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Study of strontium ferrites substituted by lanthanum on the structural and magnetic properties

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Abstract

M-type strontium ferrites, $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ have been synthesized by conventional ceramic process. The effects of lanthanum addition and sintering temperature on microstructures and magnetic properties of $SrFe_{12}O_{19}$ and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ samples were investigated. Microstructural analysis of the $SrFe_{12}O_{19}$ and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ specimens, sintered at different temperatures revealed that average grain sizes of $SrFe_{12}O_{19}$ ferrites were larger than that of $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrite and increased with increasing sintering temperature. The X-ray diffraction (XRD) results confirmed the strontium hexagonal ferrite phase of $SrFe_{12}O_{19}$ and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ compounds. A maximum coercivity value of 4850 Oe and maximum saturation magnetization value of 102 emu/g were obtained for the $SrFe_{12}O_{19}$ ferrite sintered at 1150 °C and for the $SrFe_{12}O_{19}$ and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrites sintered at 1300 °C, respectively. The remanence (Mr) of $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ sample sintered at 1200 °C possesses the maximum value of 60 emu/g.

Keywords: A. Sintering; C. Magnetic properties; D. Ferrites; E. Hard magnets

1. Introduction

Magnetic materials are widely used as components in various applications of industrial and medical equipments. A very well-established class of magnetic materials is made from magnetic ceramic materials, or ferrites [1], which are essential in devices for storing energy in a static magnetic field. Major applications involve the conversion of mechanical to electrical energy. The applications of magnetic materials in information technology have been growing continuously [2].

The ferrite materials may be classified into three different classes; spinel ferrites, garnet ferrites and hexagonal ferrites [3]. The magnetic spinel has the general formula of MFe_2O_4, where M is the divalent metal ion, usually Ni, Co, Mn, or Zn. During the last few years spinel ferrites have drawn a major attention because of their technological importance in magnetic recording, magnetic fluid and catalyst. The garnet ferrites are the basis of materials for many high-technology devices for magneto-optic, microwave and memory applications [1]. The ferrites used for permanent-magnet purposes are the hexagonal ferrites, also called hard ferrites or M-type ferrites. These are hexagonal compounds of the general formula $MeFe_{12}O_{19}$, where Me = Ba, Sr, or Pb [2]. M-type strontium ferrites with substitution of Sr^{2+} by rare-earth La^{3+}, according to the formula $Sr_{1-x}La_xFe_{12}O_{19}$ have been of much interest to be used as permanent magnets since their discovery in the 1950s due to their rather good energy product and the best performance to cost ratio. In addition, they also show promising properties for their use as magnetic and magneto-optic recording media, as well as in microwave devices.

Various processing techniques have been employed for fabrication of the strontium ferrites, including the chemical coprecipitation method, the glass crystallization, the organic resin method, the sol–gel method and the ceramic process. However, the simple ceramic process has been extensively used in industrial manufacturing.

This paper has an attempt to investigate and give further insight about the magnetic properties of strontium ferrite,

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$SrFe_{12}O_{19}$, and La doped-strontium ferrite, $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$. The investigation covers the study of the effect of La substitution and sintering temperature on the properties of the prepared strontium ferrite ceramics.

2. Experimental

The $SrFe_{12}O_{19}$ and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrites were fabricated by the conventional ceramic process. The powders were milled in distilled water in a steel cylindrical mill with steel balls (SPEX CertiPrep, 8000-D Mixer/MILL) to produce finer and homogenous particles. The resulting slurry was dried and then calcined at 1100 °C for 2 h. The calcined powders were pressed into a disk shape compact in the presence of magnetic field of 12.5 kOe. The green bodies were sintered in air at temperatures ranging from 1150 to 1300 °C for 1 h. Phase formation of the powder and ceramic samples was studied by X-ray diffraction technique (XRD). The microstructure of the samples was investigated using a scanning electron microscope (SEM, LEO 1455VP). Average grain sizes of the samples were determined by the intercept method of ASTM E112, which is based on the number of the grain boundary intersections per unit length [4]. Magnetic properties were measured at room temperature on the sintered samples in the applied static magnetic fields up to 10 kOe employing a vibrating sample magnetometer (VSM, LakeShore 7407).

