

## Research Article

# Structural, Electrical, and Magnetic Study of $\text{SrNi}^{2+}(\text{Li}^{1+}\text{Fe}^{3+})_{0.5}\text{Fe}_{16}\text{O}_{27}$ Ferrite

P. R. Arjunwadkar, M. Y. Salunkhe, and C. M. Dudhe

Department of Physics, Government Institute of Science, R.T. Road, Nagpur 440001, Maharashtra, India

Correspondence should be addressed to P. R. Arjunwadkar; [parjunwadkar@yahoo.com](mailto:parjunwadkar@yahoo.com)

Received 29 August 2013; Revised 8 November 2013; Accepted 8 November 2013

Academic Editor: Veer Pal Singh Awana

Copyright © 2013 P. R. Arjunwadkar et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

W-type ferrite having chemical formula  $\text{SrNi}(\text{LiFe})_{0.5}\text{Fe}_{16}\text{O}_{27}$  was prepared by using conventional solid state reaction method at little low temperature (1100°C). The prolonged and continuous heating resulted in better product formation and it has validated that the Lithium present in the compound facilitates the synthesis. Typical IR bands observed are assigned to the Fe–O bonds in S block of W ferrite structure and the band near  $914.3\text{ cm}^{-1}$  is assigned to the stretching vibrations of Sr–O. High resistivity is found which suggested presence of very small amount of mixed valency cations on equivalent lattice apart from the little amount created due to the release of an electron by divalent Ni to become trivalent. The magnetic properties of compound do not differ much from those of the reported for  $\text{SrNi}_2\text{W}$  ferrite except a little decrease in saturation magnetization at room temperature due to canting effect. The experimental observations support presumed site preferences to a greater extent and also the prediction that the Li present on  $4f_{VI}$  sub-lattice results in small canting effect of 12k cations. The low value of coercivity observed is attributed to the larger particle size resulting due to prolonged heating.

## 1. Introduction

The W-type hexagonal ferrites, having chemical formula  $\text{Ba/SrM}_2\text{Fe}_{16}\text{O}_{27}$  where M stands for divalent metal ion, belong to a very large family of hexagonal ferromagnetic oxides. The crystal structure of W-type ferrite has been described for the first time by Braun [1]. It can be considered as a stacking of R and S blocks along the hexagonal *c* axis: RSSR\*S\*S\*... The space group assigned for W-type ferrite is  $P6_3/mmc$  or  $D_{6h}^4$  (number 194) [2].

Because of the technological applications such as permanent magnets and microwave device materials, hexagonal ferrites are being studied. Among them, the W-type ferrites are investigated largely because of the different substitutions feasible by suitable choice of divalent metal ion [3–6]. W-type ferrite does not contain any monovalent cation, but a combination of monovalent cation with some multivalent cations for charge compensation may be substituted for the divalent metal ion. The critical literature survey showed that meagre work has been done in this direction except for the compound  $\text{SrZn}(\text{LiFe})_{0.5}\text{Fe}_{16}\text{O}_{27}$  [7–10].

Ni substitution has found to play an important role in tailoring properties of ferrites and hence it was decided to investigate the electromagnetic properties of the compound having chemical formula  $\text{SrNi}(\text{LiFe})_{0.5}\text{Fe}_{16}\text{O}_{27}$ . As far as we know, the compound studied in the present investigations, is being reported for the first time.

## 2. Materials and Methods

The  $\text{SrNi}(\text{LiFe})_{0.5}$ -W-type compound, in the present investigations, was prepared using the standard solid state reaction method [11]. The AR grade reacting oxides and carbonates were first heated at 200°C for 2-3 hours for removal of traces of moisture if present. After cooling them to room temperature, their stoichiometric quantities were taken by using monopan balance. These were then mixed together in an agate mortar with AR grade acetone continuously about 5-6 hours to achieve uniform grain size and also homogeneity.

