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LOW-FIELD MAGNETORESISTANCE IN MANGANITE THIN FILMS

E.S. VLAKHOV[a,b*], K. DÖRR[a], K.-H. MÜLLER[a], A. HANDSTEIN[a], K. NENKOV[a,b*], T. WALTER[a], R.A. CHAKALOV[c], R.I. CHAKALOVA[c] AND A.Y. SPASOV[c]

[a]Institut für Festkörper- und Werkstofforschung Dresden
P.O. Box 270016, 01171 Dresden, Germany
[b]International Laboratory of High Magnetic Fields and Low Temperatures
Gajowicka 95, 53-529 Wrocław, Poland
[c]Institute of Electronics, Bulgarian Academy of Sciences, 1784 Sofia, Bulgaria

Grain boundaries play an important role in low-field magnetoresistance of $La_{0.7}Ca_{0.3}MnO_3$ and $La_{0.7}Sr_{0.3}MnO_3$ thin films deposited by magnetron sputtering and pulsed laser deposition on YSZ(100) and silicon substrates buffered by YSZ. Well-pronounced low-field magnetoresistance hysteresis was observed in magnetic fields applied in in-plane and out-of-plane directions. High values of local magnetoresistance sensitivity $\mathrm{d}(MR)/\mathrm{d}H$ in the vicinity of the coercive field were obtained reaching up to 0.2%/Oe for $La_{0.7}Ca_{0.3}MnO_3$ samples at 5 K.

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Recently the colossal magnetoresistance (CMR) phenomenon has attracted much attention as both a fundamental research and an applied science challenge [1]. It has been demonstrated that low-field magnetoresistance (LFMR) effects have an important influence in bulk polycrystalline materials [2, 3], polycrystalline thin films [4–6], and thin films with reduced epitaxy [7, 8]. It was established that the control of crystallinity perfection of thin manganite films, such as epitaxial strain or granularity, could be utilized for tuning of their MR properties, especially of LFMR [6–8]. In this paper, the influence of preparation conditions during magnetron sputtering (MS) or pulsed laser deposition (PLD) using various substrates on the resulting MR behaviour is investigated.

$La_{0.7}Ca_{0.3}MnO_3$ (LCMO) thin films were prepared by magnetron sputtering and $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) thin films by PLD using ceramic targets (cf. Refs. [5, 6]). The substrates were monocrystalline plates (i) of Y-stabilised ZrO_2 (100) (YSZ) and (ii) of silicon buffered by YSZ layers. The structure of the deposited films was characterized by SEM and X-ray diffraction using Co K_α radiation. Magnetic measurements were carried out in an ac susceptometer and a SQUID magnetometer at fields up to 50 kOe. The resistivity was measured by the four-probe technique in a superconducting split-coil magnet at fields

*On leave from the Institute of Solid State Physics, BAS, 1784 Sofia, Bulgaria.

up to 70 kOe applied in parallel (in-plane) and perpendicular (out-of-plane) directions to the sample surface. The magnetoresistance ratio was determined by $MR = [(R(H) - R(0)]/R(0)$.

It was shown in our previous work [5, 6] that the deposition temperature and mismatch of the lattice constants between the manganite film and the substrate have a crucial influence on the film growth. For a very low lattice mismatch the obtained films are single crystalline independent of employed deposition technique. Here, the obtained LCMO films sputtered on YSZ substrates at a substrate temperature $T_{sub} = 700°C$ are polycrystalline consisting of a mixture of (100) and (110) oriented grains with a size of about 50–100 nm. The influence of substrate temperature on the growth of LSMO thin films on YSZ substrates resulted in a gradual change of the grain orientation. Epitaxial growth has been found around $T_{sub} = 800°C$ [6].

TABLE

Characteristic parameters of thin films: δ — thickness of the manganite layer, T_{peak} — temperature of resistance maximum, T_C — Curie temperature.

