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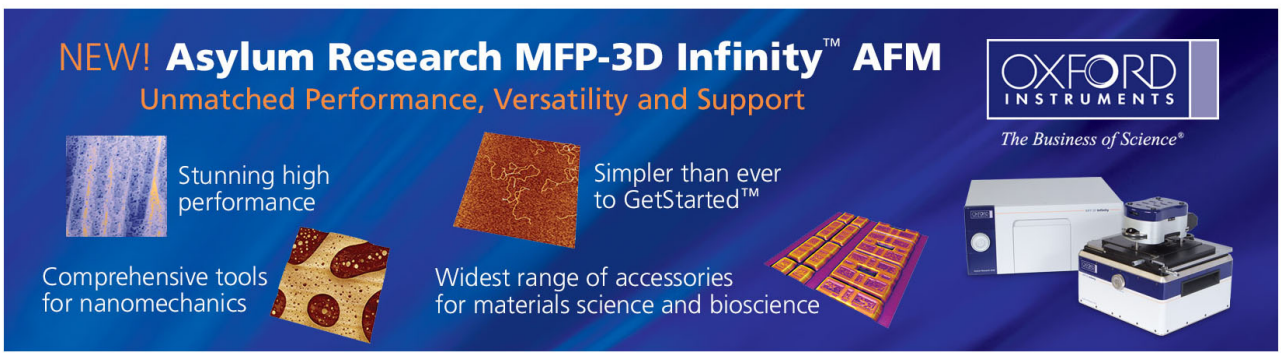

Influence of electrode material on the resistive memory switching property of indium gallium zinc oxide thin films

Min-Chen Chen,[1] Ting-Chang Chang,[1,2,a)] Chih-Tsung Tsai,[1] Sheng-Yao Huang,[1] Shih-Ching Chen,[1] Chih-Wei Hu,[3] Simon M. Sze,[3] and Ming-Jinn Tsai[4]
[1]*Department of Physics, National Sun Yat-Sen University, Kaohsiung 804, Taiwan*
[2]*Center for Nanoscience and Nanotechnology, National Sun Yat-Sen University, Kaohsiung 804, Taiwan*
[3]*Department of Electronics Engineering and Institute of Electronics, National Chiao Tung University, Hsinchu 300, Taiwan*
[4]*Electronics and Opto-electronics Research Laboratories, Industrial Technology Research Institute, Hsinchu 300, Taiwan*

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The InGaZnO taken as switching layer in resistive nonvolatile memory is proposed in this paper. The memory cells composed of Ti/InGaZnO/TiN reveal the bipolar switching behavior that keeps stable resistance ratio of 10^2 with switching responses over 100 cycles. The resistance switching is ascribed to the formation/disruption of conducting filaments upon electrochemical reaction near/at the bias-applied electrode. The influence of electrode material on resistance switching is investigated through Pt/InGaZnO/TiN devices, which perform the unipolar and bipolar behavior as applying bias on Pt and TiN electrode, respectively. Experimental results demonstrate that the switching behavior is selective by the electrode. © *2010 American Institute of Physics*. [doi:10.1063/1.3456379]

Modern semiconductor nonvolatile memories (NVMs) are shared constantly to achieve the large capacity. For conventional charge-storage-based memories, the increasing demand for device densities by scaling dimension is expected to be a major challenge due to the technical and physical limitation.[1,2] To overcome this significant issue, various NVMs including ferroelectric, phase-change, polymer, magnetic, and resistance random access memory (ReRAM), have been widely investigated. Among these NVMs, ReRAM is a promising candidate owing to its simple structure, rapid operation, and high density integration.[3–5] The ZnO-based film is one of the attractive materials to produce ReRAMs because of owning a good transparency to visible light.[6–10] Additionally, many researches had testified that InGaZnO (IGZO) are favorable to serve as active layer in thin film transistors (TFTs).[11] Therefore, the ReRAMs using ZnO-based films as switching layer is appropriate to combine with IGZO-TFTs for development of the advanced and full transparent system-on-panel display.[12] In this paper, the switching characteristics of ReRAMs composed of IGZO switching layer is discussed to realize the driving mechanism of resistive switching. Besides, our works will focus on the switching behaviors of the memory cells prepared with different electrodes, including active (Ti, TiN) and inert (Pt) material, to figure out the influence of electrode material on the properties of IGZO-ReRAMs.

The resistive NVMs were fabricated as follow: a 30 nm thick IGZO thin film was deposited on $TiN/SiO_2/Si$ substrates at room temperature by rf magnetron sputter deposition system using a target of $In:Ga:ZnO=1:1:1$ (4″ in diameter, 99.999%). The sputtering was carried out with a power of 50 W in argon ambient of a pressure of 4 mTorr. Finally, the Ti and Pt with a thickness of 80 nm were grown on the IGZO films to complete the Ti/IGZO/TiN and Pt/IGZO/TiN sandwiched memory cells individually, by dc magnetron sputtering. The photolithography and lift-off technique were employed to shape the cells into a square pattern of 0.64–64 μm^2. All of the electric characteristics were measured in dark by the Keithley 4200 semiconductor characterization analyzer in dc sweeping mode.