The mixture thus obtained was added with 5% polyvinyl acetate (PVA) solution in AR grade acetone as a binder and mixed thoroughly. This PVA mixed compound was then

pressed in a hydraulic press for few minutes at pressure up to 5 tones. The pellets thus obtained were heated in an electric furnace at 300°C for about 4 hours to remove the binder. The temperature of the furnace was then raised slowly to 900°C and maintained for 24 hours. The preheated pellets of compound were taken out of the furnace and again crushed to fine powder. When mixed thoroughly, pellets were again prepared as described above. These pellets were then transferred to an electrically heated furnace for final heating. In this sintering process the temperature of furnace was initially raised up to 400°C, then maintained at this temperature for 4-5 hours, and then finally raised to 1100°C. This temperature was maintained for about 100 hours. The compound fired in this way was then cooled slowly at the rate of 1°C per minute till it reached 800°C. Afterwards, it was allowed to cool to room temperature by switching off the furnace.

In the present work X-ray diffractometer with filtered Cu K $\alpha$  radiation from X-ray tube, operating at 40 KV and 20 mA, was used for identification of compound. The X-ray diffraction graph, in the 2 $\theta$  range from 20 to 90 degrees, is recorded. The IR spectra of ferrites give information about the various vibrational modes in the ferrites which depend on the cation mass, cation-oxygen bonding force and distance, ionic radii, chemical nature of neighbouring cations, the unit cell dimensions, and so forth. The spectra in the range from 400 to 4000 cm<sup>-1</sup> were recorded at room temperature on infrared spectrometer; for this the ferrite powder was dispersed in KBr and pressed to get a clear disc.

Scanning electron microscope was used to study the morphology and get the idea about the particle size distribution. Standard procedure was adopted to get the SEM micrographs.

The critical literature survey revealed that the electrical properties of hexagonal W-type ferrites are less studied, compared to their magnetic properties. This may be due to the fact that they were developed initially as permanent magnet. Today W-type ferrites are finding applications in many diverse fields like microwave and hence their electrical properties are also becoming important. Two-probe method was employed for measurement of dc conductivity. The set-up consists of a sample holder made up of two brass electrodes and placed in an electrically heated furnace. The pellet specially prepared for the study was placed between the flat faces of electrodes. The resistance of the pellet at various temperatures was measured with the help of a LCR meter by connecting it across the electrodes.

In order to prepare pellet for the above observations the compound prepared was grounded to fine particle size in an agate mortar. The powder was mixed with 5% polyvinyl acetate solution made in AR grade acetone, as binder, and mixed thoroughly. This mass was then transferred to a die and pressed under pressure of 5 tons per cm<sup>2</sup> using a hydraulic press. The pellets, so prepared, were then heated in a furnace up to 500°C to remove the binder. After maintaining this temperature for few hours the pellets were slowly cooled to room temperature. In this way crack free pellets in the shape of a cylinder of small height were obtained. The end faces of the pellets, so prepared, were gently grounded over

zero number sand paper to ensure smooth surfaces. The dimensions of the pellets were measured accurately. The smooth and flat parallel faces of the pellets were coated with uniform thin layer of silver paste to facilitate a good electrical contact with the electrodes. The silver paste was dried by heating the pellet slowly for few hours in air at 500°C. The thin coating of silver paste thus formed was adherent and chemically inert pellets were stored in desiccators.

The graph of ln  $\sigma$  against 1/T was plotted and from the slope of the graph the activation energy for the compound was calculated using the following relation:

$$\Delta E = 8.617 \times 10^{-5} \left[ \frac{\Delta \ln(1/\sigma)}{\Delta(1/T)} \right]. \quad (1)$$

The thermoelectric studies were carried out using two-probe set-up fabricated in the laboratory. The set-up again consists of two electrodes; one is having flat surface while another, which was heated, is tapering. A thick pellet was placed between the electrodes and the emf generated across the electrodes at various temperature differences between the two electrodes was measured. The measurements were taken in the temperature difference range of 350°K to 450°K. The type of carriers responsible for conduction process was determined from this study.

Magnetic susceptibilities of the compound in the paramagnetic region were measured by Gouy's method using mercury tetra thiocyanate HgCo(CNS)<sub>4</sub> as calibrant. From the experimental data obtained in Gouy's method, molar susceptibilities ( $\chi_M$ ) for the compound, at various temperatures were determined. A graph was plotted between 1/ $\chi_M$  against temperature. The Curie molar constant  $C_M$  for the compound was determined from the plot and was compared with the theoretically calculated value. Also the Curie temperature for the compound was determined.

