## Jordan Journal of Physics

## ARTICLE

### Study of Structural and Magnetic Properties of Co-doped M-Type Sr-Hexaferrite Nanoparticles

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*Doi:* https://doi.org/10.47011/15.1.8 *Received on: 01/08/2020;* 

Accepted on: 08/07/2021

**Abstract:** The aim of this work is to synthesize nanocrystalline  $SrFe_{10}Co_3O_{19}$  with M-type hexaferrites *via Sol-gel* auto-combustion method. The synthesized powders were consequently subjected to calcination at 900°C for 6h. The synthesized samples are characterized by X-ray diffraction (XRD) to find structural parameters. The XRD results exposed single hexagonal magnetoplumbite phase formation in the heated samples. The morphology of the compound was revealed by Field Emission Gun Scanning Electron Microscopy (FEG-SEM). Vibration Scanning Magnetometer (VSM) provides the magnetic nature of the compound. It shows that the decrease in coercivity was affected by doping of  $Co^{2+}$  ions.

Keywords: M-type hexagonal ferrites, SEM, Sol-gel, VSM, XRD.

#### Introduction

The M-type hexaferrite  $SrFe_{12}O_{19}$  (Sr-*M*) was discovered in the early 1950s. In view of the large volume of the market and over this long time, many attempts have been made to improve the key magnetic properties by various techniques, including doping on the Co<sup>2+</sup> sublattices [1].

Magnetic properties of calcium hexaferrite strongly depend on the preparation technique and nature of applied precursors. In recent years, magnetic nanoparticles have been subjected to intense research, because finite-size effects dominate the magnetic properties of nano-sized particles and become more important with the decrease of the particle size. These properties lead to the large application of nanomaterials in loading coils, magnetic storage media and biosensor devices. This critical diameter typically lies in the range of a few tens of nanometers and depends on the material [2, 3].

Five different positions of iron ions define the magnetic structure of the M-type hexaferrite crystals and replacing one or more iron ions by other elements changes the magnetic and microwave material properties dramatically [2]. Hexaferrites are widely used in microelectronics because of their possible modification. The most prospective materials for electronics are lead, barium, strontium M-type hexaferrites and their doped compositions [4, 5]. The Cobalt divalent ions diffuse into magnetoplumbite hexaferrites with other divalent materials with heating treatment then found distribution of ions in tetrahedral and octahedral sites which gives its possible applications [13]. The prime objective of the present study is to achieve higher magnitudes of M<sub>S</sub> and maximum value of [B-H] curve without significant drop in  $H_C$  for the sintered isotropic SrFe<sub>12</sub>O<sub>19</sub>[6].

This paper is devoted to structural and magnetic study of Sr-M-type hexaferrites.

#### Experimental

Sr-M hexaferrites compound was synthesized in polycrystalline form by the Sol-gel autocombustion method. Strontium Nitrate (0.8827 gm), Cobalt Nitrate (7.284 gm), Ferric Nitrate (13.48 gm) and Urea (8.4355 gm) with molar concentrations were mixed with 30 ml. of deionized water to form a solution. Here, Urea is used as a fuel and works as a catalyst. The metallic ions solution is gradually heated on a metallic hot plate for 4 hours for the formation of a gel. This mixture of metallic gel is further burnt in microwave oven for very short period of time to get better molecular homogeneity. Finally, extracted burnt dry ash is grained mechanically by a pestle and mortal and calcinated in a muffle furnace at 900°C for 6 hours [7].

#### **Results and Discussion**

#### X-Ray Diffraction (XRD) Analysis

The prepared sample of  $SrCo_3Fe_{10}O_{19}$  was examined by X-ray diffraction graphs in order to study the ferrite phase and to determine the particle size. Powder method was used where Xrays are diffracted, not by a single crystal, but a sample consisting of a very large number of randomly oriented crystalline particles; i.e.,in powder form.

The XRD patterns for the  $SrCo_3Fe_{10}O_{19}$ ferrite are shown in Fig 1. Phase formation studied by XRD (MDI-Jade) revealed the identification of hexagonal ferrite phases similar to JCPDS card no. 27-1029. It is evident from the XRD plots that the samples are composed of magnetoplumbite crystal structure; namely, hexagonal M-phase ferrite. There were no metal oxide phases in the burnt powder and no extra lines were detected, hence confirming the single magnetoplumbite phase in the reported samples. The space group for the samples is observed to be P<sub>6</sub>mmc [7].



