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Magnetic Phase Diagram and Effect of Capping Layer on Ferromagnetism in High T_C Ferromagnetic Oxide Semiconductor Anatase Co-doped TiO_2

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Abstract

The Curie temperature of anatase Co-doped TiO_2 was investigated as functions of carrier density and Co content by analyzing transport and magnetization below 400 K. Ultrathin capping layer was found to serve as a protective layer for surface magnetization of this compound. As a result, the magnetization was increased with improved perpendicular magnetic anisotropy.

1. Introduction

Transition metal doped oxide semiconductor is one promising candidate material for room temperature ferromagnetic semiconductor spintronics [1]. Recently, electrical induction of room temperature ferromagnetism was demonstrated in anatase Co-doped TiO_2 [2]. However, the mechanism of extraordinary high Curie temperature T_C ($\leq$ 600 K) has not been resolved yet. In order to discuss the mechanism magnetic phase diagram, T_C as functions of carrier density and Co content, is a fundamental information.

Another unresolved problem of this compound is the presence of magnetically dead layer. From the x-ray magnetic circular dichroism spectroscopy, the surface magnetization was found to be much smaller than the bulk magnetization measured by superconducting quantum interference device magnetometer [3]. Such suppressed surface magnetization will be an obstacle for future thin film and heterostructure devices. If the surface magnetization is recovered, magnetic domain structure will be observed more clearly than recent study [4].

In this study, we show a magnetic phase diagram of anatase Co-doped TiO_2 as functions of systematically varied carrier density and Co content, evaluated by transport and magnetization properties below 400 K. Also, we show magnetization properties of Co-doped TiO_2 with ultrathin TiO_2 capping layer.

2. Experimental

Co-doped TiO_2 (001) thin films were epitaxially grown on $LaAlO_3$ substrates by pulsed laser deposition. The detail procedure was described elsewhere [5]. Capping layer TiO_2 was grown on Co-doped TiO_2 thin film epitaxially. The typical thickness was 2-5 nm. For evaluation of the T_C, the non-capped Co-doped TiO_2 thin films were used. The evaluation method was described elsewhere [6]. Transport and magnetization properties of the capped Co-doped TiO_2 thin films were also measured.

3. Results and discussion

Figure 1 shows temperature dependence of resistivity for $Ti_{0.95}Co_{0.05}O_2$ with different carrier density. Intermediate carrier density samples possessed kink structure that is usually close to the T_C as are often observed in various ferromagnetic conductors. The temperature at the kink was varied with the carrier density, corresponding to the varied T_C as a function of carrier density. By taking the temperature derivative of resistivity, the T_C was evaluated. Independently, the T_C was also evaluated by temperature dependence of magnetization according to the Kouvel-Fischer plot [7].

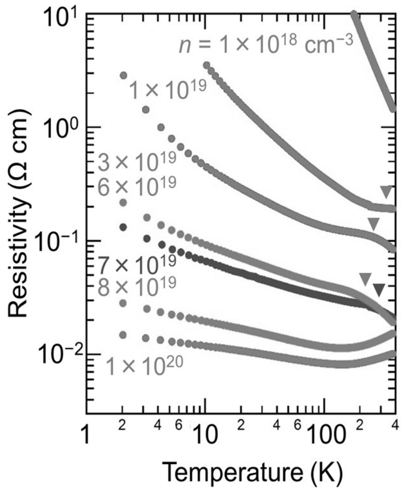

Fig. 1 Temperature dependence of resistivity for $Ti_{0.95}Co_{0.05}O_2$ with different carrier density. The carrier density was measured at 300 K.

Figure 2 shows in-plane and out-of-plane magnetization curves for $Ti_{0.95}Co_{0.05}O_2$ without (left) and with 2 nm thick capping layer (right). By adopting the capping layer, the out-of-plane magnetization was significantly enhanced indicating enhanced perpendicular magnetic anisotropy. This was probably caused by suppressed surface oxidation, because the oxidation reduces the amount of carrier that intermediates exchange coupling.

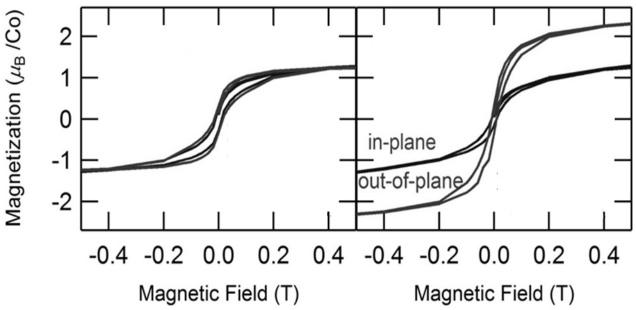

Fig. 2 In-plane and out-of-plane magnetization curves of $Ti_{0.95}Co_{0.05}O_2$ at 300 K without (left) and with 2nm thick capping layer (right).

4. Conclusions

The Curie temperature of Co-doped TiO_2 was investigated as a systematic function of sample parameters. Also, the capping layer was adopted to eliminate magnetically dead layer at surface. In this presentation, the details of the magnetic phase diagram and the effect of capping layer on the ferromagnetism will be shown.

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