3. Results and discussion

The microstructures and magnetic properties of undoped ($SrFe_{12}O_{19}$) and La doped ($Sr_{0.8}La_{0.2}Fe_{12}O_{19}$) ferrites prepared at sintering temperatures ranging from 1150 to 1300 °C for 1 h were studied. XRD patterns of the undoped samples ($SrFe_{12}O_{19}$) are shown in Fig. 1. As can be seen in Fig. 1, the diffraction peak (*) of hematite phase (α-Fe_2O_3) was observed in the samples sintered at 1150–1250 °C and the single phase of strontium hexagonal was obtained in the sample sintered at 1300 °C. In case of La doped samples, amount of hematite phase decreased with the increase of sintering temperatures (Fig. 2). It should be noted that the diffraction pattern of the $SrFe_{12}O_{19}$ sample (Fig. 1) is similar to that of the $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$. In addition, as in the case of $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$, the intensity of the hematite phase as shown in Fig. 2 is higher than that of $SrFe_{12}O_{19}$ (see also Fig. 1) the diffraction peaks of $LaFeO_3$ were observed at 1150 °C, suggesting that the La doping promoted the formation of second or impurity phases.

The as-sintered bulk surface morphologies of the undoped and doped samples were investigated using scanning electron

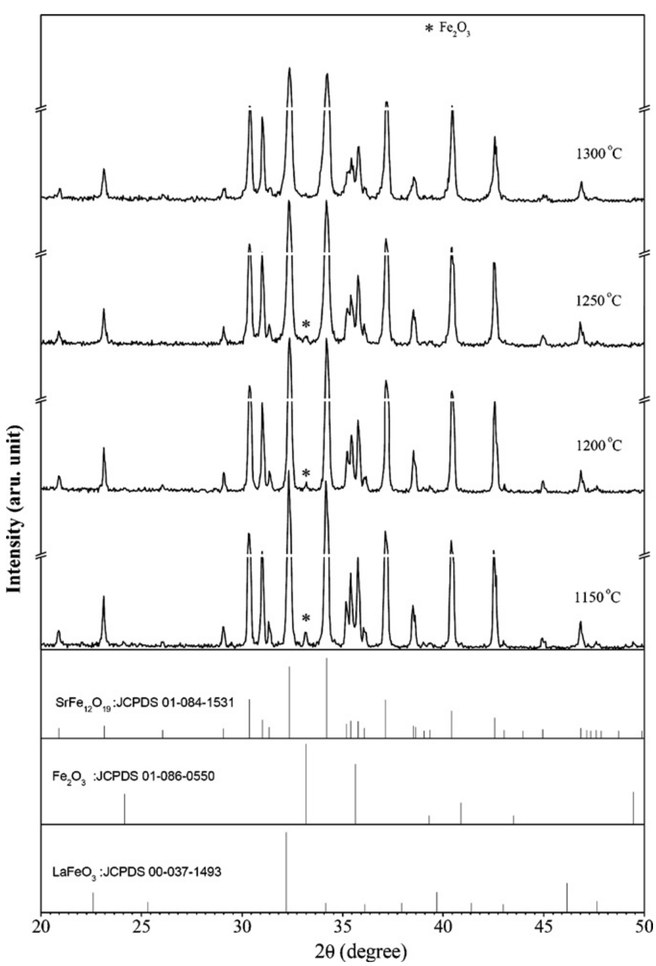

Fig. 1. X-ray diffraction patterns of $SrFe_{12}O_{19}$ ferrites sintered at different sintering temperatures for 1 h.

