EITP25: Lab

Lab Group 8
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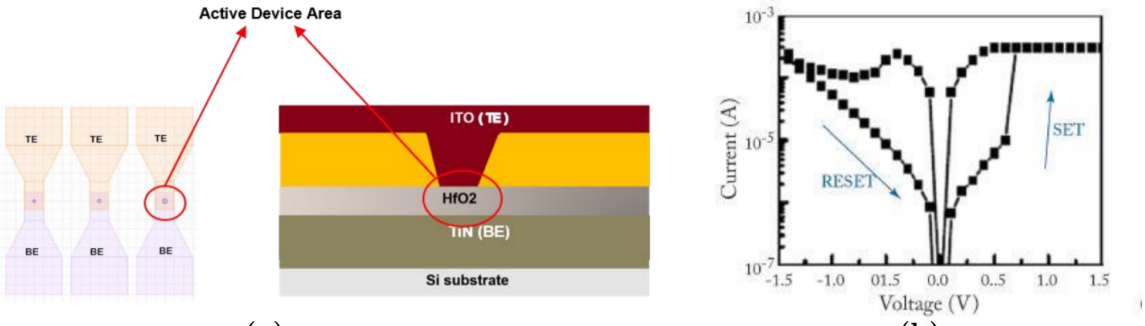
1 Introduction

This lab is meant for familiarizing ourselves with the concept of resistive random access memory (ReRAM), where memory is stored in the form a resistive state. ReRAM technology can be realized in various different ways, however the memory used in this lab is based on a metal insulator metal (MIM) cap structure using oxygen vacancies to form conducting paths between the metals. Measurements are performed using current-voltage (IV) sweeps as well as pulsed measurements for endurance.

2 Theory

The measured devices are MIM-caps fabricated in Lund Nano Lab utlizing a TiN-HfO2-ITO stack for the ReRAM, see Fig 1-(a).[1] The memory-cells is fabricated on top of Si with a pad layout designed for probed measurements. The ReRAM technology is based on field migration of oxygen vacancies in order to form a conducting filament path between the top (TE) and bottom (BE) electrode. Once the filament is formed this is considered the low resistive state (LRS) since a conducting path is connecting the electrodes. The filament is formed by applying a large positive bias V_{SET} to force the migration and alignment of oxygen vacancies. To switch memory states the process can be reversed by applying a large negative bias V_{RESET}, basically breaking the physical filament connection. With a severed conducting path the device enters its so called high resitive state (HRS).

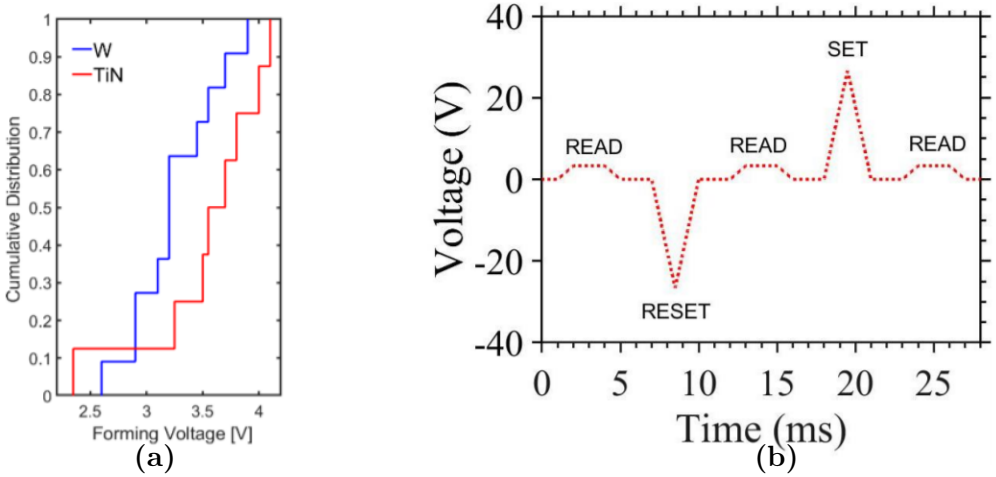
A typical IV-sweep is presented in Fig 5-(b). Here, set occurs around 0.7 V and reset is a more gradual process but nonetheless occurs at -1.5V. The resistive values for LRS and HRS can be registered between 0 and V_{SET} voltages with and without the conducting path respectively.



(a) (b)

Figure 1: (a) Device structure of the ReRAM showing the TiN-HfO2-ITO cross-section connected in a pad-layout for top (TE) and bottom (BE) electrode. (b) A typical, ideal, IV-sweep of the ReRAM showing the set and reset cycles. Taken from [1].

The ReRAM switching relies on physically moving atoms, which limits both speed but also endurance. ReRAM in essence is a balancing act between filament formation and hard breakdown of the device. To quantify the behaviour of the memory cell during stress, cumulative distribution is often presented, see Fig 2, showing the set and reset bias shift over several cycles. To be able to record endurance pulsed measurement regimes are utilized. The reset and set cycles are normally repeated 10^4 times in order to establish if the memory endurance is commercially viable.



