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

Teruo Kanki[1], Koji Horiba[2,3], Naoka Nagamura[2,3], Tsubasa Sasaki[1], Masaharu Oshima[2,3], and Hidekazu Tanaka[1]

[1]*The Institute of Scientific and Industrial Research, Osaka University*

[2]*Department of Applied Chemistry, The University of Tokyo*

[3]*Synchrotron Radiation Research Organization, The University of Tokyo*

Introduction

Vanadium dioxide (VO_2) shows 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. From a nanoscopic point of view, VO_2 shows mixed electronic phases consisting of the metallic and insulating states in the vicinity of MIT temperature. This electronic inhomogeneity plays an essential role in determination of physical properties

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 by using three-dimensional (3D) spatially resolved electron spectroscopy for chemical analysis (3D-nanoESCA) [1], leading new findings of nano-physical properties and design guide of Mott nano-devices in the future. This system has been installed at the University of Tokyo Materials Science Outstation beamline, BL07LSU, at Spring-8.

Experimental

VO_2 thin films were fabricated on Al_2O_3 (0001) substrates using a pulsed laser deposition technique (ArF excimer laser). VO_2 thin films were patterned to microwire geometries with 10 μm in width using a photolithography process. Microheaters are monolithically equipped in the sample as shown in Fig.1(a). Figure 1(b) shows temperature dependence of resistance in the VO_2 microwire. The resistance changes from 424 kΩ at 300 K in insulator states to 0.9 kΩ at 370 K in metallic states. Based on this resistive change, we checked the microheater performance. The range of controlled temperature by applying current bias in the heater fully covers from insulator to metallic states as shown in Fig.1(c). Thus we can investigate PES of insulating, metallic and the coexistence states in the 3D-nano ESCA chamber equipped with external electric terminals.

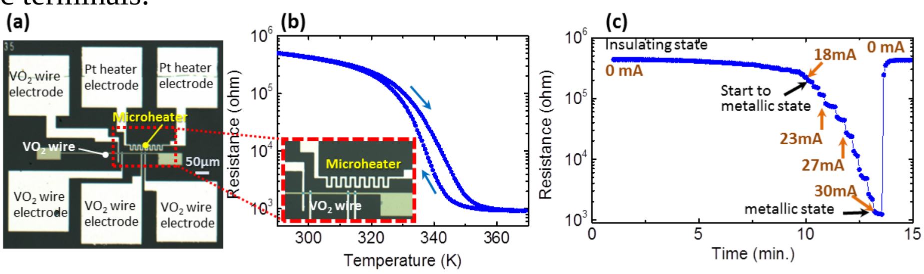

Figure 1 (a) The optical microscope image of VO_2 wire with Pt –microheater. (b) Temperature dependence of resistance in VO_2 microwire. (c) Applied current bias in the Pt-microheater dependence of resistance in the VO_2 microwire

Results and discussion

Valence-band spectra of a VO_2 microwire were measured using photon energy at 510 eV near the resonant energy across the V 2*p*-3*d* threshold [2]. Regarding a spatial mapping of valence-band PES using this energy, the VO_2 wire and the Pt electrode area can be clearly distinguished as shown in the inset of Fig.2(a) and it is shown that the spectrum in the insulting state at the Fermi level (E_F) is lower than that in the metallic state in Fig. 2(a). However, clear insulating spectrum without electronic states at E_F could not be observed. In this experiment, we can simultaneously monitor the resistive behaviour of the VO_2 wire during the PES measurements. Thus two spectra in the insulating and metallic states can be compared with the resistive behaviour in the insulating and metallic states in Fig.2(b), respectively. The resistance in the insulating states continuously and gradually decreases during the PES measurement as shown in magnified resistive curve in Fig.2(c). This may imply the generation of photo-induced metallic states [3].

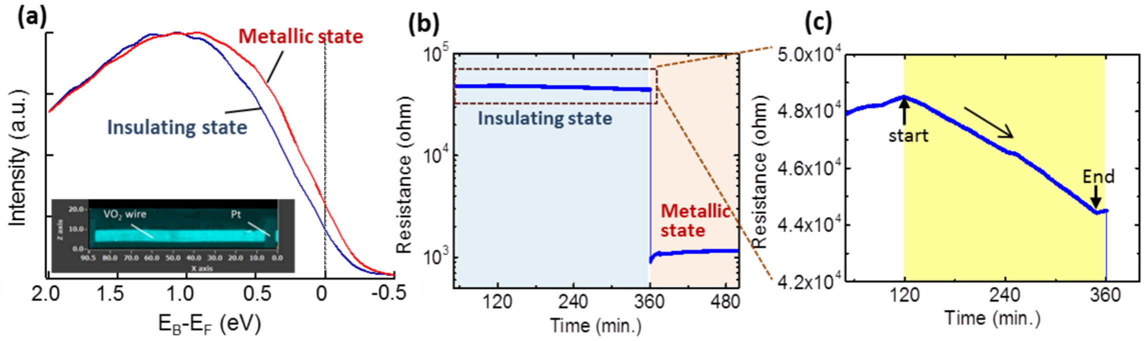

Figure 2 (a) The optical microscope image of VO_2 wire with Pt –microheater. (b) Temperature dependence of resistance in VO_2 microwire. (c) Resistance behavior in the VO_2 microwire during PES measurement. The arrows indicates the measurement start time to the end.

Conclusion

In summary, we successfully distinguish PES spectra in the insulating and metallic states of the VO_2 wire monolithically equipped with the Pt-microheater using resonant photon energy at 510 eV. Also we have shown that the coincident measurements of PES and electronic property are powerful to check and investigate the sample status. In the future work, we will try to make nano-scale maps of phase separation between metallic and insulating states on VO_2.

References

[1] K. Horiba, Y. Nakamura, N. Nagamura, S. Toyoda, H. Kumigashira, M. Oshima, K. Amemiya, Y.Senba, and H. Ohashi, Rev. Sci. Instrum. **82**, 113701 (2011).

[2] R. Eguchi, M. Taguchi, M. Matsunami, K. Horiba, K. Yamamoto, Y. Ishida, A. Chainani, Y. Takata, M. Yabashi, D. Miwa, Y. Nishino, K. Tamasaku, T. Ishikawa, Y. Senba, H. Ohashi, Y. Muraoka, Z. Hiroi, and S. Shin, Phys. Rev. B **78**, 075115 (2008).

[3] K. Shibuya, D. Okuyama, R. Kumai, Y. Yamasaki, H. Nakao, Y. Muraoka, Y. Taguchi, T. Arima, M. Kawasaki, Y. Tokura, Phys. Rev. B 84, 165108 (2011).