

Magnetic and Electrical Properties of (La, Sr)MnO₃ Sputtered on SrTiO₃-buffered Si Substrate

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1. Introduction

A perovskite type of (La,Sr)MnO₃ (LSMO) has attracted much attention, because of its superior magnetic properties, including a half-metallic nature and a colossal magnetoresistance effect [1]. Most of the LSMO films were deposited on the oxide substrates, such as SrTiO₃ (STO), MgO, or LaAlO₃ by pulsed laser deposition (PLD). It is however, indispensable to grow the LSMO films on the semiconductor substrate to integrate both the LSMO-based magnetic devices and semiconductor devices. Furthermore, the PLD method is inadequate from the practical point of view. Although there have been several reports on the fabrication and characterization of the LSMO film grown on Si substrate[2], no systematic characterization for electrical and magnetic properties as well as structural one has been available. In this paper, we report on the systematic characterization of the LSMO thin film deposited on Si substrate by RF magnetron sputtering.

2. Experiment

A 270-nm-thick STO buffer layer and a 240-nm-thick LSMO layer were grown on Si(001) substrate by RF magnetron sputtering. The Sr content of the LSMO target was 30%. Typical growth conditions were a substrate temperature of 700°C, RF power of 2.5 W/cm², O₂ and Ar mixed gas pressure of 3.5 mTorr with O₂ partial pressure of 5%. The STO was chosen as a buffer layer between Si and LSMO, since STO has a close lattice match to LSMO. The lattice mismatch between Si and STO is also quite small when the STO unit cell is rotated 45° around [001] axis, normal to Si surface. For comparison the LSMO was grown on STO(001) substrate with the same growth conditions.

The crystalline structure of the films were characterized by X-ray diffraction measurement. The electrical resistivity and magnetoresistance (MR) were measured by conventional dc four-terminal method, and the magnetization, M , was measured using a superconducting quantum interference device (SQUID) magnetometer at temperatures from 5 to 370 K.

3. Results and Discussion

From the X-ray pole figure analysis, it was found that the LSMO and STO buffer layer on Si substrate were poly-crystalline with a strong preferred orientation to c -axis, while the LSMO grown on STO substrate was a single crystal.

Figure 1(a) shows the temperature dependences of the magnetization and electrical resistivity for the LSMO on

the STO-buffered Si, and Figure 1(b) shows those for the LSMO on STO substrate. The M was measured at the magnetic field of 2000 Oe. In case for the films on the STO substrate, both the temperature, T_{C1} , at which the metal-insulator transition occurs, and the temperature, T_{C2} , at which the magnetization disappears, were almost equal, as is expected from the double-exchange mechanism for the LSMO materials system [3]. In case for the films on the Si substrate, on the other hand, the T_{C1} was lowered to 150 K, while the T_{C2} was approximately 270 K. In addition, the resistivity was two orders of magnitude larger than that for the single-crystalline LSMO. The separation of the T_{C1} and T_{C2} suggests the existence of the localized magnetic inhomogeneous regions such as a granular film or diluted magnetic system. The origin of the localized ferromagnetic regions is considered to be a crystal grain boundary due to poly-crystalline nature. The electrical conductivity is, then, governed by the conduction between the grains.

Figure 2 shows the temperature dependences of the MR ratio for both samples. The MR was measured under the magnetic field between -1880 and 1880 Oe applied in parallel to current direction. The MR ratio was defined as $[R(1880)-R(0)]/R(0)$, where $R(H)$ indicates the resistance under the magnetic field of H Oe. In case for the LSMO on the STO-buffered Si, large negative MR with clear hysteresis was observed at low temperature, as shown in the inset of Fig. 2. Compared to the single crystalline LSMO on STO substrate, in which the MR ratio takes a maximum value at Curie temperature (~ 280 K), the MR ratio was enhanced at low temperature regime. Furthermore, the MR modulation was observed up to 240 K, which is close to the T_{C2} , the temperature at which the M disappeared.

These results on the MR measurement can be explained by the spin-polarized tunneling between grains [4]. The large negative MR at low fields is associated with magnetic domain rotation at the grain boundaries. This phenomena is greatly enhanced by the high degree of spin polarization in the low temperature ferromagnetic regime, which is consistent with the temperature dependence of the MR ratio.