Samples	Structure	δ [nm]	T_{peak} [K]	T_C [K]
VZ3	YSZ/LCMO	208	199	225
VZ10	YSZ/LCMO	100	271	265
VZ12	YSZ/LCMO	50	266	–
VZ13	YSZ/LCMO	25	266	–
VSZ28	Si/YSZ/LCMO	200	246	–
B	YSZ/LSMO	76	150	360
G	YSZ/LSMO	76	> 320	356
R	Si/YSZ/LSMO	100	150	365

Table provides an overview of some characteristic parameters of representative films. In the low magnetic field region a well-pronounced hysteretic behaviour of resistance of $La_{0.7}Ca_{0.3}MnO_3$ thin films was registered by in-plane and out-of-plane measurements as shown in Fig. 1.

Both runs of MR exhibit qualitatively the same behaviour — a peak in the low magnetic field region with a strong MR slope and nearly a constant small slope at higher fields. The peaks of MR for the in-plane case are located at lower fields and their amplitudes are higher. The analysis of the MR hysteresis for the case of in-plane measurement has shown that the field value of the MR peak (the so-called "switching" field H_{sw}) practically coincides with that of the coercive field H_c (see Fig. 2a). Such behaviour was also found for the PLD $La_{0.7}Sr_{0.3}MnO_3$ thin films obtained by deposition at lower substrate temperatures (600–710°C). The reason for this behaviour is that carrier transport in a granular system becomes easier when the magnetic vectors of grains are ordered. Therefore, the resistivity should be a maximum near the coercive field H_c, where the magnetization vanishes.

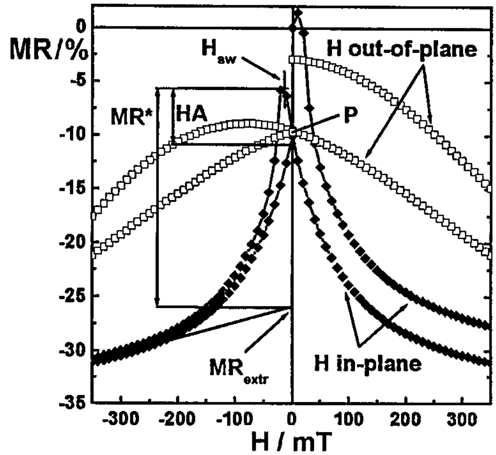

Fig. 1. Magnetoresistance ratio MR of the sample VZ3 measured at $T = 20$ K. (MR^*, MR_{extr}, HA, and P are explained in the text).

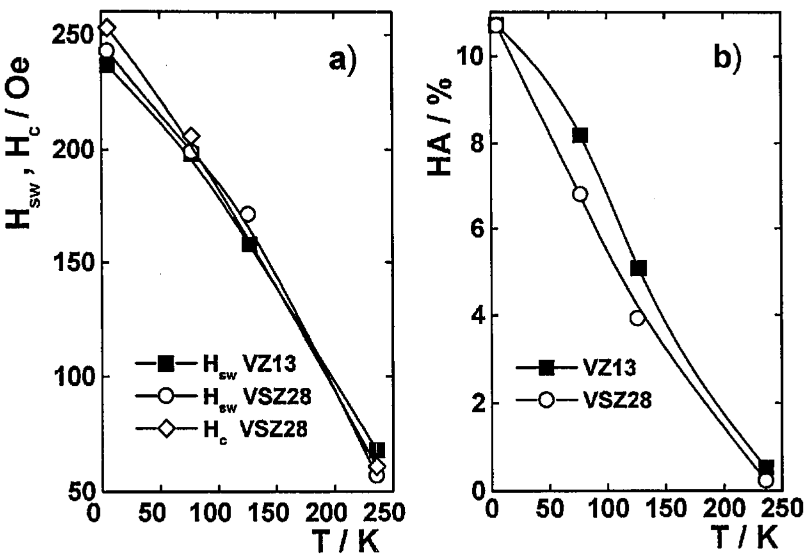

Fig. 2. Temperature dependences of (a) switching field H_{sw} and coercive field H_c and (b) hysteresis amplitude $HA = \Delta R(H_{\mathrm{sw}})/R(0)$ of samples VZ13 and VSZ28.

