Nano-scale mapping of electronic states in metal-insulator inhomogeneous space of wire-type VO_2 thin films

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Introduction

Vanadium dioxide (VO_2) has attractive electronic properties, showing orders-of-magnitude changes in resistivity at its metal-insulator transition (MIT) around 340 K. The MIT is accompanied by structural deformation between the low-temperature monoclinic insulating phase and the high-temperature rutile metallic phase. A characteristic phenomenon during the MIT is the appearance of phase separation with the metallic and insulating domains over several hundreds of nanometers, playing an essential role in determination of physical properties in samples.

Investigation into the physical aspect in nano-spatial area behind the MIT is important to understand origin of the transition and their nano scale behaviour of domains, leading to improve efficiency for device performance using the phase transition.

In this research, we aim to clarify nano-spatial electronic states in VO_2 films on the state of a phase separation in order to gain a new understanding of nano-physical properties and design guide of Mott nano-devices in the future by using three-dimensional (3D) spatially resolved electron spectroscopy for chemical analysis (3D-nanoESCA) [1]. This system has been installed at the University of Tokyo Materials Science Outstation beamline, BL07LSU, at Spring-8.

Experimental

In the sample preparation, W(1.5 wt%)-doped VO_2 (VWO) thin films were deposited on Al_2O_3 (0001) substrates using a pulsed laser deposition technique (ArF excimer laser). The reason for the W doping is to decrease the transition temperature down to around room temperature [2]. Thus it is possible to evaluate the inhomogeneous electronic states by the 3D nano-ESCA without a sample stage equipped temperature control. The film thickness was approximately 50 nm. Micro-sized VWO wires were prepared by photolithography. Figure 1 shows temperature dependence of resistance in a prepared VWO wire with 10 μm in width (see the sample structure in the inset). The resistance drastically changed around 300 K and a temperature hysteresis can be observed. The coexistence of the metallic and insulating phases should be realized around room temperature.

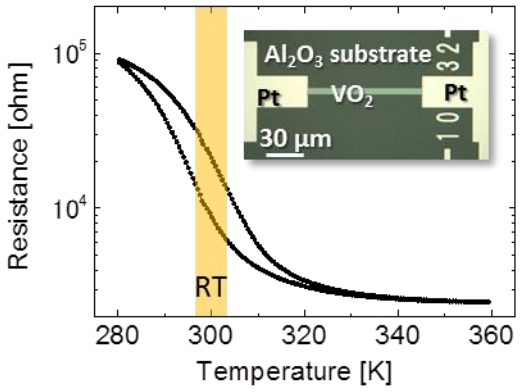
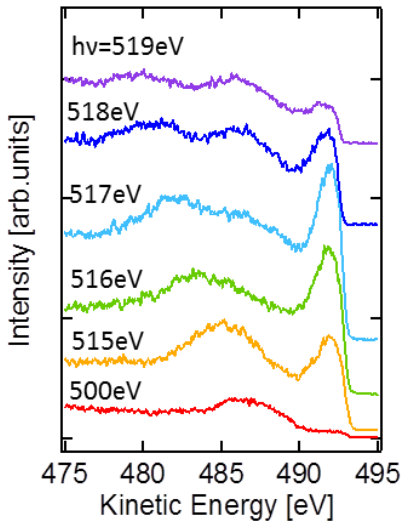


Figure 1 Temperature dependence of resistance in a W(1.5wt%)-doped VO_2 wire. The inset shows an optical microscope image in the typical structure.

Results and discussion

Figure 2 shows valence-band PES of VO_2 films using various photon energies from 500 eV to 519 eV. Especially at hν=517 eV, the V 3*d* electronic structure is enhanced due to resonance across the V 2*p*-3*d* threshold [3]. Using this photon energy at 517 eV, we performed a spatial mapping of valence-band PES. A VO_2 wire and a Pt electrode area can be clearly distinguished in the valence-band PES mapping in Fig.3(a). The spectra on a point of VO_2, Pt and Al_2O_3 substrate, respectively, are significantly different as shown in Fig.3 (b).



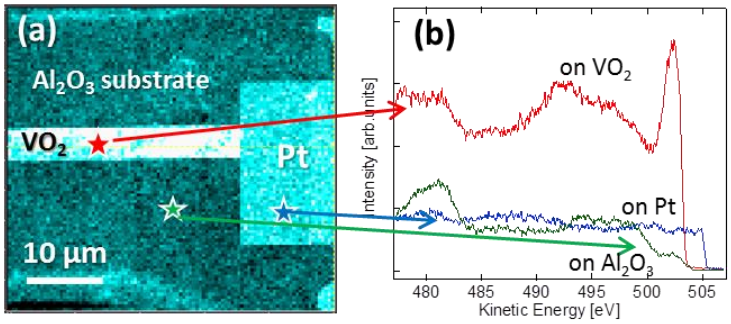


Figure 3 (a) Valence band PES map (b) Valence band PES on VO_2 (red), Pt (blue) and Al_2O_3 (green)

Figure 2 Resonant PES across the V 2*p*-3*d* threshold

Conclusion

In summary, we successfully obtained the PES map of the VO_2 wire with Pt electrodes on an Al_2O_3 (0001) substrate using resonant photon energy at 517 eV and could fully distinguish VO_2 from other parts. In the future work, we will try to make a map of phase separation between metallic and insulating states on VO_2.

References

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