

# Nickel ferrite Nanomaterials by Pulsed laser ablation in Water; Structural, Optical and Magnetic Characterizations

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## ABSTRACT

Nickel ferrite nanoparticles are synthesized by pulsed laser ablation of corresponding bulk target in the double distilled water. Focused output of fundamental and third harmonics from pulsed Nd:YAG laser operating at 40 and 25 mJ/pulse energy respectively was allowed to irradiate the target. Produced colloidal solution was red in color and stable for several days. XRD, FTIR, VSM techniques are used for the characterization of synthesized Nanomaterials. Materials synthesized with 1064 nm laser ablation have high degree of magnetization as compared to that synthesized by 355nm laser ablation.

## 1. INTRODUCTION

Nanoscale spinel ferrites have received much more attention of scientists due to its wide range applications in the field of magnetic recording media, ferrofluids, catalysts, medical diagnostics, drug delivery systems and pigments in paints and ceramics [1-3]. Ferrites with the spinel structure have a general formula  $MFe_2O_4$ . In a spinel unit cell, oxygen ions form close packing units with  $M^{2+}$  and  $Fe^{3+}$  ions distributed between tetrahedral A (8a) and octahedral B (16d) interstitial sites in the space group (SG)  $Fd\bar{3}m$ . In most cases ferrites with spinel structure have  $MFe_2O_4$  stoichiometry, where the cation/anion ratio is 3:4, although deviation from stoichiometry is possible. In the case of cation deficient spinels, the presence of vacancies leads to the modification of the cation valence, thus influencing the change of physical properties. Among all the spinel ferrites, Nickel ferrite has generated a large research effort in the past decades due to its high magnetic properties. Nickel ferrite is a typical soft ferromagnetic material, which crystallizes in a completely inverse spinel type with all nickel ions located in octahedral sites and iron ions occupying tetrahedral and octahedral sites. There are several reports have been described for synthesis of nickel ferrite Nanomaterial by ball milling, co-precipitation, sonochemical, wire discharge, microwave plasma, co-precipitation in reverse micelle, sol-gel, hydrothermal and laser ablation methods [4-8]. Compared to the chemical routes, laser ablation technique in liquid media appears to be promising.

The goals of this work are: (i) to synthesize Nanoscale ferrites by pulsed laser ablation, (ii) to analyze the x-ray powder diffraction, (iii) to investigate structural

characterization by FTIR spectroscopy, (iv) to study magnetic properties using VSM measurements, along with change in magnetization with temperature (v) Effect of laser wavelength on the magnetic behavior of synthesized ferrites. .

## 2. EXPERIMENTAL

### 2.1 Preparation of bulk target

For synthesizing the bulk target of nickel ferrite,  $NiFe_2O_4$ , Nickel oxide and  $\alpha-Fe_2O_3$  of AR Grade were taken in the 3:7 ratio and mixed in homogenizer pot for 2 hours and the obtained powder was annealed at  $600^\circ C$  for 10 hours. After the annealing the powder was again mixed by homogenizer and then powder was pressed to make pellet at 10 Torr pressure.

### 2.2 Nanoparticles synthesis & characterizations

The pellet target of Nickel ferrite was placed on the bottom of glass vessel containing pure deionized water was allowed to irradiate with focused output of 1064nm and 355nm from pulsed Nd:YAG laser (Spectra Phys., Quanta Ray, USA) operating at 40 mJ/pulse energy and 25 mJ/pulse energy, for 2 hours. Produced colloidal solution was red in color and stable for several days.

The colloidal solution of nickel ferrite was centrifuged and dried at  $70^\circ C$  to obtained powder for further characterizations. XRD spectrum of the powder was recorded on Pan- Alytical X-ray diffractometer using  $Cu-K\alpha$  line. Dried powder was dispersed into KBr discs and palletized at 10-ton pressure. Obtained pellet was suspended in the path of IR beam of Perkin Elmer RX-1 IR spectrometer, for recording FTIR spectrum in the wavenumber region of  $400 - 4000\text{ cm}^{-1}$ . For magnetic characterization VSM spectra were recorded on ADE-DMS, VSM, model EV-7, made in USA.

