UNIVERSITÀ DEGLI STUDI DI MILANO

CNR - IMM Laboratorio MDM

Nanoscale resistive switching devices based on metal oxides

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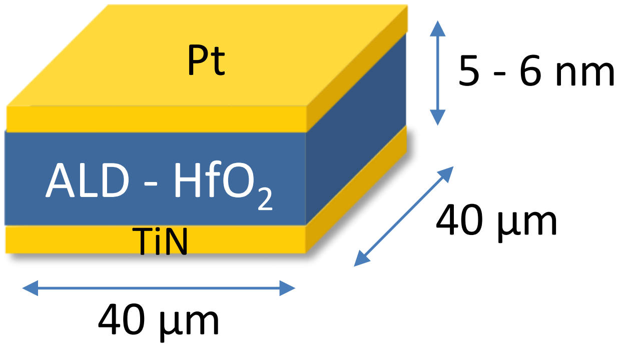
Supervisor Prof. Alberto Pullia

Co-Supervisor Dr. Sabina Spiga

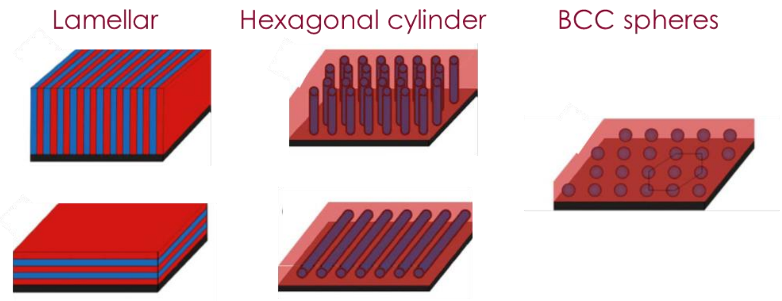
Outline

- Resistive switching:
  phenomenology and applications



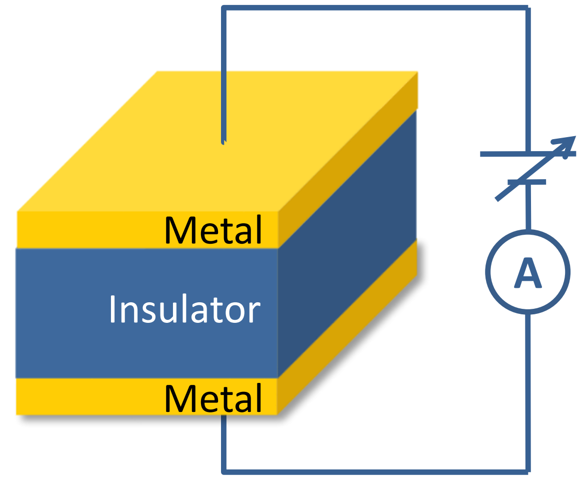
- Device characterization

- Nano devices using block copolymers



Resistive switching in MIM structures

Capacitor-like structure with electrically alterable resistivity

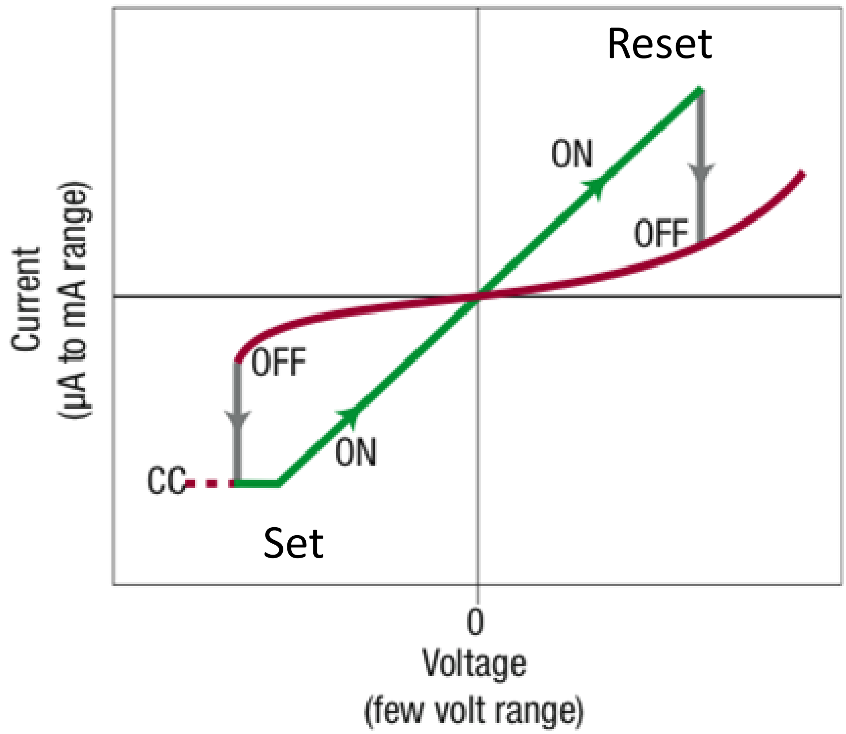


A large variety of insulating materials shows resistive switching properties:

- Transition metal oxides (TMO)
- metal doped perovskites
- Polymers
- …

Switching behavior

Applying a proper potential difference at the two electrodes, the device resistance changes



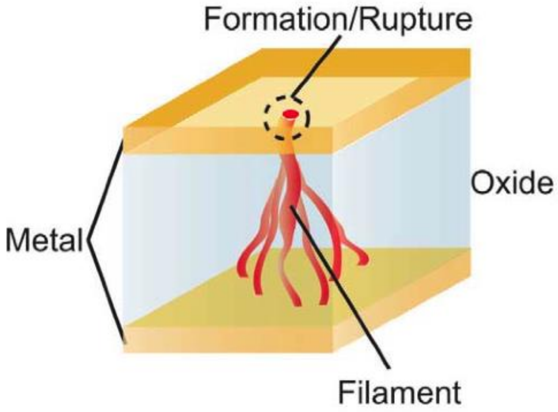
Resistive switching mechanism in TMO

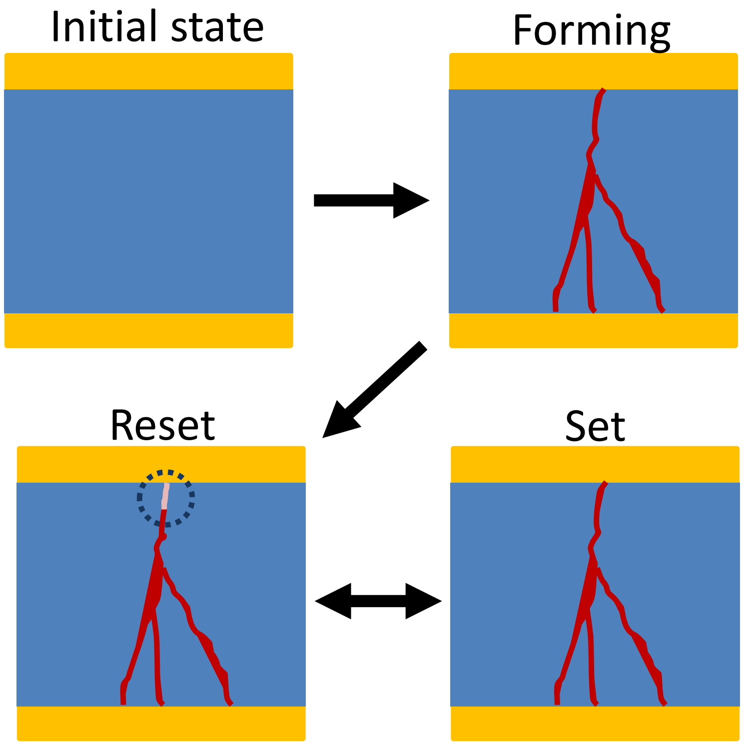
R. Waser, Adv. Mater. 2009 and ref. therein;
A. Sawa, Materials Today 2008

The anion motion leads to a **valence change** of the metal sublattice (cations) → R change

