Uniformity Improvement of Resistance State by Using Novel Electrical Operation for the Flexible AIN Unipolar Resistive RAM (RRAM)

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1. Instructions

Resistive RAM (RRAM) has been considered as one of the most promising candidates for the next generation memory technology due to the simple structure, high density and low power consumption [1,2]. Recently, flexible electronic product attracts much attention and it has been considered as the next new technology [3,4]. But the uniformity (or stability) of high and low resistance state of flexible RRAM is inferior [5,6]. Some improvements on the resistance stability such as the electrical operation method and multilayer dielectrics can improve this issue [5,7,8]. But the more effective method needs to be developed. For switching layer, AlN thin film possesses a high thermal conductivity and good insulating properties [9], and it can be as the transparent dielectric for the flexible and transparent RRAM application [10].

In this work, a short pre-set and pre-reset bias is extra-applied before the normal set/reset operation (denote as traditional operation) to investigate the characteristics of AZO(top electrode)/AlN/Al(bottom electrode) deposited on flexible PEN substrate. A transparent AZO metal is used as the top electrode to evaluate the characteristics of RRAM. The improvement mechanisms of HRS and LRS are also studied.

2. Experimental

 125µm thick DuPont Q65 PEN substrate was used for the flexible substrate. First, the PEN was cleaned by the DI water in an ultrasonic cleaner. Then 100-nm thick Al was deposited by dual E-Gun evaporator as bottom electrode (BE). Then, 15-nm-thick AlN was RF-sputtered by an AlN target (99.9%) at a power of 200W and a working pressure of 7.6mTorr. After that, the top electrode of AZO was RF-sputtered by a AZO target [99.99%, Al: ZnO (wt.%) = 2%:98%] at a power of 180W, and patterned by circular shadow mask with a diameter of 200 μ m. Fig. 1 shows the final sample structure and the process steps. The physical photograph of the flexible AIN RRAM sample is shown in Fig. 2. The electrical characteristics of the RRAMs were measured by an Agilent 4155C, including IV curve, endurance, and retention. The pre-set operation is a bias from 0 to 1.2V was applied before the typical set process. In the other hand, the pre-reset operation is applied a bias from 0 to 2V. The crystal structure of AlN film was identified by X-ray diffraction (XRD) analysis.

3. Results and Discussion

Fig. 3 shows the TEM cross-sectional view (on Si substrate), and SEM plan view and AFM images (on PEN) of AlN thin film. The AlN film thickness is about 15 nm confirmed by the TEM image. In addition, the crystallization was observed and the grain size is about 8 nm from the SEM. AlN film roughness is about 2.77 nm [Fig. 3(c)]. Fig. 4 shows X-ray diffraction pattern of AlN film, AlN(200) and AlN(102) crystal phase were observed in the figure. Fig. 5 shows the current-voltage (IV) characteristics (first 30 cycles) for the AlN RRAM operated in typical (traditional), with pre-set bias and with pre-reset bias before the typical set/reset process. Obvious uniformity improvement of set voltages and current in the set process were observed for the RRAM with pre-set bias. In other hand, the RRAMs with pre-reset bias operation reveal better uniformity of reset voltage and current. Fig. 6 shows the endurances of the three kinds of electrical operation of AlN RRAM. From the Fig. 6, it can be seen the pre-set operation reveals the better uniformity of HRS than that of the

