Effects of sintering temperature on structure, magnetic and dielectric properties of $\text{La}_{0.5}\text{Sr}_{0.5}\text{Fe}_{0.9}\text{Mn}_{0.05}\text{Ti}_{0.05}\text{O}_3$ material

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Abstract. We have investigated structure, magnetic and dielectric of $\text{La}_{0.5}\text{Sr}_{0.5}\text{Fe}_{0.9}\text{Mn}_{0.05}\text{Ti}_{0.05}\text{O}_3$ (LSFMTO) system using ultrasonic mixing method. LSFMTO system is driven by 40 kHz frequency and calcinate process up to 750°C for 30 minutes. Then sintering process also carried out by systematic various of temperature 900 °C, 1000 °C, and 1100 °C respectively, as same time previously. Very interestingly, the LSFMTO system exhibits ferroelectric $(\text{La,Sr})(\text{Fe,Mn,Ti})\text{O}_3$ and ferromagnetic $\text{SrFe}_{12}\text{O}_{19}$ properties and minor phase La_2O_3 by XRD interpretation analyzation. We have also carried out the measurement of LSFMTO system using a systematic applied the external magnetic field from 0 to 1 T and the electric polarization from 0 to 50 kV/m. The hysteresis curve of LSFMTO system shows the electric coercive (E_c) increases while the saturation polarization (P_c) and the remanent polarization are tendency constant at the magnetic strength of 0.12 T. We believed that our finding of LSFMTO system is potensial to multiferroic material as magnetic sensor application.

1 Introduction

In recent years multiferroic composites have been a lot of interest in class of multi-functional materials which exhibit strong magnetoelectric (ME) [1–4]. The ME materials can couple with stimulating either by electric or magnetic fields [5–10]. Perovskite structure with ABO_3 system such as BaTiO_3 and LaMnO_3 is considered to be a good ferroelectric and $(\text{Ba,Sr})\text{Fe}_{12}\text{O}_{19}$ is as a permanent magnet with high thermal stability and mainly used as a magnetic data storage [11–15]. Multiferroic composites in which ferroelectricity and ferromagnetism materials can result Magnetoelectric (ME) effect. Especially, $(\text{La,Sr})\text{MnO}_3$ or LSMO attracts a lot of attention because the manganites form a class of magnetic materials [16–19]. In the present paper, we studied the different sintering temperature of $\text{La}_{0.5}\text{Sr}_{0.5}\text{Fe}_{0.9}\text{Mn}_{0.05}\text{Ti}_{0.05}\text{O}_3$ (LSFMTO) system that was prepared by solid state method. The preparation method affects the morphological, dielectric and magnetic properties of $\text{La}_{0.5}\text{Sr}_{0.5}\text{Fe}_{0.9}\text{Mn}_{0.05}\text{Ti}_{0.05}\text{O}_3$ (LSFMTO) system. In a similar way, we study not only the substitution of the Fe by Mn and Ti ions, but also effect of the substitution of the Lanthanum by more Sr ions. We also have investigated magnetic and electric coercive behavior of LSFMTO.

2 Experimental method

Perovskite structure with $\text{La}_{0.5}\text{Sr}_{0.5}\text{Fe}_{0.9}\text{Mn}_{0.05}\text{Ti}_{0.05}\text{O}_3$ (LSFMTO) was synthesized by ultrasonic mixing method

