Study of structural and magnetic properties for the magnetic system \( \text{Ba}_{0.2}\text{Sr}_{0.8}\text{Fe}_{12}\text{O}_{19} \) nanoparticle powder via chemical coprecipitation method

Mustafa Ali Abbas\(^1\)\(^,\) Khalid I. Ajeel\(^1\)\(^,\) and Raheem Abed jeber\(^3\)

\(^1\)Department of physics, College of education for pure science, University of Basrah, Basrah, Iraq.
\(^2\)Department of physics, College of education, University of Al-Qadisiyah, Al-Qadisiyah, Iraq.
\(^3\)College of dentistry, University of Al-Qadisiyah, Al-Qadisiyah, Iraq

E-mail: \(^a\) Mustufa.alobaidi@qu.edu.iq
\(^b\) hlo221180@gmail.com

Abstract. The present work is an experimental study and interested in hexaferrite samples preparation of the system \( \text{Ba}_{0.2}\text{Sr}_{0.8}\text{Fe}_{12}\text{O}_{19} \) nanoparticle powder by chemical coprecipitation method used to prepare fine nanoparticles. The structural properties of this system have been investigated using scanning electron microscopy-Energy dispersive X-Ray spectroscopy (SEM-EDS) and were found the average grain size to be (33.685)nm. Magnetic properties were calculated by vibrating sample magnetometry (VSM), it was the results proved that the saturation magnetization reaches to (85.633)emu/gr and the residual magnetization is (39.342)emu/gr. The coercivity of (4665.909)Oe is also observed. The hysteresis loop was studied and shown that, this system of hard ferrite materials.

1. Introduction

The hexagonal ferrites with a magnetic structure It is classified as a semiconductor and a general formula It can be expressed as \( \text{MO.6Fe}_2\text{O}_3 \) where (M= Ba, Sr, pb) are well known permanent magnets. In view of ferrite's excellent magnetic properties and chemical stability, ferrite is commonly used as permanent magnets and in magnetic recording media. For example, glass crystallization, hydrothermal precipitation, sol-gel \([1]\), chemical coprecipitation \([1,2]\), and mechanical alloying \([3,4]\) are some of the techniques for ferrite powder synthesis that have been identified. The traditional method for making barium-strontium ferrite magnets is to sinter stoichiometric mixtures of hematite (\( \text{Fe}_2\text{O}_3 \)) and barium-strontium carbonate after firing at a high temperature of reach to 1200 °C. Noting that it is not easy to obtain a complete and clear concept of the melting point of such compounds that are described as oxide compounds because the surrounding conditions have a clear effect on the composition of these compounds, and this will certainly lead to the inaccuracy of the required measurements, but the approximate melting point of the ferrite compounds is very important to determine. The sintering temperatures, which is usually done at temperatures lower than the melting point. Also due to the high sintering temperature induces an increase in crystal growth and lowers the coercivity below the measured theoretical values. Permanent magnet applications \([5,6]\) and microwave absorption devices in the GHz range \([7,8]\) use magnetic materials with high coercivity magnetization and remnant
magnetization, while data storage magnetic recording applications [9,10] use materials with modest coercivity magnetization and high remnant magnetization. Because of excellent properties for these hexagonal ferrites, such as high saturation magnetization [11], high resistivity, tunable coercivity magnetization [12,13], high temperature [14], and low cost [15,16], these hexagonal ferrites have been widely studied in recent years.

In this work, chemical coprecipitation was used to make barium-strontium ferrite because it is a simple procedure and the mixture of substrates formed during the precipitation can prevent high temperatures, obviating the need for post-firing grinding. When it comes to chemical coprecipitation, to produce ultrafine dispersed barium-strontium ferrite particles, mechanical milling with a dispersing agent has been successfully used. Therefore the method produced barium-strontium ferrite with excellent magnetic properties. Then the structural and magnetic properties of the formed ferrite compound were studied by proportions $\text{Ba}^{1-x}\text{Sr}^x\text{Fe}_{12}\text{O}_{19}$ according to the phase diagram shown in the figure 1.