Figures 1(a) and 1(b) show I-V curves of Ti/IGZO/TiN cells with the grounded TiN and Ti, respectively. Such memory cells perform bipolar behaviors in the operation of applying bias on either electrode, and no unipolar switching characteristics were observed under unipolar measurement protocol. The "forming process" is required to activate the as-deposited cells, using dc voltage sweeping with a compliance current of 0.1 mA. A sudden increase in current occurs at a voltage of 6.4 V, and the cell was translated from high resistance state (HRS) to low resistance state (LRS). By sweeping the bias over reset voltage (V_{reset}), an abrupt decrease in current was observed where the cell switches from LRS to HRS, called as "reset process." Conversely, the cell turns back to LRS while applying a positive bias over set voltage (V_{set}), i.e., "set process," and a compliance current of 1 mA is assigned to prevent the permanent breakdown. In the case of grounding TiN, the resistance ratio of HRS to LRS is 10^2 times at a reading voltage of 0.1 V, and no degradation after continuous I-V sweep of 100 cycles [inset of Fig. 1(a)]. Two mechanisms classified into "interface type" and "filament type" conductive path had been responded to clarify the bipolar behavior.[13,14] For interface type path, the resistive switching is considered as a result of modulating the interfacial barrier (between bias-applied electrode and switching layer) upon electrical driving. Nevertheless, interface type path is unthinkable to support the results in Figs. 1(a) and 1(b). The bipolar behaviors in Figs. 1(a) and 1(b) indicate the existence of the individual barrier at Ti/IGZO and IGZO/TiN interface if resistive switching is caused by interface type

a)Author to whom correspondence should be addressed. Electronic mail: tcchang@mail.phys.nsysu.edu.tw.

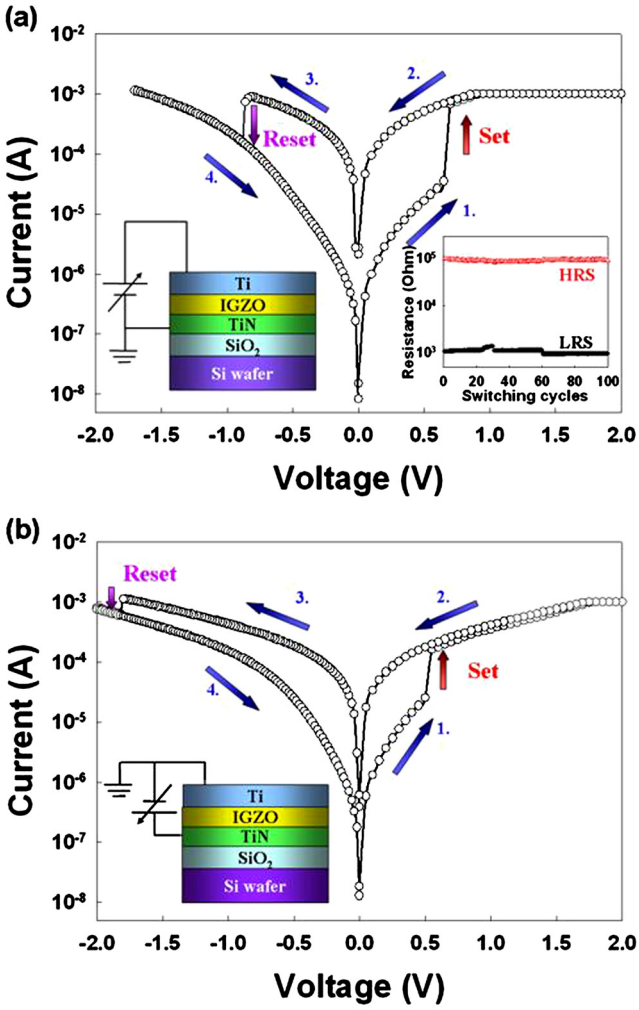

FIG. 1. (Color online) Typical bipolar resistance switching I–V curves of Ti/IGZO/TiN, measured with grounded (a) TiN electrode (the lower right inset plots the resistance switching characteristics detected at a reading voltage of 0.1 V during continuous I-V sweep of 100 cycles), and (b) Ti electrode.