(a) (b)

Figure 2: (a) Showing cumulative distribution for different BE materials for the forming voltage V_{SET} over serveral cycles. (b) A pulsed measurement cycle for endurance measurements. Taken from [1].

3 Analysis and discussion

The Electrical characterization of the bipolar ReRAM as discussed above is done using DC I-V switching and pulsed measurements for endurance test by applying voltage between TE and BE.

3.1 DC Measurements

For DC measurements, first we selected a suitable voltage range to perform the forming of the ReRAM which is then followed by the selecting the compliance level to prevent the device breakdown. This is followed by setting the voltage sweep ranges for the SET and RESET operations. The voltage sweeps where from -2 to 3.5V for our measurements. The measurement was done for two different compliance levels: 10uA, 24uA having 10 successive switching.The basic I-V characteristics of the ReRAM is shown in the figure 3 for different complainces.

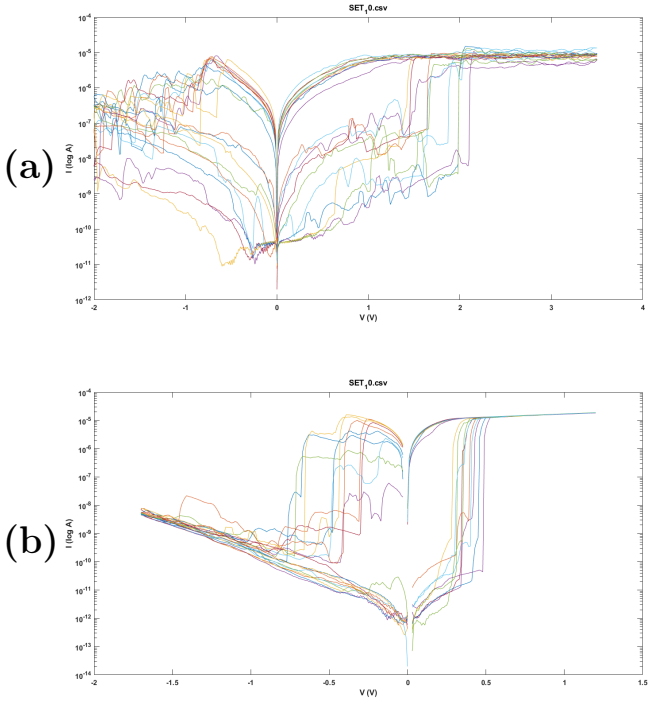


Figure 3: I-V characteristics of ReRAM for 10 switching cycles at compliance current of (a) 10uA, (b) 24uA.

We extract SET, RESET voltages from the I-V characteristics. The SET/RESET voltages are defined as the point where the resistance is 30% of the resistance at the maximum positive or negative voltages. The SET,RESET,LRS,HRS values are noted in the Table 1,2 for compliance 10uA,24uA respectively. Note that LRS, HRS values are calculated at 0.1V for different compliances.
Thd CD of SET,RESET voltages for different compliance's is shown in figure 4,5. For higher compliance the diameter of the filament formed must be large giving higher current. In this measurement 24uA is the best suited compliance level. If the compliance level is set low, then the filament formed might be unstable. Therefore, it is advisable to have a high compliance level.

SET (V)	RESET(V)	HRS (GΩ)	LRS (MΩ)
-1.56	1.61	0.0526	1.5873
-1.54	1.73	0.6250	0.4587
-1.6	1.97	0.06	0.4348
-1.9	1.5	0.2041	0.3226
-1.7	2.02	1.9231	0.8130
-1.51	1.67	0.0312	0.5882
-1.64	1.47	2.3256	0.4762
-1.42	2.13	1.9231	0.5882
-1.86	2.01	2.22	0.3704
-1.68	2.1	0.83	0.2237

Table 1: For compliance of 10uA

SET (V)	RESET(V)	HRS (GΩ)	LRS (KΩ)
-0.69	0.34	55.5	22.2
-0.31	0.35	145	22.2
-0.5	0.39	14	21.7
-0.46	0.33	50	50
-0.73	0.41	55.5	27
-0.5	0.39	2.8	25
-0.31	0.28	26	33
-0.5	0.48	25	45
-0.46	0.3	27.8	24
-0.66	0.3	11.25	24

Table 2: For compliance of 24uA

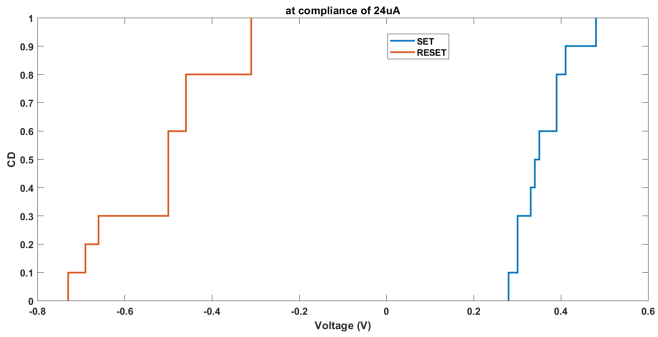


Figure 4: SET, RESET Cumulative distribution plots of the ReRAM is compliances currents 10uA

