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Transport Properties of Photocarrier-Doped $SrTiO_3$

Department of Advanced Materials Science 56117 Yusuke Kozuka
Supervisor: Associate Professor Harold Y. Hwang

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INTRODUCTION

In a future prospect of materials science beyond the current technologies based on semiconductors, transition metal oxides can be promising materials because of their diverse physical properties. One of the most intensively studied materials is layered-perovskite cuprate as a high-temperature superconductor and another may be perovskite manganite to be used in a magnetically operated devices. $SrTiO_3$ is another key material, serving as a bridge between oxide materials and conventional semiconductors. This is mainly because of its high mobility exceeding 10^4 cm^2 V^{-1} s^{-1}, which motivated us to study coherent electronic transport of this material particularly in two dimensions at low temperature as in GaAs [1].

In order to realize such coherent conduction in semiconductors, doping is a crucial technique. Chemical substitution is the most common way but often degrades the mobility of carriers due to enhanced scattering by ionized impurities. Electrostatic field-effect doping and modulation doping at a heterointerface have been utilized in order to avoid the effect of ionized impurities and particularly to form two-dimensional electron gas. Another promising way is photocarrier doping because it is not necessary to fabricate any complicated structures. In addition, because the surface of $SrTiO_3$ is intrinsically fragile due to its large dielectric constant, it may be preferable that the conduction layer is located inside of the material.

In this study, we characterized the transport properties of $SrTiO_3$ single crystals and thin films under ultraviolet illumination, particularly at low temperature. This study is intended eventually to realize two-dimensional electron gas but also leads to other applications such as photocarrier injection to oxide thin films grown on $SrTiO_3$ substrates [2]. We hope that this study will open a wide range of applications in the field of oxide materials.

EXPERIMENTAL

$SrTiO_3$ single crystals were purchased from Furuuchi Chemical Co. or Shinkosha Co. and $SrTiO_3$ thin films were fabricated by pulsed laser deposition. The film thickness was measured by a stylus profilometer. The photoconductivity measurement was carried out in a Physical Properties Measurement System (Quantum Design Co.), and Xe lamp was employed as a light source. The light can be attenuated by neutral density filters and band-pass filtered with the bandwidth of about 10 nm.

RESULTS AND DISCUSSIONS

<u>Temperature dependence of photoconductivity</u>

On the measurement of photoconductivity as a function of temperature, we found sample dependence at intermediate temperature between 30 K and 100 K as shown in Fig. 1.

Hall measurement indicated that the difference is ascribed to the change of carrier density rather than mobility. Similar sample dependence has also been reported in precise measurement by x-ray diffraction and may come from the state of sample surface [3]. Nevertheless magnetotransport properties were similar independent of samples at low temperature.

<u>Low-field magnetotransport property at 2 K</u>

Low-temperature magnetotransport property was measured at 2 K as functions of the intensity and wavelength of illumination. Under 310 nm illumination, when the sheet resistance is of the order of h/e^2 (=25.8 kΩ), small negative magnetoresistance was observed, which is reminiscent of weak localization, where e is the electronic charge and h is the Planck constant. In addition, as shown in Fig. 2, its geometrical dependence indicated that the electronic conduction is nearly two-dimensional because geometry 1 and 3 in Fig. 2 (a) must be equivalent in three-dimensional system. Nevertheless an attempt to analyze the data by the theory of weak localization failed probably because this system is not strictly two dimensional and situated at the crossover point between weak localization and strong localization. On the other hand, when we used 370 nm illumination, we did not observe such negative magnetoresistance. This could be because of three-dimensional conduction as the penetration depth is the order of 10 μm.

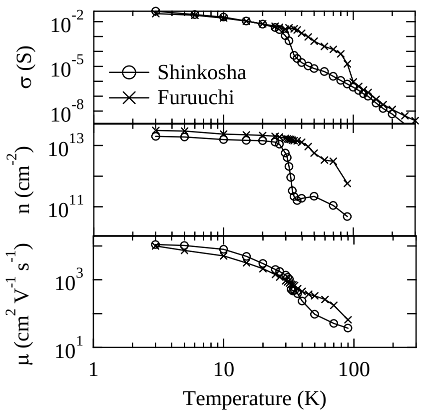

Fig. 1: The temperature dependence of conductivity (top), carrier density (middle), and Hall mobility (bottom) under illumination. The wavelength of the light is 370 nm.

<u>High-field Hall measurement</u>

We found that Hall resistance showed strong nonlinearity as a function of magnetic field as shown in Fig. 3 (a). Moreover, this cannot be explained by the theories of conventional anomalous Hall effect because low-field limit value gives reasonable carrier density rather than high-field value in terms of temperature dependence as shown in Fig. 3 (b). Furthermore, we can exclude other conventional mechanisms such as magnetic breakdown and two-band conduction, which is inconsistent with a strong temperature dependence of the nonlinearity.

