SET polarity dependent resistive switching memory characteristics using 
IrO\textsubscript{x}/GdO\textsubscript{x}/WO\textsubscript{x}/W structure

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1. Introduction

With conventional nonvolatile floating gate memory approaching certain technical and physical limits in the future, alternative nanoscale nonvolatile memory is becoming interesting subject. Recently, resistive switching random access memory (ReRAM) is showing alternative choice for the potential in future replacement of DRAM and conventional floating gate memory. Many materials have been demonstrated to possess ReRAM characteristics such as GeSe\textsubscript{x}, NiO, WO\textsubscript{x}, ZnO, ZrO\textsubscript{x}, HfO\textsubscript{x}, TaO\textsubscript{x}, TiO\textsubscript{x}, and so on [1-6]. However, the resistive switching characteristics are observed.

2. Experiment

Tungsten (W) metal as a bottom electrode (BE) was deposited by sputtering on SiO\textsubscript{2}/Si 8 inch substrate. To form the ReRAM device, the SiO\textsubscript{2} layer with a thickness of ~150 nm was deposited. Then a small via with an active area of 2x2 \(\mu\text{m}^2\) was fabricated using standard lithography. Photo-resist was used to deposit resistive switching material and top electrode (TE). Then high-kGd\textsubscript{2}O\textsubscript{3} with a thickness of 15 nm was deposited by E-beam evaporation using pure Gd\textsubscript{2}O\textsubscript{3} grains with sizes of 2-3 nm. Then IrO\textsubscript{x} as a TE with a thickness of ~300 nm was deposited by rf sputtering. The lift-off process was used to fabricate the ReRAM device. Schematic view of our IrO\textsubscript{x}/GdO\textsubscript{x}/WO\textsubscript{x}/W ReRAM device is shown in Fig. 1. Fig. 2 shows cross-sectional high-resolution transmission electron microscope (HRTEM) image of our novel IrO\textsubscript{x}/GdO\textsubscript{x}/WO\textsubscript{x}/W ReRAM device with a via size of 2x2 \(\mu\text{m}^2\). Due to a small size, the device was prepared by FIB for TEM observation. The thicknesses of the Gd\textsubscript{2}O\textsubscript{3} and WO\textsubscript{x} layers were ~15 and 5.5 nm, respectively. The EDX spectra confirm the presence of expected elements of Ir, Gr, Wd, and W in respective layers (Fig. 3). The W-O bonding with an energy peak at 35.48 eV was confirmed by X-ray photoelectron spectroscopy [Fig. 4(a)]. The WO\textsubscript{3} layer was formed at the W/GdO\textsubscript{3} interface during deposition of GdO\textsubscript{3} and IrO\textsubscript{x} layers. It is also advantageous to control resistive switching phenomena using GdO\textsubscript{3}/WO\textsubscript{3} bilayer structure. Fig. 4(b) represents the chemical bonding states of Gd\textsubscript{2}O\textsubscript{3} film. The Gd 3d\textsubscript{5}/2 and GdO\textsubscript{3} 3d\textsubscript{5}/2 peaks are at 1186.73 eV and 1189 eV, respectively, which proves Gd: GdO\textsubscript{3} mixture. Fig. 5 shows the SET polarity dependent formation process of the pristine devices. The leakage currents are 1.47x10\textsuperscript{-7} and 1.64x10\textsuperscript{-6} \(\mu\text{A}\) at the read voltages of +2V and -2V, respectively.

