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Magnetic Properties of Barium Titanate – Barium Ferrite Composites

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Abstract: Composite materials containing both ferroelectric and ferromagnetic phases from Barium Titanate ($BaTiO_3$) and Barium Ferrite ($BaFe_{12}O_{19}$) have been studied. The coexistence of magnetic hysteresis in the composite material has been observed in the temperature range 90-300 K. It is found that both remnant magnetization M_r and the saturation magnetization M_S decrease with increasing the temperature and they increase with decreasing the concentration of $BaTiO_3$ in the system. The coercive field H_C increases almost linearly with increasing the temperature and with increasing the concentration of $BaTiO_3$ in the system.
Keywords: Ferroelectric materials; Ferromagnetic materials; Magnetic hysteresis; Barium titanate; Barium ferrite.

Introduction

Composite materials containing both ferroelectric and ferromagnetic phases have recently attracted a great deal of attention because of their potential applications in practical electronic devices [1, 2].

When ferromagnetism and ferroelectricity coexist in a material magnetic-eclectic effect phenomena are expected due to the interaction between the magnetization and the electric polarization [3-7]. There are very few single phase materials with such combined properties [8]. It should be noted that bulk materials of $BaFe_{12}O_{19}$ have in general large magneto-crystalline anisotropy and sufficient saturation magnetization. To have the combined properties, simply make a composite of two materials having such properties.

It is known that Barium titanate is an excellent ferroelectric material that has been used in capacitors for half a century and Barium ferrite is known as ferromagnetic material and has been used in the production of multilayer chip inductors [6]. There are many reported work on these materials. Srinivas et. al. studied the magnetic and magneto-electric properties of $Bi_8Fe_4Ti_3O_{24}$. They found that the material has antiferromagnetic nature and the magnetic moment has greater values at low temperatures [9]. Duong et. al. studied the magnetic properties of nano-crystalline $BaFe_{12}O_{19}$ prepared by hydrothermal method. They reported that for nano-sized grains, properties such as magnetization and coercivity are strongly influenced by the grain size [10]. Kang et. al. studied the magnetic and electric properties of $0.3BiFeO_3$-$0.7PbTi_3$ thin films prepared by RF magnetron sputtering. They claimed that the origin of ferromagnetism, observed in their samples, may be due to the canting of spins and that the Fe-O-Fe spins are not collinear and the creation of lattice defects (addition of Ti^{+4} would give rise to bulk magnetization) [11]. Ziebinska et. al. studied the temperature dependence of the birefringence above T_c in high quality single

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crystals and they related the anomalous birefringence to the existence of polar clusters connected with jumps between the off-center positions of Ti ions [12]. Hernando *et.al.* studied the thermal dependence of coercivity in soft magnetic nano-crystals. These magnetic nano-crystals were formed by α-Fe(Si) nanocrystals embedded in a residual amorphous matrix. They reported a quantitative expression for thermal dependence of coercivity and a good agreement between experimental and theoretical results was obtained [13].

In this article we study the effect of mixing ferroelectric Barium titanate ($BaTiO_3$) with ferromagnetic Barium ferrite ($BaFe_{12}O_{19}$) on their magnetic properties in the temperature range 90-300K.

Experimental Procedure

Barium ferrite ($BaFe_{12}O_{19}$) with grain sizes less than 40μm and Barium titanate ($BaTiO_3$) with grain sizes less than 3μm, both bought from ALDRICH, were used to prepare the magneto-electric composites. Samples of the composite material having the formula $(BaTiO_3)_x(BaFe_{12}O_{19})_{1-x}$ for x = 0.2, 0.4, 0.5 have been prepared. The two phases of desired ratios were mixed and ball milled in a FRITSCH-Planetary Micro Mill "Pulverisette 7" for one hour to ensure more grinding and homogeneity. The powder was pressed into pellets and then sintered at 1150^{o} C for 16 hours.

Structural studies of the composites were carried out using X-ray diffraction, (XRD), analysis performed using PHILIPS-X, Pert/ Model PW 3040.

The magnetization measurements were carried out using an automated Vibrating Sample Magnetometer (VSM) in the temperature range 90-300K.