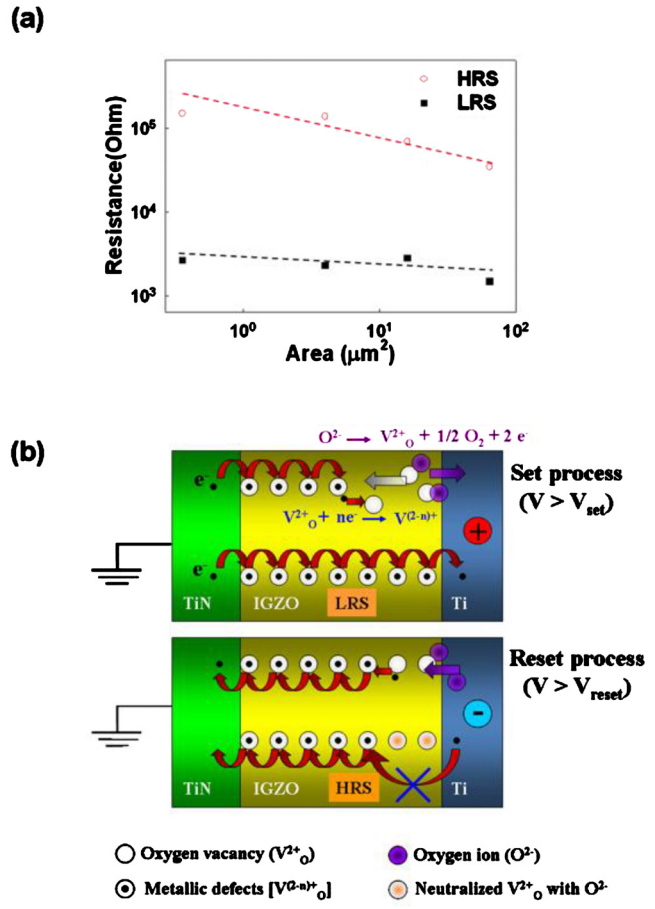

FIG. 2. (Color online) (a) Cell area dependence of the resistance value in HRS and LRS. (b) Schematic diagrams of driving mechanism of bipolar switching through the electrochemical reaction to form/disrupt the conducting filaments for LRS/HRS during set/reset process.

path but it is difficult to adjust both barriers simultaneously to change the resistance state.

The dependences of the resistance value of HRS and LRS (R_{off} and R_{on}) on pattern sizes are plotted in Fig. 2(a), measured by grounding TiN electrode. The R_{off} is inversely proportional to the cell size, whereas the R_{on} seems to be insensitive to the cell size. If the resistive switching originates from interface type path, both of R_{off} and R_{on} have to be dependent on the cell size.[13] Therefore, the formation/disruption of localized conducting filaments is preferred as the driving mechanism of resistive switching. During the forming process triggered by sufficient electric field, oxygen ions (O^{2-}) are created accompanying oxygen vacancies (V^{2+}_O) and drifts toward the anode, as diagramed in Fig. 2(b).[14] At the anode, the oxygen ions were transformed into oxygen or absorbed by the anode. Simultaneously, an electroreduction process for metal cations (V^{2+}_O) takes place at the cathode to change the oxide into metallically conducting phase. The conducting region consisted of metallic defects extends toward the anode to form conductive paths. By reversing the polarity of bias, oxygen ions released from Ti/IGZO interface will neutralize oxygen vacancies, so the bipolar behavior is induced upon the recovery/rupture of conducting filaments. In Fig. 2(b), the reduction/oxidization of oxygen ions occurs near the electrode bias-applied (at Ti/IGZO interface), and the TiN acts a normal contact electrode. Similarly, in the case of grounding Ti, the reduction/oxidization of oxygen ions occurs near TiN electrode.

For Pt/IGZO/TiN cells, in Fig. 3(a), the I-V curves determined by applying bias on Pt electrode exhibit the unipolar behavior. On the other hand, the bipolar behavior still performs in the operation of applying bias on TiN, as shown in Fig. 3(b). These results express that the switching behavior is related to the electrode bias-applied. As applying bias on TiN, according to the model in Fig. 2(b), the TiN electrode can play the role of oxygen reservoir to absorb/discharge oxygen ions to expose the bipolar behavior.[15,16] However, the Pt is inactive to adopt oxygen ions, and the oxidation of oxygen ions will discharge oxygen gas when the electrochemical reaction implements at Pt/IGZO interface. During reset process of unipolar switching, the rupture of filaments can be attributed to the Joule heating enhanced oxidation that is irrelevant to the polarity of bias, rather than the neutralization of oxygen vacancies by the anode-released oxygen ions, as the schematic diagram in Fig. 4.[17] The rupture of conductive paths probably takes place randomly and leads to a large variation in HRS resistance during continuous switching cycles [inset of Fig. 3(a)]. Moreover, in Ti/IGZO/TiN cell, the bipolar behavior can be reproduced over

