High Performance Oxide Diode

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Abstract

We report the fabrication of oxide diodes with size down to 40×40nm² which could be used for selector applications in high density nonvolatile memory arrays. The diodes consist of VO₂ and TiO₂ while the electrodes are TiN. The diodes show current density up 10⁵A/cm² and ideality factors less than 2.3. Turn-on time is shorter than 5ns, and cycling endurance higher than 10⁹cy.

1. Introduction

The major roadblock for the implementation of resistive memory in multilayer high density arrays is the lack of an appropriate selector device. The selector has to limit the leakage current through unselected memory cells in arrays. Diodes are the most studied devices for this application. Oxide diodes can be built either as p-n junctions or as Schottky diodes. While many n-type semiconducting oxides are known (TiO₂ is the most prominent example), very few p-type oxides are available and typically have a large band gap which results in devices with a large turn-on voltage and low current [1]. Schottky diodes where an oxide is sandwiched between two metals have been investigated extensively [2]. Schottky barriers are easily destroyed by bias stress and often use metals with a high work function such as Pt, which are not CMOS compatible. In these devices it is also difficult to control between diode behavior and nonvolatile resistive switching [3]. VO₂ is reported to have a work function of ~5.2eV [4] and be p or n doped depending on the production conditions.

2. Results and discussion

Material and device fabrication

The devices are fabricated on 300nm Si wafers. The electrodes have a cross-bar geometry (Fig.1). TiN bottom electrodes (BE) are patterned and planarized on SiO₂ isolation. VO₂ [5] and TiO₂ [6] are deposited via atomic layer deposition (ALD). The TiN top electrode is sputter deposited on dry etching stopping on BE. There are 2 types of active stacks investigated: 1) ALD VO₂ followed by a crystallization ammend and ALD of TiO₂; 2) ALD TiO₂ followed by the deposition of VO₂ and the ammend. The ammend was the same for all stacks. A TEM cross-section of a device is presented in Fig. 2 showing that both the VO₂ and the TiO₂ are fully crystalline. X-ray diffraction (XRD) patterns of the 2 types of stacks are shown in Fig. 3. Independent of the order of the 2 oxides in the stack, only one XRD peak (other than TiN) is observed. This peak is compatible with the plane (011) of VO₂ and (110) of rutile TiO₂.

Electrical characterization

Typical rectifying behavior is shown in Fig. 4 for both types of stacks. Upon reversing the stack, the polarity of the forward bias changes accordingly. Devices fabricated with the VO₂/TiO₂ stack show area scaling of the current only at large current while those with the TiO₂/VO₂ stack show perfect area scaling at all currents levels. This can be explained by the fact that the VO₂ has a relatively low resistivity and the whole oxides stack is present under the top electrode. This creates an extra conduction path which is visible only at low currents.

The diode factor is lower than 2.3 for all stacks, demonstrating excellent diode behavior, better than typical oxide diodes [1]. The current density increases with decreasing thickness of the TiO₂ and is as high as 10⁵A/cm² at 2V for devices with 4nm TiO₂/9nm VO₂.

3. Conclusions

We have demonstrated high performance VO₂/TiO₂ diodes with dimensions as small as 40×40nm² and current density as high as 10⁵A/cm² at 2V. The diodes show response times faster than 5ns. We report for the first time oxides diodes with endurance higher than 10⁹ cycles.

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References

Fig. 1: SEM image of a cross-bar device.

Fig. 2: TEM cross-section of a device.

Fig. 3: XRD data showing no difference between stacks with VO₂/TiO₂ and TiO₂/VO₂.

Fig. 4: Current density vs. bias for devices with 9nm VO₂/12nm TiO₂ (left), 9nm VO₂/9nm TiO₂ (middle) and 4nm TiO₂/9nm VO₂ (right). Perfect area scaling of current is observed for devices with 4nm TiO₂/9nm VO₂.

Fig. 5: Temperature dependence of the current density vs. bias for devices with 9nm VO₂/12nm TiO₂ (left), 9nm VO₂/9nm TiO₂ (middle) and 4nm TiO₂/9nm VO₂ (right). Device size is marked on the figure. Temperature is increased in steps of 10°C.

Fig. 6: Sketch of the pulsed measurement setup used to acquire data in Fig 7 and 8.

Fig. 7: Pulse shapes in forward (a) and reverse (b) bias for devices with 9nm VO₂/9nm TiO₂ showing that the diodes turn on in less than 5 ns.

Fig. 8: Endurance test of a 10x10μm² device with 9nm VO₂/9nm TiO₂ over 10⁸ cycles.

Fig. 9: Stress test of a 65x65nm² device with 4nm TiO₂/9nm VO₂ showing little change in current levels over 1000s.