Mobile species:
Oxygen ions – oxygen vacancies

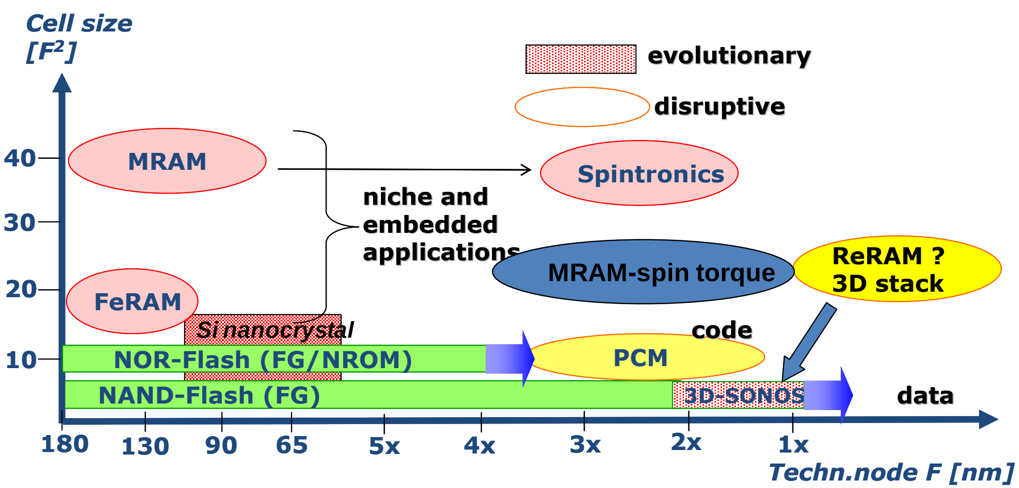
Filamentary type





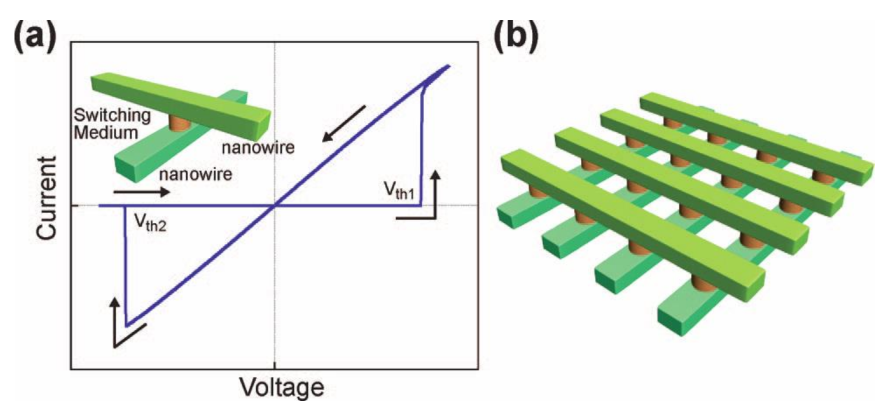
Resistive switching applications

Memory



- Very simple structure
- Highly **scalable**
- CMOS process compatibility
- Low switching time
- Low power consumption

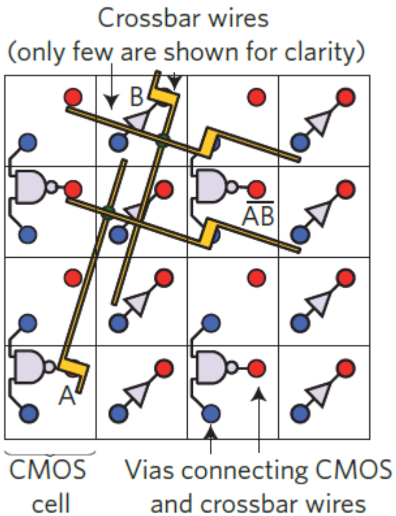
Crossbar array

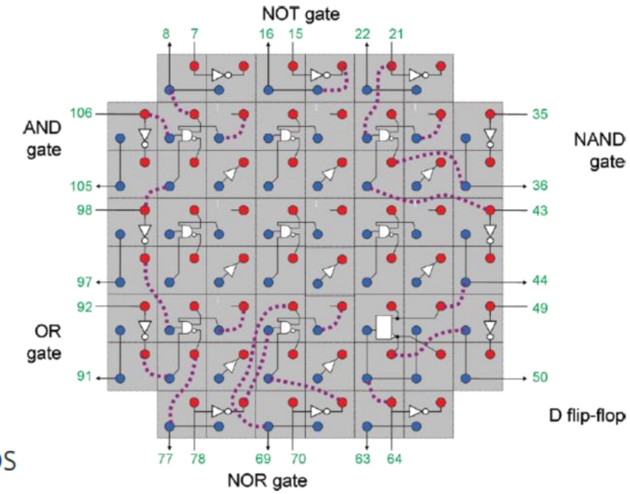


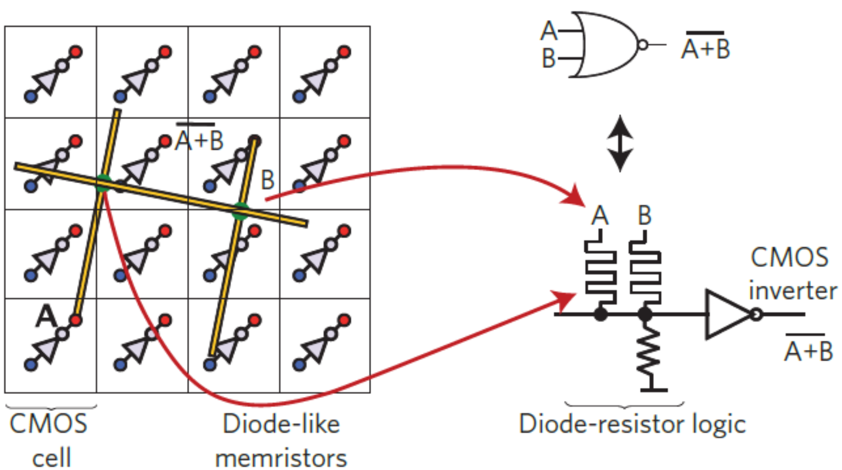
Need for a lithographic technology to enable cell scaling

Resistive switching applications

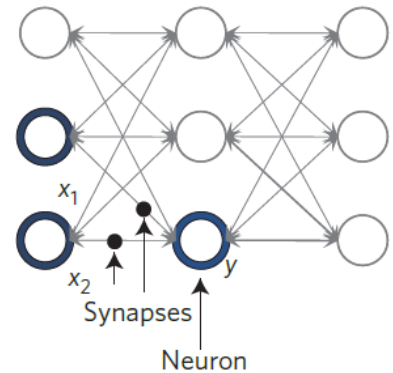
Logic

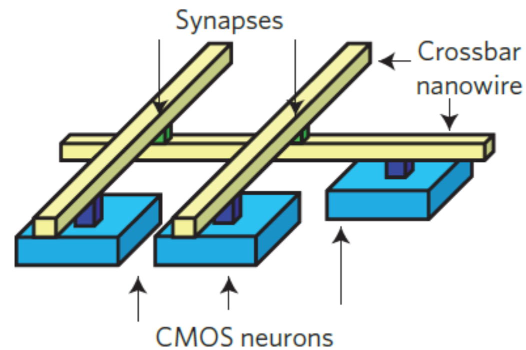






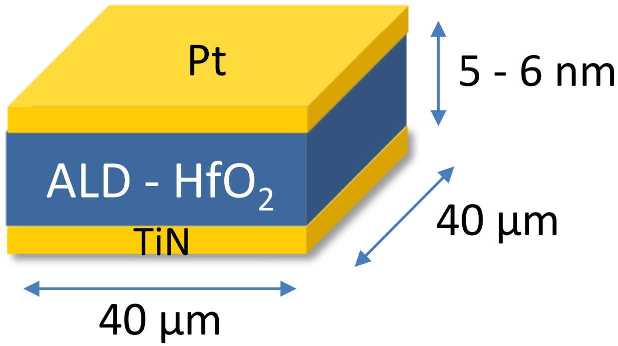
Artificial neural networks



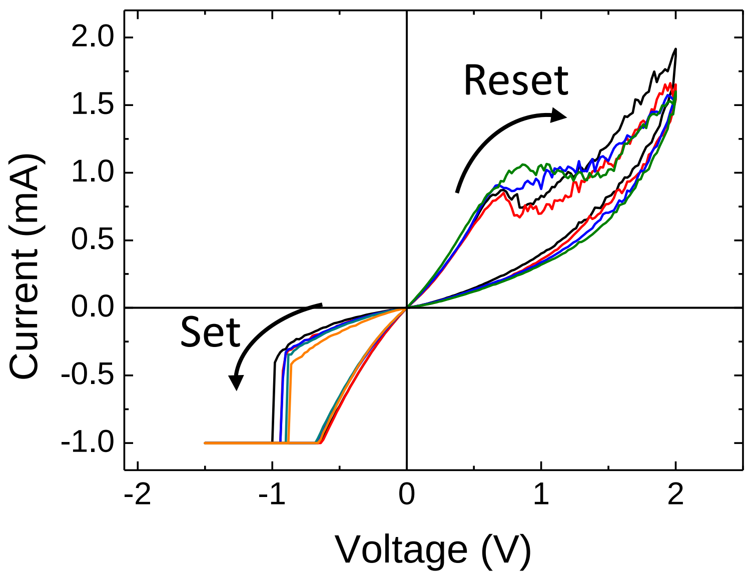


Yang, J. Joshua, Dmitri B. Strukov, and Duncan R. Stewart. "Memristive devices for computing" Nature nanotechnology 8.1 (2012)