Vibrating sample magnetometer was used to obtain hysteresis loop at room temperature. From this loop the coercivity, retentivity, and saturation magnetization of the compound were determined.

### 3. Results and Discussion

**3.1. Structural Studies.** The prolonged and continuous heating used in present work resulted in better product formation as was anticipated. Such heating is supposed to give sufficient time to the ions to diffuse. Figure 1 shows the diffraction pattern of the final product. The graph is compared with the JCPDS powder diffraction file number 75-0727 of a similar compound SrZn<sub>2</sub>-W ferrite with crystal structure belonging to phase group P6<sub>3</sub>/mmc. The peaks observed in the present work are indexed and checked with those reported for SrZn<sub>2</sub>-W ferrite and thus the formation of predominant phase corresponding to the desired SrNi(LiFe)<sub>0.5</sub>-W-type ferrite compound, without any appreciable presence of impurities, is confirmed.

The lattice parameters determined for the SrNi(LiFe)<sub>0.5</sub>-W ferrite are  $a = 5.9030 \text{ \AA}$  and  $c = 32.868 \text{ \AA}$ . The  $c/a$  ratio is thus 5.568 and the X-ray volume density is 4.973 gm/cc. The average radius of Li<sup>+</sup> and Fe<sup>3+</sup> calculated

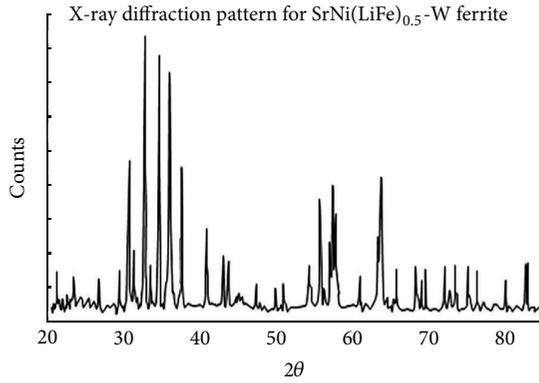


FIGURE 1: X-ray diffraction pattern.

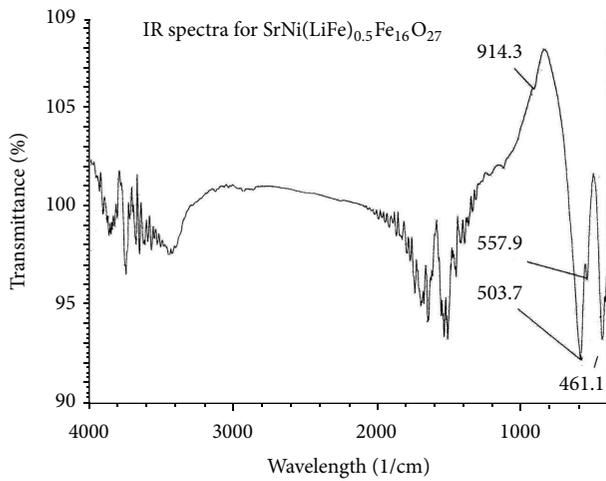


FIGURE 2: IR spectra.

using Shannon & Prewitt radii for six coordination  $\{(0.72 + 0.64)/2 = 0.69 \text{ \AA}\}$  is smaller than the radius of  $\text{Ni}^{2+}$  ( $0.74 \text{ \AA}$ ). Therefore one might expect smaller lattice parameters as compared to those of  $\text{SrNi}_2\text{-W}$  when  $\text{Ni}^{2+}$  is replaced by  $\text{Li}^+$  and  $\text{Fe}^{3+}$  combination. Such decrease in lattice parameter is normally observed in case of spinels, in which Li goes in octahedral sites. But in case of W-type hexagonal ferrites the  $\text{Li}^+$  enters into the hexagonal R block instead of S block and  $\text{Fe}^{3+}$  of larger radius enters into the S block. As a result the substitution of Li, having smaller ionic radius, has not resulted in any decrease in lattice parameter in W-type ferrite, as may be expected. This may account for the lattice parameters observed for the  $\text{SrNi(LiFe)}_{0.5}\text{Fe}_{16}\text{O}_{27}$  in present work which are near those of the  $\text{SrNi}_2\text{-W}$  ferrite which are  $a = 5.882 \text{ \AA}$  and  $c = 32.884 \text{ \AA}$  as reported [12].

