In-plane crystalline orientations of LSMO/ZnO double layers

Tamio Endo[1], Kenichi Uehara[1], Miyoshi Yokura[1,2], Katsuhiko Inaba[3], Tomohiko Nakajima[4], Tetsuo Tsuchiya[4], Hiroshi Kezuka[5], Kazuhiro Endo[6]

[1] Graduate School of Engineering, Mie University, 1577 Tsu, Mie 514-8507, Japan
[2] Kawamura Sangyo Co., LTD., Yokkaichi, Mie 512-8052, Japan
[3] Rigaku Corp., XRL, 3-9-12 Matsubara, Akishima, Tokyo 196-8666, Japan
[4] National Institute of Advanced Industrial Science and Technology, 1-1-1 Higashi, Tsukuba 305-8565, Japan
[5] Tokyo University of Technology, 1404-1 Katakura, Hachioji, Tokyo 192-0982, Japan
[6] Kanazawa Institute of Technology, The Research Laboratory for Integrated Technological Systems, Hakusan, Ishikawa 924-0838, Japan

Introduction

Manganites of La(Sr)MnO_3 (LSMO) and La(Ba)MnO_3 (LBMO) are perovskite p-type semiconductors showing versatile electrical and magnetic properties such as curious colossal magnetoresistance [1]. ZnO is a wide-gap n-type semiconductor, which also has variety of useful properties. Recently ZnO thin film can be finely fabricated to show room temperature laser oscillation [2]. A goal of this study is to fabricate p-n junctions using these p-type manganites and n-type ZnO. They (LSMO/ZnO, LBMO/ZnO) are expected as new devices, because the p-n junction characteristics [3] can be largely modulated by magnetic field, temperature and UV light. We, however, have to solve issues of variety of orientation growths [4] prior to applications.

Experimental

ZnO thin films were deposited on LAO-(001) and Sapphire-(001) substrates by ion beam sputtering (IBS). LSMO (and LBMO) thin films were deposited on these ZnO under-layers by the same IBS at various substrate temperatures T_s and oxygen partial pressures P_o using oxygen molecules (ML) or oxygen plasma (PL). Their crystallinities were estimated by out-of-plane XRD (θ-2θ and ω-scan), then out-of-plane phase orientation ratios R_o were calculated using intensities of the θ-2θ peaks corresponding to their phases.
In-plane XRD measurement was performed on the same samples using Rigaku (SmartLab), then Reciprocal Space Mapping (RMS) was obtained, which shows in-plane crystalline orientations. Surface morphology and surface roughness were obtained by AFM. Electrical, magnetic and optical properties on the single and double layers were characterized [1].
We calculated lattice matching in terms of lattice contraction (or expansion) of the over-layers. In this process, we considered least-common-multiples matchings and thermal lattice expansions. Finally we obtained lattice distortion area S_d which corresponds to distortion energy of the over-layers.

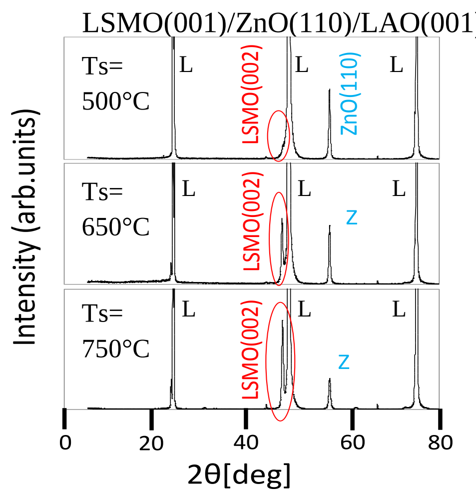

Fig. 1 XRD patterns for LSMO/ZnO/LAO. LSMO were deposited at various *T*s shown and *P*o=1 mTorr by PL.

Results and Discussion

Out-of-plane Orientations
XRD patterns obtained by θ-2θ scan are shown in Fig.1 for the double layers of LSMO/ZnO(110)/LAO (substrate), where LSMO over-layers were deposited at T_s=500, 650 and 750°C and P_o=1 mTorr by PL. All the ZnO under-layer shows (110) peak, then (110) oriented single phase of ZnO is always grown on LAO-(001) substrate. All the LSMO show strong (002) peak, then c-axis (001) oriented single phase of LSMO over-layer is always grown on ZnO-(110) under-layer. On the other hand, XRD patterns are shown in Fig.2 for the double layers of LSMO/ZnO(001)/Sapphire(substrate), where LSMO over-layers were deposited at T_s=500, 650 and 750℃ and P_o=1 mTorr by PL. All the ZnO under-layer shows (002) and (004) peaks, then c-axis (001) oriented single phase of ZnO is always grown on Sapphire-(001) substrate. At low T_s as 500℃, LSMO peak is not observed, then the crystalline LSMO cannot be grown. While at middle T_s, LSMO over-layer shows (110),

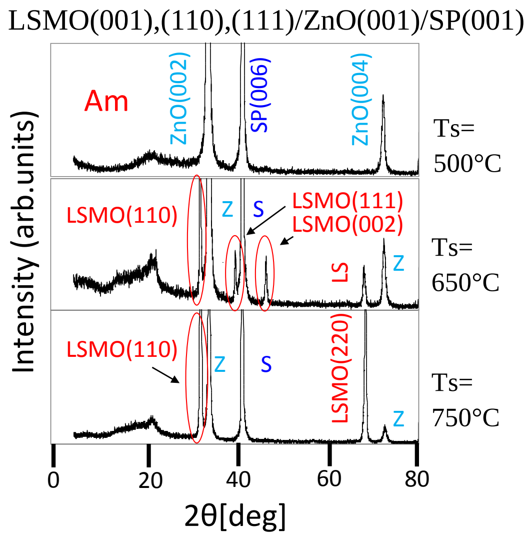

Fig. 2 XRD patterns for LSMO/ZnO/Sapphire. LSMO were deposited at various *Ts* shown and *Po*=1 mTorr by PL.