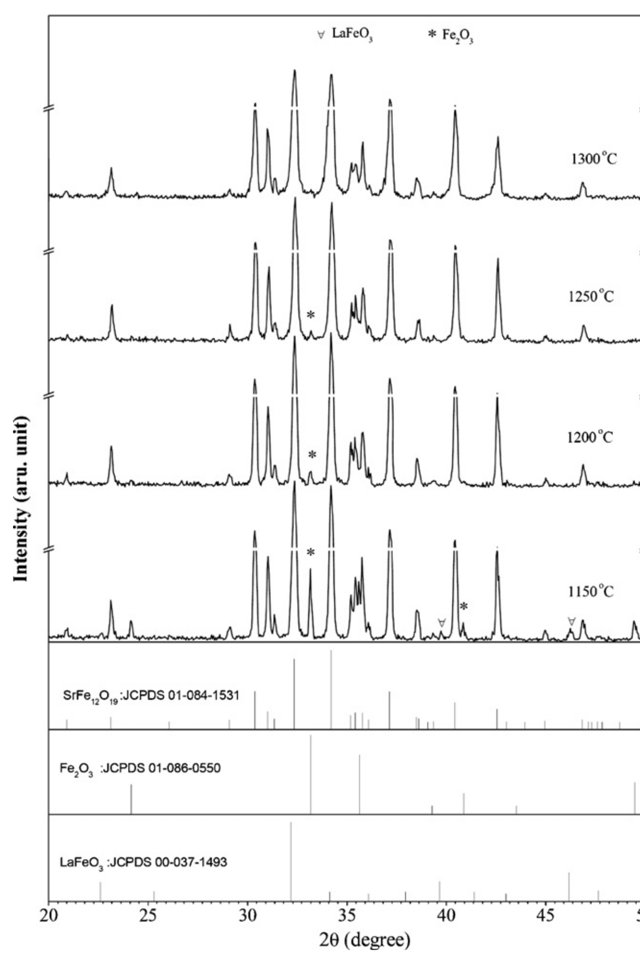

Fig. 2. X-ray diffraction patterns of $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrites sintered at different sintering temperatures for 1 h.

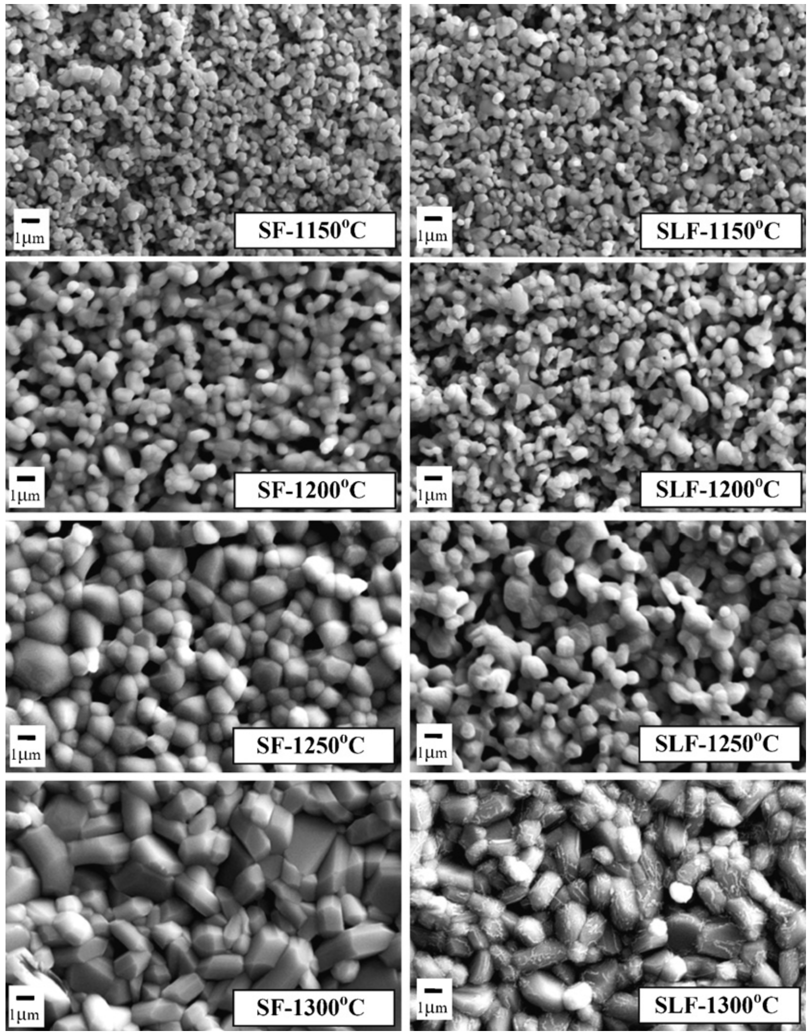

Fig. 3. SEM micrographs of $SrFe_{12}O_{19}$ ferrites (SF) and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrites (SLF) sintered at different sintering temperatures.

microscopy (SEM) and the results are shown in Fig. 3. The average grain sizes with sintering temperature for the undoped and doped samples are shown in Fig. 4. It is seen that the average grain size increased from 0.4 to 2.5 μm and 0.4 to 2.1 μm for the undoped and doped samples, respectively. It may be assumed that adding of La^{3+} into $SrFe_{12}O_{19}$ causes the reduction in the average grain sizes of the ceramics. The increase of grain size with increasing sintering temperature is due to the enhancement of crystallinity in the ceramics at higher sintering temperatures.

