# Investigation on Structural, Dielectric and Ferromagnetic Properties of Yttrium Doped Nickel Ferrites ($NiY_{0.05}Fe_{1.95}O_4$) Prepared by Modified Sol–gel Route

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## 1 Introduction

Magnetic nanoparticles have currently become the hottest topic to discuss among the researchers because of their extremely good physical and chemical properties. Among them, nickel ferrite comes under the category of soft spinel ferrites having some $Fe^{3+}$ ions occupying the tetrahedral or A sites of the inverse spinel structure, while some $Ni^{2+}$ ions and few $Fe^{3+}$ ions occupy the octahedral or B sites [1]. Nickel ferrites nanoparticles find suitable for their applications in gas sensing and humidity sensing, dye degradation, MERAM and RERAMs, switching device applications, electronic, electrical and catalytic applications [2]. They come under the category of multiferroics because they are capable enough to exhibit more than two ferroic orderings at the same time. It can also exhibit M-E coupling effect in which electric field can be varied by magnetic field or vice-versa [3]. Also, nickel ferrites have low eddy current loss, high expansion coefficient, low saturation magnetic moment, high electrical resistivity and high chemical as well as electrical stability [4]. The multiferroics can be used to study the various applications performed in day-to-day life. Nickel ferrites are utilized as good core materials for power transformers in electronics and telecommunication because they have high electrical resistivity and low coercivity [5]. The 4f orbital of rare earth elements interacts with transition metal 3d electrons while being filtered by the 5 s and 5p orbitals. The reported electrical and magnetic properties of spinel ferrites are considerably impacted by the addition of rare-earth elements. The reason behind the doping of yttrium is to increase the porosity in the sample so that the material can be suggested to show good water sensing properties. Yttrium has been chosen as a dopant because it has the capability

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to reduce the coercivity of the pure nickel ferrite by decreasing its saturation magnetization. Less coercivity can be useful in many applications like fabricating soft core of transforms, high storage density recorders, etc. [6]. Thus this material can be suggested for many useful future applications and so we have fabricated the Y-doped cobalt ferrite nanoparticles having particle size <40 nm using sol–gel cost-effective auto combustion route.

## 2 Experimental Procedure

Yttrium doped $NiFe_2O_4$, ($NiY_xFe_{2-x}O_4$ where x = 0.05) nanoparticles (NPs) were synthesized using modified auto-combustion sol–gel method. Ferric Nitrate (99% purity, Loba Chemie) Yttrium(III) nitrate hexahydrate (99% purity, Sigma-Aldrich) and Nickel(II) Nitrate hexahydrate (98% purity, Loba Chemie) were mixed in stoichiometric ratio in distilled water separately using a magnetic stirrer for 30 min each. Then citric acid with ethylene glycol as a chelating agent in a ratio of 3:7 was added. With continuous 3 h of heating and stirring leads to formation of viscous YNFO gel. This formed YNFO gel is again heated to 200 °C until formation of dry brown powder takes place. The obtained powder was then grounded using pestle mortar for 10 min to form fine YNFO sample. This sample is then sintered at 700 °C for 5 h with the rise of 5°C/min in a muffle furnace and then circular pellets of diameter 10 mm were formed and characterization was done further to investigate its properties.

## 3 Results and Discussion

### *3.1 Structural Analysis*

The inset of Fig. 1 shows the XRD pattern of the yttrium doped nickel ferrite ($NiY_xFe_{2-x}O_4$ where x = 0.05) prepared by using sol–gel citrate method. All the peaks were correctly indexed using JCPDS card number # 074–2081. The nanocrystalline nature has been confirmed from the sharpened peaks as depicted by Fig. 1a while Fig. 1b shows that crystallite size varies linearly with the Bragg's diffraction angles. Using the Debye–Scherrer equation, the sample's crystallite size was determined to be around 15.4229 nm.

$$D = k\lambda/\beta Cos\theta \tag{1}$$

where K is the Scherrer constant, D is the crystallite size, FWHM is the full-width half maxima (FWHM), $\theta$ is the Bragg's diffraction angle, and λ is the wavelength of Cu–kα radiations.

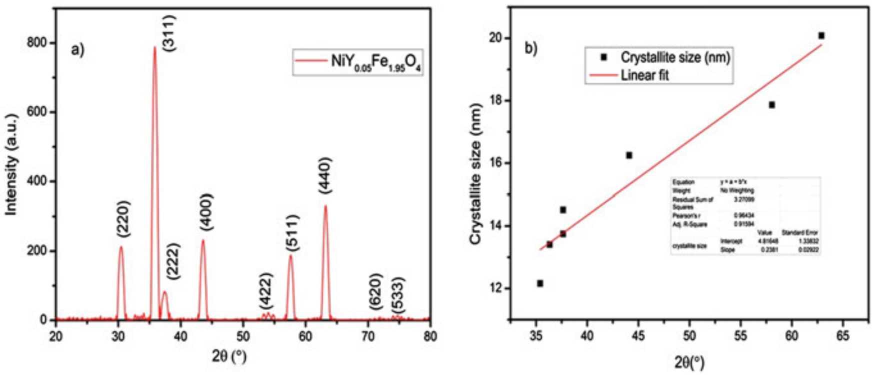


**Fig.1** **a** X-Ray diffraction patterns of yttrium doped nickel ferrites, **b** Crystallite size vs bragg's angle

## *3.2 Morphological Analysis*

FESEM (Field Emission Scanning electron microscopy) images have been obtained using Zeiss instrument as shown in Fig. 3a, b respectively. The grain size of the prepared samples have been calculated using ImageJ software and it comes around 34 nm. The particles obtained are circular in shape with huge amount of porosity can be observed. Also, with doping of yttrium in nickel ferrite, the particle size has also increased to ±20% ($NiY_{0.05}Fe_{1.95}O_4$) (Fig. 2).