![Figure 1. (left) Phase diagram of SrO-Fe$_2$O$_3$ and (right) Phase diagram of BaO-Fe$_2$O$_3$.](image)

2. Experimental

2.1 Materials and synthesis
Barium nitrate $[\text{Ba(NO}_3^2]$], strontium nitrate $[\text{Sr(NO}_3^2]$ and iron nitrate $[\text{Fe(NO}_3^3]$ were used as the preliminary materials with the chemical coprecipitation method. The weight ratio between $[\text{Ba(NO}_3^2]$ and $[\text{Fe(NO}_3^3]$ also between $[\text{Sr(NO}_3^2]$ and $[\text{Fe(NO}_3^3]$ was 1:12. So that both barium ferrite and strontium ferrite were prepared and mixed in proportion $(X=0.8)$ let's get $\text{Ba}_{0.2}\text{Sr}_{0.8}\text{Fe}_{12}\text{O}_{19}$ from $\text{Ba}^{1-x}\text{Sr}^x\text{Fe}_{12}\text{O}_{19}$. The nitrate salts were dissolved in deionized water, then ammonium hydroxide solution $(\text{NH}_4\text{OH})$ gradually was added to grow the pH degree of the solution to 10 in order to coprecipitate the mixture. The precipitate material was by filtration method and washed more than once with distilled water and then dried process by heating at 120 °C for 4-8 hrs. The dried material is ground into a powder with a ceramic mill and then a sintering process at 1000 °C for 6 hrs which is the final burn. Therefore the ferrite $(\text{MFe}_{12}\text{O}_{19})$ where $(\text{M}= \text{Ba, Sr})$ is obtained with this method.

2.2 Measurements
The structure was sampled using x-ray diffraction (XRD - Cu Ka1 1.54 Å) at room temperature to identify the crystal structure of the powder sample. VSM with an applied magnetic field around 15 kOe at room temperature is used to study the magnetic properties of the saturation magnetization, residual magnetization and coercivity of this sample. The surface morphology of the sample was checked by scanning electron microscope – energy dispersive spectroscopy (SEM-EDS) to photograph and determine the average grain size of the sample.
3. Results and discussion

3.1. Structural properties of hexagonal ferrite

Through measurements, the XRD diffraction for calcined samples of barium ferrite BaFe$_{12}$O$_{19}$ and strontium ferrite SrFe$_{12}$O$_{19}$ prepared by chemical coprecipitation. BaFe$_{12}$O$_{19}$ (00-027-1029) was compared with international standard specifications ASTM-276 [17] and SrFe$_{12}$O$_{19}$ (00-033-1340) is also corresponding to international standard specifications [18] the phases are proved by the X-ray reflections. Distinctly revealing that hexaferrite phases are structured after calcined at 1000 °C, where all the diffraction peaks could be identified in the hexagonal phases from BaFe$_{12}$O$_{19}$ and SrFe$_{12}$O$_{19}$ shown in figure 2. The average crystallite size $D$ (nm) from of width-maximum at the prominent peaks FWHM using the relation of the Scherrer’s and density of dislocations $\partial$ (Line/Cm$^2$) of crystallite size $D$ (nm) were the calculated and showed in the table 1.

Table 1. Shown the average crystallite size and density of dislocations for prepared compounds of the barium-strontium.

| Compound  | 2 $\Theta$ (deg) | $d$ (Å) | hkl | FWHM (deg) | $\lambda$ (Å) | $D$ (nm) | $\partial$ (Line/Cm$^2$) |
|-----------|-------------------|---------|-----|-------------|--------------|---------|------------------|
| BaFe$_{12}$O$_{19}$ | 33.245            | 2.692   | 104 | 0.219       | 1.54         | 38.5    | 0.0006           |
| SrFe$_{12}$O$_{19}$ | 32.485            | 2.753   | 107 | 0.291       | 1.54         | 28.87   | 0.0011           |

XRD measurements showed that the prepared ferrite is a nano-compound and the crystals of the compound possessed the characteristic of sphericity.