Experimental results



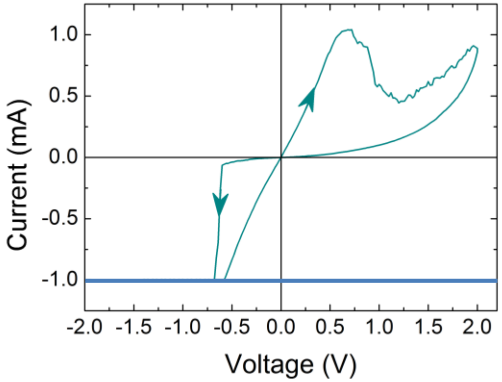
Microscopic device characterization



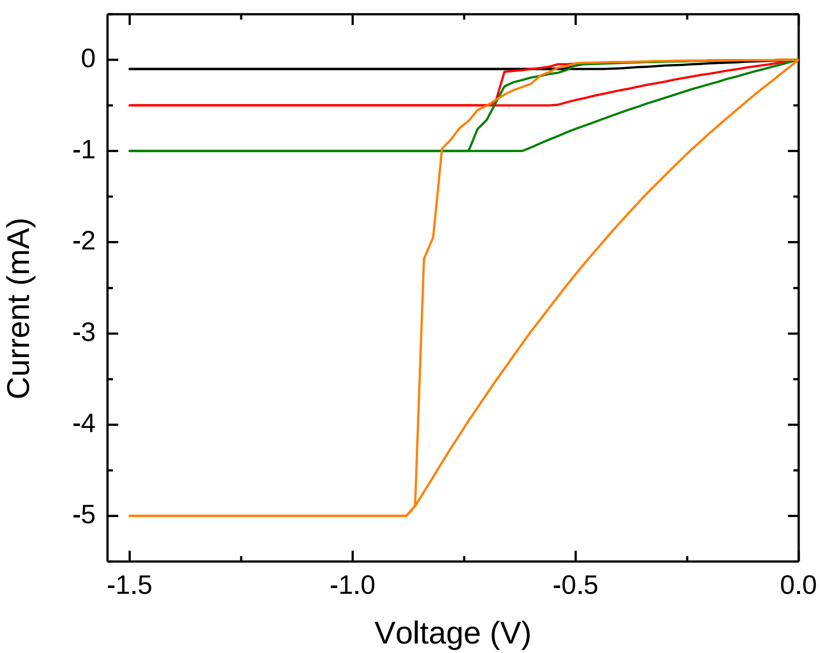
Up to 2000 reproducible switching cycles demonstrated

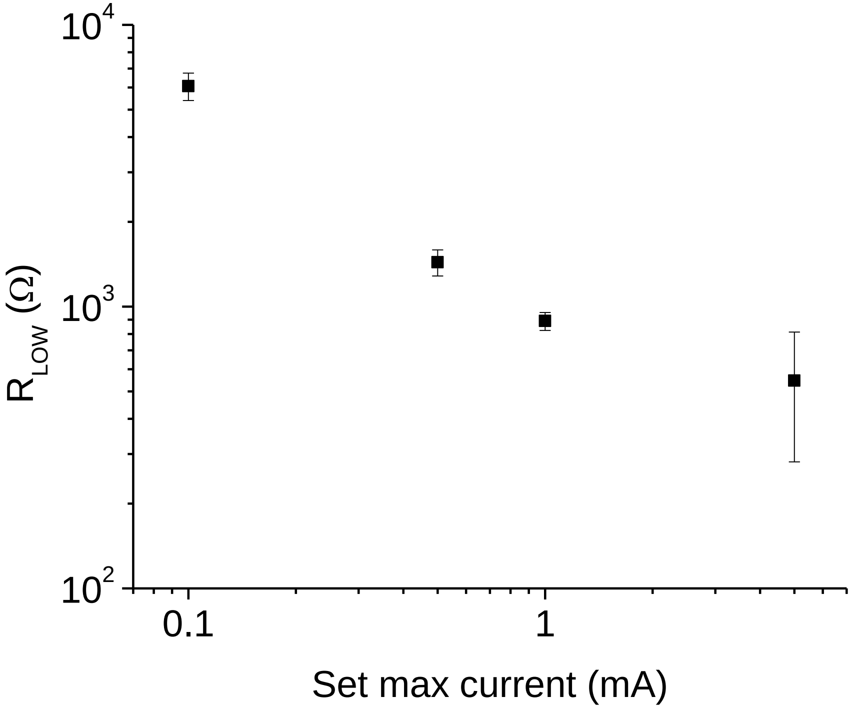
Experimental results

Electrical characterization



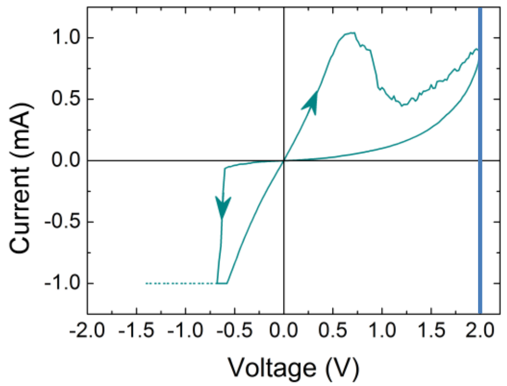
Possible to tune the low resistance varying the maximum allowed current during set (current compliance)