from La_2O_3 , SrCO_3 , Fe_2O_3 , MnCO_3 , and TiO_2 . The nominal composition and the stoichiometry of $\text{La}_{0.5}\text{Sr}_{0.5}\text{Fe}_{0.9}\text{Mn}_{0.05}\text{Ti}_{0.05}\text{O}_3$ were mixed in glass with aquades by 40 kHz frequency. Then, the mixture was calcinated up to 750°C for 30 minutes. And sintering process also carried out by systematic various of temperature 900 °C, 1000 °C, and 1100 °C respectively, with time preparation is same previously. $\text{La}_{0.5}\text{Sr}_{0.5}\text{Fe}_{0.9}\text{Mn}_{0.05}\text{Ti}_{0.05}\text{O}_3$ powders were obtained. Powder X-ray diffraction (XRD) patterns were measured by Phillips diffractometer using $\text{CoK}\alpha$ radiation and with JEOL JSM 5310LV scanning electron microscope (SEM) observed the microstructures of LSFTMO. The magnetic datas were recorded at room temperature with Permagraph in maximum magnetic field 2 T to find magnetic properties of LSFTMO. The electric polarization were used Electrometer Keithley.

3 Results and discussion

3.1 Microstructure

Fig 1. Show the results of XRD pattern of LSFMTO sample with various of temperature are multi phase of ferroelectric $(\text{La,Sr})(\text{Fe,Mn,Ti})\text{O}_3$, ferromagnetic $\text{SrFe}_{12}\text{O}_{19}$ properties and minor phase La_2O_3 .

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Fig 1. Calculated result (solid lines) of XRD patterns of LSFMTO samples were calcinated up to 750°C for 30 minutes and sintered systematic various of temperature (a). 900 °C, (b). 1000 °C, and (c). 1100 °C.

LSFMTO samples are identified in all heat treatment as the main phase. Includes $\text{SrFe}_{12}\text{O}_{19}$ and La_2O_3 as the second phases. From x-ray diffraction data refinement can be determined the quantitative number of phases in the measured material. Table 1 shows the measured magnetic properties. The weight fraction increasing of primary phase indicates that the main phase greatly affected by magnetic and dielectric properties.

Table 1. Refined structure results of LSFMTO were sintered systematic various of temperature.

Sample	Temperature (°C)		
	900	1000	1100
Main phase (LSFMTO)			
Wt. frac (%)	58.8	71.5	75.2
Other phases			
Wt. frac (%)	41.2	28.5	24.8

The morphology of $\text{La}_{0.5}\text{Sr}_{0.5}\text{Fe}_{0.9}\text{Mn}_{0.05}\text{Ti}_{0.05}\text{O}_3$ (LSFMTO) sintered systematic various of temperature 900 °C, 1000 °C, and 1100 °C observed with the scanning electron microscope (SEM) as shown in Fig. 2.

Fig. 2. SEM photographs of $\text{La}_{0.5}\text{Sr}_{0.5}\text{Fe}_{0.9}\text{Mn}_{0.05}\text{Ti}_{0.05}\text{O}_3$ (LSFMTO) were calcinated up to 750°C for 30 minutes and sintered systematic various of temperature (a). 900 °C, (b). 1000 °C, and (c).1100 °C.

The change of microstructures is observed. This seems to inform that the sintering process determine to form phases and their microstructure. Microstructure of LSFMTO composition appeared in the form of ferroelectric phase

(La,Sr)(Fe,Mn,Ti) O₃ as the majority phase. Some elements of La, Sr, and Fe are found in ferroelectric phase with elements Mn and Ti, in which all of them substitute Fe entirely. In addition, minor elements of Sr and Fe formed as ferromagnetic phase and may not substituted by Mn and Ti. While some La elements found in small quantities as La₂O₃. Visually, Figure 1a is differ with Figure 1b and 1c which have the same morphology. It can be concluded that the sintering process of 900°C was not enough to form LSFMTO as the expected phase. While images 1b and 1c explained that the establishment of LSFMTO phase is more progressive with increasing the sintering temperature.