The IR spectra for the  $\text{SrNi(LiFe)}_{0.5}\text{-W}$ -type compound is as shown in Figure 2. The absorption bands, below  $1000 \text{ cm}^{-1}$ , which are only relevant to the ferrite structure, and hence the absorption bands to be taken into consideration for the present compound are at  $461.1 \text{ cm}^{-1}$ ,  $557.9 \text{ cm}^{-1}$ ,  $603.7 \text{ cm}^{-1}$ , and  $914.3 \text{ cm}^{-1}$ . The absorption bands above  $1000 \text{ cm}^{-1}$  are mainly due to the water molecules and other impurities,

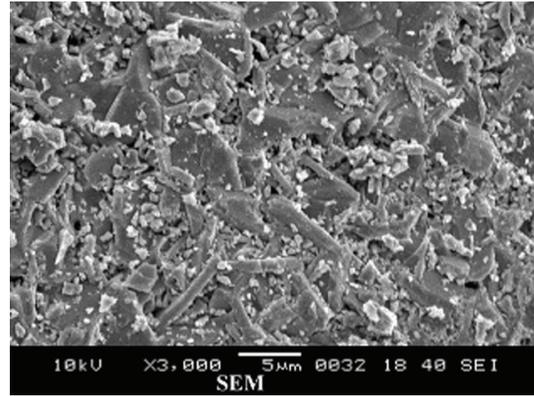


FIGURE 3: SEM Micrograph.

which are organic in nature, and are always seen in the IR spectra and hence not taken into account. The presence of typical absorption bands in the IR spectra further supports the formation of desired compound.

The unit cell of the W-type ferrite is built up by superimposition of spinel blocks (S block) and R blocks containing Ba or Sr or Pb ions. Hence the IR spectra of the W-type ferrite may be identified in the light of well-studied IR spectra of Spinel ferrites. The absorption band observed at  $603.7 \text{ cm}^{-1}$  may be assigned to the bond stretching vibrations of tetrahedral complexes ( $E^t$ ). The band at about  $557.9 \text{ cm}^{-1}$  may be assigned to the bond stretching vibrations of the octahedral complexes ( $E^o$ ) while the bands at about  $461.1 \text{ cm}^{-1}$  may be assigned to the bond bending vibrations of tetrahedral complexes ( $T^t$ ) in the S block of the W ferrite structure [13–15].

The higher frequency absorption band near  $914.3 \text{ cm}^{-1}$  is also observed. This band is assigned to the stretching vibrations of Sr–O. In fact this band gives the confirmation of formation of a strontium ferrite [16].

The SEM study revealed that the  $\text{SrNi(LiFe)}_{0.5}\text{-W}$ -type compound, of well-defined shapes with particle sizes ranging from  $1 \mu\text{m}$  to  $10 \mu\text{m}$  and negligible presence of spherical spots which correspond to the iron oxide particles, is formed (Figure 3). Very good crystal formation with compositional homogeneity could be identified from the micrograph. Since the final sintering was carried out for very long time, the thermal diffusion of reaction centres across the pores dominated and crystallization and growth of the crystallites into larger grains occurred.

**3.2. Electrical Studies.** The results of dc electrical conductivity study are shown in the form of a plot of  $\ln$  of conductivity against inverse absolute temperature in Figure 4. The activation energy and the resistivity at  $250^\circ\text{C}$  found in present work for  $\text{SrNi(LiFe)}_{0.5}\text{-W}$ -type compound are  $0.813 \text{ eV}$  and  $3.5 \times 10^4 \text{ ohm.cm}$ , respectively. It can be seen that the conductivity increases with temperature and follows Wilson's law  $\sigma = \sigma_0 \exp(\Delta E/kT)$ . This indicates semiconducting nature of the compound. The large values of activation energy and resistivity are usually attributed to the relatively