### 3. RESULTS and DISCUSSION

#### 3.1 X-ray diffraction (XRD)

Figure 1 shows XRD spectrum of as synthesized nickel ferrite synthesized by laser ablation using 1064nm wavelength of Nd:YAG laser. The peak at  $2\theta = 35.66^\circ$ ,  $43.20^\circ$ ,  $57.37^\circ$  and  $62.85^\circ$  correspond to (311), (400), (333), and (440) plane of  $\text{NiFe}_2\text{O}_4$  confirm the synthesis of nickel ferrite (JCPDS No. 03-875).

The crystallite size can be calculated from XRD spectrum by using Scherrer formula

$$D = 0.9\lambda / \beta \cos\theta$$

Where D is the crystallite size,  $\beta$  is full width at half maxima for the peak corresponding to  $\theta$ .

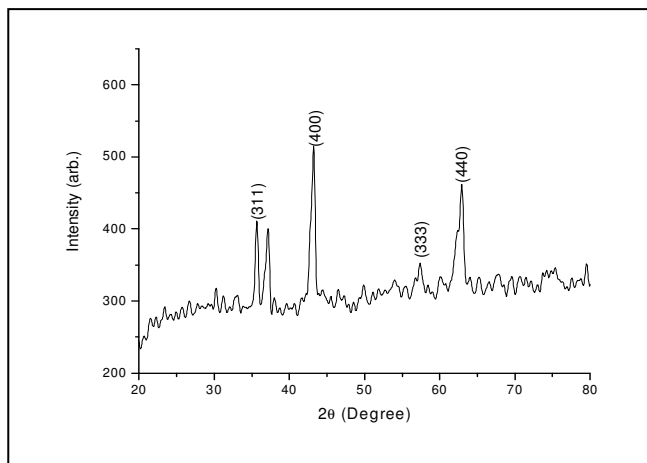


Figure 1: XRD spectrum of nickel ferrite material synthesized by pulsed laser ablation using 1064nm wavelength of laser.

The crystallite size is found to be 16 nm corresponding to (400) plane of the Nickel ferrite. Thus, XRD results confirm the synthesis of nano size Nickel ferrite.

#### 3.2 Vibrating Sample Magnetometer (VSM)

The hysteresis loop of nickel ferrite Nanomaterial synthesized by pulsed laser ablation using laser wavelength of 355nm and 1064 nm are shown in figure 2 (a) and (b) respectively. Saturation magnetization ( $M_s$ ), remanent magnetization ( $M_r$ ), and coercivity ( $H_c$ ) of the sample (a) is found to be 0.72 emu/gram, 0.17 emu/gram and 146.6 Oe respectively, while that of case (b) these are found to be 8.23 emu/gram, 2.13 emu/gram and 143.45 Oe respectively. At particular applied magnetic field, magnetization value for the material synthesized by 1064 nm is 10-12 times higher than that synthesized with 355 nm laser light. It shows that change in laser wavelength induces some strong domains or defects or alignment of magnetic domains, which are responsible for magnetization. Variation in the

magnetization with temperature of the sample synthesized by 1064 nm wavelength of Nd:YAG laser with 350 Oe applied field is depicted in figure 3. It is clear from figure 3 as temperature increases magnetization of the Nanomaterial decreases. There is 2.0 emu/gm magnetization at  $710^\circ\text{K}$ , which becomes constant with temperature. It is evident from figure 3, that the room temperature ( $298^\circ\text{K}$ ) magnetization is 3.8 emu/gm, while 2.0 emu/gm magnetization becomes constant above  $710^\circ\text{K}$ . Such type of magnetic materials may be applicable for the fabrication of storage media working at high temperature space research. The comparative plot of hysteresis loop of Nickel ferrite Nanomaterial synthesized by pulsed laser ablation using 355nm and 1064nm wavelength of Nd:YAG laser is shown in figure 4.

