Structural, Dielectric and Magnetic properties of Yttrium doped Hematite Nanoparticle

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Abstract:
Applicability of magnetic crystalline nanoparticles particularly in the diagnostic field of health care and magnetic data storage makes them highly important for various technological researches. Novel properties of prepared nanoparticles can be tuned with doping of rare earth metals. In the present research, Yttrium (Y) doped hematite nanocrystalline samples have been prepared at various compositions, Fe₂₋₂ₓY₂ₓO₃ (x=0.00, 0.02, 0.05, 0.08, 0.10) and magnetic properties are seen sensitive with dopants concentration. The variation in grain size from FE-SEM is found well collaborated with the crystallite size and strain determined by XRD measurements. Rietveld refinement of XRD patterns reveals the formation of rhombohedral symmetry with R\(^{\text{̃}}\)3c space group of the samples. The dielectric and magnetic properties show wiggling behaviour with the concentration of doping metal. A shift towards weakly ferromagnetic conduct like behaviour has been confirmed with the doping of Y in hematite crystalline particles.

Keywords: Crystal structure, Rietveld refinement, Fe–SEM, Raman Spectroscopy, Dielectric analysis, Magnetic properties.

1. Introduction
Magnetic nanoparticles (MNPs) have emerged as an important materials for various technological investigations [1,2]. These investigations are interdisciplinary in nature like diagnostics field, large density magnetic data storage and devices for energy storage, highly efficient catalysis and many more. Among these, iron oxide nanoparticles acclaimed a special place being used in High Resolution Magnetic Resonance Imaging (HRMRI) for the diagnostic of cancer, permeation enhancer, cell separation, magnetic data storage and
ultrafast data retrieval [3-11]. Among the various iron oxides, nanoparticles of Fe$_2$O$_3$ are of great interest due to their large variety of applications in the area of adsorbents, catalysis and in storage devices. Generally, Fe$_2$O$_3$ exists in four crystalline phases, α-Fe$_2$O$_3$, β-Fe$_2$O$_3$, γ-Fe$_2$O$_3$ and ε-Fe$_2$O$_3$. Out of these four, hematite (α-Fe$_2$O$_3$) is the most stable iron oxide that can exhibit interesting chemical, electrical and magnetic properties [12-14] The crystal structure of α-Fe$_2$O$_3$, which belongs to rhombohedral symmetry with space group R$\bar{3}$c [15]. The structure may easily be understood in hexagonal setting as the arrangement of O$^{2-}$ ions in an hcp structure with Fe$^{3+}$ exist in ordered style in 2/3 of the octahedral site. Being a canted spin structure a small amount of magnetization evolves in the direction of basal plane and the weak ferromagnetic state occurs due to partially canted spins [16]. The doping of rare earth metals has a great impact on crystalline structure and magnetism in the compound. Goyal et al. [17] reported the modification in the magnetism with Neodymium (Nd) doping in α-Fe$_2$O$_3$ and correlated the same with reduction in particle size due to agglomeration of particles. Enhancement in magnetisation below and above the Morin temperature is observed by Freyria et al. [18]. Mathevula et al. [19] have shown the enhancement in optical properties with doping of Holmium (Ho). Wan et al [20] also reported the enhancement in magnetic properties with the incorporation of Gd$^{3+}$ ions in α-Fe$_2$O$_3$. Bhat et al [21] study the synthesis and optical studies of α-Fe$_2$O$_3$ and erbium (Er$^{3+}$) ion-doped α-Fe$_2$O$_3$ nanoparticles (NPs) and confirms the hexagonal (rhombohedral) crystal structure, with no additional phase formation. The average particle size decreases with Er$^{3+}$ ion doping in α-Fe$_2$O$_3$ NPs. Inspite of having extensive research on chemical substitution in α-Fe$_2$O$_3$ nanoparticles, none of research group in our knowledge, has reported the structural, dielectric and magnetic properties simultaneously with the doping of Yttrium (Y) in α-Fe$_2$O$_3$ nanoparticle. The present study aims to explore the influence of Y dopants on crystal structure, dielectric behaviour and magnetic parameters of α-Fe$_{2-2x}$Y$_{2x}$O$_3$ (x= 0.00, 0.02, 0.05, 0.08, 0.10) nanoparticles.

