinc ferrite sample.

3.3. Cation distribution study

The dispersion of cations at two interstitial locales to be specific tetrahedral (A) site and octahedral [B] site of spinel ferrite gives helpful information which decides the structural and magnetic properties of materials. The cation conveyance in spinel ferrite can be gotten by comparing the x-ray diffraction intensities observed from hypothetical or speculative crystal structures experimentally and those determined for a vast number as clarified in Bertaut strategy. In this technique, the observed intensity ratios are contrasted and the hypothetically determined intensity ratios. Consequently, the cation dispersion for present zinc ferrite sample can be represented by,

\[ (\text{Zn}^{2+})^4(\text{Fe}^{3+})^6\text{O}_4^2- \]

3.4. Scanning electron microscopy (SEM)

Surface morphology of the prepared zinc ferrite nanoparticles was considered through field emission scanning electron microscopy (FE-SEM) technique. Figures 4(a) and (b) represents the FE-SEM micrographs for ZnFe₂O₄ with EDAX spectra. FE-SEM images show the development of round shaped spherical grains. Additionally, it indicates agglomeration of the grains which might be because of the amalgamation method and condition. EDAX spectra uncovered that, the elemental percentages were very much coordinated with the determined weight percentage (wt %) and atomic percentage (at %) of all elements (i.e. Zn, Fe and O) according to stoichiometry. The average grain size was determined by linear intercept method and was found to be in nanometer range i.e. 37 nm.

![Figure 3. X-ray diffraction pattern of zinc ferrite nanoparticles.](image)

Table 1. Values of lattice constant (a), crystallite size (t), average grain size (G), specific surface area (S), Pore volume (Vp) and Pore radius (Rp) of zinc ferrite nanoparticles.

| Sample      | a (Å) | t (nm) | G (nm) | S (m²/gm) | Vp (c.c./gm) | Rp (nm) |
|-------------|-------|--------|--------|-----------|--------------|---------|
| ZnFe₂O₄     | 8.440 | 21     | 37     | 39.81     | 3.41         | 1.34    |

\[ a = d\sqrt{h^2 + k^2 + l^2} \text{ Å} \]  

The obtained value of lattice constant is given in table 1.

The crystallite size (t) estimation was calculated from the most intense peak i.e. (311) presented in the XRD patterns using the outstanding Debye–Scherrer’s formula [60].
3.5. BET analysis
The N\textsubscript{2} adsorption–desorption isotherm bends and pore measure conveyance of prepared zinc ferrite nanoparticles is appeared in figure 5. The distinctive parameters, for example, specific surface area (S), Pore volume (V\textsubscript{p}) and average Pore radius (R\textsubscript{p}) of prepaid zinc ferrite sample were inferred. From BET examination, the surface area of prepared zinc ferrite nanoparticles was observed to be 39.812 m\textsuperscript{2} g\textsuperscript{−1}. The volume of pores displayed in materials depends on the measure of nitrogen gas adsorbed by the strong pores. It is seen that the prepared sample adsorbed most extreme measure of the nitrogen gas with the equal to relative weight of in the scope of 0.1 to 0.9. It is observed might be because of the appearance of pore volume (3.41 cc g\textsuperscript{−1}) in the sample. The hysteresis bend of prepared specimen as it relies on the shape and size of pores present in the specimen \cite{14}. The circulations of pore size of zinc ferrite nanoparticles were gotten from desorption isotherms by Barrett-Joyner-Halenda (BJH) condition. Prepared zinc ferrite sample have a wide pore measure appropriation with broad pore span of 1.34 nm and demonstrated a crest in mesopores locale (1–10 nm) by implying that the mesopores in the zinc ferrite nanoparticles have stayed unblemished, even in the wake of sintering/annealing.

3.6. FTIR spectroscopy
The Fourier transform infrared (FTIR) spectrum of ZnFe\textsubscript{2}O\textsubscript{4} nanoparticles was recorded in the range 400 cm\textsuperscript{−1}–1000 cm\textsuperscript{−1}. The spectrum is depicted in figure 6. It uncovers from the spectrum that, one broad absorption band in between 600 cm\textsuperscript{−1} and 400 cm\textsuperscript{−1} was observed. The higher frequency band \nu\textsubscript{1} and lower frequency band \nu\textsubscript{2} were observed in the range of 600–500 cm\textsuperscript{−1} and 450–380 cm\textsuperscript{−1} and was assigned to tetrahedral (A) and octahedral (B) metal stretching, which are considered to be the typical bands of spinel structure according to the Waldron \cite{61}. Deshmukh et al \cite{62} observed the two absorption frequency bands in the range of 400 to 600 cm\textsuperscript{−1} equivalents to the tetra and octahedral sites, which confirms the formation of spinel cubic structure. Borhan et al \cite{63} and Patil et al \cite{64} also reported the same kind of IR spectra which confirms the spinel structure of the prepared ferrite nanoparticles.
3.7. Magnetic properties