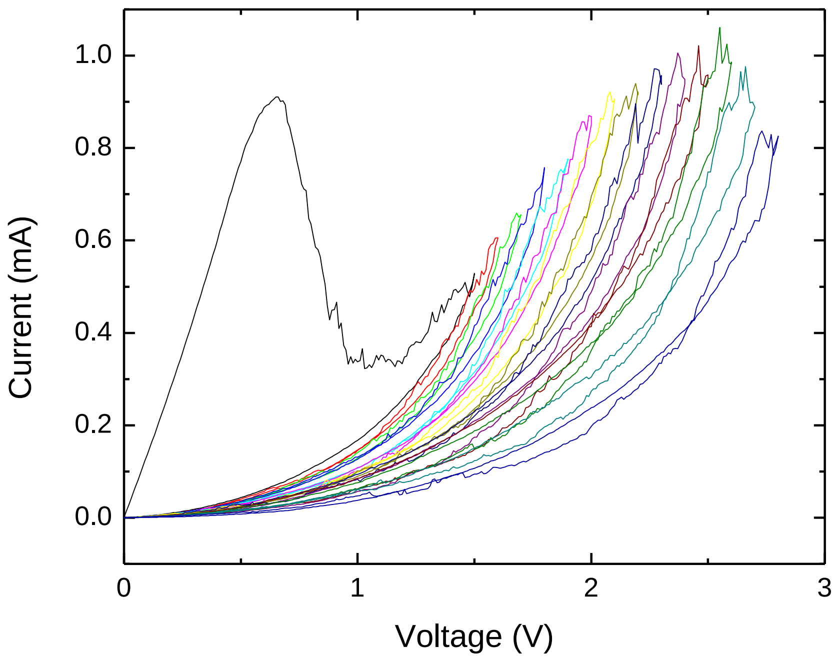


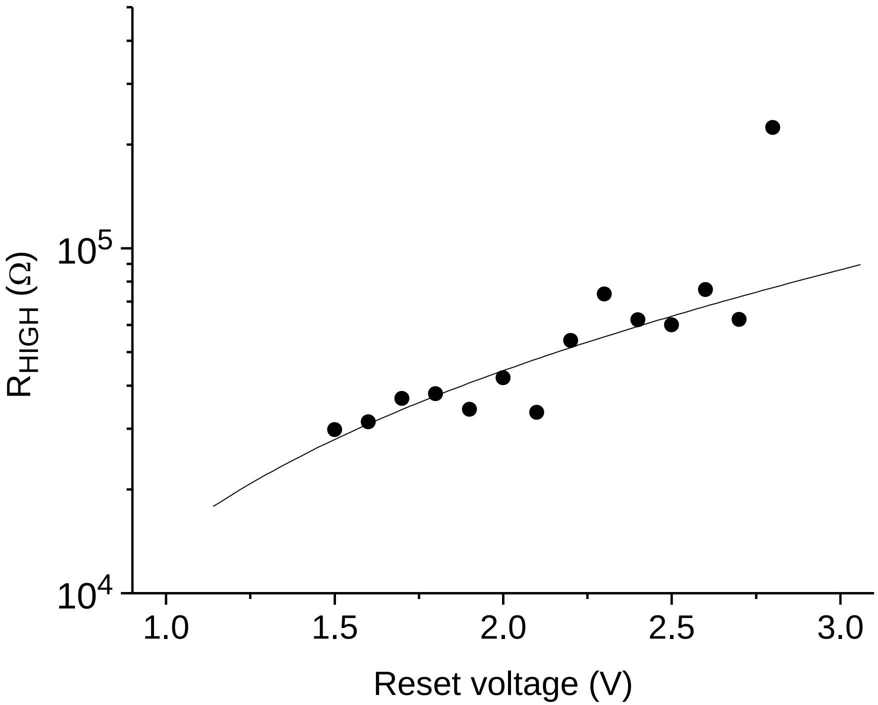
Experimental results

Electrical characterization



Possible to tune the high resistance varying the maximum reset voltage

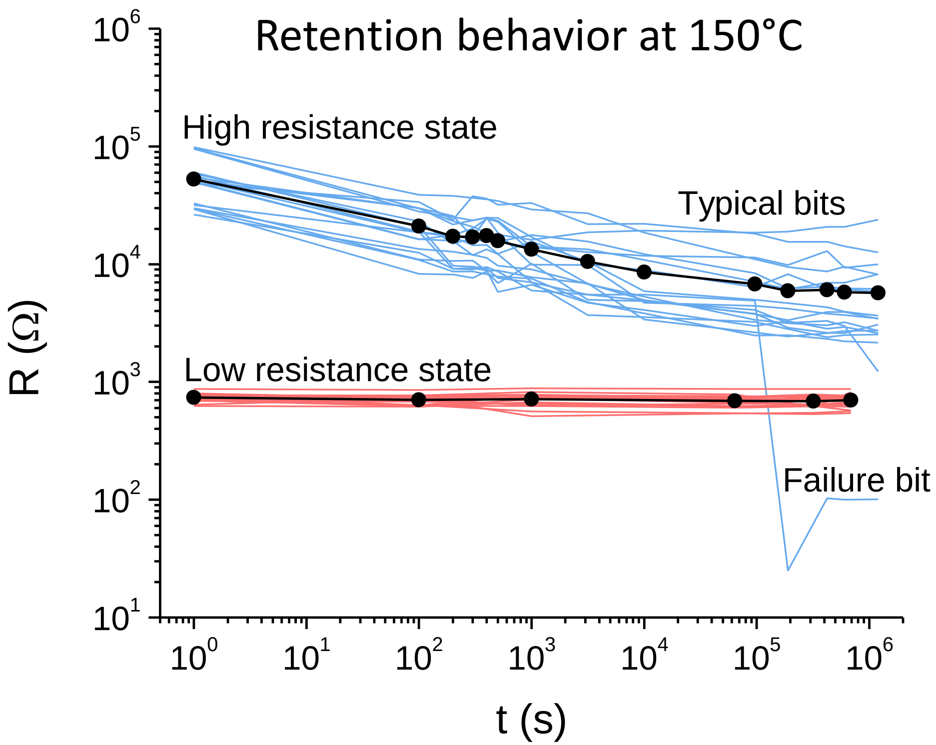


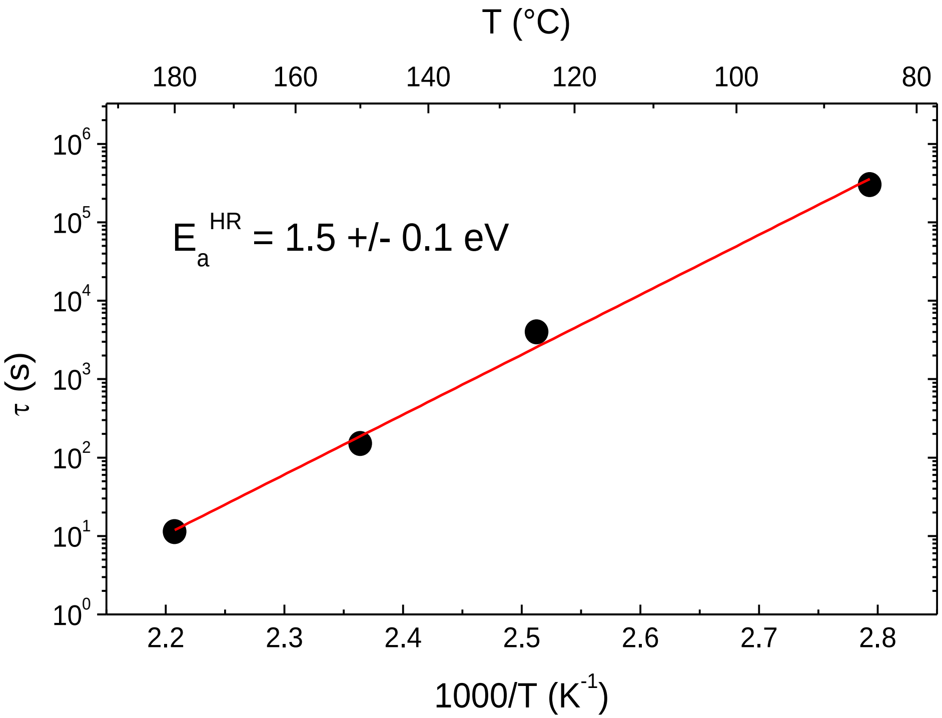


Experimental results

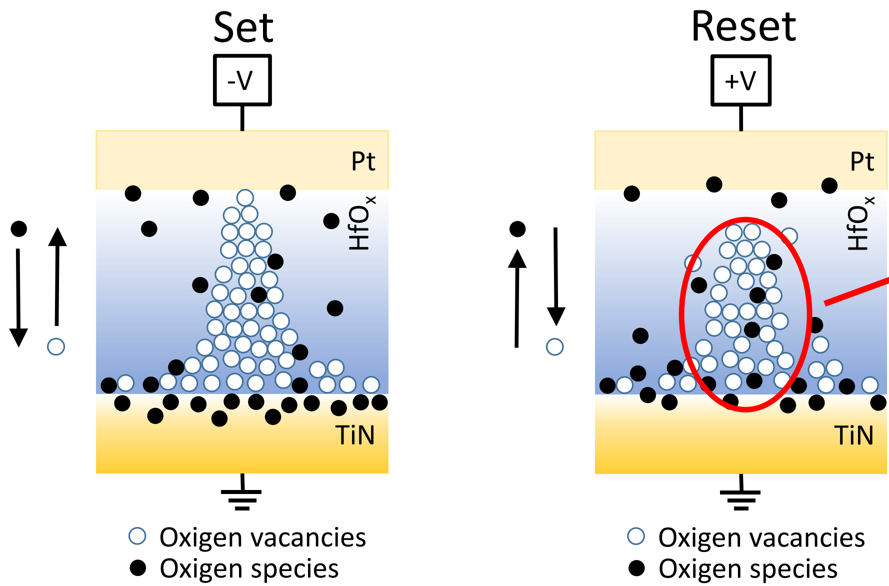
Retention behavior

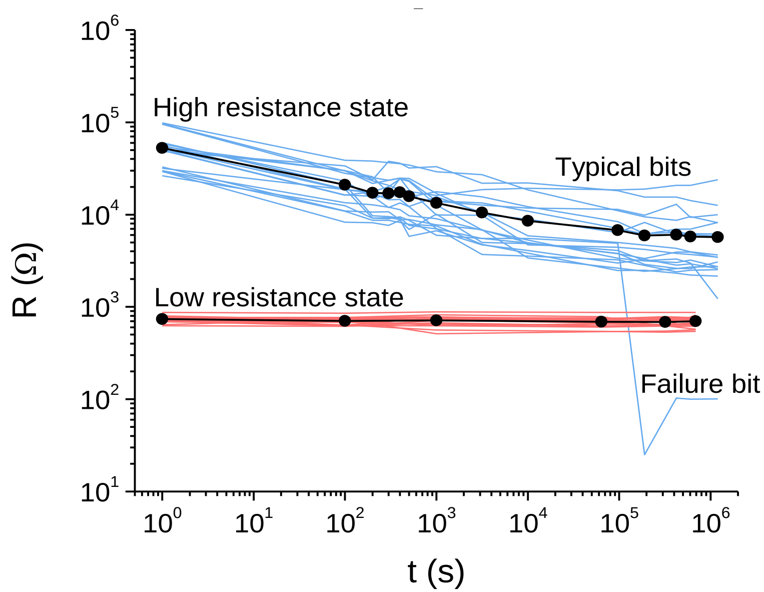
- Two different retention behaviors
- Arrhenius dependence of the retention time on temperature





Experimental results





Retention modeling

Slow retention loss

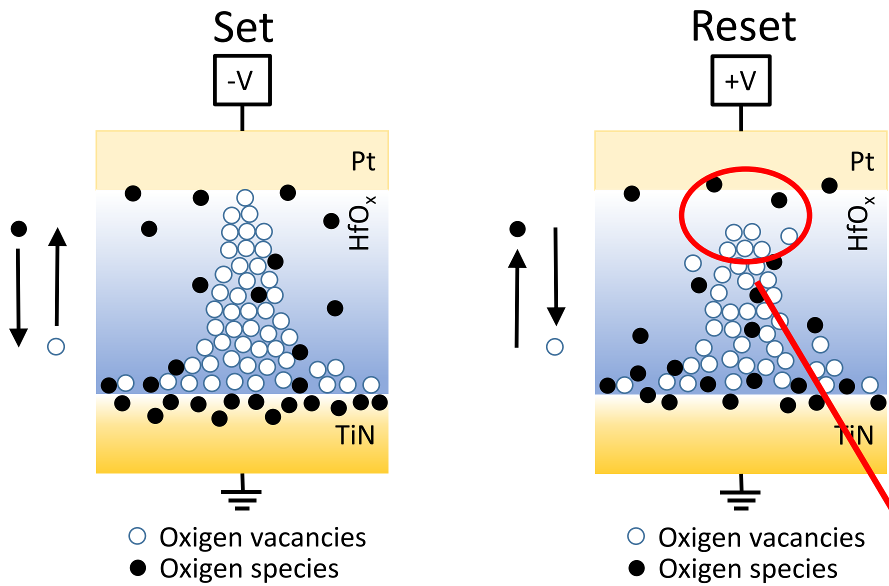
- Modification of the residual filament
- The TiO_xN_y / HfO_2 interface may play a role