2. Experimental details

2.1. Synthesis
Yttrium doped Hematite magnetic nanoparticles with the compositions of Fe$_{2-2x}$Y$_{2x}$O$_3$ ($x$= 0.00, 0.02, 0.05, 0.08, 0.10) were prepared by sol-gel method. For this, stoichiometry amount of Fe(NO$_3$)$_3$.9H$_2$O and Y(NO$_3$)$_3$.6H$_2$O were dissolved in deionised (DI) water and heated at to 80°C till it convert into gel form. The obtained gel were heated at 120°C for 2 hours to convert this gel in to solid form and has been dried at 200 °C for 3 hours to remove the liquid phase. Now, in order to attain the homogeneity of mixture the powdered form of samples was mixed and ground thoroughly in an Agate mortar and pestle. After grinding, the powdered samples were pelletized in a hydraulic press using a die of 10 mm diameter and applying a pressure of 5 tonne. The obtained pellets were finally sintered in air at 600°C for 6 hours to obtain dense samples.

2.2. Characterizations

The crystalline structure of the samples has been determined by XRD method using Bruker-AXSD8 advanced diffractometer with Cu K$_\alpha$ source having wavelength 1.54Å. The scan range and rate were 20°-70° and 0.02°per second respectively. The In-via microscope set up (Renishaw) along with Ar$^+$ ion laser beam at 514.5 nm and power 50 mW of laser power has been used for Raman measurements[22]. Dielectric constants at different temperatures of synthesized samples were studied using kaithley electrometer-6517 B interfaced with lab-view software. Dielectric measurements of hematite samples were made by two probes technique in the temperature range of 100K to 400K. Magnetic measurements have been obtained in the form of M–H loops using vibrating samples magnetometer (VSM) at 295K with applied magnetic field upto ±10KOe.

3. Results and Discussion

3.1. XRD analysis

The XRD patterns of Fe$_{2-2x}$Y$_{2x}$O$_3$ ($x$=0.00, 0.02, 0.05, 0.08, 0.10) nanoparticles are shown in Fig.1. From these diffraction patterns, Fe$_{2-2x}$Y$_{2x}$O$_3$ ($x$=0.00) showing most intense peak at 33.15° corresponding to (104) plane indicates the pure hematite phase. The structure of pure hematite may be visualized as O$^{2-}$ ions occupying the corner positions in a hexagonal
close-packing (hcp structure) with Fe$^{3+}$ being distributed in an ordered fashion in 2/3 of the octahedral site [23]
Figure 1: (a) XRD observations of Fe$_{2-2x}$Y$_{2x}$O$_3$ (x=0.00, 0.02, 0.05, 0.08, 0.10) nanoparticles, (b) enlarged view of XRD patterns between 33°-36°.