The magnetic properties of the ZnFe₂O₄ nanoparticles were studied by utilizing pulsed field hysteresis loop tracing method at room temperature. The M-H plot for the ZnFe₂O₄ nanoparticles is appeared in figure 7. These prepared zinc ferrite nanoparticles display the superparamagnetic nature which can be described by hysteresis curve with the magnetic parameters as moderate saturation magnetization, lower remanence magnetization and unimportant coercivity esteem. This proposes the prepared zinc ferrite catalyst show magnetic character, which demonstrates that no magnetization remained when the applied attractive field is expelled. Taking points of interest of these magnetic properties, the catalyst ought to almost certainly effectively separate from reaction mixture by applying an outside guest magnetic field. The estimations of saturation magnetization (Mₛ), coercivity (H_c), remanence magnetization (M_r), remanence ratio (M_r/Mₛ) and magneton number (n_B) are exhibited in table 2. Pan et al [65] reported nano-composites of ‘Fe₂Ni₂N/SiO₂’ prepared by thermal reduction route. Their study revealed that as synthesized ‘Fe₂Ni₂N/SiO₂’ nano-composite exhibits superior magnetic losses in comparison with the soft magnetic/dielectric nano-composites. They also have reported the typical superparamagnetic nature of these materials with zero coercivity and remanence value. The same kind of nature was observed in our sample which possesses the moderate saturation magnetization and negligible coercivity/remanence value. Zhang et al [66] carried out the preparation of FeCo nano-chains made up of assembly having nanoparticles with approximately 1 nm gap and studied their electro-magnetic absorption properties in the GHz range. The superparamagnetism was also observed in this report which is analogous to the magnetic behaviour.

Figure 6. Infrared spectrum of zinc ferrite nanoparticles.

Figure 7. M-H plot of zinc ferrite nanoparticles.
of present sample as the size of zinc ferrite nanoparticles is smaller than the superparamagnetic critical
dimension. Gong et al.\cite{67} demonstrated the tuning electro-magnetic absorption studies of Ni/SiO$_2$
nano-composites fabricated by wet chemical approach. Typical ferromagnetic behavior and the dependence of
magnetic properties on the grain size were observed by them. It also shows high coercivity with decrease in
particle size as compared to the present sample which can be attributed the presence of particles in multi domain
region.

3.8. Dielectric properties
The dielectric properties for the ZnFe$_2$O$_4$ can be clarified based on the instrument of polarization process in
ferrite. The electronic exchange of Fe$^{3+}$ $\leftrightarrow$ Fe$^{2+}$ gives the nearby relocation of electrons toward a connected
field, which instigates polarization in Zn ferrites. The variation of dielectric constant ($\varepsilon'$) with applied frequency
for ZnFe$_2$O$_4$ nanoparticles was seen as appeared in figure 8. It is observed from figure 8 that the dielectric
constant declines ceaselessly with increment in frequency. The dielectric properties of ferrite are reliant on a few
variables including the method of preparation, chemical composition and grain structure and size. The
reduction in dielectric constant ($\varepsilon'$) at lower frequencies is clarified dependent on space charge polarization and credited to the way that ferroelectric areas are encompassed by non-ferroelectric locales. The dielectric constant accomplishes a steady
esteem just at higher frequencies because of electronic polarizability. The conduct of dielectric constant is like
the conduct of other spinel ferrites. In traditional heating energy ranges to reactant particle from outside source
through responding vessel divider, so it is moderate, repetitive and tedious procedures. In microwave irradiation
technique microwaves straightforwardly assimilate by the responding reaction mixture and rises the
temperature of the framework by coupling of microwave to dipole revolution or ionic conductivity of atom.

3.9. UV–vis properties
The optical properties of zinc ferrite nanoparticles were considered by utilizing UV–vis spectrophotometer.
Figure 9(a) demonstrates that, the absorption spectra of nanocrystalline ZnFe$_2$O$_4$ nanoparticles recorded at
room temperature in the wavelength scope of 400–1000 nm by subtracting the absorbance of the reference
material. The estimation of the band gap of the ZnFe$_2$O$_4$ nanoparticles has been resolved from transmission
spectra by utilizing the following relation appropriate to near edge optical absorption of semiconductors;

![Figure 8. Variation of dielectric constant of zinc ferrite nanoparticles.](image-url)
The band gap energy of ZnFe$_2$O$_4$ nanoparticles has been determined by Tauc plot based on the above formula as shown in Figure 9(b). The optical band gap value was found to be 2.098 eV which is in good agreement with that of reported values. The low value of energy band gap (2.098 eV) demonstrates its pertinence in synergist application as it encourages reactant response.

