Scaling behavior of loop area, magnetic remanence and coercivity in thermal dependence of double perovskite Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ compound

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Abstract. We have detailed investigated the scaling behavior of loop area with respect to temperature for Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ double perovskite compound. The hysteresis loop was performed on a vibrating sample magnetometer (VSM-Lakeshore 331) from below to critical temperature with a fixed applied field. Based on field dependence of magnetization, we observed that the loop area remains constant within the range below to near critical temperature then decreases abruptly at around critical temperature, exhibits scaling behavior with respect to temperature. The scaling exponent of magnetic remanence and coercivity field with respect to temperature are analyzed together. The result indicates a coexistence of loop area, magnetic remanence and coercivity field in Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ double perovskite compound.

Keywords: scaling, perovskite, magnetic remanence, coercivity

1. Introduction

Double perovskite (DP) materials could be found in many complex phases in $A_{2}$BB'O$_6$ formula (A = alkaline-earth or rare-earth elements, $B$ = transition-metal ions, $B$ and $B'$ reside on both sublattices of a cubic lattice) [1]. Recently, an improved interest in the double perovskite, with an interesting phenomenon such as Curie temperature $T_C>300$ K in ferromagnetic-paramagnetic (FM-PM) phase transition, high magnetoresistance ratio (MR) in room temperature, strong behavior in half-metallic antiferromagnetic (AFM) and magnetocaloric effect (MCE) has been increased [2–4]. Based on these properties, DP becomes one promising family material for the fabrication of spin-valve devices such as soft magnetic field detecting [5], the improvement of novel magnetic recording media [6] and strong candidate for the production of enhanced sources of spin-polarized electrons for “spin-tronic” applications [7].

Among the double perovskite family, Ba$_2$La$_{3-x}$FeMoO$_6$ becomes the most promising material. A number of comprehensive observations have been done for Ba$_2$La$_{3-x}$FeMoO$_6$ compounds [8–10], especially in structure, electrical-magnetic properties, and magnetocaloric effect. By partial substitution of La$^{3+}$ for Ba$^{2+}$ in BFMO, some properties have been changed such as: (1) effective decreasing of ionic radius with stable cubic symmetry unit cell (2) modification of magnetic moment and valence state by electron doping of Fe/Mo ions. Furthermore, this substitution influences the Fe/Mo structural disordering and the magnitude of saturation magnetization ($M_s$) respectively [11].

However, to our knowledge, no study has been dedicated for the effect of temperature to the hysteresis scaling behavior. In the same time, structure disordering and saturation magnetization plays an important...
role in hysteresis scaling behavior. In this article, we address to discover intensively some properties of partial substitution of La$^{3+}$ for Ba$^{2+}$ on scaling behavior of loop area, magnetic remanence and coercivity in thermal dependence of BFMO materials. Materials with the chemical formula Ba$_{2-x}$La$_x$FeMoO$_6$ (BLFMO) have been examined completely.

2. Experimental
The standard solid-state reaction method was used to prepare the DP-structured Ba$_{2-x}$La$_x$FeMoO$_6$ compound with $x = 0.1$, 0.2, and 0.3 samples. The starting material, BaCo$_3$, La$_2$O$_3$, Fe$_2$O$_3$, and MoO$_3$, were mixed and milled by using small quantity of alcohol. Annealing was performed at 1220 K for 12 hours and at 1270 K for 10 hours. Furthermore, after accomplished to be pellet, the powder was pressed and fired in a stream of 5 % H$_2$/Ar gas at 1420 K for 21 hours. The temperature-dependent magnetic hysteresis loop measurements have been done by using a vibrating sample magnetometer under 10 kOe maximum applied magnetic field and varied temperature from 100 to 354 K with 2 K increment.

3. Results and discussion
Figure 1 shows field-dependent magnetic hysteresis loops of Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ double perovskite compound at 100, 330 and 354 K. As the applied field increases the magnetization rapidly increase and then saturates to a value of $M_s$. This saturate magnetization has been observed to be decreased linearly as the ambient temperature varied from 100 to 330 K. At further increasing temperature, the magnetization rapidly decreases and tends to be constant. The temperature dependence of magnetization $M(T)$ is depicted in inset of figure 1. The tiny sharp variation in $M(T)$ indicates the occurrence of magnetic ordering in the Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ compound.

Below the Curie temperature ($T_c$), in the range 100 to 300 K, the attributes of the hysteresis loops reveal a very small remanences and coercivities, exhibits a clear soft FM oxide behavior in Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ compound. However, the curve corresponding to 354 K reflects practically typical paramagnetic characteristics.

To observe the scaling behavior of Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ double perovskite compound, we have determined an area of each hysteresis loop as a function of temperature, as shown in figure 2. In the log- log scale, the loop area tends to be decreased monotonically as the temperature increases. Approaching Curie temperature, the loop area becomes more rapidly decrease. The loop area exhibits a scaling behavior and is fitted by expression, $A \sim T^\gamma$ where $A$ is a loop area, $T$ is ambient temperature and $\gamma$ is the scaling exponent. We observed different scaling exponent value for different sample, as shown in inset of figure 2. These differences affected by the different decreasing of coercive field and reducing lattice deformation at elevated temperatures. It exhibits that higher thermal fluctuation promotes the switching process of domain and decreases the activation energy [12].

![Figure 1. Hysteresis loop that obtained by VSM at 100, 300, and 354 K, the inset shows M-T curve for 3 different Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ samples.](image)
Figure 2. Loop area with respect to temperature for 3 different Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ samples.

Figure 3. Magnetic remanence as a function of temperature for 3 different Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ samples.

For further understanding of scaling behavior, the magnetic remanence of the compound with respect to temperature has been determined. As shown in figure 3, the magnetic remanence shows different behavior for different sample compound. As temperature increases, the magnetic remanence of the sample 1 decreases monotonically then while approaching Curie temperature it rapidly decreases. Different behavior is shown by sample 2 and sample 3. The magnetic remanence decreases almost constant as temperature increases, especially for sample 3, the scaling behavior exhibits a linear relation between magnetic remanence and temperature. The modification of the magnetic remanence scaling behavior should be associated with the phase distribution in Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ compound.

For further understanding of scaling behavior, the coercive field as a function of temperature has
Figure 4. Coercivity as a function of temperature for 3 different Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ samples.

been determined. As shown in figure 4, the evolution of coercivity with respect to temperature for 3 different Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ compound samples respectively shows similar behavior. The coercivity tends to be linearly decreases as temperature increases with same slope due to the similar temperature-dependent behaviors ascribed to the inherent hysteresis loops for all different Ba$_{1.7}$La$_{0.3}$FeMoO$_6$ compound samples within the temperature range. Since the y-intercept could not be meaningfully defined, only the magnitudes of the slopes are shown in inset of figure 4.

4. Conclusions
We have carefully synthesized and observed the Ba$_{2-x}$La$_x$FeMoO$_6$ compound of La$^{3+}$ partial substitution that there is scaling behavior of magnetic hysteresis loop parameter with respect to temperature ambient observation. The loop area and coercivity exhibit decreasing value as temperature increases while magnetization has a random behavior.

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