![XRD pattern of the powder samples prepared at 1000 °C, (left) barium ferrite and (right) strontium ferrite.](image)

Figure 2. XRD pattern of the powder samples prepared at 1000 °C, (left) barium ferrite and (right) strontium ferrite.

The SEM-EDS measurements for Ba$_{1-x}$Sr$_x$Fe$_{12}$O$_{19}$ show the morphologies of the ferrite high soft and have characterized a homogeneous hexagonal morphology calcined at 1000 °C for 6 hrs. Comparing the sample's surface characteristics the pores gradually become more with the Ba decreasing from (X = 0) to (X = 0.8). Then, with (X = 1), the surface porosity decreases, as shown in figures 3-5.
Figure 3. $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ when ($X = 0$).

Figure 4. $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ when ($X = 0.8$).

Figure 5. $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ when ($X = 1$).

EDS analysis showed that the samples were very high purity and rich in Iron oxide elements and the sample generated was mixed from barium, strontium and Iron oxide, as shown in figures 6-8.
Figure 6. $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ when ($X = 0$).

Figure 7. $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ when ($X = 0.8$).

Figure 8. $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ when ($X = 1$).
3.2. Magnetic properties of hexagonal ferrite

From the VSM, the saturation magnetization ($M_s$), residual magnetization ($M_r$) and coercivity field ($H_c$) values are identified [19,20] for $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ when $(X = 0, 0.8, 1)$, as shown in table 2. The hysteresis loops for barium-strontium ferrite, are shown in figures 9-11.

**Figure 9.** $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ when $(X = 0)$.

**Figure 10.** $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ when $(X = 0.8)$.

**Figure 11.** $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ when $(X = 1)$. 
Table 2. Shown the values are identified by VSM for samples (x =0, 0.8, 1).

|        | T (°C) | M₀ (emu/gr) | Mᵣ (emu/gr) | Hₑ (Oe)  |
|--------|--------|-------------|--------------|----------|
| X = 0  | 1000   | 77.7        | 34.763       | 4375.049 |
| X = 0.8| 1000   | 85.633      | 39.342       | 4665.909 |
| X = 1  | 1000   | 83.640      | 38.469       | 4953.664 |

The saturation magnetization, residual magnetization and coercivity field calculated at room temperature, of the barium-strontium ferrite particles are shown in figure 12. However, the high saturation magnetization and residual magnetization when (X = 0.8) of this sample indicated the substitution method of barium with strontium ferrite In a certain percentage. The difference in the values of this sample (X = 0.8), as shown in figures 13,14.

![Figure 12](image1.png)

**Figure 12.** Ba₁₋ₓSrₓFe₁₂O₁₉ when (X = 0, 0.8, 1).

![Figure 13](image2.png)

**Figure 13.** The sample (X = 0.8) shows a different behavior from the rest of the samples.
Figure 14. The sample ($X = 0.8$) shows a different behavior from the rest of the samples.

Figure 15. This is an illustration of what's inside the circles.

4. Conclusion

The barium-strontium ferrite in the form $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ ($X = 0, 0.8, 1$) has been successfully prepared via method chemical coprecipitation. The $\text{Ba}_{1-x}\text{Sr}_x\text{Fe}_{12}\text{O}_{19}$ ferrites are of powder with the semimagnetization structure formed. The barium-strontium ferrite particles, have a hexagonal morphology and especially with the calcination temperature high. The magnetic properties are clearly influenced by chemical composition and the average grain size. The $M_s$ and $M_r$ values of the barium-
strontium ferrite increase at (X = 0.8) more than at (X = 0, 1) respectively because of the arrangement and distribution of dipoles in the barium with strontium substitution in certain proportions.

5. References

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