3.10. Photoluminescence properties (PL)

The Photoluminescence (PL) spectroscopy is a great method to acquire helpful data about energy as well as dynamics of charge bearers created amid the exposure of fluorescense light. Figure 10 indicates room temperature PL spectrum of zinc ferrite nanoparticles. The PL spectrum demonstrated the near band-edge (NBE) emission at 523 nm. The photoluminescence spectrum is firmly identified with the basic defect density in the lattice structure, which offers ascend to new electronic dimensions with the band gap and charge transporters in profound snares of surface confined. In this way, such deformities are in charge of the upgraded luminescent properties and improve Photocatalytic movement of the prepared nanomaterials.

3.11. Catalytic activity

Chalcones are generally combined by Claisen-Schmidt buildup response under essential or acidic condition in presence of a polar solvent. This reaction involves cleansing procedures as the buildup response often provides to a complex mixture $^{68,69}$. Zinc ferrite magnetic nanoparticles catalyses the synthesis of (E)-chalcone derivatives, which was carried out with substituted benzaldehydes and substituted acetophenone under solvent

\[ \alpha = \frac{A(h\nu - E_g)^{n/2}}{h\nu} \quad (4) \]

where, notations have their usual meanings. The band gap energy of ZnFe$_2$O$_4$ nanoparticles has been determined by Tauc plot based on the above formula as shown in figure 9(b). The optical band gap value was found to be 2.098 eV which is in good agreement with that of reported values. The low value of energy band gap (2.098 eV) demonstrates its pertinence in synergist application as it encourages reactant response.
free microwave irradiation at 80°C, 160 W with phenomenal yield and selectivity, without generation of any side product (scheme 1). It is found that zinc ferrite being a Lewis acid facilitates the enolisation of aryl ketone as well as activates the carbonyl carbon of the benzaldehyde towards the nucleophilic assault.

From the stereochemistry perspectives aspects we examined the $^1$H NMR spectra of synthesized chalcone derivatives and it was found that, this methodology produces explicitly $E$ isomers from substituted benzaldehyde and substituted acetophenones. $^1$H NMR spectra unmistakably demonstrates that the chalcones were geometrically unadulterated and trans-configurated with higher proton estimations of peaks near about 7.728 ppm with coupling constant ($J$) of 15.72 Hz to 16 Hz ($H-\mathrm{C}_α=\mathrm{C}_β-H$). The large pore size and high surface area of this catalyst provide enough space for reaction of the reactants with active sites inside the catalyst wall.

We additionally contemplate the synergist impact of zinc ferrite nanocatalyst on the combination of (E)-3-(4'-chlorophenyl)-1-phenylprop-2-en-1-one (scheme 3) fluctuating the measure of catalyst from 0 mol % to 10 mol % without changing other reaction conditions. Without catalyst there was no formation of any
product. As the catalyst amount increments from 1 mol %, 2 mol %, 5 mol % and 10 mol %, the level of yield increments from 70% to 95%. The ideal amount of catalyst loading was found to be 5 mol %, i.e. 12 mg as appeared in table 3. Further expanding the amount of catalyst, there was no huge increment in the yield of item was observed.

So as to sum up the synergist use of zinc ferrite magnetic nanoparticles in the dissolvable free microwave amalgamation of chaolcones through Claisen-Schmidt buildup response, we have utilized distinctive aldehydes and ketones for union of different chalcones. The observed outcomes are condensed in table 4. It very well may be seen that the presence of electron pulling back gathering on acetophenone and benzaldehyde does not

![Figure 12. (a) FT-IR (b) 1H NMR (c) 13C NMR and (d) mass spectra of (E)-3-(furan-2-yl)-1-(4-methoxyphenyl)prop-2-en-1-one.](image-url)
Figure 13. (a) FT-IR (b) $^1$H NMR (c) $^{13}$C NMR and (d) mass spectra of (E)-1-(4-methoxyphenyl)-3-(4-nitrophenyl)prop-2-en-1-one.

Scheme 3. Preparation of (E)-3-(4'-chlorophenyl)-1-phenylprop-2-en-1-one chalcone using zinc ferrite nanocatalyst.
Table 3. Optimization of catalyst concentration in the synthesis of (E)-3-(4'-chlorophenyl)-1-(4'-methoxyphenyl)prop-2-en-1-one (\(^{d}\) Isolated yield).

| Entry | Concentration of ZnFe\(_2\)O\(_4\) in mole\(\%\) | Yields\(^{d}\) (%) |
|-------|---------------------------------|-----------------|
| 1     | 0                               | No reaction    |
| 2     | 1                               | 70              |
| 3     | 2                               | 80              |
| 4     | 5                               | 95              |
| 5     | 10                              | 95              |
Table 4. Claisen–Schmidt condensation of substituted benzaldehyde with substituted acetophenone using ZnFe$_2$O$_4$ MNPs in Microwave irradiated synthesis $^a$.