3. Results and discussion

Fig. 6 shows the typical bipolar switching current-voltage (I-V) characteristics after negative formation process. The sweeping voltages with an I\textsubscript{CC} of 1 mA are as follows: 1\textperiodcentered4. The SET (V\textsubscript{SET}) and RESET (V\textsubscript{RESET}) voltages are -2.4 and +1.9V, respectively. The current transports of high resistance state (HRS) and low resistance state (LRS) show Schottky emission and Ohmic behaviors. Under negative polarity on TE (-V\textless V\textsubscript{SET}), the oxygen ions (O\textsuperscript{2-}) will migrate from GdO\textsubscript{3} layer toward WO\textsubscript{x} layer. On the other hand, the oxygen vacancies (V\textsubscript{O}) will migrate from WO\textsubscript{x} layer toward GdO\textsubscript{3} layer and the oxygen vacancy filament will form in the GdO\textsubscript{3} layer and sets a LRS. The conducting filament will be ruptured by applying positive voltage (+V\textgreater V\textsubscript{RESET}) on the TE. It is expected that the filament is ruptured by Joule heating process. That’s why the DC cycles under negative SET polarity are not so stable. On the other hand, excellent 700 consecutive DC cycles are observed after positive formation process (Fig. 7). The V\textsubscript{SET} and V\textsubscript{RESET} are +1.8V and -1.8V, respectively. Both HRS and LRS show trap-charge controlled current transport mechanisms. It suggests that the current transport is controlled by initial barrier height, which depends on \(\Phi\textsubscript{m}\) of the electrodes. Improved repeatable I-V characteristics are due to barrier height control current transport mechanism. Fig. 8 shows tight distribution of (a) HRS/LRS and (b) SET/RESET voltages with cycle-to-cycle (C-C) and device-to-device (D-D). Average LRS and HRS are 8.6 k\Omega and 206.2 k\Omega, respectively. Tight distribution of the V\textsubscript{SET} from +1.7V to +1.9V and V\textsubscript{RESET} from -1.6V to -1.9V is observed. Fig. 9 shows good program/erase endurance of >10\textsuperscript{4} cycles. A good resistance ratio of >10 is obtained. Fig.10 shows excellent read endurance characteristics of 10\textsuperscript{4} times at a read voltage of +0.1V. Fig.11 shows the retention characteristics of the memory device at room temperature (RT) and 85\degree C under negative SET polarity. The device shows good retention with maintaining a high resistance ratio of >10\textsuperscript{3}. Excellent data retention characteristics are also observed for positive SET polarity at RT and 85\degree C (Fig.12). Extrapolation of data retention with an acceptable resistance ratio of ~10 can guarantee 10 years nanoscale nonvolatile memory applications in future. Due to improve resistive switching characteristics of IrO\textsubscript{x}/GdO\textsubscript{x}/WO\textsubscript{x}/W structure under positive SET polarity, this structure could be used in future nanoscale nonvolatile memory for flexible display panel.

4. Conclusions

Novel memory device in an IrO\textsubscript{x}/GdO\textsubscript{x}/WO\textsubscript{x}/W structure under negative/positive SET polarity is investigated. Improved resistive switching characteristics with repeatable cycles, SET/RESET voltages, HRS/LRS, and endurance are obtained under positive SET polarity. Excellent read endurance (10\textsuperscript{4} times) and extrapolated 10 years data retention at 85\degree C under positive SET polarity are useful in future nanoscale transparency nonvolatile memory applications.

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References

oxygen vacancies are possible easily. WOx/W memory device using IrOx/GdOx/WOx/W structure. The device size is 2x2 μm². During deposition of GdOx and IrOx, the interfacial WOx layer was formed.

It was formed. It proves layer-by-layer structure with presence of GdOx resistive memory layer.

Fig. 2 Cross-sectional HRTEM image of IrOx/GdOx/WOx/W memory device. Thickness of GdOx layer ~ 15 nm and WOx layer ~ 5.5 nm. So GdOx/WOx bilayer is observed.

It is interesting to note that Gd is mixed with Gd2O3 film. It suggests that oxygen vacancies are possible easily.

The formation process was positive polarity. During application.

The device could be operated within ±4V.

Fig. 3 Energy dispersive X-ray spectra (EDX) show Ir, Gd, W, and O elements from Fig. 2.

The formation process was positive polarity. During application.

The device could be operated within ±4V.

Fig. 4 XPS characteristics of (a) WOx and (b) Gd3d in W and GdOx layers, respectively for our IrOx/GdOx/WOx/W structure. It is interesting to note that Gd is mixed with Gd2O3 film. It suggests that
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