Oxygen vacancy in $SrTiO_3$ homoepitaxial films grown by pulsed laser deposition
(パルスレーザ堆積法で作製したチタン酸ストロンチウム薄膜中の酸素欠損)

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1 Introduction

Electronics has been a central pillar of modern technology and has still been developed and developed. The development of electronics has been realized mostly owing to the availability of high quality Si crystal and processing techniques. So far high quality interfaces fabricated with Si or GaAs have intensively been studied both for device application and for fundamental understanding of low-dimensional electronic states. Molecular beam epitaxy (MBE) is one of the key techniques in such fields and makes it possible to deposit one atomic layer on another atomic layer.

Recently, oxides have attracted much attention as another system for the study of low-dimensional physics. Since some of novel properties found in oxides in the bulk form such as high temperature superconductivity are clearly related to the low dimensionality, it is quite interesting to study the characteristics of ideal low-dimensional structures fabricated with oxides. Among various oxides, $SrTiO_3$ is a representative material of the perovskite oxides. It has been used widely as a substrate for perovskite oxide thin films since the procedure of preparing an atomically flat surface is established. Since transition metal atom in oxides can be in various valence states, a large number of oxygen vacancy can easily be introduced into transition-metal oxides. It has been reported that the transport properties of $SrTiO_3$ strongly depend on the density of oxygen vacancy. The central aim of this study is optimization of the growth conditions to control the oxygen vacancy concentration in the homoepitaxial $SrTiO_3$ films.

2 Experimental

Pulsed laser deposition (PLD) has much flexibility in the geometrical configuration due to the decoupling of the vacuum chamber and the deposition power source. Optical elements can be set outside the chamber to guide the laser onto the surface of the target inside the chamber. Since it has been reported that laser profiles have the significant effect on the properties of the grown films, investigation of the roles of optical parameters is crucial for precise growth oxide films. In the present work we fabricated four lens system as shown in Fig. 2(A), where we can adjust the laser energy density and spot size independently: We can make the sharp and energetically-homogeneous image of the aperture with variable magnification just at the target surface as visible in Fig. 2(B).

3 Results and Discussion

We have fabricated $SrTiO_3$ homoepitaxial films by PLD technique in various conditions. We have found that in addition to the substrate temperature and the oxygen pressure during growth, both of which are believed to important parameters for PLD growth, the laser spot size at the target surface significantly affects the transport properties of the grown films. Figure 3(A) shows that c-axis lattice constant is dramatically modified by changing the spot size and energy intensity. Figure 3(B) shows the spot size and the energy density dependence of the resistivity of grown films. We found that the effect of the spot size is more significant than that of the energy density. Under the same oxygen partial pressure and the substrate temperature, the grown film can either metallic or insulating by changing the spot size. Since the profile of the plume is dramatically modified by changing the spot size, the present result would indicate that the bombardment of the surface of films by the plume is crucial in the characteristics of $SrTiO_3$.

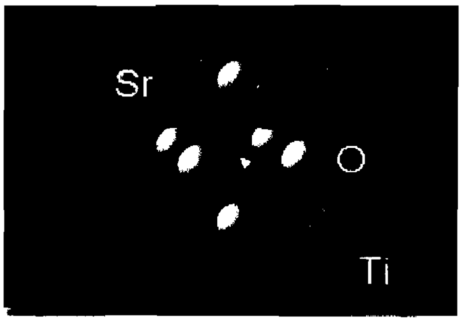

Figure 1: Atomic model of $SrTiO_3$. Ti atom is at the cube center surrounded by O atoms octahedrally and Sr atoms at the cube corners.