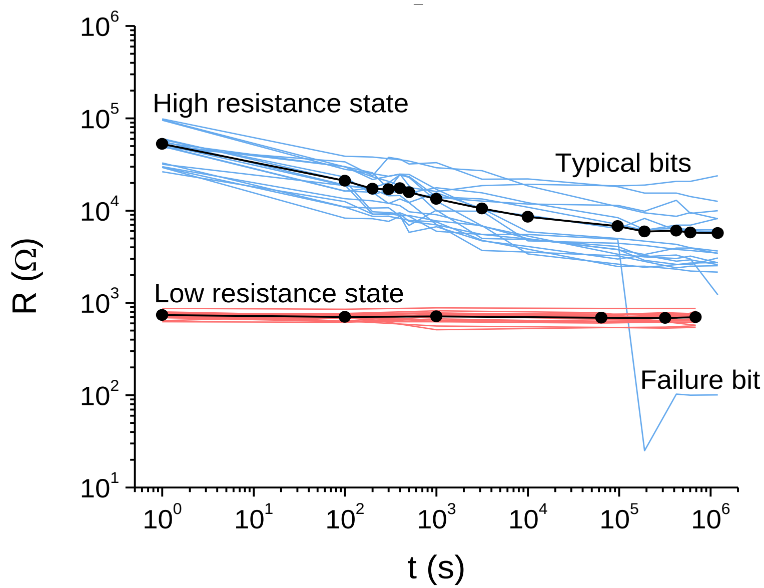
Fast retention loss

- Very narrow gap.
  Diffusion of a few vacancies can reconstruct the conductive channel

J. Frascaroli et al., in preparation

Experimental results





Retention modeling

Slow retention loss

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Fast retention loss

- Very narrow gap. Diffusion of a few vacancies can reconstruct the conductive channel

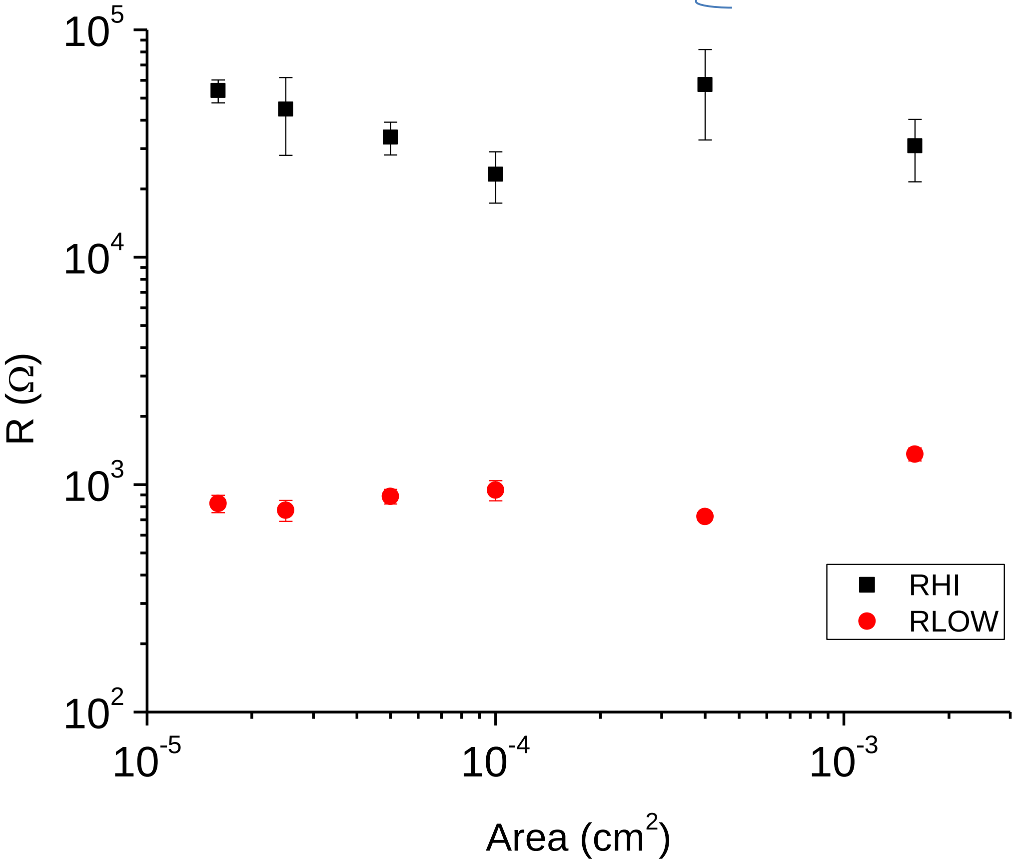
J. Frascaroli et al., in preparation

Experimental results

Device area dependence

No area dependence of the resistance

- Filamentary conduction
- High scalability potential



Previous works

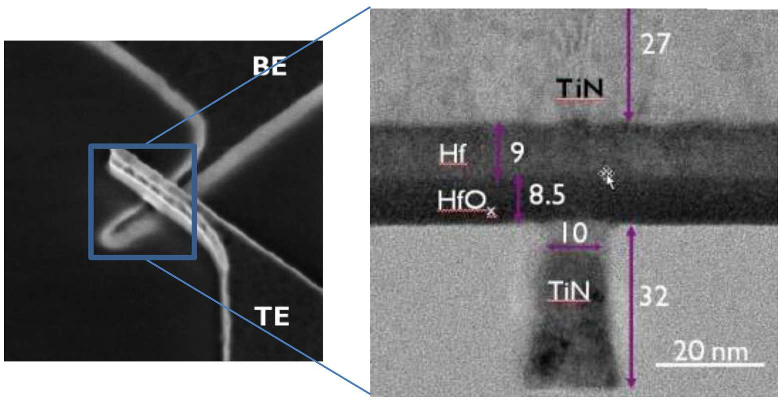
B. Govoreanu et al.
IEEE *Electron Devices Meeting* (2011)