Results and Discussion

The X-ray diffraction measurements were first carried out on Barium titanate and Barium Ferrite separately. And using X-ray diffraction we obtained the diffraction patterns of the composites. The diffraction patterns of the composites showed that they were made of two separate phases: Barium titanate and Barium ferrite with a diffraction pattern of both phases overlapped with each other. No new phases were detected and there was no change in the position of the peaks indicating no change in lattice constants of the phases. However, the intensity of Barium titanate peaks and the intensity of Barium ferrite peaks increase with increasing their respective percentages in the composite.

The best method for determining the ferromagnetic nature of a material is to experimentally measure the magnetization-magnetic filed (M-H) hysteresis curves. Fig. 1 shows the magnetic –hysteresis loops of the composite material with x = 0.2 at different temperatures. The composite material exhibits typical magnetic-hysteresis loops, as well as remnant magnetizations, which indicate the presence of an ordered magnetic structure. It is evident from the curves that the magnetization increases with decreasing temperature. From each loop, saturation magnetization, remnant magnetization, and coercive field were calculated.

In Fig. 2 we plotted saturation magnetization, M_S, versus temperature. It is clear from this figure that the saturation magnetization, M_S, increases almost linearly with decreasing temperature. This is because thermal effects provide more kinetic energy at higher temperatures, rendering domains motion/rotation easier at higher temperatures. Therefore, as the temperature increases, thermal effects randomize spin orientations and hence reduce the overall magnetization. Kumar et al [14] found similar behavior in $BiFeO_3$-$BaTiO_3$ solid solutions and attributed the increase in magnetization with decreasing temperature to the flipping of spins towards the field direction. It is also clear, as expected, that M_S decreases with decreasing barium ferrite content (the magnetic phase), which shows the similar pattern as in [7].

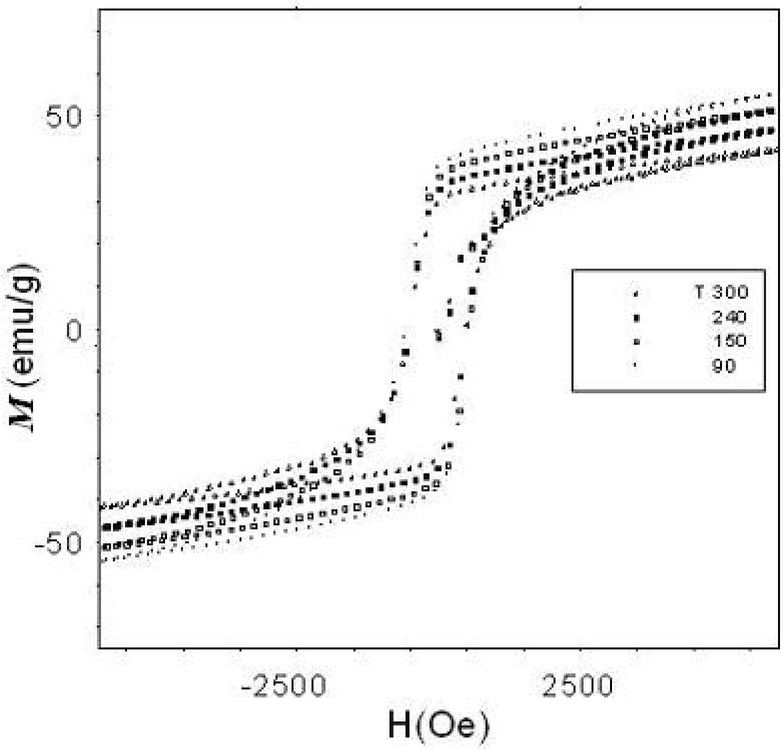

FIG.1. Hysteresis of $(BaTiO_3)_{0.2}(BaFe_{12}O_{19})_{0.8}$ at different temperatures