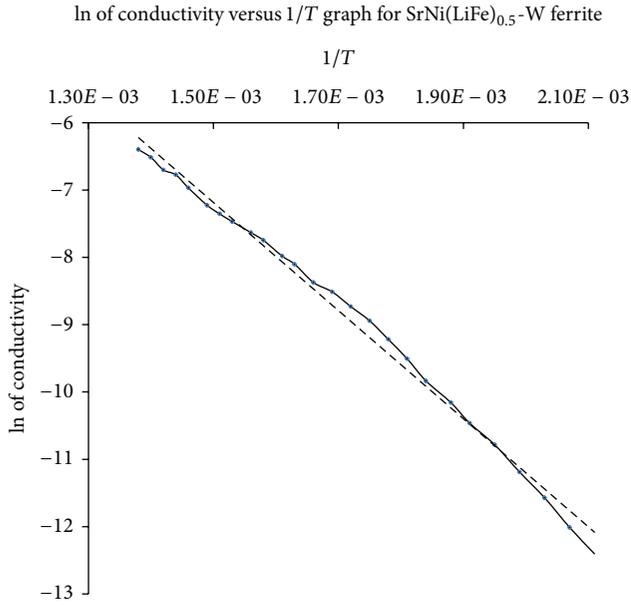


FIGURE 4: Conductivity graph.

low number of mixed valency state of an element on an equivalent lattice sites. The increase in conductivity with temperature is due to the greater overlap of orbitals owing to the increased lattice vibrations. Since the overall distances get reduced during overlap, there will be a greater probability of exchange of charges between the two overlapping ions. Increased exchange due to overlap of orbitals led to increase in the conduction.

Changes in the magnetic order give rise to new types of scattering and alter the energy spectrum of carriers. Therefore electrical transport effects are known to be sensitive to changes in the magnetic order. These changes are usually reflected in the changes in the slope of the  $\ln$  of conductivity against inverse absolute temperature. Since the nature of the graph observed in the present work is a straight line, it is concluded that no such change in the magnetic order takes place over the range of temperature studied [17].

The electrical property in the ferrites has been explained on the basis of the hopping of electrons in between the ferrous and ferric cations ( $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$ ) present on the octahedral sites. The  $\text{Ni}^{2+}$  prefers octahedral sites 12k in W-type ferrite [18]. The presence of Ni on octahedral sites in the compound prepared in present work favours the mechanism of conduction given by  $\text{Ni}^{2+} + \text{Fe}^{3+} \rightarrow \text{Ni}^{3+} + \text{Fe}^{2+}$  [3]. This led to the presence of cations of mixed valency on the octahedral sites, which is accountable for the observed electrical conduction.

**3.3. Magnetic Studies.** The compound is found ferrimagnetic at room temperature with Curie temperature  $810^\circ\text{C}$ . The determined Curie Molar constant ( $C_M$ ) in the paramagnetic region for the  $\text{SrNi}(\text{LiFe})_{0.5}\text{-W}$  compound is 73.27, which fairly match with the theoretical Curie Molar constant of the compound (72), calculated using Curie Molar constants (spin

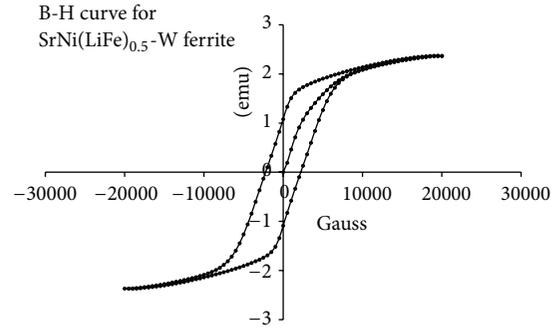


FIGURE 5: Hysteresis loop.

only values) of the constituting ions. The majority of ions responsible for magnetic character of the compound are from 3d series in which the orbital momentum is quenched and only spins decide the magnetic parameters. Therefore the use of spin-only based calculations in present case is justified. This suggests that the compound is formed as per its formula. This again augments the earlier conclusion drawn regarding the formation of the compound.

The hysteresis loop observed for the compound at room temperature is shown in Figure 5. The saturation magnetization, coercivity, and retentivity observed are 60.74 emu/gm, 2216.8 gauss, and 1.0835 emu, respectively.

The Curie temperature and room temperature saturated magnetization mainly depend on the density of magnetic ions and superexchange interactions (A-B) between the cations. The magnetic nature and the location of the cation in unit cell governed by its site preferences are responsible for the magnetic properties of the ferrites.