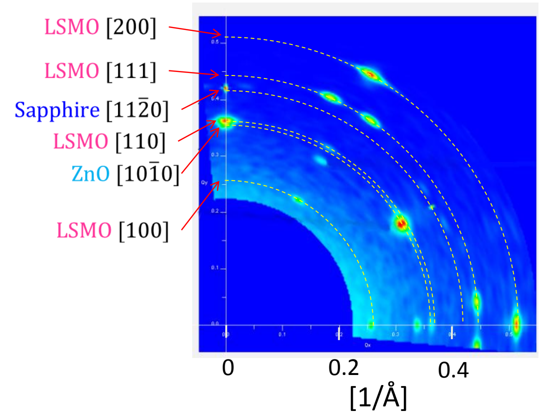

Fig. 3 In-plane RSM for LSMO(110)/ZnO(001) /Sapphire(001). Possible crystalline planes are indicated for spots.

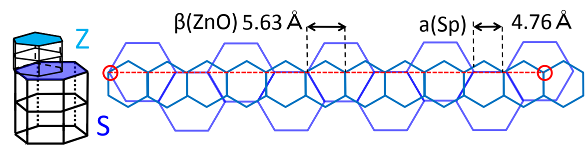

Fig. 4 Possible in-plane orientation of ZnO under-layer on Sapphire. β(ZnO)//a(Sapphire).

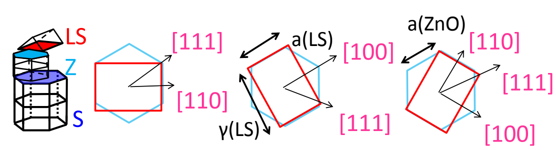

Fig. 5 Possible in-plane orientations of LSMO over-layer on ZnO. a(LSMO)//a(ZnO).

(111) and (002) peaks, then the (110), (111) and (001) phases are mixed. At high T_s, LSMO shows only the (110) and (220) peaks, then the single phase of LSMO-(110) is grown on ZnO-(001).

In-plane orientations

In-plane RSM is shown in Fig.3 for LSMO(110)/ZnO(001)/Sapphire(001), where LSMO was grown at T_s=750℃ and P_o=1 mTorr by PL. This RSM clearly indicates that diagonal β-axis of ZnO is parallel to a-axis of Sapphire as schematically shown in Fig.4. This in-plane orientation is interpreted by the least-common-multiples of lattice matching, that is, 11β(ZnO)≃ 13 a(Sapphire). We calculated these values using the bulk lattice values and obtained as 11β(ZnO)=61.97 Å and 13a(Sapphire)=61.85 Å, they are very close. Then ZnO(001) under-layer is grown with its in-plane lattice contracted a little to match with Sapphire.

From RSM it is known that a-axis of LSMO(110) over-layer is parallel to a-axis of ZnO(001) under-layer (we call it A-mode). We can recognize three equivalent domains of LSMO(110) as shown in Fig.5. This A-mode in-plane orientation can be interpreted by the lattice matching calculation. The lattice distortion area S_d of LSMO(110) is smaller for A-mode than for B-mode where diagonal (γ)-axis of LSMO is parallel to the a-axis of ZnO. It means that the strain energy for A-mode is smaller than that for B-mode, then A-mode LSMO(110) is grown on ZnO(001).

Summary

The double layers of LSMO(001)/ZnO(110)/LAO(001) and LSMO(110)/ZnO(001)/Sapphire(001) were fabricated. The single phase of ZnO(110) is always grown on LAO(001), and the single phase of LSMO(001) is always grown on ZnO(110). The single phase of ZnO(001) is always grown on Sapphire(001) due to the least-common-multiples of lattice matching. The three phases of LSMO(110), (111) and (001) are mixed at middle Ts on ZnO(001). The A-mode in-plane orientation of LSMO(110) is preferable due to the smaller lattice distortion, i.e., smaller interface energy.

References

1. T. Endo, K. Uehara, T. Yoshii, M. Yokura, H. Zhu, J. Nogues, J. Colino and K. Endo, *Trans. MRS-J*, **35-4** (2010) 727-738.
2. Y. Segawa, A. Ohtomo, M. Kawasaki, H. Koinuma, Z. K. Tang, P. Yu and G. K. L. Wong, *Phys. Stat. Sol.* **(b) 202** (1997) 669.
3. K. Lord, D. Hunter, T. M. Williams and A. K. Pradhan, *Appl. Phys. Lett.* **89** (2006) 052116.
4. T. Yoshii, K. Morikawa, Y. Nakamura, K. Endo, S. L. Reddy, Y. Strzhemechny and T. Endo, *presented at MRS-J Meeting* (Yokohama, 2009).