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MAGNETIC TRANSITION IN $La_{1/3}Nd_{1/3}Ca_{1/3}MnO_3$ PEROVSKITE INDUCED BY ELECTRIC FIELD AT A GIVEN MAGNETIC FIELD

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We report the discovery of new effect in $La_{1/3}Nd_{1/3}Ca_{1/3}MnO_3$ — the jump of magnetization induced by external electric field E (2.5–4)V/cm at a given magnetic field H (18–25) kOe at $T = 4.2$ K. This effect is large when compared with a metamagnetic transition induced by the magnetic field in many substances. The origin of the magnetization jump induced by external electric field has not yet been explained. We assume that this transition is induced by the hopping of E-excited e_g electrons and that this is a source of a jumpwise increase in magnetization in the non-collinear magnetic phase within the perovskite. This effect can be attributed to a strong coupling between carriers induced by the electric field (the conduction electrons e_g), and the local magnetic moments (t_{2g}-localized spins) through a mechanism of the Zener double exchange.

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1. Introduction

The observation of a colossal magnetoresistance effect (CMR), near the ferromagnetic ordering temperature, in perovskite-type manganese oxide $R_{1-x}A_xMnO_3$ (R = rare earth, A = divalent alkaline earth) has generated considerable interest in these materials. Arising from the competition between antiferromagnetic superexchange and ferromagnetic double-exchange interaction, various magnetic structures have been observed with the substitution of R for A. Some intrinsic physical properties have been discovered such as a magnetic field induced antiferromagnetic (AFM) insulator-to-ferromagnetic (FM) metal transition [1] and in particular the coexistence of interacting AFM and FM subsystems at La-based manganites [2], photoinduced insulator-to-metal transition [3], current switching of resistive states [4]. This switching of resistive states in the manganites $Pr_{1-x}Ca_xMnO_3$ can be achieved not only by a magnetic field, but also by an electric field.

In perovskite manganites charge, spin, orbital, and lattice act as independent degrees of freedom, yet they are strongly coupled so that the balance between the

resulting phases is very subtle and susceptible to the external stimuli. The replacement of La by smaller rare earth (e.g. Nd) in La–Mn–O causes a large distortion of the Mn–O–Mn bond, thus the weakening of the double exchange effect (DEM) [5] and the reducing of the transfer interaction of e_g electrons. Thus the composition $La_{1/3}Nd_{1/3}Ca_{1/3}MnO_3$ is magnetically inhomogeneous. This inhomogeneity could originate from different local distortion of the lattice around La^{3+} and Nd^{3+} ions: Nd^{3+} ions are in tension, while La^{3+} ions are in compression [6].

This paper reports the discovery of a new effect at $La_{1/3}Nd_{1/3}Ca_{1/3}MnO_3$ — the jump of magnetization induced by an external field at a given magnetic field at $T = 4.2$ K. This effect can be attributed to a strong coupling between the conduction electrons e_g, created via electric field and the local magnetic moments (t_{2g}-localized spins) through a mechanism called double exchange [5]. The effect of hysteresis loops shaped by electric field was reported in our previous paper [7].

2. Experimental details

The sample preparation was described in detail in Ref. [8]. The X-ray diffraction patterns have revealed the single-phase perovskite structure with lattice parameters $a = 5.428$ Å, $c = 5.441$ Å, and $c = 7.684$ Å.

Magnetic properties were studied by vibrating sample magnetometer in a magnetic field up to 6 T at $T = 4.2$ K.

3. Results and discussion

Figure 1 shows the dependence of magnetization M under magnetic field $H = 20$ kOe versus the intensity of external electric field E, which is a function of time. For $E = 4$ V/cm we observed the jump of magnetization M from values 25 up to 85 emu/g.

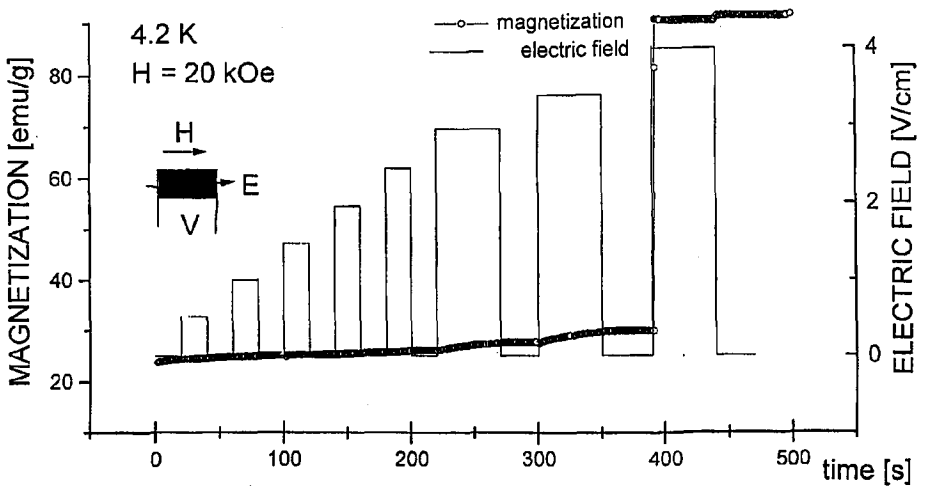

Fig. 1. A plot of magnetization M vs. the intensity of external electric field E, which is the function at the time at magnetic field $H = 20$ kOe. The measurements were performed after zero field cooling to 4.2 K.

