Materials Science in Semiconductor Processing 27 (2014) 140–144

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

Electrically-driven metal–insulator transition of vanadium dioxide thin films in a metal–oxide-insulator–metal device structure

Dong-Hong Qiu [a], Qi-Ye Wen [a,*], Qing-Hui Yang [a], Zhi Chen [b], Yu-Lan Jing [a], Huai-Wu Zhang [a]

[a] State Key Laboratory of Electronic Films and Integrated Devices, University of Electronic Science and Technology of China, Chengdu 610054, China
[b] National Key Laboratory of Science and Technology of Communication, University of Electronic Science and Technology of China, Chengdu 610054, China

ARTICLE INFO

Available online 9 July 2014

Keywords:
Metal–insulator transition
Electrical switching characteristics
Metal–oxide-insulator–metal junction
Vanadium dioxide

ABSTRACT

We report the successful growth of vanadium dioxide (VO_2) films on SiO_2 buffered metal electrode and the fabrication of metal–oxide-insulator–metal (MOIM) junction. The VO_2 film has an abrupt thermal-induced metal–insulator transition (MIT) with a change of resistance of 2 orders of magnitude. The electrically-driven MIT (E-MIT) switching characteristics have been investigated by applying perpendicular voltage to VO_2 based MOIM device at particular temperatures, sharp jumps in electric current were observed in the *I–V* characteristics under a low threshold voltage of 1.6 V. The Ohmic behavior, non-Ohmic super-linear one, and metallic regime are sequentially observed in the MOIM device with the increase of voltage. It is expected to be of significance in exploring ultrafast electronic devices incorporating correlated oxides based MOIM structure.

1. Introduction

Vanadium dioxide (VO_2) is a phase transition material which undergoes a reversible metal–insulator transition (MIT) near 68 °C accompanied by a lattice structural transition from the monoclinic to tetragonal, an abrupt change of conductivity, and significant changes of the optical properties at almost all wavelengths [1–6]. Furthermore, the MIT of VO_2 can also be triggered by external stimuli such as an applied voltage or optical excitation [7,8]. Particularly, electrically triggered phase transition (E-MIT) in vanadium dioxide is of interest in novel devices for electric switches, resistance random access memory (ReRAM) networks, and so on [9–12].

Recently, out-of-plane metal–VO_2–semiconductor (metal) structures have attracted much attention [13–16]. It is recently reported that with particular perpendicular structures, for example metal/VO_2/metal structure, the device size can be significant reduced to submicron scale and the OFF (insulating state)/ON (metallic state) switch time can be improved to less than 2 ns [13]. The ultrafast E-MIT is believed to be induced by electronic correlation effects rather than the joule heating, because the heating driven MIT would give rise to a longer switch time [17]. However, the current-driven joule heating effect in a metal/VO_2/metal structure is inevitable once the metallic state of VO_2 is established, which will hinder the On–OFF process of the device. In this work, we proposed a metal–oxide-insulator–metal (MOIM) structure by introducing a thin SiO_2 insulating

---

[*] Corresponding author.
E-mail address: qywen@uestc.edu.cn (Q.-Y. Wen).

http://dx.doi.org/10.1016/j.mssp.2014.06.030
1369-8001/© 2014 Elsevier Ltd. All rights reserved.

layer between the VO_2 film and the bottom metal layer. With the SiO_2 layer, the current value will be small both before and after the MIT of VO_2, thus the Joule heating effect can be effectively depressed. Furthermore, the SiO_2 buffer layer can eliminate the stress between the VO_2 film and the metal electrode thus can improve the quality of VO_2 film. SiO_2 has excellent thermal, mechanical and optical properties, and is compatible with micro-electromechanical devices, which have great application in the semiconductor process [18,19]. All these features indicate that the SiO_2 based MOIM structure is very desirable in ultrafast electronic devices, and can find applications in optoelectronics and communications technologies.

2. Experimental details

Si/Pt substrate (actually Si/SiO_2/Ti/Pt) were prepared by depositing Ti (20 nm)/Pt (200 nm) layers onto Si/SiO_2 using electron-beam evaporation. The SiO_2 buffer was grown directly on Si/Pt substrate using plasma enhanced chemical-vapor-deposition (PECVD). The synthesis conditions of SiO_2 is as following: the substrate temperature (T) is fixed at 300 °C, the working pressure is 600 mTorr, RF source gun power is 60 W, mixed gas flows: SiH_4=150 sccm, N_2O:140 sccm, N_2:100 sccm. VO_2 thin films were synthesized by using RF magnetron sputtering with a high purity vanadium (V) target (99.99% in purity) on the SiO_2 buffer. A 100 μm × 100 μm Au patch was finally deposited on top of the VO_2 to form the MOIM structure. For VO_2 deposition, the temperature of the substrate and the RF source gun power were set as 550 °C and 200 W, respectively. The operation gas was a mixture of high purity Ar (99.999% pure) and O_2 (99.999% pure). The sputtering pressure was set at 1.0 Pa with various oxygen partial pressures of 3%, 5% and 7% (correspondingly the samples are labeled as 1, 2, and 3, respectively). No post-growth annealing process was carried out.

