Effect of Deposition Parameters in RF-Sputtering of Titanium Dioxide Thin Films for Non-Volatile Memory

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Abstract:

Resistive switching of titanium dioxide (TiO_2) has attracted attention due to its potential application in non-volatile memory devices. However, the exact mechanism of switching is unknown. In this work, TiO_2 thin films are deposited onto platinum substrates using reactive radio-frequency (RF) magnetron sputtering. We vary the substrate deposition temperature and substrate bias in order to modify the chemical composition, microstructure, and electrical properties of the TiO_2 film. After photolithography, platinum electrodes are sputtered. The final device structure is Pt/TiO_2/Pt. IV curves are measured to characterize the switching behavior of the TiO_2 films. The results of this work will help us understand how deposition conditions affect the electrical properties of the film and give us insight into the optimization of TiO_2 films for non-volatile memory applications.

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Introduction and Motivation:

TiO_2 exhibits bistable resistance switching behavior as a resistance change memory material [1]. It can reversibly switch between high and low resistance states when appropriate voltages are applied, either unipolar or bipolar [2]. The technical difficulties that hinder the application of TiO_2 are reproducibility, large set/reset current and voltage, and the required electrical forming process. In addition, how switching happens on an atomic level is unknown even though it has been determined that the formation and disruption of conducting filament is the mechanism [3]. The goal for this project was to study how varying sputtering parameters would affect the electrical properties of the film and hopefully gain some insight into how switching works.

Experimental Procedures:

Forty nanometers of TiO_2 thin film was deposited on Pt/Ti/SiO_2/Si and Si substrates by reactive RF magnetron sputtering using a titanium target. 27 sccm of argon and 3 sccm of oxygen gases were used to form a film consisting of TiO_2,Ti_2O_3, TiO, and Ti. We varied the substrate deposition temperature (room temperature, 100°C, and 200°C) and the substrate bias (0V, 60V, and 100V) to study their effects on the electrical properties of the film. After deposition, photolithography was used to pattern the film and 50 nm top platinum electrodes were sputtered. Excess photoresist and platinum were removed to get the final device that had the structure Pt/TiO_2/Pt. IV characteristics were tested using a probe station with an Agilent 4156C semiconductor analyzer.

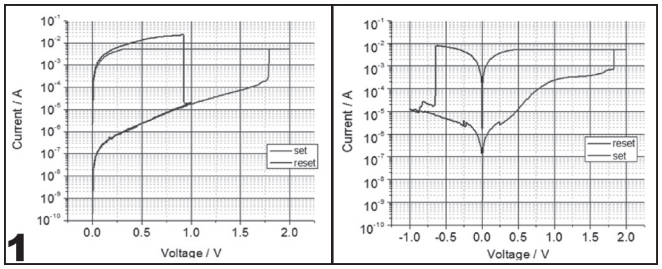
Results and Discussion:

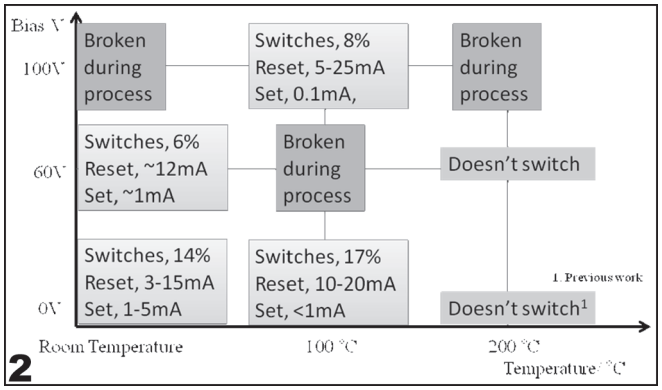
All the devices were found to require an electrical forming process regardless of the deposition conditions, which suggested that changing sputtering parameters would not eliminate the forming process. The forming voltage was ~4-5 V and forming current was ~ 5-10 mA. The device was then in a low resistance state and could not return to its fresh state after forming.

