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Effects of Shear Strain on Metal-Insulator Transition of V_2O_3

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Vanadium oxide V_2O_3 is a strongly correlated transition-metal oxide and exhibits a first-order type of metal-insulator (MI) transition at 168 K. The MI transition occurred within a temperature range of 160 K ± 10 K, whereas HPT processing with ten-revolutions expanded the temperature range to 180 K ± 60 K. Herein, the onset temperature of MI transition was enhanced from approximately 170 to 240 K, and the HPT processing on V_2O_3 increased the temperature range of low-temperature insulating phase.

1 Introduction

V_2O_3 is one of strongly correlated transition-metal-oxides, in which the electrons have strong coupling with the lattice system [1-3]. It exhibited a first-order MI transition at 168 K [4-7]. At room temperature (RT), V_2O_3 is paramagnetic (PM), and the hexagonal crystal structure exhibits metallic electrical resistance. In contrast, below the MI transition temperature, the monoclinic crystal structure shows antiferromagnetic (AFM) and insulating properties.

In this study, we inserted shear strain to V_2O_3 by a high-pressure torsion (HPT) processing, so that we attempted to control the lattice defects and oxygen vacancies, and change the valence of vanadium. Consequently, we can understand the shear strain effects on strongly correlated electron systems.

2 Experiment

The V_2O_3 powder (99.9 %) was formed into disks with 10 mm in diameter using a hand press machine. In the HPT processing, a disk sample was uniaxially compressed between opposite-faced anvils made of WC (SR16C, NOTOALLOY Co., Ltd.) using a 50-ton pressing machine [8]. The HPT processing was performed under a pressure P_{HPT} = 6 GPa for N = 1 and 10 with an angular velocity of ω = 1 rpm at RT. In HPT processing, the amount of strain introduced varies depending on N and r [9, 10]. The following measurements were performed in the outer region of the sample, where the shear strain was large. X-ray diffraction (XRD) experiments were conducted using a synchrotron radiation XRD system equipped with a cylindrical imaging plate at the Photon Factory of the Institute for Materials Structure Science (IMSS) at the High Energy Accelerator Research Organization (KEK) [11]. The X-ray energy was 16 keV, the exposure time is 10 min. The correct X-ray wavelength was calibrated using the reference material CeO_2. The measured X-ray diffraction patterns were analyzed using the Rietveld method with RIETAN-FP [12]. The direct-current magnetization M was measured using a superconducting quantum interference device (SQUID) magnetometer in zero-field cooling mode at a magnetic field of H_{dc} = 10 mT at temperatures ranging from 5 to 310 K.

3 Results and Discussion

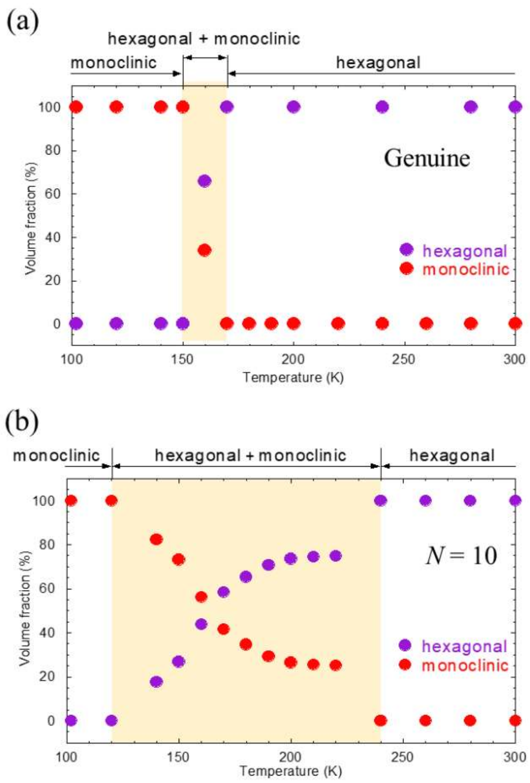

Fig. 1: Volume fractions of the HT (hexagonal) and LT (monoclinic) phases for the genuine (a) and HPT-processed (N = 10) (b) specimens as a function of temperature T [13]. The orange-shaded region indicates the temperature range where both phases coexist.