It can be seen clearly from Fig.1 that the patterns for Y doped samples are in coherence with that obtained for pure Fe$_2$O$_3$ sample, which reveals that Y$^{3+}$ has been well incorporated in the α-Fe$_2$O$_3$ crystal lattice. A shift in main peaks (in vicinity of 2θ = 35°) (Fig. 1.b) towards lower values of 2θ, which may be attributed to the fact that lower radii ion Fe$^{3+}$ (0.645 Å) is substituted by larger ion Y$^{3+}$ (0.9 Å) and this will produce strain in the samples, which is correlated to the increase in width and intensity of XRD peaks [24-26]. The Rietveld refinement has been performed on XRD patterns using Full-Prof software in order for examine the structural phase and to obtain the crystal lattice parameters [27]. Refinement confirms the formation of the pristine α-Fe$_2$O$_3$ structure, rhombohedral R̅3c phase in all the prepared samples. Fig.2. Shows the Rietveld refined XRD results of synthesized hematite samplesα-Fe$_{2-2x}$Y$_{2x}$O$_3$ (x=0.00, 0.02, 0.05, 0.08, 0.10). The lower values of refinement profile parameters indicates reasonably good fitting. The obtained lattice parameters can be shown in Table 1.
Figure 2: Rietveld refined XRD patterns for $\alpha$-$\text{Fe}_{2-2x}\text{Y}_{2x}\text{O}_3$ ($x = 0.00, 0.02, 0.05, 0.08, 0.10$) nanoparticles.
The refinement of the obtained XRD patterns confirms the formation of the pristine α-Fe$_2$O$_3$ structure, which indicates that Y$^{+3}$ ions are well adjusted in the α-Fe$_2$O$_3$ crystal lattice. Similar behaviour has been observed in previous investigations on lanthanides doping in hematite. The lattice parameters obtained shows non-systematic variation with concentration. The similar behaviour has been reported by Goyal et al [17] in an Nd doped Fe$_2$O$_3$ nanoparticles. Such non-systematic variation in the lattice parameters with rare earth dopants may be accorded to various effects such as reduction in particle size along with forming agglomeration. The crystallite size has been calculated from the obtained XRD patterns using Debye-Scherer’s formula as shown in equations (1)[28].

\[ D = \frac{0.89\lambda}{\beta\cos\theta} \]  

(1)

Where, \( \lambda \), \( \beta \) and \( \theta \) are wavelength, FWHM and Bragg’s angle respectively[29, 30].

Table 1: Crystal lattice parameters, crystallite size and grain size of Fe$_{2-2x}$Y$_{2x}$O$_3$ (x = 0.00, 0.02, 0.05, 0.08, 0.10) nanoparticle obtained by Rietveld analysis.

| Doping Concentration (x) | Atom | X     | Y     | Z     | Profile Parameters | Crystallite size (nm) | Grain Size (µm) |
|--------------------------|------|-------|-------|-------|---------------------|-----------------------|------------------|
| x=0.00                   | Fe   | 0.0000| 0.0000| 0.3542| Rp= 2.12            | 48                    | 0.795            |
|                          | O    | 0.3113| 0.0000| 0.0000| Rwp= 2.66           |                       |                  |
| x=0.02                   | Fe/Y | 0.0000| 0.0000| 0.3546| Rp= 1.59            | 27                    | 0.765            |
|                          | O    | 0.3196| 0.0000| 0.0000| Rwp= 1.99           |                       |                  |
| x=0.05                   | Fe/Y | 0.0000| 0.0000| 0.3547| Rp= 1.64            | 23                    | 0.701            |
|                          | O    | 0.3187| 0.0000| 0.0000| Rwp= 2.08           |                       |                  |
| x=0.08                   | Fe/Y | 0.0000| 0.0000| 0.3547| Rp= 1.62            | 23                    | 0.470            |
|                          | O    | 0.3267| 0.0000| 0.0000| Rwp= 2.05           |                       |                  |
| x=0.10                   | Fe/Y | 0.0000| 0.0000| 0.3546| Rp= 1.62            | 26                    | 0.849            |
|                          | O    | 0.3214| 0.0000| 0.0000| Rwp= 2.06           |                       |                  |

The calculated values of lattice parameters and crystallite size for Fe$_{2-2x}$Y$_{2x}$O$_3$ (x= 0.00) are found to be, \( a = b = 5.03 \ \text{Å}, \ c=13.76 \ \text{Å} \) and 48 nm respectively and have been summarized in
the Table 1. The crystallite size is found to be reduced significantly with Y doping. A gradual decrease is observed up to \( x = 0.05 \) in Y doped samples whereas a subtle increase is observed while going from \( x = 0.08 \) to \( x = 0.10 \). Such a variation indicates that the agglomeration of particles plays an important role in the individual samples for enunciating the particle size. The observed decreasing trend for the mean crystallite size (calculated from the most intense peak in XRD pattern) with increasing Y concentration is in well agreement with the earlier reported work [31].