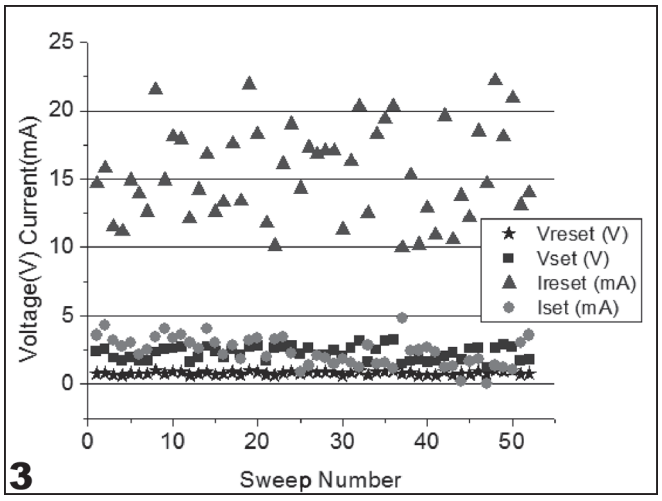
TiO_2 film exhibited both unipolar and bipolar switching behavior [2], as shown in Figure 1. The switching window of unipolar switching was ~ 1000 and is larger than for bipolar switching, which was ~ 100, as shown in Figure 1. This difference might be explained by the conducting filament mechanism.

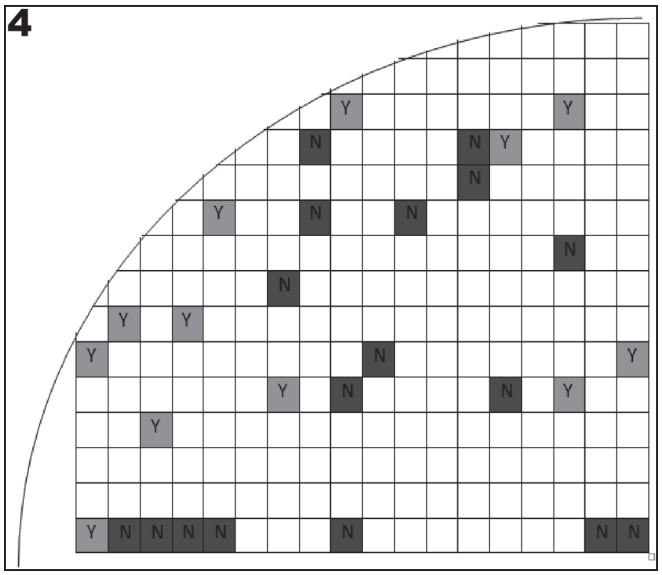
Film performance for different deposition conditions were plotted (Figure 2). The set and reset voltage were roughly in the same range for different conditions, with set voltage ~ 1-2V and reset voltage ~ 0.6- 0.8V. The reset current seemed to get larger, from 5 mA for 0V, room temperature, to 25 mA for 100V, 100°C, while the set current was getting smaller, from more than 1 mA to less than 0.1 mA, as we increased substrate temperature and applied bias. All the films deposited at 200°C were conductive, possibly because the film was reduced from the heat and had more oxygen vacancies.

Multiple bipolar sweeps were conducted on one device to test endurance. Figure 3 shows the distribution of set/ reset current and voltage. The set voltage was higher than the reset voltage. The set current was lower than the reset current. Over time, they were scattered and there was no obvious trend. However, there were large variations between each sweep. This suggests









that the film was unstable and film performance might have depended on the previous sweep.

The 10% to 20% yield was low. The location of working and non-working devices on a quarter silicon substrate was plotted (Figure 4). Each block had 100 devices and 5 to 10 devices were tested from each block. "Y" represents area with working devices and "N" represents non-working ones. The devices on the perimeter worked better than the ones in the center of the film. This kind of distribution was probably related to the photoresist process. The distribution pattern was consistent with the circular photoresist pattern after spinning.

It is possible that the thicker photoresist at the edges protected the devices from outgasing. The distribution might also relate to the sputtering process because of different film thickness and stress of the film.

Summary:

We explored how different deposition parameters affect the switching behavior of a TiO_2 film and studied device variation and tested film endurance. We found out that for different deposition conditions, the reset current seems to get larger and the set current seems to get smaller, as we increase substrate temperature and apply bias. Large device variation exists for the same film possibly due to film stress from deposition or trace contamination from the photolithography process.

Future Plans:

We will characterize the TiO_2 film deposited on Si substrates to study how sputtering parameters affect the physical properties of the film and how they correlate with electrical properties. We will also test endurance with transistor in series so we can precisely control the current through the device.

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Figure 1: Left: IV characteristics of device showing unipolar switching; right: characteristics showing bipolar switching.

Figure 2: Device performance for different deposition conditions.

Figure 3: Bipolar switching endurance test.

Figure 4: Schematic of a quarter silicon wafer showing tested devices, with working devices labeled with Y and non-working labeled with N.