FIG. 1. XRD pattern of SrFe<sub>10</sub>Co<sub>3</sub>O<sub>19</sub>hexaferrite.

The structure and crystallite size were evaluated from XRD measurements. The crystallite size of the nano-crystalline samples was measured using Debye-Scherer formula [8]:

$$D_{XRD} = 0.98\lambda/\beta \cos\theta \tag{1}$$

where,  $\lambda$  is the wavelength of X-ray used in Å,  $\beta$  is the full width at half-maximum (FWHM) in radians for 2 $\theta$  scale,  $\theta$  is the Bragg angle,  $D_{XRD}$  is the crystallite size in nm. The burnt powders were calcined at 900 °C for 6 hrs to get a more crystalline homogeneous hexagonal phase. The average crystallite size of calcined powder was 22 nm.

#### Morphological Study by Scanning Electron Microscopy (SEM)

In this section, morphological properties of the synthesized samples are recorded and studied. Typical FE-SEM image [JSM-7600F] at IIT Bombay Powai, of the sample Sr-M hexaferrite synthesis *via* Sol-gel method annealed at 900°C, is shown in Fig 2. The image reveals that the particles have an almost regular shape and homogeneous distribution. It is also observed that the nanoparticles have nearly spherical morphology and are agglomerated with each other with average particle size and particle size distribution from SEM analysis is found to be from 20 to 40 nm.



FIG. 2. SEM micrograph of SrFe<sub>10</sub>Co<sub>3</sub>O<sub>19</sub>hexaferrites.

TABLE 1. Tabular rep	resentation of	sample	parameters.
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Composition	a Å	c Å	c/a	Average Particle Size (nm)
SrFe <sub>10</sub> Co <sub>3</sub> O <sub>19</sub>	6.13	23.05	7.76	22

#### Magnetic Study by VSM

The magnetic properties of the synthesized nanoparticles are analyzed using a Vibrational Sample Magnetometer (Lakeshore VSM 7410, SAIF IIT Madras) at room temperature (300 K) in the range of approximately -1500 to +1500

Gauss. Fig. 3 shows the M-H curves of the prepared  $SrFe_{10}Co_3O_{19}$  nanocrystals. The coercivity (H<sub>c</sub>) and saturation magnetization (M<sub>s</sub>) values have been directly extracted from these curves and have been listed for x = 3 concentrations of Co<sup>+2</sup> ions.



FIG. 3. VSM pattern of SrFe<sub>10</sub>Co<sub>3</sub>O<sub>19</sub> hexaferriite.

Strontium hexaferrite, with the chemical formula  $SrFe_{10}Co_3O_{19}$ , is one of the M-type hexagonal ferrites and belongs to the magneto-plumbite group of oxides. In magneto-plumbite, the interaction between two close sites, such as

2a-12k, 2a-4 $f_1$  and 4 $f_1$ -12k, has been decisive for the strong magnetic character [10-12].

In this section, magnetic properties of samples directly extracted from VSM data, like

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Strontium Hexaferrite Nanoparticles under the influence of the applied field [15, 16]. The large value of coercivity shows that the sample belongs to the hard ferrite category.

THELE 2. Tuotiai representations of magnetic parameters.									
Composition <sup>a</sup> Å	а	с	c/a	Retentivity	Magnetization	Coercivity Hc	Particle Size		
	Å	Å		Mr(emu)	Ms (emu/g)	(Gauss)	(nm)		
SrFe <sub>10</sub> Co <sub>3</sub> O <sub>19</sub>	6.13	23.05	7.76	0.11549	36.28	1625	22		

TABLE 2. Tabular representations of magnetic parameters

#### Conclusion

Nanoparticles of cobalt-doped strontium hexaferrite have been successfully synthesized using the sol-gel technique. Cobalt substitution has brought about remarkable improvements in the structural and magnetic properties of strontium ferrite.

The XRD analysis confirmed the formation of nanocrystalline hexagonal magnetoplumbide

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structure. The crystallite size of the synthesized nanoparticles was calculated by Debye-Scherer formula and found to be 22 nm. The values of crystallite size and particle size are calculated from the XRD. The high saturation magnetization value can be explained by the fact that the particles are single domain with higher magnetic moments.

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