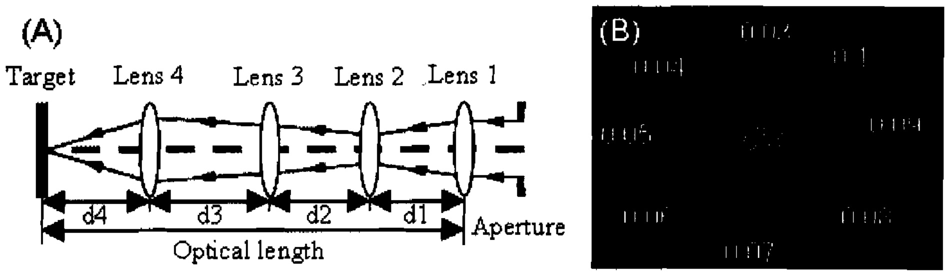

Figure 2: A schematic illustration of the optical system (A) and the profiles of laser spots on the target (B).

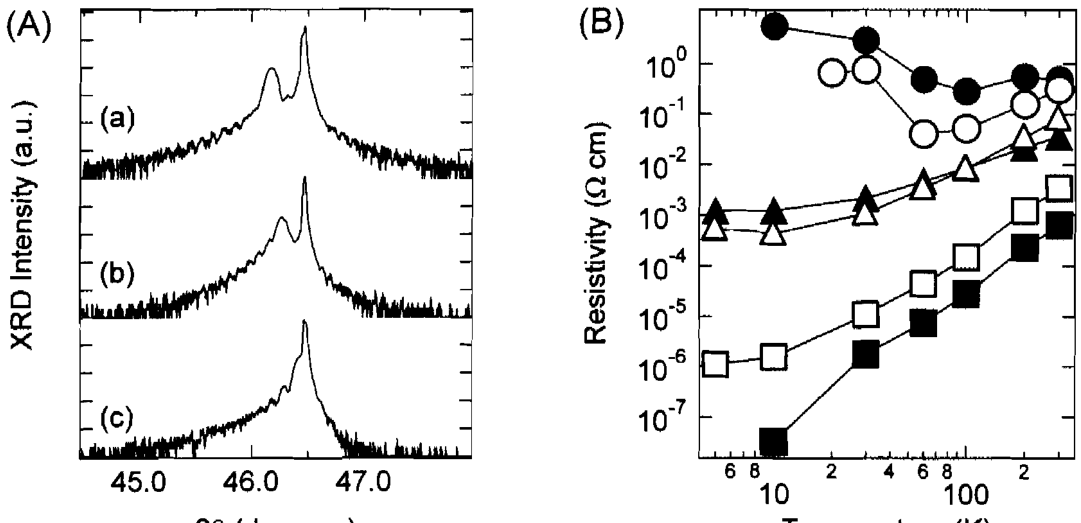

Figure 3: (A) θ-2θ x-ray diffraction patterns near the (002) Bragg condition for the films grown by varying laser parameters, spot size S and fluence$E$: (a) $S = 6.0\times10^{-3}$ cm^2 and E = 8 J/cm^2, (b) $S = 8.5\times10^{-3}$ cm^2 and E = 6.3 J/cm^2 and (c) $S = 9.3\times10^{-3}$ cm^2 and E = 8.9 J/cm^2. (B) The spot size and the energy density dependence of the electrical resistivity of the films grown at 400 °C and at the oxygen partial pressure of 1.0 $\times10^{-6}$ Torr. The closed circles correspond to $S = 5.6 \times 10^{-3}$ cm^2 and E = 6.1 J/cm^2, the open circles to $S = 5.6 \times 10^{-3}$ cm ^{2} and E = 11.8 J/cm^2, the closed triangles to $S = 9.56\times10^{-3}$ cm ^{2} and E = 3.8 J/cm^2, the open triangles to $S = 9.56\times10^{-3}$ cm ^{2} and E = 7.7 J/cm^2, the closed squares to $S = 15.6\times10^{-3}$ cm ^{2} and E = 2.4 J/cm^2 and the open squares to $S = 15.6 \times 10^{-3}$ cm ^{2} and E = 5.4 J/cm^2.