The magnetic hysteresis loops of the $SrFe_{12}O_{19}$ and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrites measured at room temperature with magnetic field up to 10 kOe are shown in Figs. 5 and 6, respectively. From these figures, the magnetic properties of the ceramics sintered at different temperatures were deduced,

Table 1
Coercivity (Hc), remanence (Mr) saturation magnetization (Ms) and Mr/Ms ratio for $SrFe_{12}O_{19}$ and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrites sintered at 1150 °C, 1200 °C, 1250 °C, and 1300 °C.

Sample	Sintering temperature (°C)	Hc (Oe)	Ms (emu/g)	Mr (emu/g)	Mr/Ms
$SrFe_{12}O_{19}$	1150	4850	89	55	0.65
	1200	4353	94	58	0.62
	1250	3393	98	59	0.60
	1300	2273	102	59	0.58
$Sr_{0.8}La_{0.2}Fe_{12}O_{19}$	1150	4796	87	54	0.62
	1200	4510	96	60	0.63
	1250	3847	67	59	0.88
	1300	1781	102	56	0.55

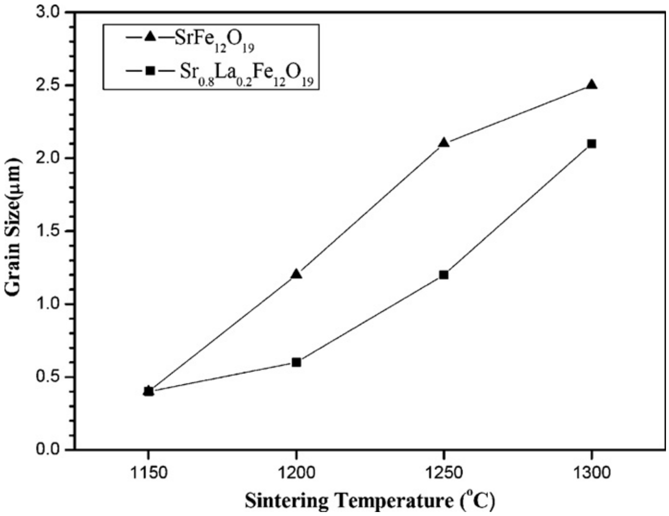

Fig. 4. Average grain sizes of undoped ($SrFe_{12}O_{19}$) and doped ($Sr_{0.8}La_{0.2}Fe_{12}O_{19}$) ferrites with sintering temperatures from 1150 to 1300 °C.

including the values of saturation magnetization (Ms), remanence (Mr), coercivity (Hc), and remanence ratio (Mr/Ms) ratio [5] (Table 1). The variations of coercivity (Hc) and remanence (Mr) with sintering temperatures for $SrFe_{12}O_{19}$ and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrites show that the $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ and $SrFe_{12}O_{19}$ ferrites possessed the remanence in the range of about 55–60 emu/g for sintering temperatures from 1150 to 1300 °C. The coercivity of the undoped and doped samples decreased with sintering temperatures. It was observed that a maximum coercivity value of 4850 Oe was obtained for the $SrFe_{12}O_{19}$ ferrite sintered at 1150 °C. Generally, the Hc of doped and undoped ferrites decreases with increasing grain size. For example, Kools et al. reported that addition of SiO_2 to strontium ferrite (in the right proportion), inhibited grain growth by forming second phase at the grain boundaries, which subsequently reduced grain growth during sintering and gave rise to the increase in the coercivity [6]. Therefore, our result also corresponds to this rule. Further, the $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrites sintered at 1300 °C showed a high Ms value of ~102 emu/g, comparing to that of the previous work (~70 emu/g) [7]. This may be due to a different processing used in this study. In this work the calcined powder was pressed under a magnetic field (12.5 kOe) before sintering. When a magnetic field was exerted, particles will rotate in the direction of the field, meaning that the crystallographic direction (the easy magnetization axis) of the powder will have partial orientation in the applied magnetic direction as a result of the higher Ms for the present ceramics.