3.2. Field emission scanning electron microscopy (FE-SEM) analysis

FE-SEM micrographs of pure and Y-doped hematite samples i.e. \( \text{Fe}_{2-2x}\text{Y}_{2x}\text{O}_3 \) (\( x = 0.00, 0.02, 0.05, 0.08, 0.10 \)) are shown in Fig.3. These images were taken with the FESEM instrument, model FEI Quanta 200 F SEM, by scanning the surface in raster scan mode which offers resolution in nanometres as well as yields a very low signal to noise ratio [32]. The average grain size of Y doped hematite samples were calculated by IMAGE-J software and given in table 1 [33]. It is clearly seen from the images (fig. 3) that microstructure were formed denser with a doping concentration of \( x = 0.08 \) due to decrease in grain size and after that, at higher concentration of Y (\( x = 0.10 \)) microstructure became less dense at higher grain size [34]. The variation in grain size is possibly due to the \( \text{Y}^{3+} \) having different ionic radii than the host \( \text{Fe}^{3+} \) ions and it is well collaborated with crystallite size as observed by XRD measurements.
Figure 3: FE-SEM images of $\alpha$-Fe$_{2-2x}$Y$_{2x}$O$_3$ ($x= 0.0, 0.02, 0.05, 0.08, 0.10$) nanoparticles, showing the variation in grain size due to Y-doping.

3.3. Raman spectroscopy

The Raman spectra of Y-doped $\alpha$-Fe$_{2-2x}$Y$_{2x}$O$_3$ ($x= 0.00, 0.02, 0.05, 0.08, 0.10$) samples from 100 cm$^{-1}$ to 700 cm$^{-1}$ at normal pressure and room temperature has been shown in Figure 3. On the basis of group theory calculations on pure hematite, $A_{1g}$ modes lies at wave numbers ~223 cm$^{-1}$ and 495 cm$^{-1}$ while those at ~ 289 cm$^{-1}$, ~ 407 cm$^{-1}$ and ~ 609 cm$^{-1}$ correspond to $E_g$ modes [35]. Usually, broadening of peaks has been observed with doping of rare earth elements in the Raman spectra due to reduction in particles size in the nanoscale. Hematite belongs to $\text{D}_{3d}$ point group and having Raman-active vibration modes (two $A_{1g}$ and three $E_g$) which has also been reported by other researchers [36]. In Figure 4, the shifting of Raman bands can be seen from higher to lower wavenumber with the increase in Y doping up to 5% in the host lattice. This shifting may be related to Y incorporated in the host lattice and reduction in the size of particles. By decrease of particle size, spectral lines become broader.
and have shifted towards lower wavenumber which is a common characteristic of nanoparticles [37, 38].

Figure 4: Intensity of Raman scattering versus Raman shift for $\alpha$-Fe$_{2-2x}$Y$_{2x}$O$_3$ ($x = 0.00$, 0.02, 0.05, 0.08, 0.10) nanoparticles.

The highest value of FWHM is observed in $A_{1g}$ mode at ~ 223 cm$^{-1}$ wavenumber, as consequences of Fe$^{3+}$ ions movement along c-axis. However, spectra shifting towards higher wavenumber side have been noticed in our results for the 8% Y doped hematite nanoparticles. Reverse shifting trend in the Raman spectra at highest concentration may be due to the segregation of Y ions as observed in our XRD measurements. The results also indicate that Raman spectra from 650 cm$^{-1}$ to 700 cm$^{-1}$ show an additional “symmetry-forbidden” $E_u$ peak at about 670 cm$^{-1}$. This peak is related to the lack of perfect lattice symmetry and is clearly visible in hematite NPs. The Raman peak width variation is probably related to the hematite particle size.