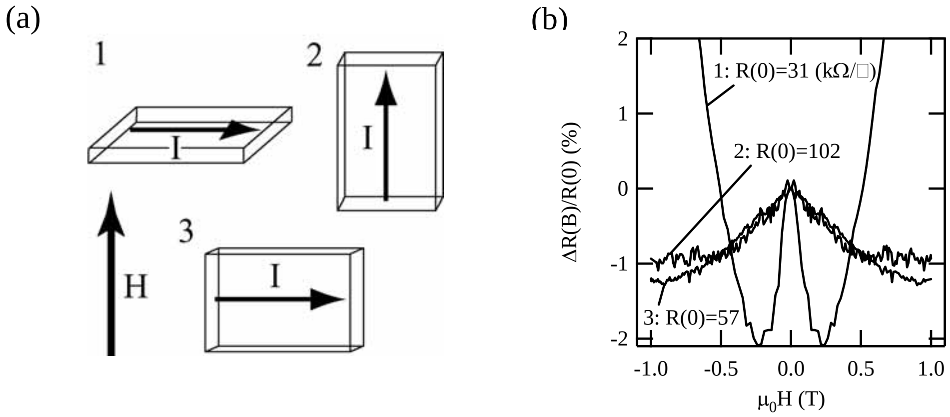

Fig. 2: (a) Geometries of magnetoresistance measurement. (b) Magnetoresistance under 310 nm illumination at 2 K. The numbers in (a) correspond to the curves in (b).

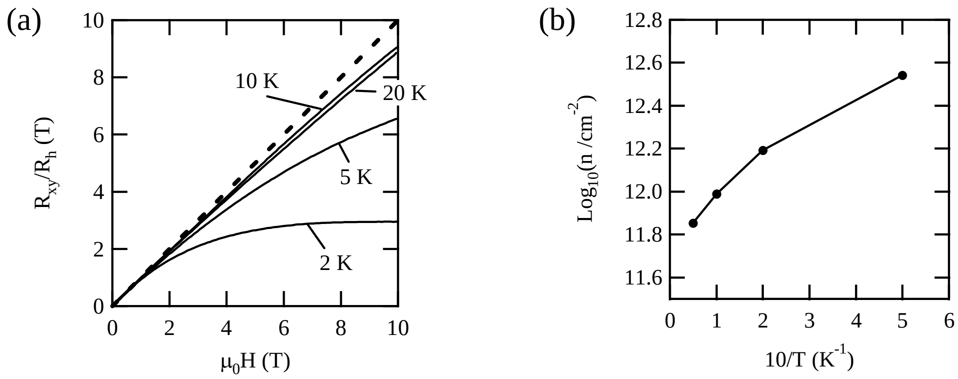

Fig. 3: (a) Hall resistance divided by Hall coefficient from low-field value as a function of applied magnetic field. (b) Temperature dependence of carrier density estimated from low-field value.

Recently, it has been proposed that anomalous Hall effect can also be caused by a spin-orbit interaction when Fermi energy is located near band degeneracy [4]. In the case of $SrTiO_3$, spin polarization can be induced by Zeeman splitting because of extremely small Fermi energy of the order of 10^{-2} meV, which can lead to anomalous Hall effect according to their scenario. The relevance of such a scenario will be examined by numerical calculation.

Photoconductivity of $SrTiO_3$ thin films

To fabricate a $SrTiO_3$ film which shows efficient photocarrier generation is an even more challenging project. Figure 4 shows the resistivity of a typical film which shows photocarrier generation. Different from single crystals, it showed rather degraded mobility and carrier generation efficiency. Such degraded transport characteristics of $SrTiO_3$ films may be related to the degraded dielectric properties in a thin film form [5].

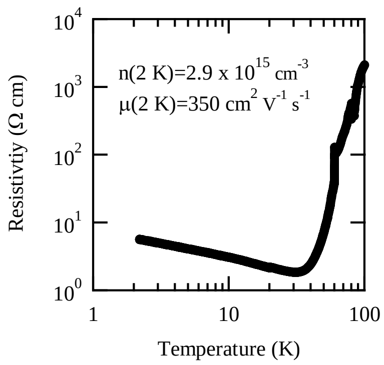

Fig. 4: Resistivity of a $SrTiO_3$ thin film, which was grown at 1100 ℃ under 1×10^{-6} Torr, as a function of temperature under 360 nm illumination.

CONCLUSIONS AND PERSPECTIVES

The low-temperature magnetotransport properties of photocarrier-doped $SrTiO_3$ suggested the existence of fairly interesting and perhaps some new kinds of physics. In spite of such attractive properties, thin films showed poor efficiency of photocarrier generation. The availability of high-quality films will lead to a variety of applications in photonic operations of oxide materials.

References

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