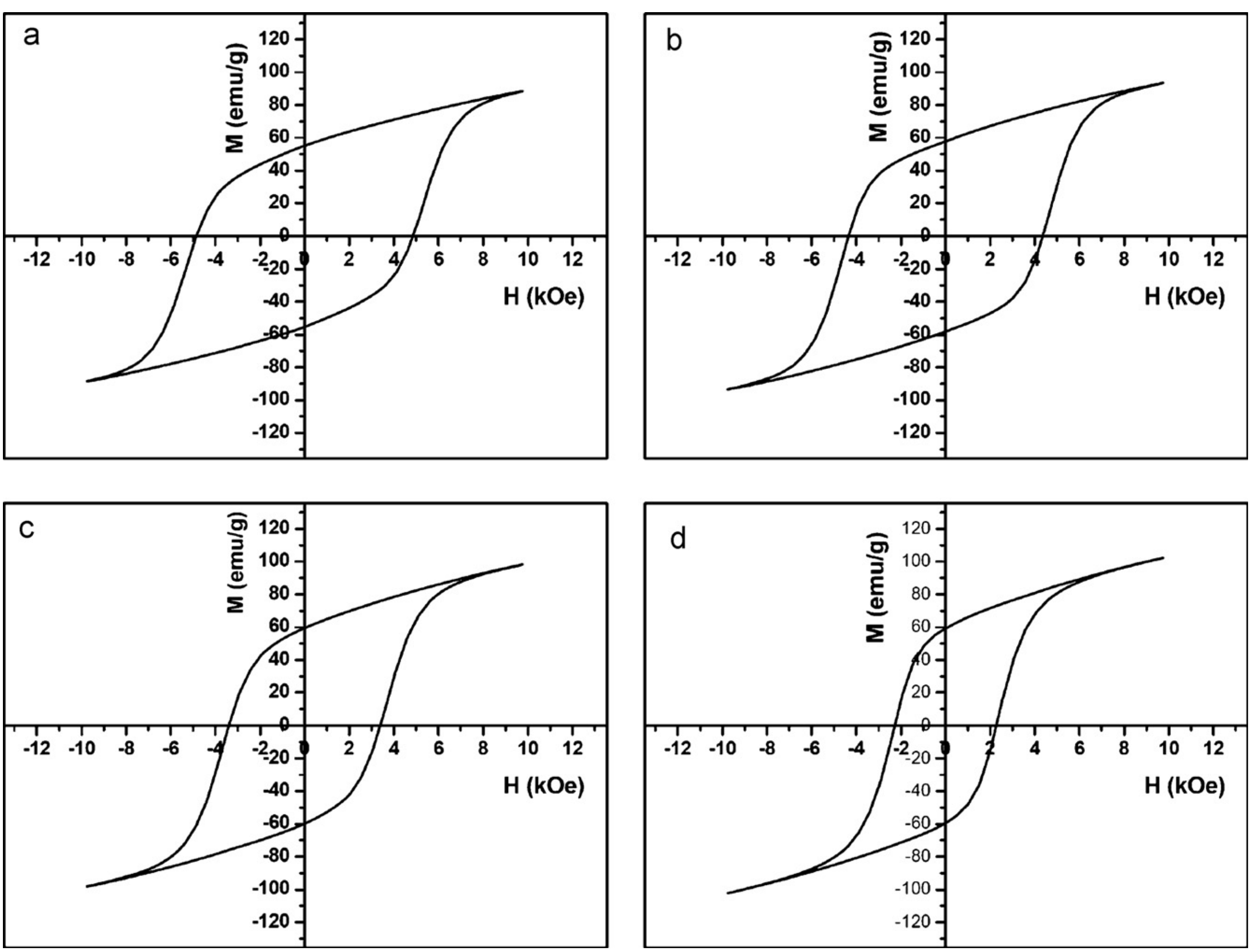

Fig. 5. Hysteresis loops of $SrFe_{12}O_{19}$ sintered at (a) 1150 °C, (b) 1200 °C, (c) 1250 °C, and (d) 1300 °C.