The crystallography properties of the film were characterized by an x-ray diffractometer (XRD: DX-2700) using Cu $K\alpha$ radiation. Surface and cross-section morphology of the film were studied by using atomic force microscope (AFM: SPA-300HV) and field-emission scanning electron microscope (FESEM: JSM-7600F). The temperature dependence of electric resistivity for the VO_2 film was measured by a standard four-point measurement method based on a Keithley 2400 sourcemeter, where the sample temperature was controlled by a thin Peltier heater/cooler. Current–voltage (I–V) curve measurements were carried out by using Agilent 4156C to investigate the electrical driven phase transition properties.

3. Results and discussion

Typical XRD patterns were obtained for the bare Si/Pt substrate and the Si/Pt/SiO_2/VO_2 samples deposited in the oxygen partial pressure of p=3%, 5% and 7%, as plotted in Fig. 1. For all the samples, the strong peak at $2\theta=39.7^\circ$ is indexed to the diffraction from the Pt (1 1 1) plane. The crystal planes diffraction peaks of the VO_2 films show an intimate dependence on the deposition oxygen pressure. The films grown at p=3% have a weak peak near 27.9°, which corresponds to the (0 1 1) plane of VO_2 phase. As to the sample deposited at p=5%, two distinct peaks are observed at 27.9° and 33.2°, referring to the (0 1 1) and (−1 0 2) planes of VO_2 phase. These results suggest that pure polycrystalline VO_2 phase is formed in sample-2, which is in agreement with the previous reports [20,21]. For the sample-3 grown at p=7%, however, the dominant phase in the film is V_6O_{13} and only a weak peak of VO_2 (0 1 1) is detected. Anyway, the XRD results confirm that the VO_2 films have been successfully grown on SiO_2 buffered Pt metal film especially at the oxygen partial pressure of 5%.

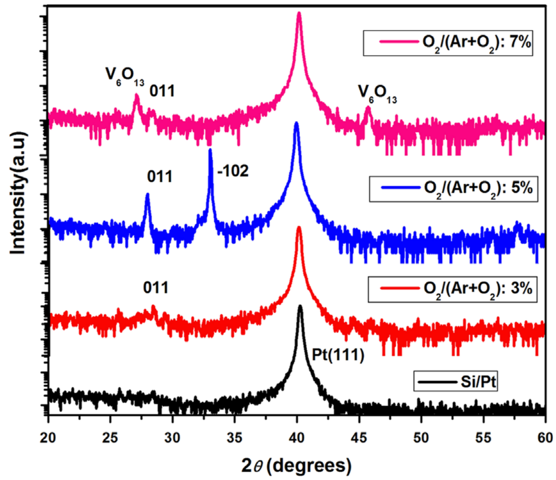

Fig. 1. X-ray diffraction (XRD) patterns of the bare Si/Pt and Si/Pt/SiO_2/VO_2 deposited in the different oxygen partial pressure of 3%, 5% and 7% at the temperature of 550 °C.

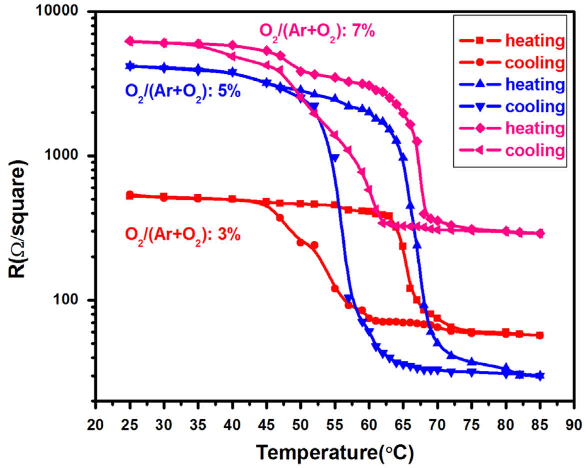

Fig. 2. Resistivity versus temperature (R–T) curves for the Si/Pt/SiO_2/VO_2 samples deposited in the different oxygen partial pressure of 3%, 5% and 7% at the temperature of 550 °C.

To confirm the MIT properties of the VO_2 films deposited in the different oxygen partial pressure, the temperature dependence of the electrical resistance were measured and plotted in Fig. 2. An abrupt change of resistance near the transition temperature T_c of 66 °C is clearly observed, which indicates the presence of the VO_2 phase in all the three films. For sample-2, the resistance at low temperature (25 °C) is