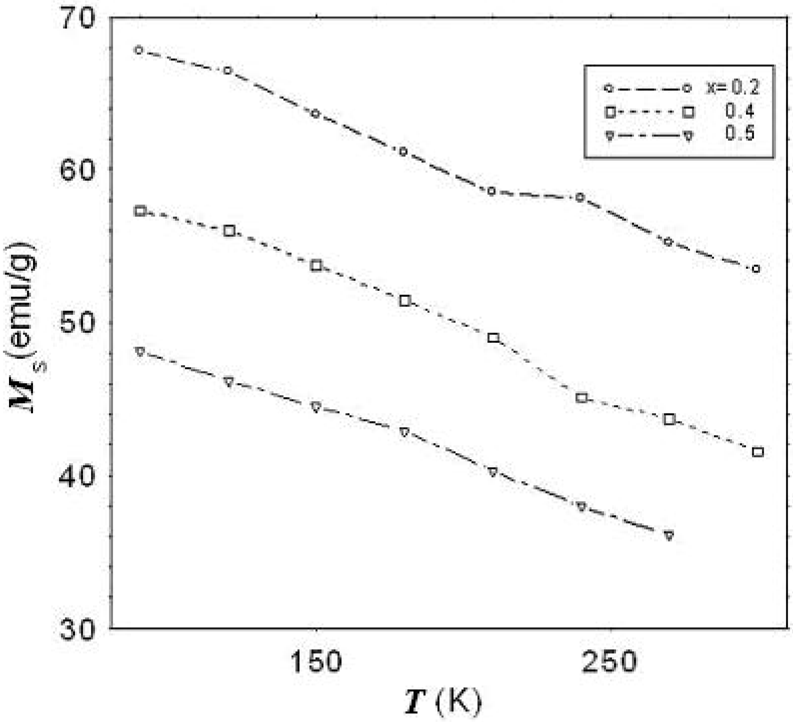

FIG.2. Saturation magnetization vs. temperature for all samples

We plotted in Fig. 3 the remnant magnetization (M_r) versus temperature. The figure reveals similar behavior as M_s. It decreases with increasing temperature and with decreasing barium ferrite phase.

Fig. 4 shows coercive field, H_c, versus temperature and it clearly shows that H_c increases with increasing temperature and decreases with decreasing concentration. This could be related to the changes in the exchange coupling between domains considering the two phase character of the samples [13]

All the results mentioned above about saturation magnetization, remnant magnetization and coercive field indicate that the magnetization becomes weak due to the presence of nonmagnetic materials in a ferromagnetic material, which causes the pinning of the domain walls [15].

The approximate linear behavior of saturation magnetization and remnant magnetization versus temperature indicate that they follow the linear effective medium approximation which means that the nonmagnetic material (barium titanate) does not interact with barium ferrite or affect its magnetic behavior.