D. Perego et al.
***Nanotechnology* 24 (2013)**

ReRAM nanoscaling

Top-down

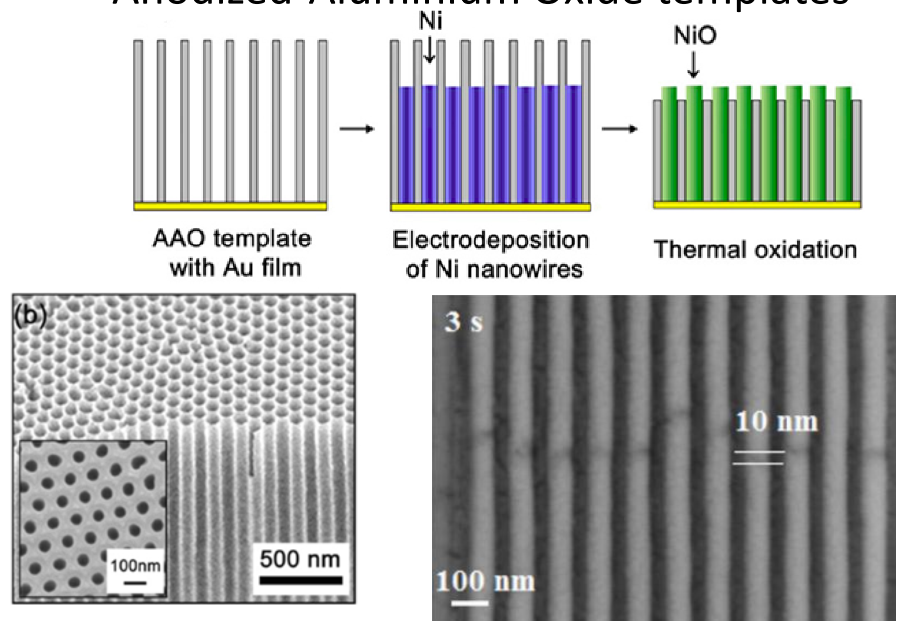
Electron beam lithography



- Slow and serial lithographic technique
- Limited number of devices

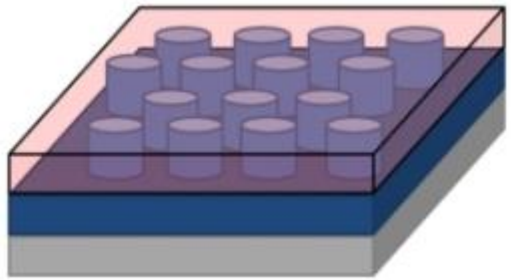
Bottom-up

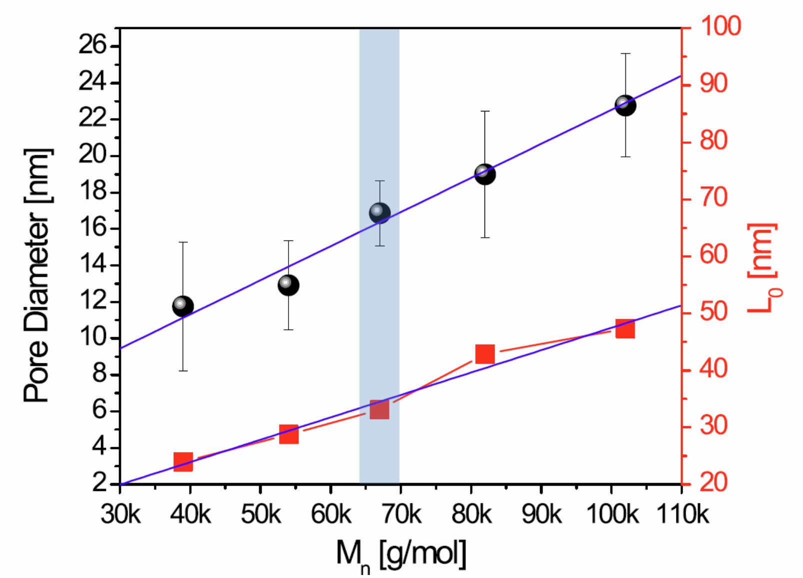
Anodized-Aluminium Oxide templates

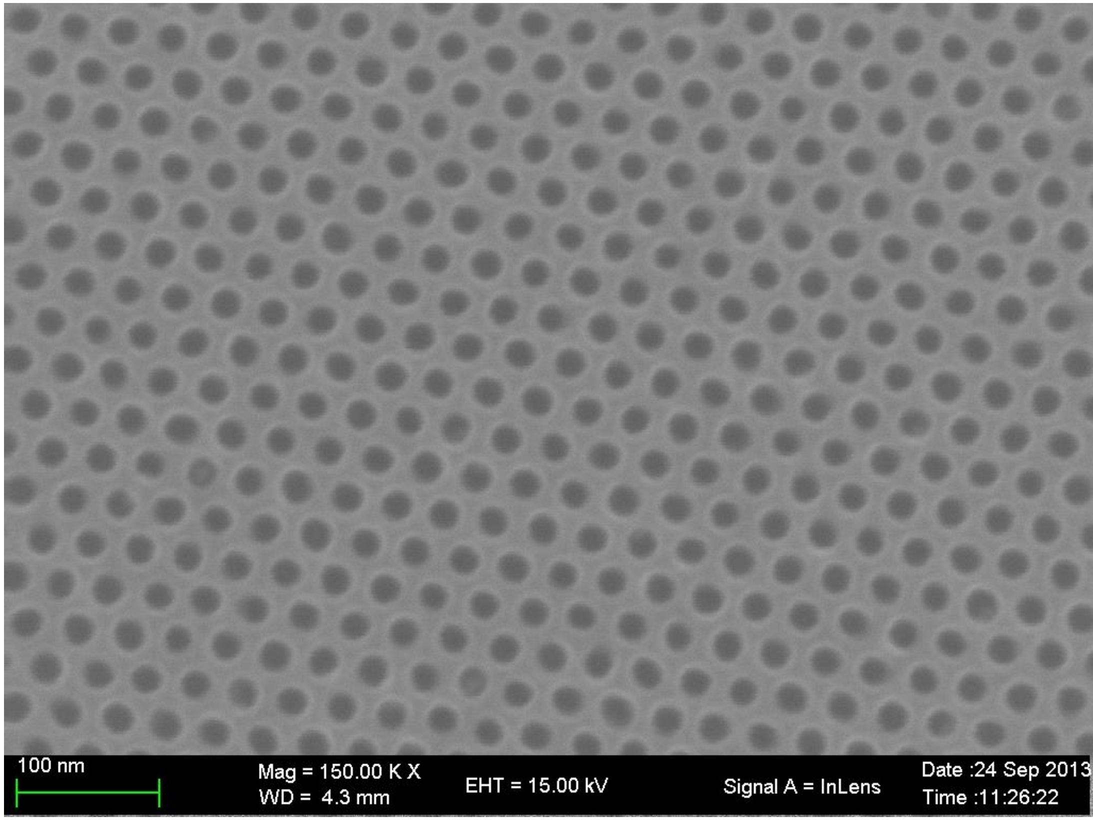


- Not compatible with actual technology

Hexagonal cylinders template



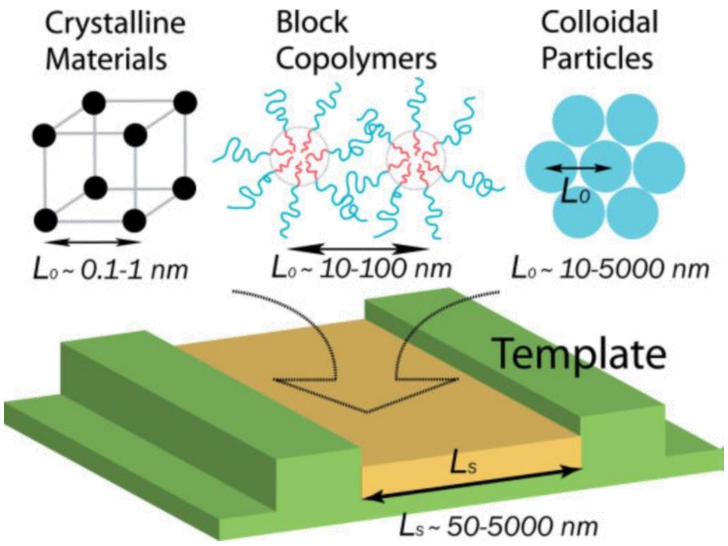




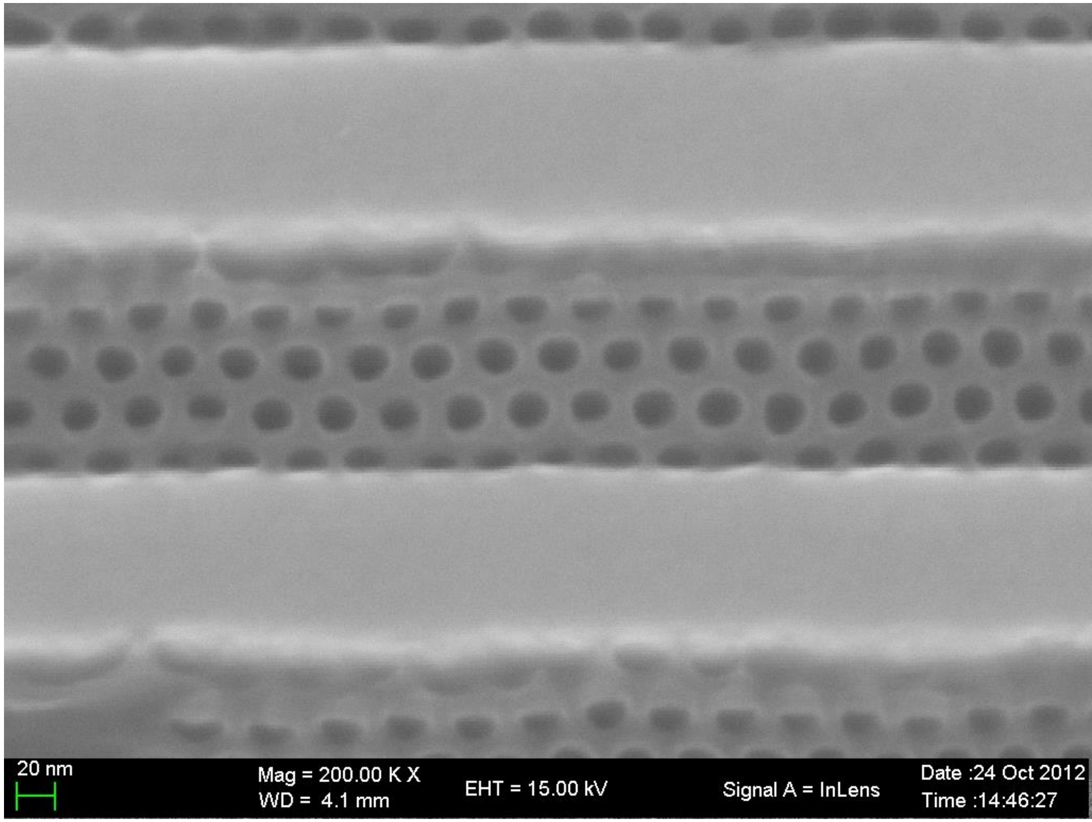
Experimental result: block copolymers self assembling of hafnium dioxide