It was found that the coercive field H_C increased pronouncedly as the temperature decreased as shown in Fig.3. Assuming that each grain consists of a uniaxial single domain particle with spherical shape, H_C was fitted by the equation, $H_C=2K/M_S [1-(T/T_b)^{1/2}]$, where K is an anisotropy magnetic energy, M_S is a saturated magnetization, and T_b is a blocking temperature [5]. From this equation, the effective grain diameter was estimated to

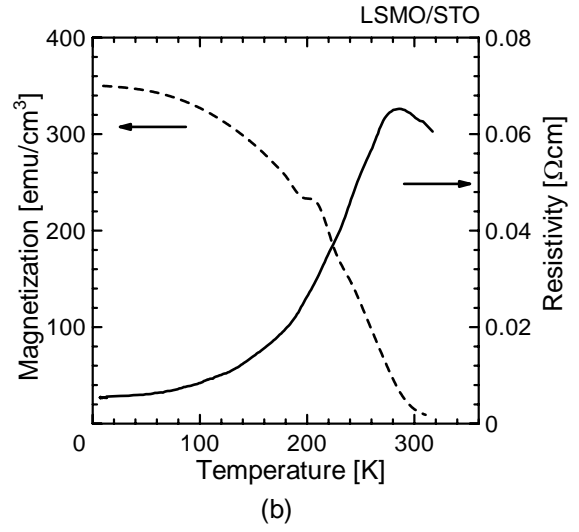
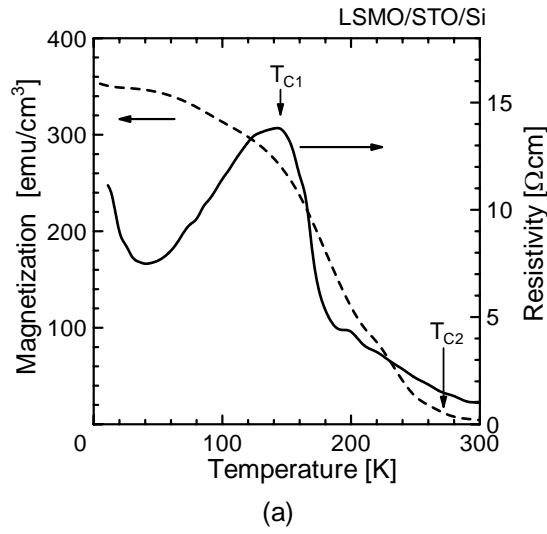


Fig. 1 Temperature dependences of the magnetization and resistivity. (a) LSMO grown on the STO-buffered Si substrate, (b) LSMO grown on STO substrate.

be 27 nm, and the blocking temperature, T_b , above which the spin alignment between grains is destroyed by thermal energy, was also estimated to be 170 K. It is noteworthy that the estimated T_b is close to the T_{C1} , the metal-insulator transition temperature.

4. Conclusion

We grew LSMO film by RF magnetron sputtering on the STO-buffered Si(001) substrate, and characterized its magnetic and electrical properties as well as its crystalline structure. The poly-crystalline LSMO film with strong preferred orientation to c -axis was grown on Si substrate. Compared to the single-crystalline LSMO film grown on STO substrate, the electrical and magnetic properties of the LSMO film on the STO-buffered Si substrate obtained in this study were different in three points; (1) the metal-insulator transition temperature T_{C1} is different from the temperature T_{C2} , at which the M disappeared. (2) the distinctive negative magnetoresistance accompanying the hysteresis and the large MR ratios below T_{C2} , and (3) the increased H_C in the low temperature region below 170 K. These features can be explained by the existence of the localized ferromagnetic grains and the spin polarized tunneling between them.

References

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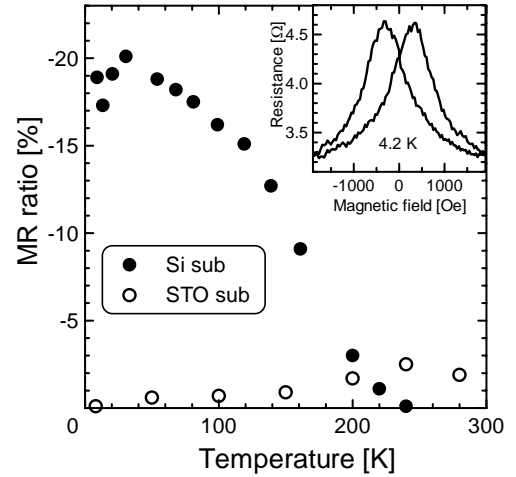


Fig. 2 Temperature dependences of the MR ratio. Inset shows the MR curve for LSMO on Si at 4.2 K.

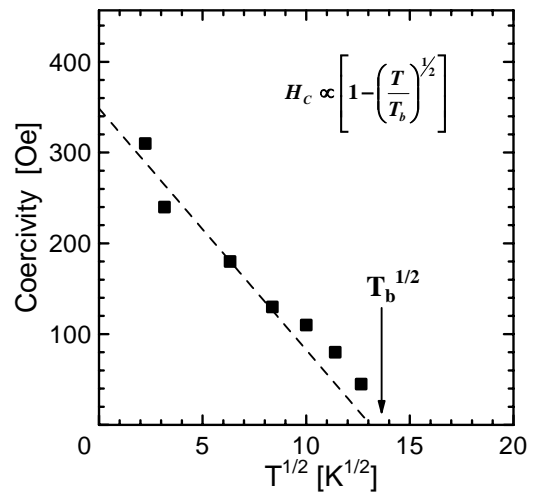


Fig. 3 Temperature dependence of the coercive field for LSMO on Si.