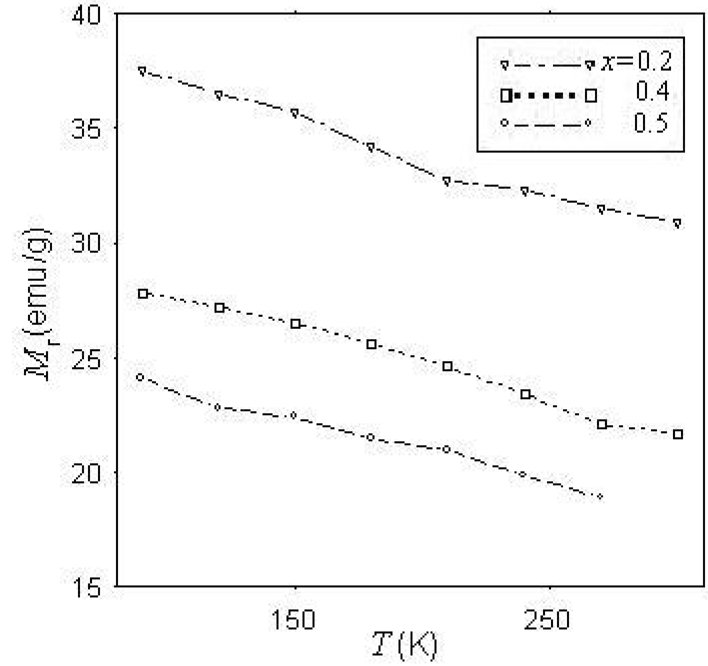

FIG.3. Remnant magnetization as a function of temperature for all samples

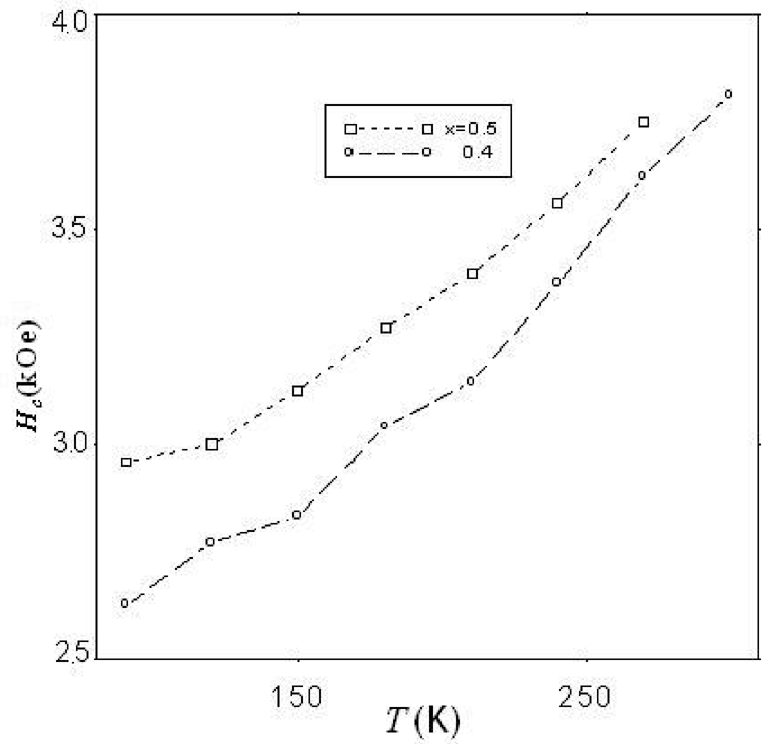

FIG.4. Coercivity, H_c, as a function of temperature

In Fig. 5 we plotted saturation magnetization versus the concentration of barium ferrite at various temperatures. It shows a consistent increase in saturation magnetization with decreasing both temperature and concentration.

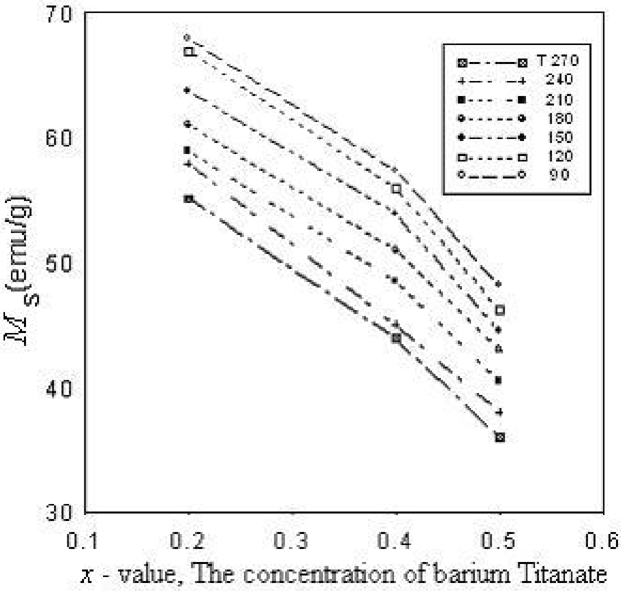

FIG.5. Saturation magnetization versus concentration of Barium Ferrite.

Conclusion

Composite materials containing both ferroelectric, Barium Titanate ($BaTiO_3$) and ferromagnetic, Barium Ferrite ($BaFe_{12}O_{19}$), phases have been prepared and studied. The existence of magnetic hysteresis in the composite material has been observed in the temperature range 90-300K. It is found that remnant magnetization, *Mr*., and saturation magnetization, M_S, both decrease with increasing the temperature and they increase with decreasing the concentration of $BaTiO_3$ in the system. The coercive field, H_C, increases almost linearly with increasing the temperature and the concentration of $BaTiO_3$ in the system.

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