3.4. Dielectric analysis
Permittivity of the material may be written as \( \varepsilon = \varepsilon' + i\varepsilon'' \), where, \( \varepsilon'' = \varepsilon' \tan \delta \). \( \tan \delta \) being dissipation factor (dielectric loss) [39] and \( \delta \) denotes phase-difference between applied field and induced current. Real part of complex permittivity (dielectric-constant) can be determined by following formula (equation 3) [40]

\[
\varepsilon' = \frac{C_p d}{\varepsilon_0 A}
\]

(3)

Where \( \varepsilon_0 \) is free space absolute permittivity, \( d \) indicates distance between the plates and \( A \) denotes area of the plates. Figure 5 shows dielectric constant response as a function of temperature from 100-400 K for \( \text{Fe}_{2-2x}\text{Y}_{2x}\text{O}_3 \) (\( x = 0.00, 0.02, 0.05, 0.08 \) and 0.10) nanoparticle at selected frequencies in the range from 0.1 MHz to 0.4 MHz. Dielectric constant indicates weak frequency dispersion and small temperature dependence at low temperature (< 200 K) for all samples as shown in figure 5. It may be attributed to the unavailability of sufficient amount of energy in the crystal for charge carriers to move freely. So localized dipoles cannot orient towards field direction or very few may be localised in the field direction and hence show small value of dielectric constant. This is a general trend exhibited by ionic solids in which more electrons are free and contribute to conduction [41, 42].
Figure 5: Dependence of dielectric constant with temperature at different frequencies for $\alpha$-Fe$_{2-2x}$Y$_{2x}$O$_3$ (x=0.00, 0.02, 0.05, 0.08, 0.10) samples.

Upto $x=0.02$, as we move towards the higher temperature region, the thermal activation of charge carriers promotes for polarization build-up and hence dielectric constant has increased. This increase in dielectric constant may also be understood on the basis of
Koop’s model [43], which considers the fact that crystalline solids are made up of grains and grains boundaries. The grains generally offer low resistivity and grain boundaries contribute high resistivity [44, 45].

For x= 0.05, a rising hump is observed about 265K. This hump may be attributed to electron hopping mechanism which may have been induced typically by oxygen vacancies generated during heat treatment for charge compensation due to Fe$^{3+}$- Fe$^{2+}$ fluctuations [46]. In the next sample at x = 0.08, the hump lowers down and also the dielectric constant values at higher temperature. In low temperature region, grain boundaries effect dominates and gives small value of dielectric constant, whereas, in high temperature region, high value of dielectric constant is due to coarsening of favourable grains [47]. Further, with increase of Y$^{+3}$ ions concentration, decrease in dielectric constant value is noted as a consequence of large ionic radius of Y$^{+3}$ ions. They occupy octahedral sites which replace the Fe$^{+3}$ ions that influence the dielectric polarisation and hence value of dielectric constant decreases at these concentrations [48]. Dielectric loss (tan$\delta$) of the samples has been obtained in the frequency range 0.1 MHz to 0.4 MHz as a function of temperature ranging from 100-400 K. The plots between dielectric loss and temperature are as shown in the Figure 6. Initially, the dielectric loss of Fe$_{2-x}$Y$_{2x}$O$_3$ (x=0.00, 0.02, 0.05, 0.08 and 0.10) synthesized samples increase with 0 % to 5 % concentration of Y doping in the host lattice, followed by decrease at 8% and 10 % concentrations. The evolution of anomaly in sample x= 0.05 about 260K may again be attributed to the possible electron hopping mechanism as discussed in the case of dielectric
Figure 6: Dielectric loss versus temperature at different frequencies for Fe$_{2-x}$Y$_x$O$_3$ (x=0.00, 0.02, 0.05, 0.08, 0.10) nanoparticles.
Table 2: Dielectric measurement parameters of Fe$_{2-2x}$Y$_{2x}$O$_3$ (x=0.00, 0.02, 0.05, 0.08, 0.10) nanoparticles at selected frequency (0.1 MHz and 0.4 MHz) and temperature (100 K and 400 K).