typical operation during the endurance testing [Fig. 6(b)]. In the other hand, the pre-reset operation reveals the better uniformity of LRS than that of the typical operation. Additionally, the pre-set operation reveals the best uniformity of both HRS and LRS and the high resistance ratio of HRS/LRS in the three kinds of operation. Fig. 7 shows the cumulative distribution of the three kinds of operation for the AlN RRAMs. Narrow distribution of the RRAM with pre-set operation is observed. The retention of the AlN RRAM for the traditional operation can pass 10-years projection of lifetime (Fig. 8). The other two kinds of RRAM also pass 10-years projection of lifetime (no shown). Fig.9 and 10 show the resistances of the HRS and LRS and the voltages of the V_{set} and V_{reset} for the three kinds of electrical operation. From the figures, it can be seen the pre-set operation shows the better uniformity (less variation) than those of the other two kinds of operations. For the endurance ability of the three kinds of electrical operation, the pre-set operation shows the best switching cycle (1155) [Fig.11(a)]. The maximum reset current of the AIN RRAM w/ and w/o pre-set or pre-reset bias shows similar level (~ 10 mA) [Fig. 11(b)]. For the successful rate of resistance switching between HRS and LRS is shown in Fig.12 for the different electrical operations. The RRAM with pre-set bias operation, the successful rate is the highest about 99.92%. Thus, the pre-set operation is beneficial for the true at programming and erasing. The switching mechanism of unipolar resistive RAM is correlated to the conduction path formation and rupture [5]. Fig. 13 shows the proposed switching mechanism of the AlN RRAM with pre-set and pre-reset bias operations. The initial HRS state shows rupture of conduction path (filament) [Fig.13(a)]. The pre-set bias extends the length of filament and shortens the distance of rupture [Fig.13(b)]. Following the set process, the conduction filament is formed with smaller branches and leads to the resistance turned to LRS [Fig.13(c)]. In the other hand, for the resistance transition from the LRS to HRS [Fig.13(d)~(f)], the pre-reset bias reduces the smaller branch of filament and keeps the main conduction filament [Fig.13(e)]. Following the reset process, the conduction filament is ruptured and leads to the resistance turned to HRS [Fig.13(f)].

4. Conclusions

This work investigates the uniformity of HRS and LRS of AlN RRAM with pre-set and pre-reset bias before the typical electrical operation. The pre-set bias reveals higher uniformity, higher resistance ratio of HRS/LRS, higher endurance and higher successful transition percentage. The switching mechanism of the RRAM with pre-set bias extends the length of filament and shortens the distance of rupture, results in the superior performance.

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References

^[1]K. M. Kim et al., APL, 91, 012907 (2007). [2] D. S. Jeong et al., nanotechnology, 20, 375201 (2009). [3] K. Kinoshita et al., Solid State Electron. 58, 48 (2011). [4] S. Kim et al., IEEE EDL, 56, 696 (2009). [5] C. L. Lin et al., SSDM, Kyoto, 2012, pp.640-641. [6] C. L. Lin et al., SSDM, Kyoto, 2012, pp.130-131. [7] J. Park et al., IEEE TED, 32, 63 (2011). **[8]** C. H. Ho et al., IEEE IEDM, 2012, p.2.8.1-2.8.4. **[9]** H. D. Kim et al., IEEE TED, 58, 3566 (2011). **[10]** H. D. Kim et al., IEEE EDL, 32, 1125 (2011).



PEN substrate clean Bottom electrode (BE) Al deposition by E-gun system AlN film (15 nm) deposited by RF sputtering using AIN (99.9%) target and Ar gas Top electrode (TE) AZO deposition and patterned by a metal mask









2θ (deg.) Fig. 4 X-ray diffraction pattern of AlN film deposited on the Al/PEN sample

of flexible AlN RRAM devices.

Fig. 3 AlN film material images of (a) TEM (cross-sectional view) deposited on Al/Si substrate, and (b) SEM (plane view) and (c) AFM deposited on the Al/PEN substrates.



Fig. 5 Currents versus voltage (I-V) characteristics of (a) traditional (typical) without pre-dc sweep operation, (b) with pre-set dc sweep, and (c) with pre-reset dc sweep operation for the AZO/AIN/AI/PEN flexible RRAM after 30 switching cycles.



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800 Resistance (Ω) Fig.7 Cumulative distribution of HRS and LRS of RRAM at 0.1V reading voltage.



Fig.8 Retention characteristics of HRS and LRS of AlN RRAM at a reading voltage of 0.1V. 0.1V stress voltage was applied in retention measurement.



Fig.11 Box plot of (a) endurance (switching cycle) and (b) maximum reset current for the three operation mode.



Fig.9 Box plots of the HRS and LRS of AZO/AlN/Al RRAM for the three electrical operations.



Fig.12 IV curve of (a) traditional (typical) w/ pre-set bias, (b) w/ pre-reset bias, and (c) the successful switching rate for the three electrical operations



Visiet Viet Visiet (Preset) (Presset) (Presset) ffrad.) (frad.) (Preset) Fig.10 Box plots of the set/reset voltages of AZO/AlN/Al RRAM for the three electrical operations.



Fig.13 Schematic switching mechanism of AlN RRAM for (a)~(c) with pre-set bias, and (d)~(f) with pre-reset bias electrical operation.