| Entry | Aldehyde      | Ketone     | Product               | Time (second) | Yield ($^b$%) |
|-------|---------------|------------|-----------------------|---------------|---------------|
| 1     | $\text{\(\text{phenyl}CHO\)}$ | $\text{\(\text{benzyl}CO\)}$ | $\text{\(\text{benzylenedioxy}CO\)}$ | 80            | 96            |
| 2     | $\text{\(\text{phenyl}CHO\)}$ | $\text{\(\text{\(\text{CH}_{3}\)benzyl}CO\)}$ | $\text{\(\text{\(\text{CH}_{3}\)benzylenedioxy}CO\)}$ | 70            | 94            |
| 3     | $\text{\(\text{Cl}phenyl}CHO\)}$ | $\text{\(\text{\(\text{CH}_{3}\)benzyl}CO\)}$ | $\text{\(\text{\(\text{CH}_{3}\)benzylenedioxy}CO\)}$ | 70            | 95            |
| 4     | $\text{\(\text{\(\text{NO}_{2}\)phenyl}CHO\)}$ | $\text{\(\text{\(\text{NO}_{2}\)benzyl}CO\)}$ | $\text{\(\text{\(\text{NO}_{2}\)benzylenedioxy}CO\)}$ | 60            | 96            |
| 5     | $\text{\(\text{\(\text{NO}_{2}\)phenyl}CHO\)}$ | $\text{\(\text{\(\text{NO}_{2}\)benzyl}CO\)}$ | $\text{\(\text{\(\text{NO}_{2}\)benzylenedioxy}CO\)}$ | 60            | 97            |

$^a$ Microwave irradiated synthesis.

$^b$ Yield.
| Entry | Aldehyde | Ketone | Product | Time (second) | Yield (\%) |
|-------|----------|--------|---------|--------------|------------|
| 6     | ![Aldehyde](image1) | ![Ketone](image2) | ![Product](image3) | 70           | 95         |
| 7     | ![Aldehyde](image4) | ![Ketone](image5) | ![Product](image6) | 70           | 94         |
| 8     | ![Aldehyde](image7) | ![Ketone](image8) | ![Product](image9) | 80           | 95         |
| 9     | ![Aldehyde](image10) | ![Ketone](image11) | ![Product](image12) | 80           | 94         |
| 10    | ![Aldehyde](image13) | ![Ketone](image14) | ![Product](image15) | 80           | 96         |

*a* Reaction condition: aldehyde (1 mmole), substituted acetophenone (1 mmole), ZnFe$_2$O$_4$ catalyst (5 mol %, 12 mg) irradiated in microwave at 80°C, 160 Watt.

*b* Isolated yield.
influence the yields of resulting chalcones, showing a superb flexibility of these zinc ferrite nanocatalyst. The FT-IR, $^1$H NMR, $^{13}$C NMR and mass spectra of prepared chalcone derivatives are given in Figure 11–15.

The cation dissemination investigation of zinc ferrite nanoparticle obviously demonstrated that the presence of Lewis acid irons (Fe$^{3+}$) in zinc ferrite nanocatalyst and extended porosity are the central point for high reactant movement of magnetic catalyst. In the conceivable system, it has been seen that nano zinc ferrite actuates the aldehyde and respond the enol type of aceophenone to shape the consolidated item. This additionally instates the lack of hydration of the aldol consolidated item to frame chalcones (scheme 4).

Many active researchers from the field of chemistry have reported the synthesis of chalcone derivatives using different synthesis protocols. Abu Dief et al [70] reported the facile preparation of Nanospinel nickel ferrite to act as efficient nanocatalyst for acetylferrocene chalcone derivatives. It also displayed an activity towards cancerous cells. Xu et al [71] investigated the chalcone preparation by solid form sulphonic acid retrieved from bamboo. Their results show that the prepared catalyst results in high yield but the recyclability tends to moderate results. Aryan et al [72] presented the surface transformed manganese ferrite nano-composites as an active nanocatalyst.
for the robust preparation of chalcone derivatives via well known Claisen Schmidt approach. These prepared nano-composites displayed strong stability whereas moderate yield and reusability. Nasr Esfahani et al[73] investigated the catalytic activity of the ‘Vanadatesulfuric Acid’ in the form of nano-rods. Their outcomes displayed the novel protocol for the preparation of chalcone derivatives under the solvent-less circumstances.

3.12. Catalyst reusability

The impact of reusability of zinc ferrite magnetic catalyst was additionally examined. For this function, we prepared (E)-3-(4’-chlorophenyl)-1-phenylprop-2-en-1-one by use of 4-chloro benzaldehyde and acetophenone (scheme 3) as preliminary material under microwave irradiation at power of 160 W without any solvent. Toward the finish of reaction, reaction mixture cooled to room temperature, 15 ml ethyl acetate was added and the catalyst was isolated by outer magnet, washed it with ethanol and dried at 80°C. After this treatment, the catalyst was utilized under comparative conditions for other consecutive runs without further

![Scheme 4. Plausible mechanism of the (E)-chalcone synthesis over zinc ferrite magnetic nanoparticles (MNP’s).](image)