| Doping concentration | At 0.1 MHz | At 0.4 MHz |
|----------------------|------------|------------|
|                      | ε’ (100 K) | ε’ (400 K) | tanδ (100 K) | tanδ (400 K) | tanδ (100 K) | tanδ (400 K) |
| x=0.00               | 60.6       | 62.1       | 0.009        | 0.048        | 58.8         | 59.5         | -0.046       | -0.029       |
| x=0.02               | 149.0      | 155.3      | 0.009        | 0.066        | 144.0        | 148.0        | -0.045       | -0.019       |
| x=0.05               | 162.0      | 162.4      | 0.010        | 0.011        | 157.0        | 157.6        | -0.042       | -0.041       |
| x=0.08               | 121.9      | 122.5      | 0.010        | 0.011        | 118.3        | 118.8        | -0.043       | -0.043       |
| x=0.10               | 137.0      | 138.0      | 0.010        | 0.010        | 133.0        | 133.9        | -0.043       | -0.043       |

Such type of variation can be explained with the help of the Debye's relation,
\[ \tan \delta = \frac{\omega \tau}{1 + \omega^2 \tau^2} \], where \( \omega \) denotes angular frequency of applied field and \( \tau \) is used for relaxation time. With the increase of \( \omega \), factor \( \tan \delta \) decreases accordingly. Further at a particular frequency, the variation in \( \tan \delta \) plot can be attributed to the relaxation time [49]. At low temperature, relaxation time is more and its value decreases with the increase in temperature which may be related to Koop’s phenomenological theory [43]. The calculated value of dielectric constant (\( \varepsilon' \)) and Dielectric loss (\( \tan \delta \)) from graph at selected frequencies (0.1 MHz and 0.4 MHz) and temperature (100 K and 400 K) has been summarized in the table 2.

3.5. Magnetic properties

In bulk form, Fe$_2$O$_3$ possess spin canted antiferromagnetic structure with d$^5$ high spin Fe(III) cations [50, 51]. The spins are oriented antiparallel in a-b plane for the adjacent cation bilayers [52, 53]. The layer structure and spin orientation may be represented in a schematic pattern along c axis as (O$_3$-M$_A$-M$_A$-O$_3$-M$_B$-M$_B$-O$_3$-M$_A$-M$_A$-O$_3$-M$_B$-M$_B$-O$_3$…), where M-M
refers to cation bilayer A and B represents the two spin orientations [54, 55]. The doping of rare earth metals in hematite is reported to alter the spin arrangement and thus modification in the magnetic properties. The replacement of smaller sized Fe$^{3+}$ by Y$^{3+}$ is expected to disturb magnetic layer setting and consequently magnetic properties have been modified in the prepared compound, shown in Fig.7. Magnetic hysteresis measurements of Fe$_{2-2x}$Y$_{2x}$O$_3$ (x=0.00, 0.02, 0.05, 0.08, 0.10) samples were carried out using a vibrating sample magnetometer (VSM) at 295K with applied field range±10 KOe. The obtained M-H loops at different doping concentration enclosing different area are shown in the Fig.7. The determined value of magnetic parameters is summarized in the Table 3.

From hysteresis curve, an interesting point worth to be noted is that the M–H loop obtained for the pure Fe$_2$O$_3$ is found to be significantly different from the previous report by Goyal et al [17]. Here, a more uniform pattern along with non-saturating loop is observed. Basically, the magnetisation Fe$_2$O$_3$ is attributed to the particle size and their agglomeration. The synthesize method, treatment time and temperature, and environment plays important role in particle size, agglomeration, ordering of spins and invoking strain. In the present study, the higher temperature and longer heat treatment time may have abolished the strains and therefore more significant ordering of spins hastaken place.