Graphoepitaxy

M. Perego et al. Nanotechnology 24, 8 (2013)



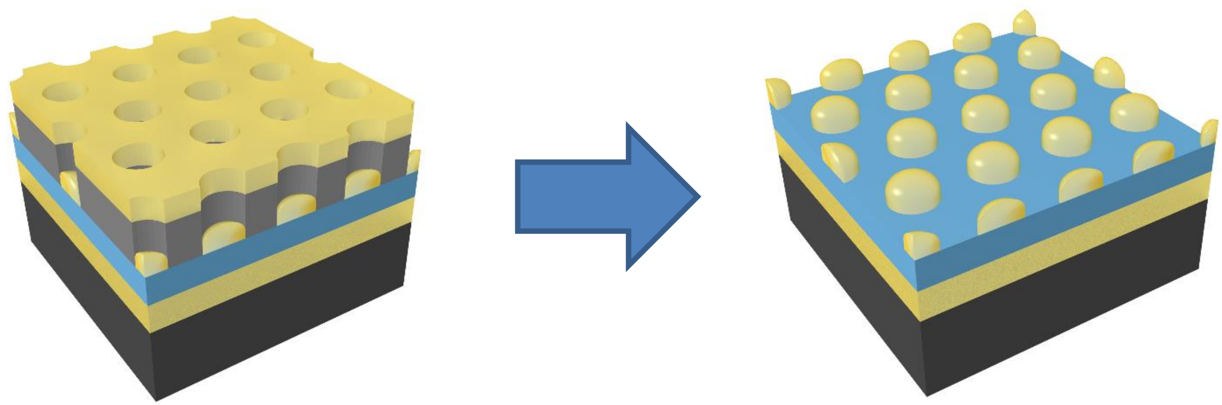
Pre-patterned structures can be used to drive the self assembly of block copolymers



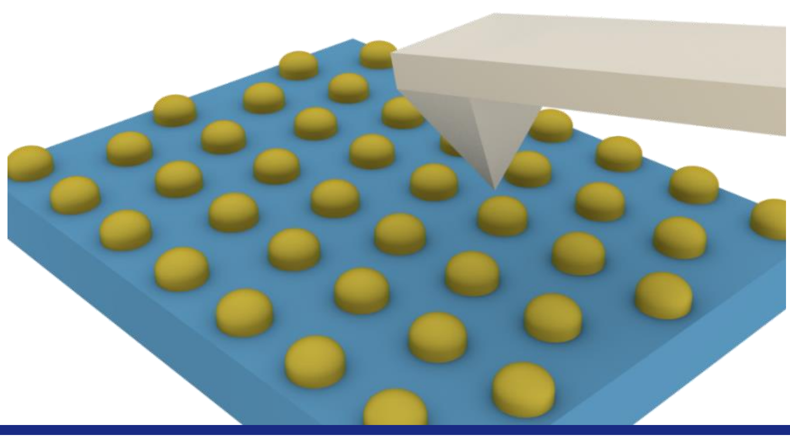
Courtesy of F. Ferrarese Lupi, MDM IMM-CNR

Top electrode nano patterning

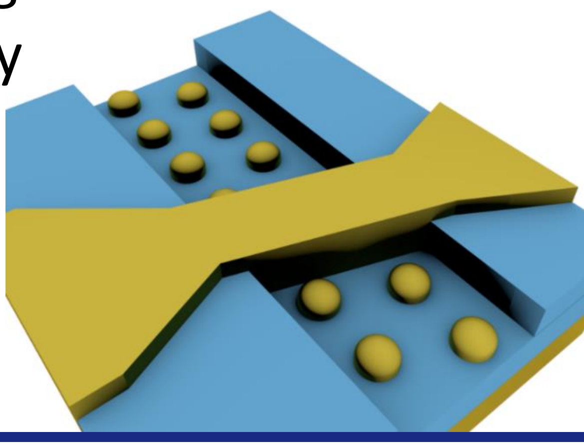
Lift-off process



Electrical measurements with c-AFM



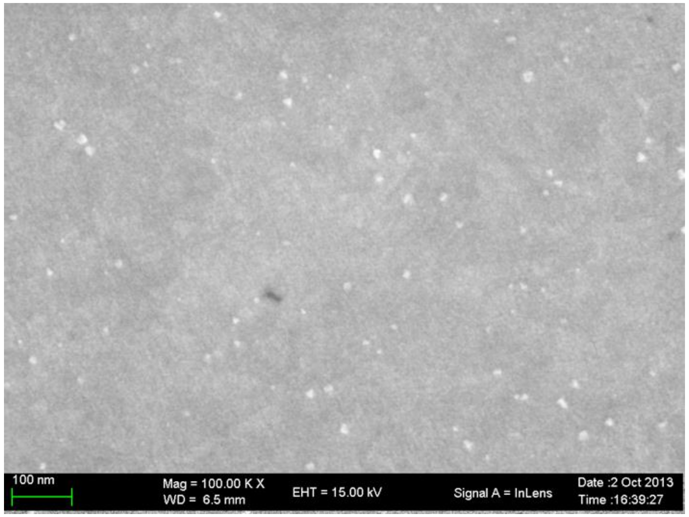
Combining directed self-assembling with electron beam lithography