![Figure 16. Recyclability experiments of the Zinc ferrite magnetic nanocatalyst for the reaction 4-chloro benzaldehyde and acetophenone in microwave irradiation without changing experimental conditions for six cycles to give synthesis of E-3-(4’-chlorophenyl)-1-phenylprop-2-en-1-one. The yield was calculated based on the same amount of catalyst and same amount of reactants for all six cycles. (‘Isolated yield).](image)
treatment as shown in figure 16. It is seen from figure 16 that, there was no wonderful misfortunes in the yield of chalcone can be seen in the consequent five continuous reuses (fresh—95%, 1st recycle—95%, 2nd recycle—94%, 3rd recycle- 93%, 4th recycle- 92%, 5th recycle- 92%), which demonstrates that zinc ferrite magnetic nanocatalyst possess excellent stability.

4. Conclusions

In conclusion, we have built up another, straightforward microwave illuminated dissolvable free strategy for the amalgamation of substituted chalcones by utilizing zinc ferrite nanocatalyst. The mild reaction circumstances, uncontaminated reaction profiles, absence of side products and cost proficiency render this methodology as a helpful option in contrast to the current strategies. The zinc ferrite nanoparticles were effectively prepared by glycine assisted sol-gel auto ignition technique. The XRD analysis affirmed the pure phase development of cubic spinel structure with nanometric crystallite measure. FE-SEM image and EDAX monograph affirmed the nanocrystalline morphology and presence of desired elements with fine purity. The BET investigation demonstrated the high surface area esteem for prepared nanoparticles. M–H hysteresis curve uncovered the superparamagnetic behavior of the zinc ferrite nanoparticles. The high dielectric constant estimation of prepared nanoparticles demonstrated its capacity to utilize it in microwave irradiated preparation of organic materials. The lower estimation of optical band gap decided from UV–vis investigation demonstrates its ease of use in photocatalytic action. These prepared zinc ferrite nanoparticles were utilized as green and eco-friendly catalyst in chemical transformations as recyclable heterogeneous catalysts because of its previously mentioned properties and as it assimilate microwave radiation and exchange heat to reactant which is adsorb on the outside of catalyst. It likewise has some superb properties, for example, high surface area of dynamic locales, can easily isolate from reaction mixture by external guest magnetic field and can be reused for multiple reaction cycles.

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Conflict of interest

We wish to confirm that there are no known conflicts of interest associated with this publication.

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References

[1] Reddy L H, Arias J L, Nicolas J and Couvreur P 2012 Magnetic nanoparticles: design and characterization, toxicity and biocompatibility, pharmaceutical and biomedical applications Chem. Rev. 112 5818–78
[2] Kharat P B, Somvanshi S B, Kounsalye J S, Deshmukh S S, Khirade P P and Jadhav K 2018 Temperature dependent viscosity of cobalt ferrite/ethylene glycol ferrofluids AIP Conference Proceedings (AIP Publishing) pp.050044
[3] Kale S B, Somvanshi S B, Sarnaik M, More S, Shukla S and Jadhav K 2018 Enhancement in surface area and magnetization of CoFe2O4 nanoparticles for targeted drug delivery application AIP Conference Proceedings (AIP Publishing) pp.030193
[4] Sheykhan M, Mohammadnejad H, Akbari J and Heydari A 2012 Superparamagnetic magnesium ferrite nanoparticles: a magnetically reusable and clean heterogeneous catalyst Tetrahedron Lett. 53 2959–64
[5] Somvanshi S B, Kaur R V, Kounsalye J S, Saraf T S and Jadhav K 2019 Investigations of structural, magnetic and induction heating properties of surface functionalized zinc ferrite nanoparticles for hyperthermia applications AIP Conference Proceedings (AIP Publishing) pp.030522
[6] Babrekar M and Jadhav K 2017 Synthesis and characterization of spray deposited lithium ferrite thin film Int. Res. J. Sci. Eng. Special 73–6
[7] Somvanshi S R, Khatar P B, Khedkar M V and Jadhav K 2019 Hydrophobic to hydrophilic surface transformation of nano-scale zinc ferrite via oleic acid coating: magnetic hyperthermia study towards biomedical applications Ceram. Int. 46

[8] Bhyor D N, Somvanshi S B, Khatar P B, Pandit A and Jadhav K 2019 Structural, infrared, magnetic and ferroelectric properties of $\text{Sn}_x \beta\text{Ba}_3 \beta\text{Ti}_1 \beta\text{Fe}_2\text{O}_9$ nanocrystals: modifications via trivalent Fe ion doping Physica B 581 411944

[9] Khatar P B, More S D, Somvanshi S B and Jadhav K M 2019 Exploration of thermoacoustics behavior of water based nickel ferrite nanofluids by ultrasonic velocity method Journal of Materials Science: Materials in Electronics 30 6364–74