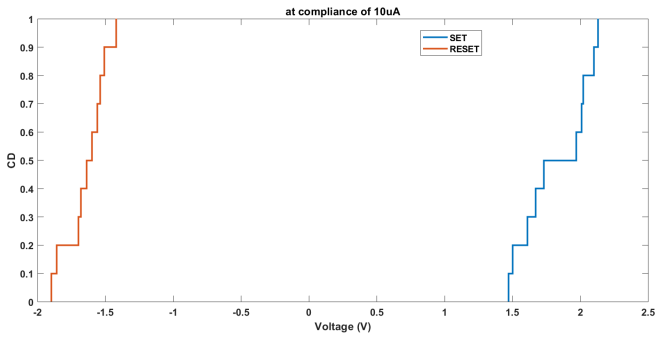


Figure 5: SET, RESET Cumulative distribution plots of the ReRAM is for compliances current 24uA

The Al2O3/HfO2 insulator stack was introduced in the RERAM to observe the multi-level switching. The cumulative distribution plot for the two different stop voltages (-1.5V:HRS2,LRS2 and -2V:HRS2,LRS2) is given below in Fig(6). It can be observed that the HRS for Vstop = -2V is higher than the HRS for Vstop = -1V. At a higher stop voltage, the resistance of the ReRAM will be high due to the large depleted gap between the oxide and the metal layer. It is the Vstop which controls the length of the depleted gap.This trend of higher stop voltage (in our case -2V) yielding a larger resistance window can be observed from the figure below.

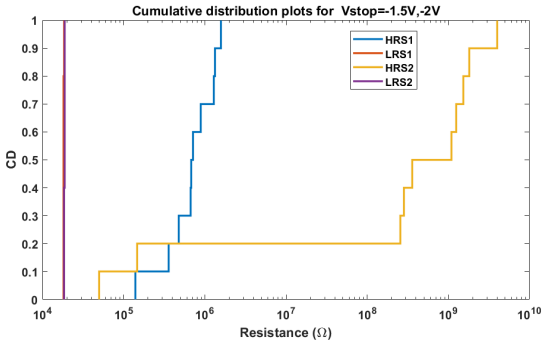


Figure 6: Cumulative Distribution plots for of Al2O3/HfO2 ReRAM for Vstop -1.5V and -2V.

3.2 Pulsed measurements

The pulsed measurements are done for the ReRAM to test the endurance. The pulse train chosen has read,RESET,read,SET,read in one cycle with total of 28mS duration. The current through the ReRAM is plotted in the figure 7.

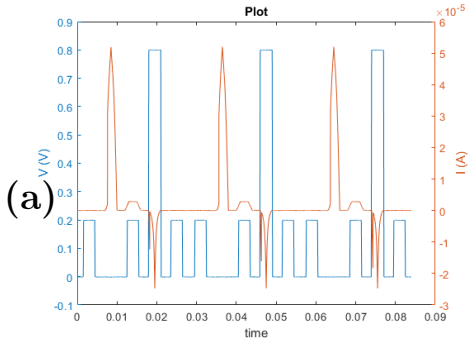


Figure 7: Measured pulse current for three cycles on the right y-axis.

The read voltage is 50mV, the read average current is around 2.8 uA, so the read resistance is 17KΩ. The window for the measured resistance is given by the resistance different between the SET and RESET states. The SET current is 50uA, RESET current is -25uA for the applied 1.5V, -1.5V respectively. The resistance window is 3kΩ to 6kΩ. When reading the ReRAM state, read voltage should be good enough to see the difference between set and reset state current. When writing to the ReRAM, the voltage should be high enough(SET/RESET voltage) to change the state of ReRAM.

For scalability of Artificial neural networks (ANNs) limitations of power, area and operating speed of CMOS based synapses should be mitigated. One approach to achieve it is to use RRAMs. As discussed in lectures, RRAM can store multi-bit non-volatile data in $4F^2$ device area with switching energy in order of pJ.

The ANN has to be trained and tested for pattern recognition. Thereby to adjust the weight of the synaptic array, the linear conductance variation of the RRAM can be utilized. This can be achieved in the measurement setup by sending 0.28 ms set pulsed signals to the gate of the transistor in 1T1R configuration (0.8 V in our RRAM device). For resetting the potentiation, reset pulse of 1 us can be applied. Moreover,for potentiation, as observed from literature [2], by varying amplitude and pulse width, conductive filament thickness can be increased leading to discernible LRSs. This gives us a leeway to play with potentials and pulse widths based on our RRAM device characteristics.

4 Conclusion

The working principle of ReRAM is understood. The electrical characterization like DC, eundurance of ReRAM is tested using pulse measurements.The SET,RESET voltage , LRS and HRS are noted for 10 switching cycles. Form the pulsed measurements, the read resistance, resistance window for the measure data is calculated.

References

1. S. Mamidala, EITP25 - Lab 1 ReRAM Characterization. Lund University.
2. K. Moon, S. Lim, J. park, C. Sung, S. Oh, J. Woo, J. lee, H. Hwang, Faraday Discuss. 2019, 213, 421.