The observed magnetic properties of  $\text{SrNi}(\text{LiFe})_{0.5}\text{-W}$ -type compound prepared in the present work are evaluated against the magnetic properties reported for the corresponding  $\text{SrNi}_2\text{-W}$ . [5, 19, 20]. The substitution may now be looked at as replacement of a Ni ion by the half of the combination of LiFe. The room temperature saturated magnetization reported for  $\text{SrNi}_2\text{W}$  is 62 emu/gm [5, 21] while that determined in present work for  $\text{SrNi}(\text{LiFe})_{0.5}\text{-W}$  compound is 60.74 emu/gm. Thus observed saturation magnetization, at room temperature in present work for  $\text{SrNi}(\text{LiFe})_{0.5}\text{-W}$  compound, is found to be little smaller than that of the reported for  $\text{SrNi}_2\text{W}$  compound.

It has been reported that the  $\text{Ni}^{2+}$  randomly distributes along with  $\text{Fe}^{3+}$  on octahedral 12k site in R-S block [5, 19–21] while the  $\text{Li}^+$  occupies mainly octahedral  $4f_{VI}$  and negligible 6g of S block in W-type ferrite [7–9]. The saturation magnetizations calculated using Gorter's rule on this presumed site distribution are shown in the Tables 1 and 2. These calculations show that for  $\text{Ni}_2\text{-W}$  and  $\text{Ni}(\text{LiFe})_{0.5}\text{-W}$  ferrites the values of the magnetic moments per unit cell are  $26 \mu_B$  and  $29.5 \mu_B$ , respectively, which are equivalent to 94.68 emu/gm and 109.6 emu/gm, respectively (Sat. Mag in emu/gm = (Sat. Mag in  $\mu_B \times 5585$ )/Mol. Wt.). Certainly, at room temperature, one expects values which are much lower than these calculated, due to the thermal effects. Nonetheless, these theoretical values give prediction of the magnetic

TABLE 1: Site distribution for Ni(LiFe)<sub>0.5</sub>-W ferrite compound.

Sr. no.	Site	Type of site	Number of ions			Bonding direction		Spin	Contribution to magnetic moment due to the site
			Fe <sup>3+</sup>	Ni <sup>2+</sup>	Li <sup>1+</sup>				
1	12k	Octahedral	6-1	1	0	R-S	Up	+ [5 * 5 + 3 * 1]	+28
2	4e	Tetrahedral	2	0	0	S	Down	- [5 * 2]	-10
3	4fiv	Tetrahedral	2	0	0	S	Down	- [5 * 2]	-10
4	4f	Octahedral	2-0.4	0	0.4	R	Down	- [5 * 1.6]	-8
5	6g	Octahedral	3-0.1	0	0.1	S-S	Up	+ [5 * 2.9]	+14.5
6	4fvi	Octahedral	2	0	0	S	Up	+ [5 * 2]	+10
7	2d	Bipyramidal	1	0	0	R	Up	+ [5 * 1]	+5
Total ions in formula unit			16.5	1	0.5				
Total magnetic moment per formula unit Bohr magneton ( $\mu_B$ )									+29.5

TABLE 2: Site distribution for Ni<sub>2</sub>-W ferrite compound.

Sr. no.	Site	Type of site	Number of ions			Bonding direction		Spin	Contribution to magnetic moment due to the site
			Fe <sup>3+</sup>	Ni <sup>2+</sup>	Li <sup>1+</sup>				
1	12k	Octahedral	6-1	2	0	R-S	Up	+ [5 * 4 + 3 * 2]	+26
2	4e	Tetrahedral	2	0	0	S	Down	- [5 * 2]	-10
3	4fiv	Tetrahedral	2	0	0	S	Down	- [5 * 2]	-10
4	4f	Octahedral	2	0	0	R	Down	- [5 * 2]	-10
5	6g	Octahedral	3	0	0	S-S	Up	+ [5 * 3]	+15
6	4fvi	Octahedral	2	0	0	S	Up	+ [5 * 2]	+10
7	2d	Bipyramidal	1	0	0	R	Up	+ [5 * 1]	+5
Total ions in formula unit			16	2	0				
Total magnetic moment per formula unit Bohr magneton ( $\mu_B$ )									+26

behaviour of these compounds. The saturation magnetization of SrNi(LiFe)<sub>0.5</sub>-W-type observed is less than that of SrNi<sub>2</sub>W type, this is contrary to that seen from the above calculations. This is attributed to the small canting effect of the 12k cations due to the presence of Li in 4f<sub>VI</sub> sub-lattice as predicted by Mignot et al. [10] to explain observed saturation magnetization of similar compound BaZn<sub>2(1-x)</sub>(LiFe)<sub>x</sub>Fe<sub>16</sub>O<sub>27</sub>.