[10] Singhameen S, Bilnyuk V N, Binke C and Tsymbal E Y 2011 Magnetic nanoparticles: recent advances in synthesis, self-assembly and applications J. Mater. Chem. 21 16819–45

[11] Bao Y, Wen T, Samia A C S, Khandhar A and Krishnan K M 2016 Magnetic nanoparticles: material engineering and emerging applications in lithography and biomedicine J. Mater. Sci. 51 513–53

[12] Li P, Wang L, Zhang L and Wang G W 2012 Magnetic nanoparticles-supported palladium: a highly efficient and reusable catalyst for the Suzuki, Sonogashira, and Heck reactions Advanced Synthesis & Catalysis 354 1307–18

[13] Baig R N and Varma R S 2013 Magnetically retrievable magnetic nanoparticles for organic synthesis Chem. Commun. 49 752–70

[14] Somvanshi S B, Khedkar M V, Khatar P B and Jadhav K 2019 Influential diamagnetic magnesium (Mg$^{2+}$) ion substitution in nanospinel zinc ferrite (ZnFe$_2$O$_4$): thermal, structural, spectral, optical and physiosorption analysis Ceram. Int. 46

[15] Alhaidlaga H A, Akhtar M J and Ahamed M 2015 Zinc ferrite nanoparticle-induced cytotoxicity and oxidative stress in different human cells Cell & Bioscience 5 55

[16] Misra R, Kal A, Srivastava R and Senkov O 2003 Synthesis of nanocrystalline nickel and zinc ferrites by microemulsion technique Mater. Sci. Technol. 19 826–30

[17] Shenoy S, Joy P and Anantharaman M 2004 Effect of mechanical milling on the structural, magnetic and dielectric properties of coprecipitated ultrafine zinc ferrite J. Magn. Magn. Mater. 269 217–26

[18] Yang Y, Liu X, Yang Y, Xiao W, Li Z, Xue D, Li F and Ding J 2013 Synthesis of nanostrictometric zinc ferrite nanoparticles with extraordinary room temperature magnetism and their diverse applications Journal of Materials Chemistry C 1 2875–85

[19] Gaozeu F, Lévy M and Wilhelm C 2008 Optimizing Magnetic Nanoparticle Design for Nanothermotherapy 3 831–44

[20] Wu W, Wu Z, Yu T, Jiang C and Kim W-S 2015 Recent progress on magnetic iron oxide nanoparticles: synthesis, surface functional strategies and biomedical applications J. Mater. Chem. Adv. 16 023501

[21] Mahmoodi N M 2013 Zinc ferrite nanoparticle as a magnetic catalyst: Synthesis and dye degradation Mater. Res. Bull. 48 4255–60

[22] Liu J, Lu G, He H, Tan H, Xu T and Xu K 1996 Studies on photocatalytic activity of zinc ferrite catalysts synthesized by shock waves Mater. Res. Bull. 31 1049–56

[23] Singh A S, Patil U B and Nagarkar J M 2013 Palladium supported on zinc ferrite: a highly active, magnetically separable catalyst for ligand free Suzuki and Heck coupling Catal. Commun. 35 11–6

[24] Stevens P D, Li G, Fan J, Yen M and Gao Y 2005 Recycling of homogeneous Pd catalysts using superparamagnetic nanoparticles as novel soluble supports for Suzuki, Heck, and Sonogashira cross-coupling reactions Chem. Commun. 4435–7

[25] Akbari J, Heydari A, Reza Kalhor H and Kohan S A 2009 Sulfonyl acid functionalized ionic liquid in combinatorial approach, a recyclable and water tolerant-acidic catalyst for one-pot Friedlander quinoline synthesis J. Comb. Chem. 12 137–40

[26] Luo S, Zheng X, Xu H, Mi X, Zhang L and Cheng J P 2007 Magnetic Nanoparticle-Supported Morita–Baylis–Hillman Catalysts, Advanced Synthesis & Catalysis 349 2431–41

[27] Stevens P D, Fan J, Gardimalla H M, Yen M and Gao Y 2005 Superparamagnetic nanoparticle-supported catalysis of Suzuki cross-coupling reactions Org. Lett. 7 2085–8

[28] Hu A, Ye G T and Lin W 2005 Magnetically recoverable chiral catalyst immobilized on magnetite nanoparticles for asymmetric hydrogenation of aromatic ketones JACS 127 12486–7

[29] Mercier C and Chabardes P 1993 Isomerisation of α-acetylcylic anilines into α,β-ethylic carbonyl derivatives in vapor phase Studies in Surface Science and Catalysis (Elsevier) pp. 677–84

[30] Izumi Y, Natsume N, Takamine H, Tamaoki I 1 and Urabe K 1989 Silica-supported heteropolyc acid catalyst for liquid-phase fructose–crafts reactions Bull. Chem. Soc. Jpn. 62 2159–62

[31] Tanabe K and Hölderich W F 1999 Industrial application of solid acid–base catalysts Applied Catalysis A: General 181 399–434