The appearance of non–saturation indicates the presence of superparamagnetic particles at room temperature. The M–H loops assert the presence of wide variety of particle sizes in the samples, which are clearly visible in the FE-SEM patterns. Further, it is observed that the doping of Y yields a series of discontinues changes in magnetisation. A robust in enhancement in magnetization is depicted with x= 0.02 doping of Y (which indeed is maximum in the present series samples). On further increasing the Y doping to x= 0.05, shape of hysteresis loop changes to that of a lossy along with steep reduction in magnetisation. Maximum magnetization (M$_S$) at x=0.02 concentration of Y is higher than pure hematite due to high magnetic moments of Y$^{3+}$ ion replaces lesser magnetic moments of Fe$^{3+}$ ion, However further increase of Y$^{3+}$ ion concentration leads to decrease in maximum
magnetisation ($M_S$). Consequently magnetic moments at higher concentration might have not accumulated, rather cancelled out each other partially and hence leading to weak magnetic behaviour. From the magnetic properties (Table 3), it can be observed that coercivity and remnant magnetization and show wiggling behaviour with $Y^{3+}$ ions concentrations.

![Magnetic hysteresis loops of Fe$_{2-2x}$Ce$_{2x}$O$_3$ ($x=0.00, 0.02, 0.05, 0.08, 0.10$) nanoparticles](image)

**Figure 7:** Magnetic hysteresis loops of Fe$_{2-2x}$Ce$_{2x}$O$_3$ ($x=0.00, 0.02, 0.05, 0.08, 0.10$) nanoparticles

**Table 3:** Magnetic parameters for Fe$_{2-2x}$Y$_{2x}$O$_3$ ($x=0.00, 0.02, 0.05, 0.08, 0.10$) obtained from VSM measurement carried at 295 K temperature, showing the variation in parameters caused due to varying doping concentration of Y.
| Doping Concentration (x) | $M_s$ (emu/g) | $M_r$ (emu/g) | $H_C$ (Oe) | Squareness Ratio ($M_r/M_s$) |
|--------------------------|--------------|--------------|-----------|-----------------------------|
| x=0.00                   | 0.256        | 0.021        | 313.2     | 0.082                       |
| x=0.02                   | 0.471        | 0.201        | 2885.4    | 0.426                       |
| x=0.05                   | 0.231        | 0.071        | 2582.2    | 0.309                       |
| x=0.08                   | 0.228        | 0.062        | 2774.3    | 0.273                       |
| x=0.10                   | 0.276        | 0.093        | 3379.8    | 0.337                       |

It is important to note that coercivity parameter of samples depends not only on the spin carrier but also on the shape or size of tiny magnet. Larger value of coercivity and remnant magnetization for Y doped samples may be attributed to enhanced shape and magneto-crystalline anisotropy [56]. The continuous change in magnetic properties with Y doping in the $\alpha$-Fe$_2$O$_3$ samples reveals that magnetic properties are sensitive with dopants concentration.

4. Conclusions

The Yttrium doped hematite nanoparticle were prepared and analysed for varying concentrations i.e. Fe$_{2-2x}$Y$_{2x}$O$_3$ (x=0.00, 0.02, 0.05, 0.08, and 0.10). There is no structural phase transformation observed in the samples i.e. the rhombohedral symmetry with R$^\text{3c}$ space group of pure hematite is retained for all concentrations of the doping metal. Variation of FE-SEM grain size is reported in well collaborated with the crystallite size and strain as observed by XRD measurements. The Raman spectra claims the effect of the particle size with doping resulting in the shifting of Raman peaks. The dielectric and magnetic properties show wiggling behaviour with composition. The dielectric constant and dielectric loss exhibit a swing with the increase in the value of x’ till x= 0.05 and approach to stability (with respect to temperature) for higher concentrations of the doping. A constant behaviour of dielectric loss over a wide temperature range at different frequencies above doping concentrations
except at x=0.05 indicates technological importance of Y doped α-Fe₂O₃. An increase in coercivity and remnant magnetization of α-Fe₂O₃ by doping of Y as compared to pure hematite nanomaterial is investigated in prepared samples. Our findings conclude that Y doped α-Fe₂O₃ seems to have high potentiality for various technological advancement and suggests for further more research.

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