The volume fractions of the HT (hexagonal) and LT (monoclinic) phases for genuine V_2O_3 and HPT-processed V_2O_3 with N =10 are shown as a function of temperature in Fig. 1. The orange-shaded regions indicate the temperature range, where both structural phases coexist. The coexistence range changes from 150-170 K for the genuine state to 120-240 K under HPT processing with N = 10. Thus, HPT processing remarkably increases the temperature range in which the HT and LT phases coexist. The HPT processing with N = 1 increases the coexistence range to both higher and lower temperature sides. However, upon further increasing N to 10, the coexistence range increases only to the higher-temperature side. In the high-temperature limit of the coexistence range, the first-order type of structural transition remains at approximately 25-30% for both phases at $N = 10$.

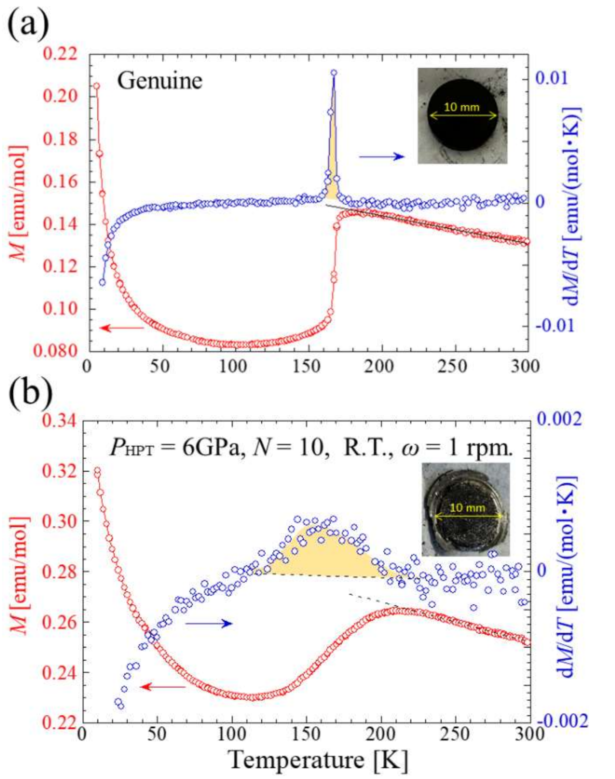

Fig. 2: T dependence of the dc magnetization M and dM/dT at H_{dc} = 10 mT for genuine V_2O_3 (a) and HPT-processed V_2O_3 under P_{HPT} = 6 GPa, T = RT, ω = 1 rpm, and $N = 10$
(b) [13]. Photographs of the disks (10 mm in diameter) for each specimen are also shown.

Figure 2 shows the temperature dependence of the dc magnetization M and dM/dT at H_{dc} = 10 mT for genuine V_2O_3 (a) and HPT-processed V_2O_3 under the conditions of P_{HPT} = 6 GPa, T = RT, ω = 1 rpm and N = 10 (b). In the genuine specimen, a PM signal due to impurities was observed below 50 K, whereas at approximately 170 K, a sharp anomaly associated with the PM-AFM transition that simultaneously accompanies the MI transition was detected via both M and dM/dT. In the HPT-processed specimen for N = 1, the change in dM/dT was observed over 120-190 K. In contrast, for N = 10, a prominent hump appeared at approximately 210 K, and an anomaly of dM/dT appeared over 120-220 K. These results indicate that compared to the genuine specimen, the HPT-processed specimens exhibit broader magnetic anomalies. Upon increasing the revolution number N, the magnetic anomaly broadens, particularly toward the higher- temperature side. The T ranges of the magnetic anomalies are almost consistent with those characterizing the coexistence of HT-LT phases, observed in the XRD experiment.

In this study, we successfully increased the onset temperature of the MI transition in a strongly correlated Transition-metal oxide V_2O_3 by subjecting it to the HPT processing. The genuine V_2O_3 transitions from the HT (hexagonal) to LT (monoclinic) phases at approximately 160K within an interval of 10 K. However, after the HPT processing with the revolution number N = 10, the high-temperature limit of the LT phase increased to 240 K. The MI transition occurs over 120-240 K because of the spatial distribution of the shear strain. When subjected to HPT processing, the HT phase exhibits unit cell expansion, whereas the LT phase shows unit cell shrinkage. Thus, we observed a significant shear-induced effect within a strongly correlated electron system.

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