Abstract #871, 223rd ECS Meeting, © 2013 The Electrochemical Society

Adjustable switching voltage via sol-gel derived and Ag in-situ doped SiO_2 thin films for ReRAM

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Introduction

Resistive random access memory (ReRAM) is considered as a promising candidate to replace the traditional charge storage memory owing to its great scalability, high switching speed and compatibility with CMOS technology [1]. In previous literature [2], that kind of ReRAM switched via metal filament formation and rupture exhibits wider memory window than other types of ReRAM but the switching voltage is undesirable. It is because switching voltage depends on the difficulty of metal filament formation inside the solid electrolyte from cathode to anode [3]. To reduce the switching voltage, in this work, a sol-gel derived SiO_2 and Ag in-situ doped SiO_2 thin film technique was presented to pre-dope Ag in the SiO_2 switching layer. Based on this technique, metal concentration can be easily controlled to adjust the switching voltage to optimum.

Experimental

For various samples, sol-gel solutions was deployed by applicable molar ratio (TEOS：H_2O：C_2H_5OH：$AgNO_3$ = 1: 4 : 5 : none/ 10^{-6} M/ 0.1 M) in beaker and stirred three hours by using magnet to transmuted into sol-gel. Subsequently, the sol-gel was spin-coated on prepared TaN/SiO_2/Si-sub wafer and heat up to 100 °C for curing surface. Then samples were annealed with 500 °C for 30 seconds by RTA. Finally, a 200-nm Ag top electrode was deposited. The schematic diagram of device structure is shown as the inset of Fig. 1.

Results and Discussion

It is necessary to declare there is no switching property of TaN/sol-gel derived SiO_2/TaN structure in advance. The J-V characteristics of the Ag/sol-gel derived SiO_2/TaN control sample and the TaN/SiO_2:Ag/TaN samples for different concentrations are shown in Fig. 1. Distributions of forming voltage and switching voltage are displayed in Fig. 2, which is corresponding to Fig. 1. The results obviously indicate that heavier Ag concentration in resistive layer resulting lower forming voltage ($V_{forming}$) and set voltage (V_{set}) because the metal filament could be formed and accumulated more easily [4]. However, due to tiny differences between conducting metal filaments, there is no significant differential of V_{reset} among three samples, as shown in the inset of Fig. 2. Moreover, as can be seen in Fig. 3, the resistance stability of 0.1 M doped sample was better than other two samples not only under high resistive state (HRS) but low resistive state (LRS). Thus, in-situ doped Ag in SiO_2 could improve the uniformity of both switching voltage and resistance distribution. It is believed that while the filament formation needed less time and energy, the conducting path would be more immovable. In addition, TaN/SiO_2:Ag/TaN ReRAMs exhibited a great data retention under 85 °C through long-term testing, as displayed in Fig. 4. The ON/OFF ratio of 0.1 M doped sample was kept wider than two orders even after 2×10^3 s. However the variation was acceptable.

Conclusion

The method of sol-gel derived with Ag in-situ doped has been demonstrated to produce the desired adjustable switching voltage for ECM-type ReRAM application. Based on this method, the metal content of resistive layer can be modulated during fabrication process. According to the above results, filaments were formed more easily under the resistive layer with heavier metal content, thus allowing for adjustments in not only forming voltage (from 2.5 V down to 1 V) but also set voltage (from 2.2 V down to 0.5 V). It is generally considered that adjusting $V_{forming}$ and V_{set} in fabrication process by Ag in-situ doped method is more suitable than operating device to aim the goal during application. Meanwhile, in-situ doped Ag inside SiO_2 film resulted in stable resistance distributions of both HRS and LRS. Also, the TaN/Ag:SiO_2/TaN ReRAM provides a stable data retention even under 85 °C after 20000 s. In addition, this technique exhibits several tempting advantages of low cost, low thermal budget and high throughput in simple process.

References

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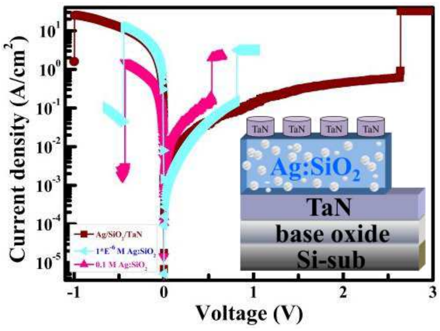

Fig. 1. The schematic device structure and J-V characteristic curves of Ag control sample, 1*E^{-6} M sample and 0.1 M sample respectively.

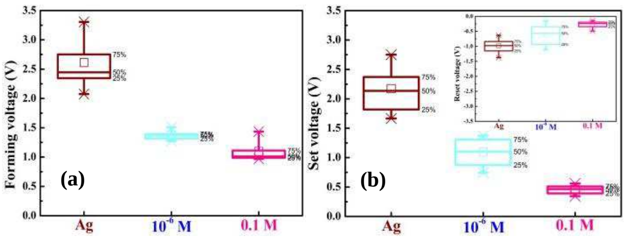

Fig. 2. Distributions of (a) forming voltage and (b) switching voltage.

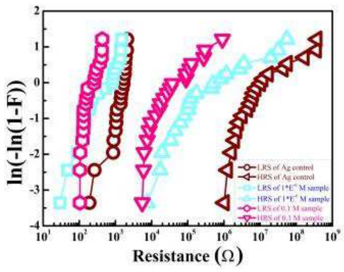

Fig. 3. Weibull distributions of HRS and LRS for each sample.

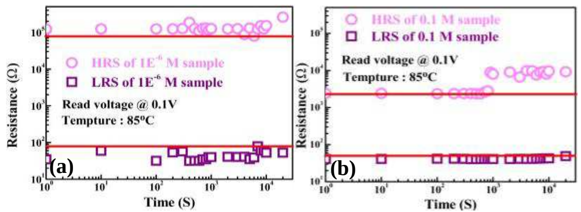

Fig. 4. Data retention properties of (a) 1*E^{-6} M sample and (b) 0.1 M sample, respectively, under 20000 s @ 85 °C.