The high value of the local MR sensitivity $\mathrm{d}(MR)/\mathrm{d}H$ in the vicinity of the peak has to be noted, reaching values up to 0.2%/Oe at 5 K for the $La_{0.7}Ca_{0.3}MnO_3$ samples VZ13 and VSZ28. Compared with that, the high-field sensitivity of these samples is some orders of magnitude smaller, with values of approximately 0.5 %/kOe. One can suppose that even higher values of LFMR sensitivity could be obtained in single layer films with a high degree of misoriented grains (for influence of misorientation angle at grain boundaries see [9]).

It is noteworthy that the values of the low-field magnetoresistance amplitude $MR^* = [MR(H_{sw}) - MR_{extr}]$ are significantly influenced by the film thickness (where $MR(H_{sw})$ was determined at the switching field H_{sw} and MR_{extr} is the zero field intercept of the linear high-field extrapolation of MR). Only a small influence of the film thickness on the values of T_{peak} was observed as shown in Table (samples VZ10 to VZ13). For example, the MR^* value of a sample decreases nearly by a factor of two in the temperature range of $T = 5 \div 77$ K by decreasing the film thickness from 100 nm (sample VZ10) down to 25 nm (sample VZ13). The maximal value, $MR^*(5\text{ K}) = 35\%$, was registered for the $La_{0.7}Ca_{0.3}MnO_3$ sample VZ10 (thickness 100 nm) which exhibits the highest value of T_{peak}.

Together with MR^* also the values of the hysteresis amplitude HA strongly decrease with increasing temperature up to T_C as shown in Fig. 2b (HA is the difference of MR values determined at H_{sw} and the crossing point P as marked in Fig. 1). The temperature dependence of HA is approximately linear. A similar strong decrease with temperature has been found for the spin polarisation of a LSMO thin film [10], that is clearly correlated with the observed decrease in low-field magnetoresistance of bulk material [2]. The reason for such behaviour of manganites is expected to be intrinsic. Therefore, new materials with higher T_C and weaker temperature dependence have been proposed.

In conclusion, the influence of extrinsic properties of manganite thin films on their LFMR has been investigated. A well-pronounced LFMR hysteresis was obtained in magnetic fields applied in the in-plane and out-of-plane directions. The high value of the sensitivity $\mathrm{d}(MR)/\mathrm{d}H$ in the vicinity of the coercive field (up to 0.2%/Oe at 5 K) has to be noted.

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References

[1] J.M.D. Coey, M. Viret, S. von Molnár, *Adv. Phys.* **48**, 167 (1998).

[2] H.Y. Hwang, S.-W. Cheong, N.P. Ong, B. Batlogg, *Phys. Rev. Lett.* **77**, 2041 (1996).

[3] P. Schiffer, A.P. Ramirez, W. Bao, S.-W. Cheong, *Phys. Rev. Lett.* **75**, 3336 (1995).

[4] A. Gupta, G.Q. Gong, G. Xiao, P.R. Duncombe, P. Lecoeur, P. Trouilloud, Y.Y. Wang, V.P. Dravid, J.Z. Sun, *Phys. Rev. B* **54**, R15629 (1996).

[5] E.S. Vlakhov, R.A. Chakalov, R.I. Chakalova, K.A. Nenkov, K. Dörr, A. Handstein, K.-H. Müller, *J. Appl. Phys.* **83**, 2152 (1998).

[6] T. Walter, K. Dörr, K.-H. Müller, B. Holzapfel, D. Eckert, M. Wolf, D. Schläfer, L. Schultz, R. Grötzschel, *Appl. Phys. Lett.* **74**, 2218 (1999).

[7] B.S. Teo, N.D. Mathur, S.P. Isaac, J.E. Evetts, M.G. Blamire, *J. Appl. Phys.* **83**, 7157 (1998).

[8] J. O'Donnell, M. Onellion, M.S. Rzchowski, J.N. Eckstein, I. Bozovic, *Phys. Rev. B* **55**, 5873 (1997).

[9] S.P. Isaac, N.D. Mathur, J.E. Evetts, M.G. Blamire, *Appl. Phys. Lett.* **72**, 2038 (1998).

[10] J.-H. Park, E. Veskovo, H.-J. Kim, C. Kwon, R. Ramesh, T. Venkatesan, *Phys. Rev. Lett.* **81**, 1953 (1998).