X-ray study metal-insulator transition in W-doped VO$_2$ thin film

Daisuke Okuyama$^{1,}$, Keisuke Shibuya$^{1,2,}$, Reiji Kuma$^{1,}$, Takehito Suzuki$^{1,}$, Yuuichi Yamasaki$^{1,3,4,}$, Hironori Nakao$^{3,}$, Youichi Murakami$^{3,}$, Masashi Kawasaki$^{1,4,}$, Yasujiro Taguchi$^{1,}$, Yoshinori Tokura$^{1,4,}$, Taka-hisa Arima$^{1,5,}$

$^1$RIKEN CEMS, Wako 351-0198, Japan
$^2$AIST, Tsukuba 305-8562, Japan
$^3$CMRC and PF, Institute of Materials Structure Science, KEK, Tsukuba 305-0801, Japan
$^4$Department of Applied Physics, University of Tokyo, Tokyo 113-8656, Japan
$^5$Department of Advanced Materials Science, University of Tokyo, Kashiwa 277-8561, Japan

An x-ray study in V$_{1-x}$W$_x$O$_2$ films has been carried out. The insulating phase for $x < 0.07$ exhibits cell-doubling with the V dimerization similar to bulk VO$_2$, while the insulating phase for $x > 0.11$ does not. The temperature and $x$ dependence of superlattice reflection casts doubt about the direct relationship between the dimerization of V ions and metal-insulator transition. X-ray-induced persistent phase transitions are observed at low temperatures in each insulating phase in the vicinity of the boundary to the metallic phase regardless of the difference in the electronic structure.

1 Introduction

VO$_2$ is known to exhibit a metal-insulator transitions (MIT) accompanying structural deformation. At the transition temperature, the crystal structure changes from tetragonal to monoclinic with V dimerization. Shibuya et al. fabricated single-crystalline thin films of V$_{1-x}$W$_x$O$_2$ and obtained the phase diagram [1]. The MIT temperature decreases with increasing W for $x < 0.07$. For $x > 0.11$, the MIT temperature increases with increasing W. If the origins of the MIT for $x < 0.07$ and for $x > 0.11$ are different, some difference in the structural property is expected. VO$_2$-related materials have been attracting interest also from the viewpoint of photo-induced effects. Recently, x-ray-induced persistent insulator-to-metal transition was observed in an $x = 0.065$ film [2].

2 Experiment

V$_{1-x}$W$_x$O$_2$ films with thicknesses 80 nm were fabricated on rutile TiO$_2$ (001)-substrates by a PLD method [1]. Note that two electrons are doped by substituting the W$^{4+}$ ion for V$^{4+}$ ion. Synchrotron x-ray diffraction experiments were performed at BL-3A and 4C. Symmetry lowering was monitored by the emergence of (0 -1/2 3/2) and (1 0 2). The lattice spacing $c$ was estimated from the peak position of (0 0 2) reflection.

3 Results and Discussion

Temperature dependence of the intensities of the superlattice reflection is compared with that of resistivity and $c$-axis length in Fig. 1 (a - c). For $x < 0.07$, the (0 -1/2 3/2) reflections appear at low temperatures, indicating that V ions are dimerized. The modulation vector of V-dimerization remains to be (0 1/2 1/2). This result would contradict a naive picture of Peierls-type MIT. Moreover, for $x = 0.065$, the cell doubling appears below room temperature, which is far above the MIT temperature, below which the $c$-axis length begins to increase. For $x = 0.11$, a MIT with a change of the $c$-axis length is observed.

The transition temperature increases with increasing $x$ to 0.17. The (0 -1/2 3/2) reflection is not observed in the $x = 0.11$ sample. These results suggest that the MIT and structural transitions without V dimerization take place.

We have investigated in detail the x-ray-induced phase transition in V$_{1-x}$W$_x$O$_2$ films. Figures 1 (d - i) show the temperature dependence of the diffraction profiles of (0 0 2) reflection before and after the irradiation of x-ray beam at 7 K. The shrinkage of the $c$-axis length is commonly observed, namely, the x-ray-induced phase transition generally takes place not only for $x < 0.07$ but also for $x > 0.11$. Detailed information is found in [3].

References


okudaisu@tagen.tohoku.ac.jp