[32] Reddy B M and Khan A 2003 Recent advances on TiO$_2$–ZrO$_2$ mixed oxides as catalysts and catalyst supports Catalyst Reviews 47 257–96

[33] Narayanan B 2012 Synthesis of green nanocatalysts and industrially important green reactions Green Chem. Lett. Rev. 5 707–25

[34] Baig R N and Varma R S 2013 Organic synthesis via magnetic attraction: benign and sustainable protocols using magnetic nanoferrites Green Chem. 15 398–417

[35] Gavande M B, Bonifácio V D, Varma R S, Nogueira I D, Bundaleski N, Ghumman C A A, Teodoro O M and Branco P S 2013 Magnetically recyclable magnetite–ceria (NanoCat-Fe-Ce) nanocatalyst–applications in multicomponent reactions under benign conditions Green Chem. 15 1226–31

[36] Dandia A, Parewa V, Jain A K and Rathore K S 2011 Step-economic, efficient, ZnS nanoparticle-catalyzed synthesis of spirooxindole derivatives in aqueous medium via Knoevenagel condensation followed by Michael addition Green Chem. 13 2135–45

[37] Biradar A V, Umbarkar B S and Dongare M 2005 Transesterification of diethyl oxalate with phenol using MoO$_3$/SiO$_2$ catalyst Applied Catalysis A: General 285 190–5

[38] Amrut A P, Bordoloi A, Lucas N, Palraj K and Halligudi S 2008 Sol–Gel Synthesis of MoO$_3$/SiO$_2$ Composite for Catalytic Application in Condensation of Anisole with Parafomaldehyde Catal. Lett. 126 286

[39] Singh S J and Jayaram R V 2008 Chemosesepicel O-tert-butyroxybenzoylation of hydrox compounds using NaLaTiO$_4$, a heterogeneous and reusable catalyst Tetrahedron Lett. 49 4249–51

[40] Gavande M B and Jayaram R V 2006 A novel catalyst for the Knoevenagel condensation of aldehydes with malononitrile and ethyl cyanoacetate under solvent free conditions Catal. Commun. 7 931–5

[41] Rafaesi E and Eavani S 2011 H3PW12O40 supported on silica-encapsulated γ-Fe$_2$O$_3$ nanoparticles: a novel magnetically-recoverable catalyst for three-component Mannich–type reactions in water Green Chem. 13 2116–22

[42] Palomo C, Oiarbide M and Garcia J M 2002 The aldol addition reaction: an old transformation at constant rebirth Chemistry–A European Journal 8 36–44

[43] Xia Y, Yang Z-Y, Xia P, Bastow K F, Naknishi Y and Lee K-H 2000 Antitumor agents. Part 202: novel 2’-amino chalcones: design, synthesis and biological evaluation Bioorganic & medicinal chemistry letters 10 699–701