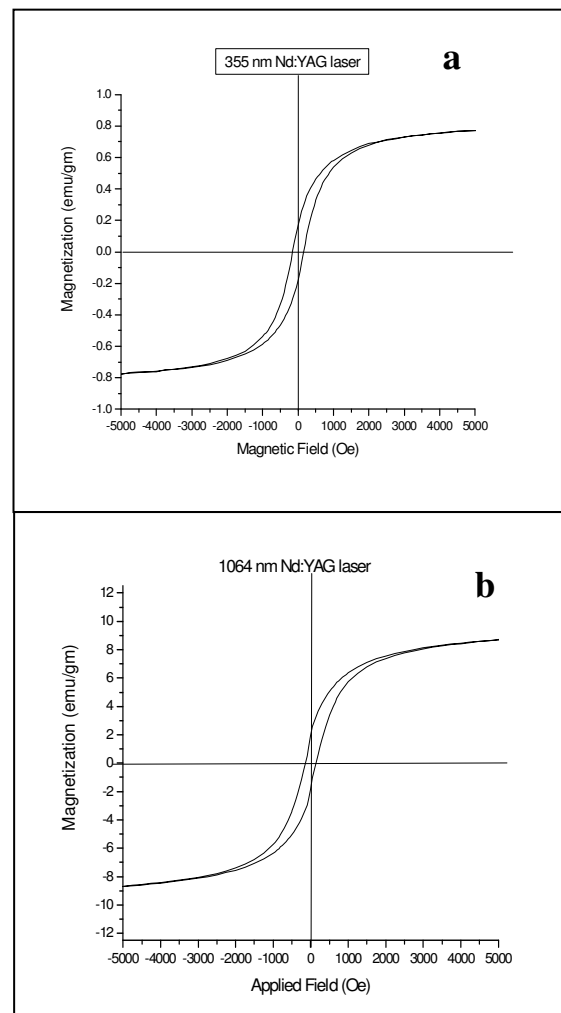


Figure 2: VSM characterization of Nickel ferrite Nanomaterial synthesized by pulsed laser ablation using (a) 355nm and (b) 1064 nm of Nd:YAG laser.

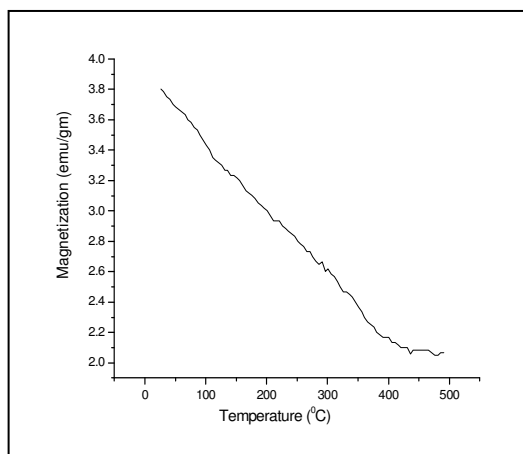


Figure 3: Magnetisation Vs. temperature plot for the Nickel ferrite Nanomaterial synthesized by pulsed laser ablation using 1064 nm wavelength of laser.

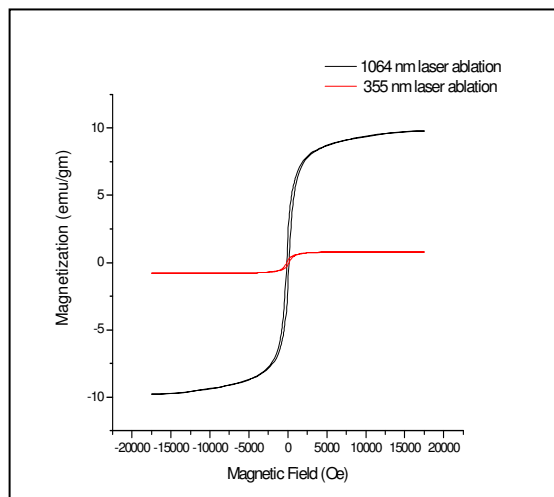


Figure 4: VSM characterization of Nickel ferrite Nanomaterial synthesized by pulsed laser ablation using (a) 355nm and (b) 1064 nm of Nd:YAG laser.