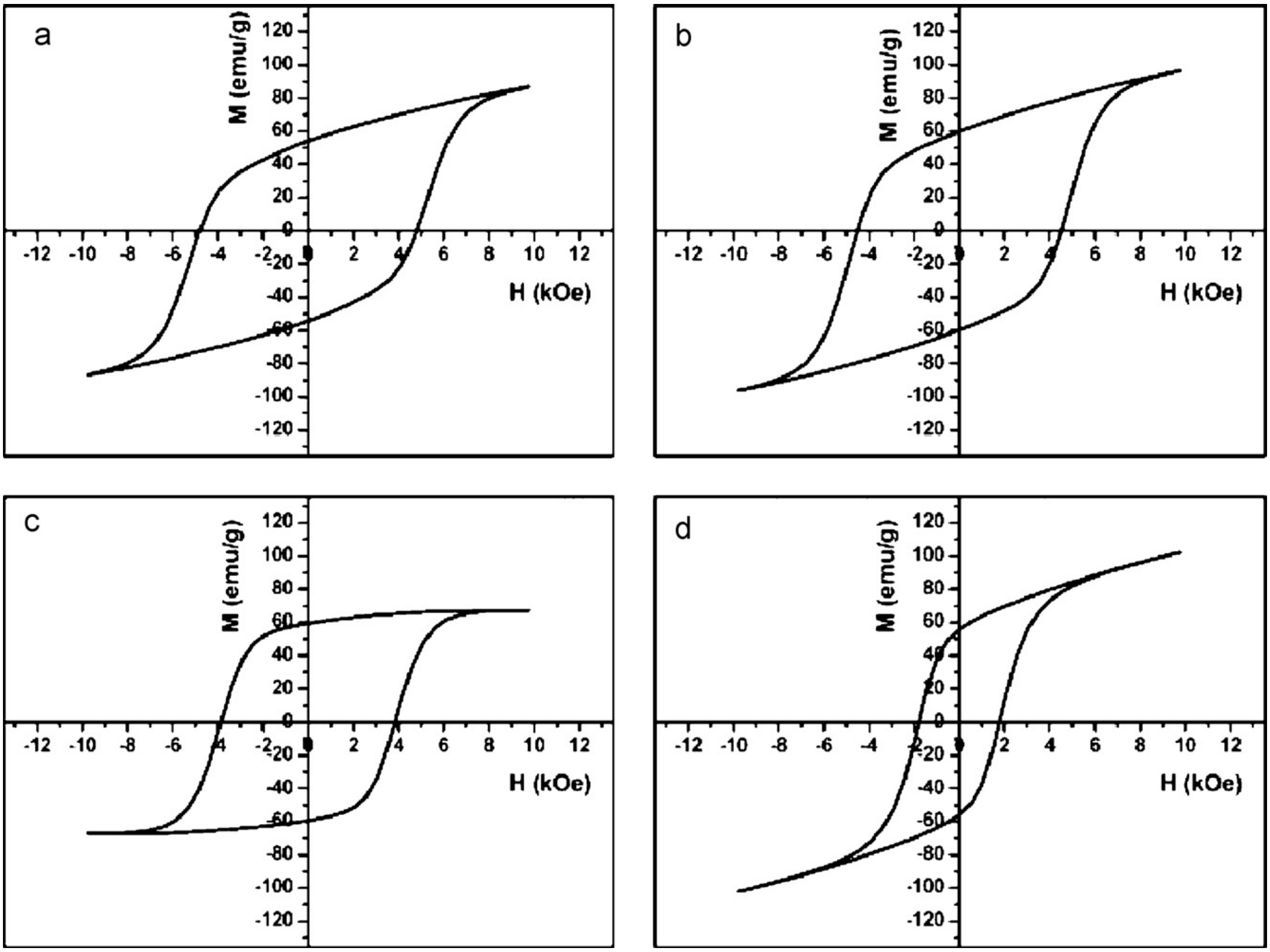

Fig. 6. Hysteresis loops of $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ sintered at (a) 1150 °C, (b) 1200 °C, (c) 1250 °C, and (d) 1300 °C.

4. Conclusions

Strontium ferrite ceramics were synthesized by conventional ceramic process. A single phase of $SrFe_{12}O_{19}$ and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrites formed after the samples were sintered at 1300 °C. A maximum coercivity value of 4850 Oe was obtained for the $SrFe_{12}O_{19}$ ferrite sintered at 1150 °C and high saturation magnetization value of 102 emu/g was achieved for the $SrFe_{12}O_{19}$ and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrites sintered at 1300 °C. The results of this experiment show that the $SrFe_{12}O_{19}$ and $Sr_{0.8}La_{0.2}Fe_{12}O_{19}$ ferrites are promising materials pointing the way to further developments for permanent magnets and high density magnetic recording media.

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