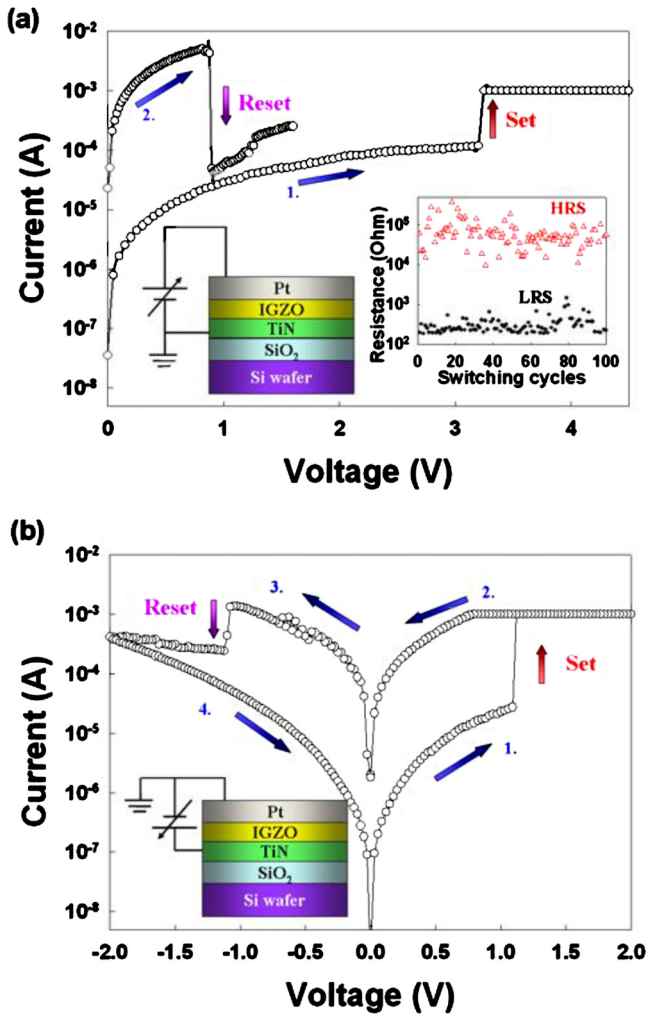

FIG. 3. (Color online) (a) Unipolar behavior in Pt/IGZO/TiN cell, measured by applying bias on Pt electrode. Lower right inset plots the resistance switching characteristics detected at a reading voltage of 0.1 V during continuous I-V sweep of 100 cycles. (b) Bipolar behavior in Pt/IGZO/TiN cell, measured by applying bias on TiN electrode.

10^3 times with slight distortion in R_{off}/R_{on} ratio. But, for the unipolar behavior in Pt/IGZO/TiN cell, the failure of resistive switching from LRS to HRS happens as increasing the switching responses over 150 times, and it may be due to the incompletely fused filaments. The bipolar switching, thereby, is more practicable to produce the high-quality ReRAMs.

In conclusion, the IGZO film is usable as the switching layer for ReRAMs cells. From the examinations of Ti/IGZO/TiN cell, the resistive switching could be regarded as the formation/disruption of conducting filaments in IGZO layer. Additionally, the switching behavior is associated with the properties of the electrode bias-applied. The electrode owning the capability of reserving oxygen ions, such as Ti and TiN, will bring out the bipolar behavior as applying bias on. For inert materials, such as Pt, the poor absorption of oxygen will cause the unipolar behavior, where the reset process is attributed to the disruption of filaments through Joule heating enhanced oxidation.

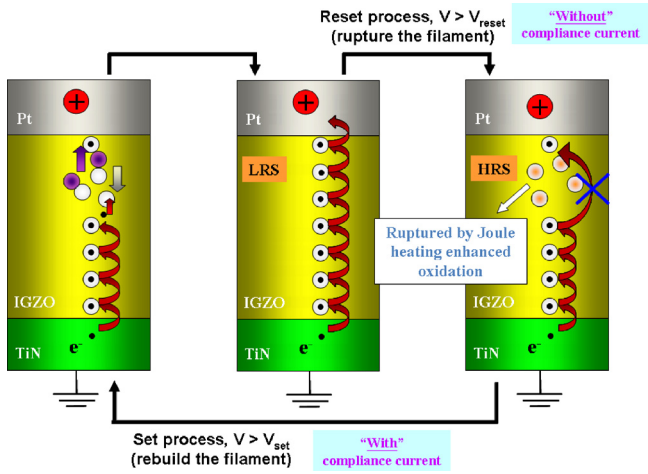

FIG. 4. (Color online) Schematic diagrams of driving mechanism of unipolar switching to form/disrupt the conducting filaments during set/reset process, where the disruption of filament is caused by the Joule heating enhanced oxidation.

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