### 3.3 Fourier Transform Infra Red (FTIR)

Fourier transform Infrared spectrum of the Nickel ferrite Nanomaterial is displayed in figure 5. It is clear from FTIR spectra that there is much more difference in the stoichiometry of Nickel ferrite Nanomaterial synthesized by 1064nm with comparison to 365nm wavelength of Nd:YAG laser. The formation of the spinel  $\text{NiFe}_2\text{O}_4$  structure in the nanocrystalline  $\text{NiFe}_2\text{O}_4$  samples is further supported by FT-IR spectra shown in figure 5. Here we consider two ranges of the absorption bands,  $400\text{--}4500\text{ cm}^{-1}$  and  $400\text{--}1200\text{ cm}^{-1}$ . The intensive broadband at  $3450\text{ cm}^{-1}$  and the less

intensive band at  $1620\text{ cm}^{-1}$  are due to O–H stretching vibration interacting through H bonds. In the range of  $400\text{--}1200\text{ cm}^{-1}$ , two main metal–oxygen bands at  $620\text{ cm}^{-1}$  and  $450\text{ cm}^{-1}$  are observed in the FT-IR spectra of all of the  $\text{NiFe}_2\text{O}_4$  samples. These two bands are usually assigned to vibration of ions in the crystal lattices. The band at  $620\text{ cm}^{-1}$  corresponds to intrinsic stretching vibrations of the metal at the tetrahedral site ( $\text{Fe} \leftrightarrow \text{O}$ ), whereas the band at  $\sim 450\text{ cm}^{-1}$  is assigned to octahedral-metal stretching ( $\text{Ni} \leftrightarrow \text{O}$ ). There are two additional

IR transmission peak in the sample synthesized by 1064 nm laser at  $620$  and  $1112\text{ cm}^{-1}$ . These IR peaks conclude laser wavelength induced structural or phase transformation in the Nickel ferrite nanoparticles. There may be some additional interaction between  $\text{NiO}$  and  $\text{Fe}_2\text{O}_3$  molecules at some

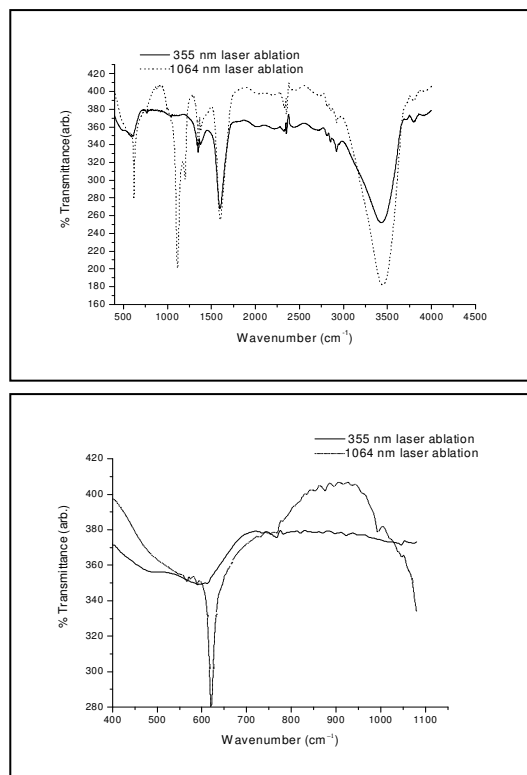


Figure 5: FTIR spectrum of Nickel ferrite Nanomaterial synthesized by laser ablation using 355nm and 1064 nm wavelengths of Nd:YAG laser.

specific sites, which may be the reason of enhanced magnetization in this sample.

It is clear from the figure 4, that there is very high magnetism, saturation magnetization and remanent magnetization in the materials synthesized by 1064 nm laser as compared to 355 nm. Therefore laser wavelength induces some specific change in the structural arrangement and phase of the nanoparticles, which is also supported by appearance of some additional IR absorption peaks at  $620$  and  $1112\text{ cm}^{-1}$ .

Temperature vs magnetization curve shows that almost 52% magnetization of the room temperature magnetization remains in the sample at quite high temperature

(710 °K), which suggest their possible application in the high density data storage at high temperature space applications.

## 5. CONCLUSIONS

We have successfully synthesized the ferrite nanoparticles by pulsed laser ablation in pure deionized water using 355nm and 1064nm wavelength of Nd:YAG laser. Strong change in magnetization with laser wavelength concluded laser induced structural and phase transformation in the nanomaterials. Synthesized nanomaterials may be applicable for high temperature data storing devices.

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