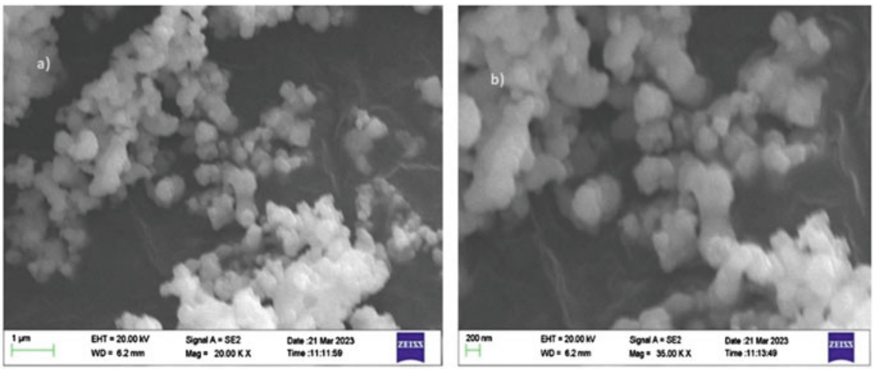


**Fig. 2** **a** FESEM image of Yttrium doped nickel ferrites nanoparticles

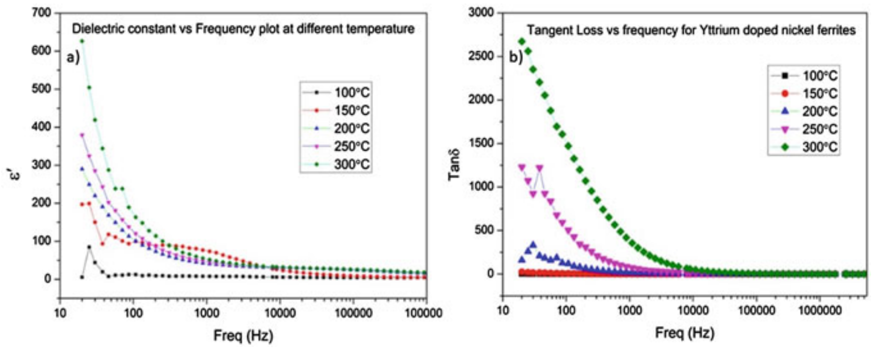


**Fig. 3** **a** $\varepsilon'$ against frequency at room temperature for yttrium doped nickel ferrite pellets sintered at 800 °C **b** and tangent loss with frequency from 10 Hz to 1 MHz

## 3.3 Dielectric Properties

The inset of Fig. 3 shows the two plots where Fig. 3a exhibits the plot of $\varepsilon'$ (dielectric permittivity) against frequency from 10 Hz to 1 MHz at room temperature (RT) while Fig. 3b shows the tangent loss with frequency at different temperature ranging from 100 °C till 300 °C. The Fig. 3a plot indicates that $\varepsilon'$ decreases with increase in frequency or we can say dielectric constant is higher at lower frequency and dielectric constant declines at higher frequency. The presence of dipolar relaxation processes is described by the significant step-like decreasing behaviour of dielectric constant with frequency. Figure 3b plot shows that the loss tangent is rising with the rise in temperature and lowers as the frequency range widens. The loss tangent's essentially insignificant value at higher frequency range suggests their use in high density storage device application [7].

## 3.4 Ferromagnetic Properties

The ferromagnetic properties in the prepared sample have been measured using VSM (vibrating spin magnetometer) which gives the variation of magnetization with the applied field as shown in Fig. 4. The M–H loop of yttrium doped nickel ferrite has very less coercivity which makes it useful for recording device, transformer cores and magnetic shielding device applications [8]. Also, the high value of saturation magnetization is also observed upon the yttrium doping. Very less value of coercivity has shown that prepared material perceives a soft magnets type nature which means that the magnetic characteristics of nickel ferrites doped with yttrium will be simpler to manage.

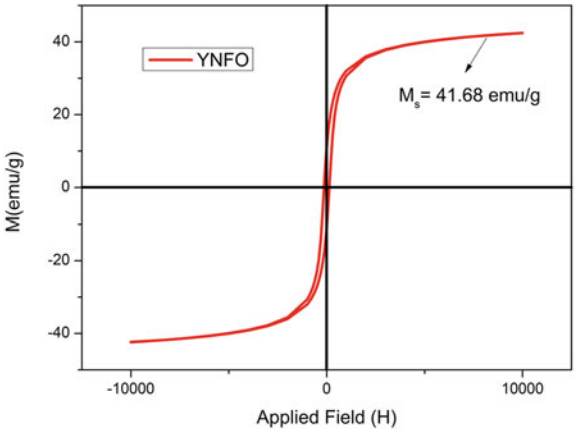


**Fig. 4** M–H loop for yttrium doped nickel ferrite nanoparticles at RT

# 4 Conclusion

The yttrium-doped nickel ferrites ($NiY_{0.05}Fe_{1.95}O_4$) effectively prepared using the affordable sol–gel auto-combustion technique. The XRD, FESEM, Dielectric and VSM analysis has been done to check the structural, dielectric and ferromagnetic properties of the material respectively. Very fine-sized nanoparticles (15 nm) have been prepared using this synthesis technique. The FESEM images show the spherical shape particles of $Y^{3+}$ doped nickel ferrites. The dielectric constant and tangent loss have been increased with the rise in temperature. The soft magnetic nature of nickel ferrites has been confirmed by the VSM analysis. Due to the porous nature, the material can be very useful for studying humidity sensors and hydroelectric cell applications.

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