3.2 Magnetic and electric properties

The magnetic properties determination of LSFMTO through magnetization process at maximum field of 2 T for all samples yields as permanent magnet hysteresis. Magnetic properties (see Table 2) like saturation magnetization (M_s) and remanent (M_r) have the same value, although small. This suggests that the composition of LSFMTO for all temperature formed as hard magnetic phase of SrFe₁₂O₁₉. Furthermore, the coercivity which tends to keep as intrinsic magnitude of SrFe₁₂O₁₉. It is certain that La_{0.5}Sr_{0.5}Fe_{0.9}Mn_{0.05}Ti_{0.05}O₃ has formed as ferroelectric multi-phase in which the (La,Sr)(Fe,Mn,Ti)O₃ as the main phase and the ferromagnetic properties of SrFe₁₂O₁₉ and La₂O₃ as the second phase.

Fig. 3. The magnetic hysteresis loops of LSFMTO that sintered at 900 °C (a), 1000 °C (b), 1100 °C (c). All of samples show ferromagnetic behaviors at room temperature.

Table 2. Magnetic properties of LSFMTO.

Sintering Temperature, T (°C)	H _c (kA/m)	M _r (T)	M _s (T)
900	247.6	0.029	0.054
1000	264.6	0.037	0.066
1100	235.7	0.024	0.045

The electric hysteresis loops of LSFMTO at 300 K were also measured. There are two conditions for the measurement of electrical properties, ie, with and without

the magnetic field at 0.12 T during electrical polarization process (Table 3). The magnetic field results for all samples produced a hysteresis curves. Hysteresis curves of the samples without the magnetic field showed a decline value of electric coercivity (E_c) with increasing sintering temperature. While the saturation polarization (P_c) and the remaining polarization (P_r) tends to remain. For samples measured with the magnetic field shown an increasing in electric coercivity (E_c) in temperature of 900° C and 1000° C (see Figure 2a and 2b). While the sample with sintering temperature of 1100°C have not change in E_c (Figure 2c). It explains that the temperature of 1100°C has increased the weight fraction of the ferroelectric phase (La,Sr)(Fe,Mn,Ti)O₃ as the main phase. While the magnetic phase is decreased (see table 1).

Fig. 4. The electric hysteresis loops of LSFMTO that sintered at 900 °C (a), 1000 °C (b), 1100 °C (c). All of samples show ferroelectric behaviors at room temperature.

Table 3. Electric properties for LSFMT0.

Condition	T (°C)	Ec (kV/m)	Pr (μC/cm ²)	Ps (μC/cm ²)
No magnetic field	900	12.8	2.46	3.15
	1000	9.8	2.42	3.11
	1100	2.8	2.43	3.29
Magnetic field 0.12 T	900	14.2	2.41	3.10
	1000	11.5	2.42	3.05
	1100	3.0	2.42	3.23

Generally, The hysteresis curve of LSFMT0 system shows the electric coercive (Ec) increases while saturation polarization (Pc) and remanent polarization (Pr) are tendency constant at the magnetic strength of 0.12 T at temperature of 900°C dan 1000°C. However, at temperatures of 1100°C has no changes in electrical coercivity (Ec) (Fig. 5).

Fig. 5. The influence of magnetic field 0.12 T on the enhancement of electric coercivity of LSFMT0 after sintering process at 900°C, 1000°C, 1100°C for 30 minutes.

4 Conclusions

For the $\text{La}_{0.5}\text{Sr}_{0.5}\text{Fe}_{0.9}\text{Mn}_{0.05}\text{Ti}_{0.05}\text{O}_3$ samples systems prepared by ultrasonic mixing method have found multi phases that they are consists of ferroelectric phase of $(\text{La,Sr})(\text{Fe,Mn,Ti})\text{O}_3$, ferromagnetic phase of $\text{SrFe}_{12}\text{O}_{19}$ and minor phase La_2O_3 . The increasing in sintering temperature will increase the weight fraction of the main phase $(\text{La,Sr})(\text{Fe,Mn,Ti})\text{O}_3$ and decreasing the second phase. The saturation polarization (Ps) and remanent polarization (Pr) tends to stable at any temperature sintering and measurement conditions. We believed that our work has showed a new innovation in LSFMT0 system and the results are very potential for multiferroic materials applications.

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