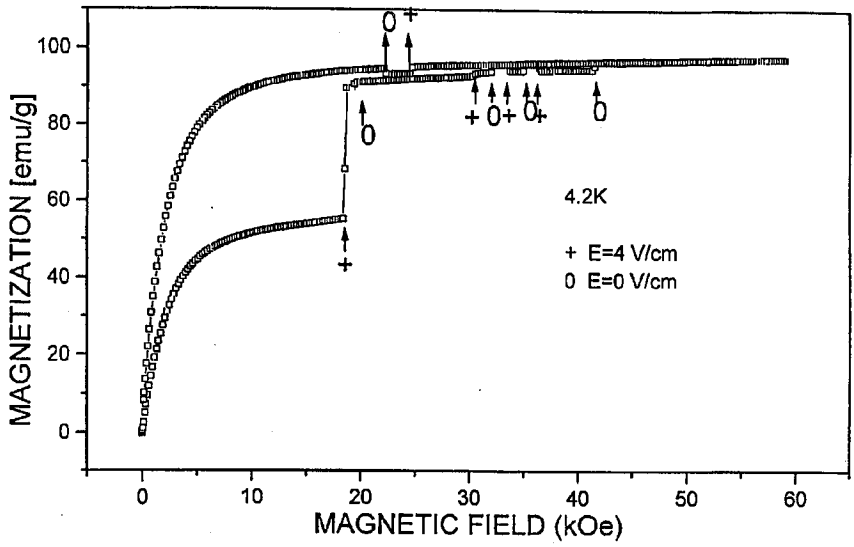

Fig. 2. Magnetic field dependence of magnetization in temperature 4.2 K at switching on (+) and off (0) electric field $E = 4$ V/cm, respectively.

Figure 2 shows magnetization versus magnetic field. One can see a jump of magnetization after applying the electric field $E = 4$ V/cm in magnetic field $H = 18$ kOe. The displayed dependence is characteristic of the metamagnetic transition. Arrows with sign + and 0 mark switching on and off the electric fields, respectively. In accordance with these results the magnetic transition is permanent, in the sense that the magnetization of the sample does not change after removal of the applied electric field.

The applied magnetic field is known to bring about a change in the canting angle or even induce a structural phase transition in manganites. Both Mn–O–Mn angle and the spin canting angle could be responsible for the spin-dependent mechanism.

The origin of the jump of the magnetization induced by external electric field in magnetically inhomogeneous $La_{1/3}Nd_{1/3}Ca_{1/3}MnO_3$ perovskite has not yet been explained. This is a large effect compared to the metamagnetic transition induced by a magnetic field in many substances. We assume that the increase magnetization may have a link to the FM transition as well because the angle between the t_{2g}-localized spins of the two Mn ions will be changed under an external electric field i.e. increased the hopping or concentration of e_g electrons. In fact, the probability of electron hoppings between two magnetic ions turns out to depend on the spinor transformation [9, 10], which is characterized by a transfer integral (analogous to the transfer probability) $t_{ij} = b_{ij}(\Theta_{ij}/2)$ where b_{ij} is a constant dependent on the distance between the ions, and Θ_{ij} is the angle between the direction of the ion spins. Thus, the electric resistance of the material is a function of its intrinsic magnetic order. This ferromagnetic structure is induced by the hopping e_g electrons and we assume that this is the source of the jump of the magnetic moment in non-collinear magnetic phase at the perovskite.

In conclusion, the present work clearly shows that for $La_{1/3}Nd_{1/3}Ca_{1/3}MnO_3$ perovskite the electric field induces the metamagnetic transition from canted ferromagnetic or antiferromagnetic state to collinear ferromagnetic ordering at a given magnetic field at low temperature.

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References

[1] Y. Tomioka, A. Asamitsu, Y. Moritomo, T. Tokura, *J. Phys. Soc. Jpn.* **64**, 3626 (1995).

[2] G. Allodi, R. De Renzi, G. Guidi, *Phys. Rev. B* **56**, 6036 (1997).

[3] K. Miyano, T. Tanaka, Y. Tomioka, Y. Tokura, *Phys. Rev. Lett.* **78**, 4257 (1997).

[4] A. Asamitsu, Y. Tomioka, H. Kuwahara, Y. Tokura, *Nature* **388**, 50 (1997).

[5] C. Zener, *Phys. Rev. B* **100**, 403 (1950).

[6] G.H. Rao, J.R. Sun, J.K. Liang, W.Y. Zhou, *Phys. Rev. B* **55**, 3742 (1997).

[7] J. Baszyński, J. Kováč, A. Kowalczyk, *Acta Phys. Slov.* **48**, 793 (1998).

[8] J. Baszyński, J. Kováč, A. Kowalczyk, *J. Magn. Magn. Mater.* **195**, 93 (1999).

[9] P.W. Anderson, H. Hasegawa, *Phys. Rev. B* **100**, 765 (1955).

[10] P.G. de Gennes, *Phys. Rev. B* **118**, 141 (1960).