Therefore one can infer from the experimental work and theoretical calculations that though the overall interactions remain fairly unaffected when Ni is replaced by the combination of LiFe, there is a small canting effect due to presence of Li.

The low value of coercivity could be attributed to the larger particle sizes. The larger size is already confirmed from SEM micrograph.

#### 4. Conclusions

The temperature which is needed for the formation of the W-type phase is more than 1300°C but the Lithium present in the compound facilitates the synthesis and makes it possible to prepare the compound at lower temperature, 1100°C. The particle sizes observed are large, due to prolonged heating which gets correlated with the lower coercivity observed for the compound.

The high resistivity of the compound SrNi(LiFe)<sub>0.5</sub>-W indicates less presence of mixed valency cations on equivalent

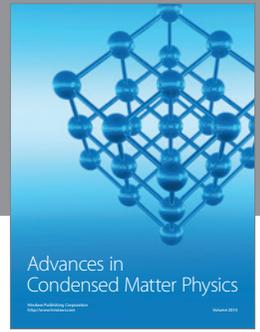
lattice apart from the small amount created due to the release of an electron by divalent Ni to become trivalent, which is accepted by trivalent Fe to turn into divalent Fe. This leads to presence of cations of mixed valency on the same sublattice which facilitates the conduction due to hopping of electron between them.

The replacement of Ni<sup>2+</sup> by combination of the LiFe does not perturb the equilibrium of the superexchange interaction between the various ion sublattices except the small canting effect. Therefore one can conclude that the experimental observations match with theory and support presumed site preferences to a greater extent. Also the prediction that the Li is present on 4f<sub>VI</sub> sub-lattice plays an important role in affecting the saturation magnetization due to its small canting effect on 12k cations.

#### References

- [1] P. B. Braun, "Crystal structure of BaFe<sub>18</sub>O<sub>27</sub>," *Nature*, vol. 170, article 708, 1952.
- [2] P. B. Braun, "Crystal structural of new group of ferromagnetic compounds," *Philips Journal of Research*, vol. 12, pp. 491-548, 1957.
- [3] V. Uitert and F. W. Swanekamp, "Permanent magnet oxides containing divalent metal ions II," *Journal of Applied Physics*, vol. 28, no. 4, pp. 482-485, 1957.