[44] HSEH H K, TSAO L T, WANG J P AND LIN C N 2000 Synthesis and anti-inflammatory effect of chalcones J. Pharm. Pharmacol. 52 163–71
[45] Marciniak G, Delgado A, Leclerc G, Velty J, Decker N and Schwartz J 1989 New 1, 4-dihydropyridine derivatives combining calcium antagonism and alpha-adrenolytic properties J. Med. Chem. 32 1402–7
[46] Patil I, Malani M and Dhoklakia B 2012 Silica sulfuric acid-catalyzed Claisen-Schmidt condensation of 1, 3, 4 trisubstituted pyrrole 2, 5 diselenides RSC Adv. 2 38371–81
[47] Bartley J K, Xu C, Lloyd R, Enache D L, Knight D W and Hutchings G J 2012 Simple method to synthesize high surface area magnesium oxide and its use as a heterogeneous base catalyst Appl. Catalysis B 128 31–8
[48] Kandel K, Althaus S M, Peerapant T, Kobayashi Y, Trewyn B G, Pruski M and Slowing J I 2012 Substrate inhibition in the heterogeneous catalyzed aldol condensation: a mechanistic study of supported organocatalysts J. Catal. 291 63–8
[49] Dong F, Jian C, Zhenghao F, Kai G and Zuliang L 2008 Synthesis of chalcones via Claisen–Schmidt condensation reaction catalyzed by acrylic acid ionic liquids Catal. Commun. 9 1924–30
[50] Kumar A, Dewan M, De A, Saxena A, Areyy S and Mozumdar S 2013 Aldol condensation in PEG-400 catalyzed by recyclable l-proline supported on nano gold surface RSC Adv. 3 603–7
[51] Xu C, Gao Y, Liu X, Xin R and Wang Z 2013 Hydrotalcite reconstructed by in situ rehydration as a highly active solid base catalyst and its application in aldol condensations RSC Adv. 3 793–801
[52] Zeidan R K, Hwang J S and Davis M E 2006 Multifunctional heterogeneous catalysts: SBA-15-containing primary amines and sulfonic acids Angewandte Chemie Int. Ed. 45 6480–3
[53] Zeidan R K and Davis M E 2007 The effect of acid–base pair catalysis on: an efficient acid–base functionalized catalyst for aldol condensation J. Catal. 247 379–82
[54] Dhakshinamoorthy A, Alvaro M and Garcia H 2010 Claisen–schmidt condensation catalyzed by metal-organic frameworks Advanced Synthesis & Catalysis 352 711–7
[55] Ke F, Qiu L-G and Zhu J 2014 Fe3O4@MOF core–shell magnetic microspheres as excellent catalysts for the Claisen–Schmidt condensation reaction Nanoscale 6 1596–601
[56] Borade R M, Shinde P R, Kale S B and Pawar R P 2018 Preparation, characterization and catalytic application of CoFe2O4 nanoparticles in the synthesis of benzimidazoles AIP Conference Proceedings (AIP Publishing) pp 030194
[57] Sutka A and Mezinskis G 2012 Sol-gel auto-combustion synthesis of spinel-type ferrite nanomaterials Frontiers Mater. Sci. 6 128–41
[58] Khedkar M V, Somvanshi S B, Humbe A V and Jadhav K M 2019 Surface modified sodium silicate based superhydrophobic silica aerogels prepared via ambient pressure drying process J. Non-Cryst. Solids 511 140–6
[59] Patade S, Andhare D, Somvanshi S, Kharat P B and Jadhav K M 2018 Preparation and characterizations of magnetic nano-fluid of zinc ferrite for hyperthermia application Nanomaterials and Energy 9 1–7
[60] Bharati V, Somvanshi S B, Humbe A V, Murumkar V, Sondar V and Jadhav K 2019 Influence of trivalent Al–Cr co-substitution on the structural, morphological and Mössbauer properties of nickel ferrite nanoparticles J. Alloys Compd. 821 153501
[61] Waldron R 1955 Infrared spectra of ferrites J. Alloys Compd. 511 140–6
[62] Deshmukh S, Humbe A V, Kumar A, Dorik R and Jadhav K 2017 Urea assisted synthesis of Ni1–xZnxFe2O4 (0 ≤ x ≤ 0.8): Magnetic and Mössbauer investigations J. Alloys Compd. 704 227–36
[63] Borhan A, Jordan A and Palamaru M 2013 Correlation between structural, magnetic and electrical properties of nanocrystalline Al1+ substituted zinc ferrite Mater. Res. Bull. 48 2549–56
[64] Patil R, Delekara S, Mane D and Hankare P 2013 Synthesis, structural and magnetic properties of different metal ion substituted nanocrystalline zinc ferrite Results in Physics 3 129–33
[65] Pan H, Cheng X, Zhang C, Gong C, Yu L, Zhang l and Zhang Z 2013 Preparation of Fe2Ni2O4 nanocomposite via a two-step route and investigation of its electromagnetic properties Appl. Phys. Lett. 102 012410
[66] Zhang X, Li Y, Liu R, Yao Y, Rong H and Qin G 2016 High-magnetization Fe2Ni2N nanochains with ultrathin interfacial gaps for broadband electromagnetic wave absorption at gigahertz ACS applied materials & interfaces 8 3494–8
[67] Gong C, Wang X, Zhang X, Zhao X, Meng H, Jia Y, Zhang Z and Zhang Z 2014 Synthesis of Ni/SiO2 nanocomposites for tunable electromagnetic absorption Mater. Lett. 121 81–4
[68] Patil C B, Mahajan S and Katti S A 2009 Chalcone: a versatile molecule Journal of Pharmaceutical sciences and research 1 11
[69] Othman M, Helwani Z and Fernando W 2009 Synthetic hydrotalcites from different routes and their application as catalysts and gas adsorbents: a review Appl. Organomet. Chem. 23 335–46
[70] Abu-Dief A M, Nasser I F and Elsayed W H 2016 Magnetic NiFe2O4 nanoparticles: efficient, heterogeneous and reusable catalyst for synthesis of acetylferrocene chalcones and their anti-tumour activity Appl. Organomet. Chem. 30 917–23
[71] Xu Q, Yang Z, Yin D and Zhang F 2008 Synthesis of chalcones catalyzed by a novel solid sulfonic acid from bamboo Catal. Commun. 9 1579–82
[72] Aryan R, Mir N, Beyzaei H and Kharaade A 2018 Design and synthesis of novel natural clinoptilolite-MnFe2O4 nanocomposites and their catalytic application in the facile and efficient synthesis of chalcone derivatives through Claisen-Schmidt reaction Res. Chem. Intermed. 44 4245–58
[73] Nasr-Esfahani M, Daghaghale M and Taei M 2017 Catalytic synthesis of chalcones and pyrazolines using nanorod vanadatesulfuric acid: an efficient and reusable catalyst J. Chin. Chem. Soc. 64 17–24