- [4] H. Kojima, C. Miyakawa, T. Sato, and K. Goto, "Magnetic properties of W-type hexaferrite powders," *Japanese Journal of Applied Physics*, vol. 24, no. 1, pp. 51–56, 1985.
- [5] F. Leccabue, G. Salviati, N. S. Almodovar, G. Albanese, and G. Leo, "Magnetic and morphological characterization of SrMe<sub>2</sub>-W and SrZn-X Hexaferrites prepared by chemical coprecipitation method," *IEEE Transactions on Magnetics*, vol. 24, no. 2, pp. 1850–1852, 1988.
- [6] G. Albanese and G. Asti, "Sublattice magnetization and cation distribution in BaMg<sub>2</sub>Fe<sub>16</sub>O<sub>27</sub>(Mg<sub>2</sub>W) ferrite," *IEEE Transactions on Magnetics*, vol. 6, no. 2, pp. 158–161, 1970.
- [7] S. Ram and J. C. Joubert, "Synthesis and magnetic properties of SrZn<sub>2</sub>-W type Hexagonal Ferrites using a partial 2Zn<sup>2+</sup> → Li<sup>+</sup>Fe<sup>3+</sup> substitution: a new series of permanent magnets materials," *Journal of Magnetism and Magnetic Materials*, vol. 99, no. 1–3, pp. 133–144, 1991.
- [8] G. Albanese, J. L. S. Li, G. Lopez, S. Diaz, F. Leccabue, and B. E. Watts, "Mossbauer and magnetic study of Sr (ZnLi<sub>0.5</sub>Fe<sub>0.5</sub>)Fe<sub>16</sub>O<sub>27</sub> Hexaferrite," *Journal of Magnetism and Magnetic Materials*, vol. 137, no. 3, pp. 313–321, 1994.
- [9] J. P. Mignot, A. Collomb, and J. C. Joubert, "Two new series of W-type hexagonal ferrites containing monovalent copper," *Journal of Magnetism and Magnetic Materials*, vol. 58, no. 3–4, pp. 239–246, 1986.
- [10] J. P. Mignot, P. Wolfers, and J. C. Joubert, "A new series of materials for permanent magnets: the W ferrites BaZn<sub>2(1-x)</sub>(LiFe)<sub>x</sub>Fe<sub>16</sub>O<sub>27</sub>," *Journal of Magnetism and Magnetic Materials*, vol. 51, no. 1–3, pp. 337–341, 1985.
- [11] G. Economos, "Magnetic ceramics: i general methods of magnetic ferrite preparation," *The Journal of the American Ceramic Society*, vol. 38, no. 7, pp. 241–243, 1955.
- [12] M. K. Fayek and M. K. Elnimr, "Study of Cd & Ni-W hexaferrites by Mossbauer spectroscopy," *Indian Journal of Pure and Applied Physics*, vol. 23, no. 3, pp. 145–151, 1985.
- [13] R. D. Waldron, "Infrared spectra of ferrites," *Physical Review*, vol. 99, no. 6, pp. 1727–1735, 1955.
- [14] J. Preudhomme and P. Tarte, "Infrared studies of spinel—I: a critical discussion of the actual interpretations," *Spectrochimica Acta A*, vol. 27, no. 7, pp. 961–968, 1971.
- [15] J. Preudhomme and P. Tarte, "Infrared studies of spinels—III: the normal II–III spinels," *Spectrochimica Acta A*, vol. 27, no. 9, pp. 1817–1835, 1971.
- [16] F. M. M. Pereira, C. A. R. Junior, M. R. P. Santos et al., "Structural and dielectric spectroscopy studies of the M-type barium strontium hexaferrite alloys (Ba<sub>x</sub>Sr<sub>1-x</sub>Fe<sub>12</sub>O<sub>19</sub>)," *Journal of Materials Science: Materials in Electronics*, vol. 19, no. 7, pp. 627–638, 2008.
- [17] K. P. Belov, E. P. Svirina, and S. S. Karneeva, "Hall effect, electrical resistivity and thermoelectric power of Co<sub>1.65</sub>W hexaferrite single crystal," *Soviet Physics, Solid State*, vol. 16, pp. 1806–1807, 1975.
- [18] A. M. van Diepen and F. K. Lotgering, "Mössbauer spectra of Fe<sup>3+</sup> and Fe<sup>2+</sup> ions in Hexagonal Ferrite with w-structure," *Solid State Communications*, vol. 27, no. 3, pp. 255–258, 1978.
- [19] T. Besagni, A. Deriu, F. Licci, L. Pareti, and S. Rinaldi, "Nickel and Copper Substitution in Zn<sub>2</sub>-W," *IEEE Transactions Magnetics*, vol. 17, no. 6, pp. 2636–2638, 1981.
- [20] S. Dey and R. Valenzuela, "Magnetic properties of substituted W and X Hexaferrites," *Journal of Applied Physics*, vol. 55, no. 6, pp. 2340–2342, 1984.
- [21] F. Leccabue, R. Panizzieri, G. Albanese, G. Leo, and N. S. Almodovar, "Magnetic and mossbauer study of coprecipitated SrNi<sub>2</sub>Fe<sub>16</sub>O<sub>27</sub> (SrNi<sub>2</sub>-W) and SrCo<sub>2</sub>Fe<sub>16</sub>O<sub>27</sub> (SrCo<sub>2</sub>-W) Hexagonal Ferrites," *Materials Research Bulletin*, vol. 23, no. 2, pp. 263–275, 1988.



**Hindawi**

Submit your manuscripts at  
<http://www.hindawi.com>