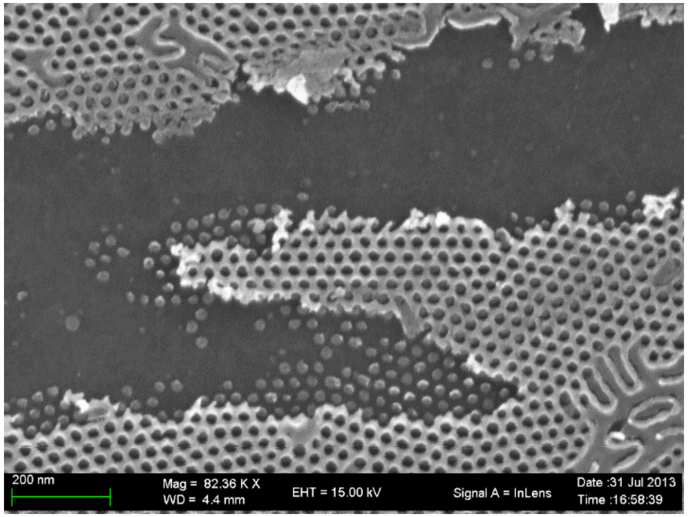


Experimental result

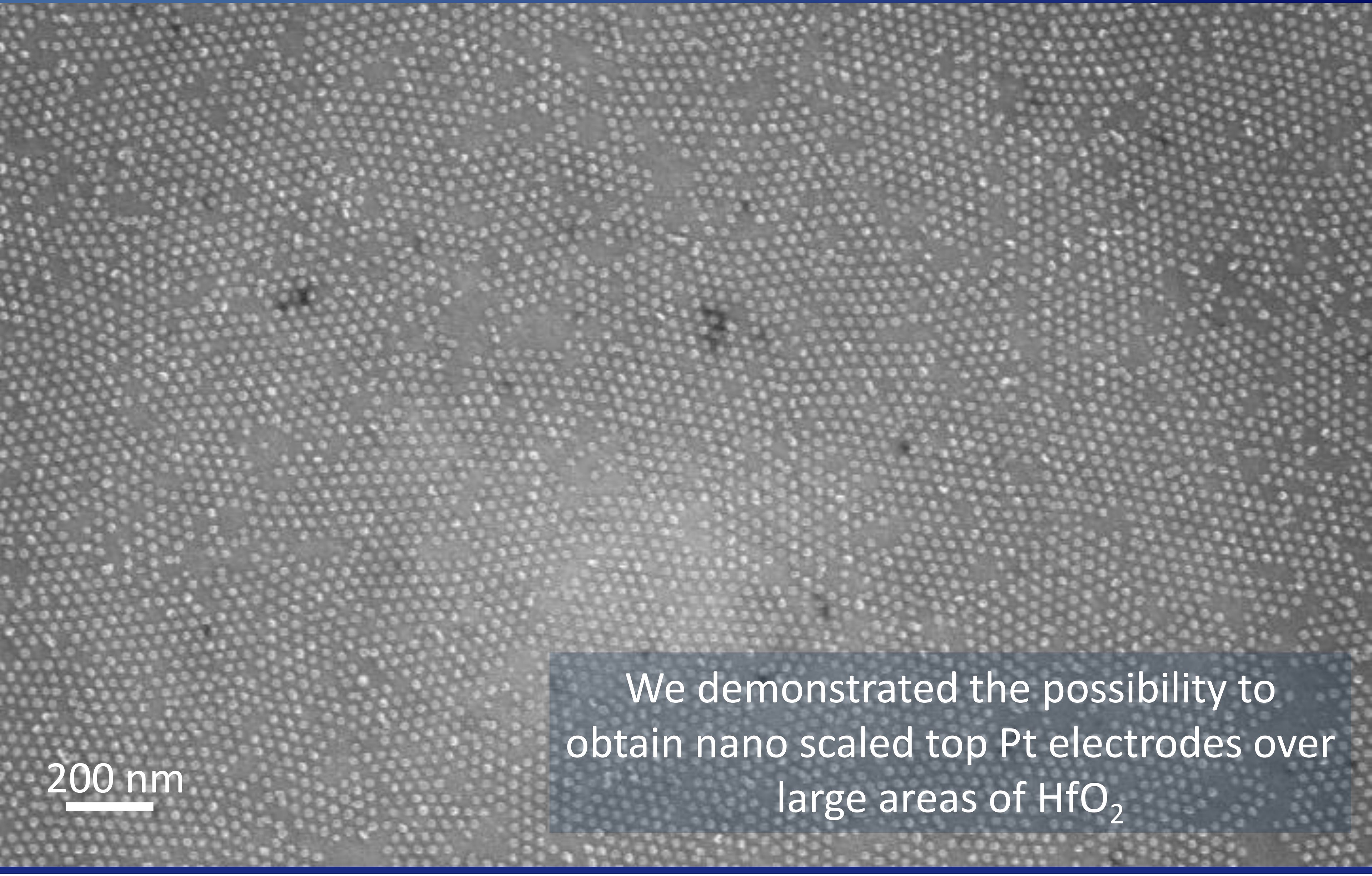
Lift-off process study

Substrate: ALD – HfO_2		
Metal	Physical deposition	Thickness
Tungsten (W)	sputtering	5 nm
Platinum (Pt)	sputtering	5 nm
	ebeam	5 nm



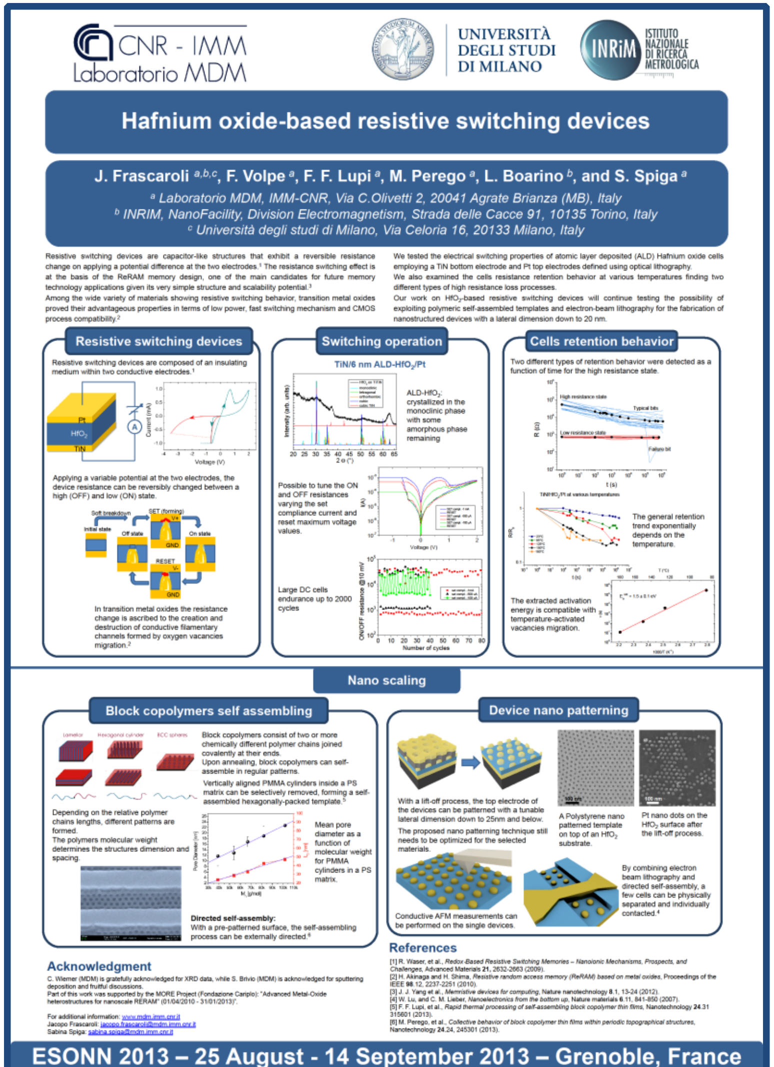


Experimental result



We demonstrated the possibility to obtain nano scaled top Pt electrodes over large areas of HfO_2

Current activity



- Device characterization and study of the retention behavior
- Implementing the block copolymer self-assembling on HfO_2
- Study of the lift-off process for top electrodes nano patterning

Future outlook

- Electrical characterization of the nano devices using C-AFM to inspect the physical properties at the nano scale

- Find alternative strategies for the fabrication of resistive switching devices using block copolymers self-assembly

The end

Resistive switching mechanism

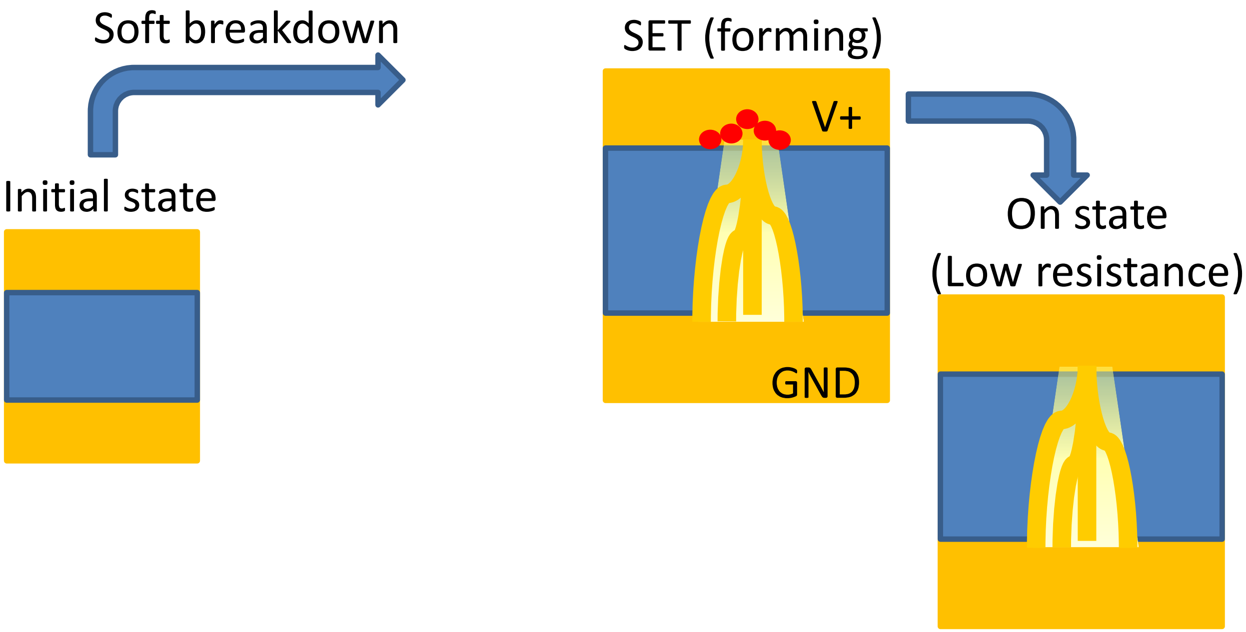
H. Akinaga and H. Shima, *Proceedings of the IEEE* 2010

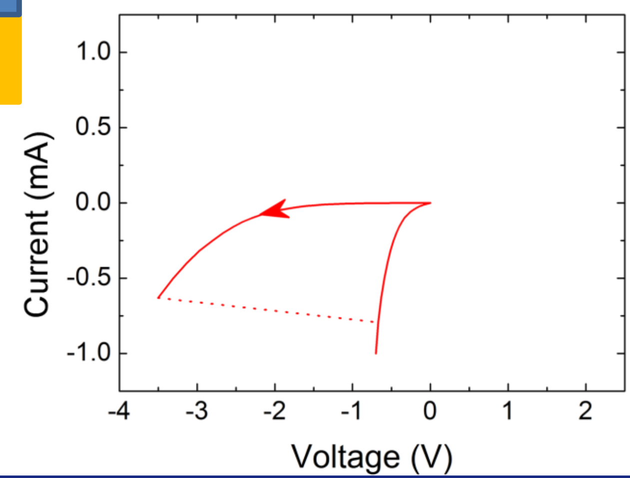
- Fresh cell

Initial state

Resistive switching mechanism

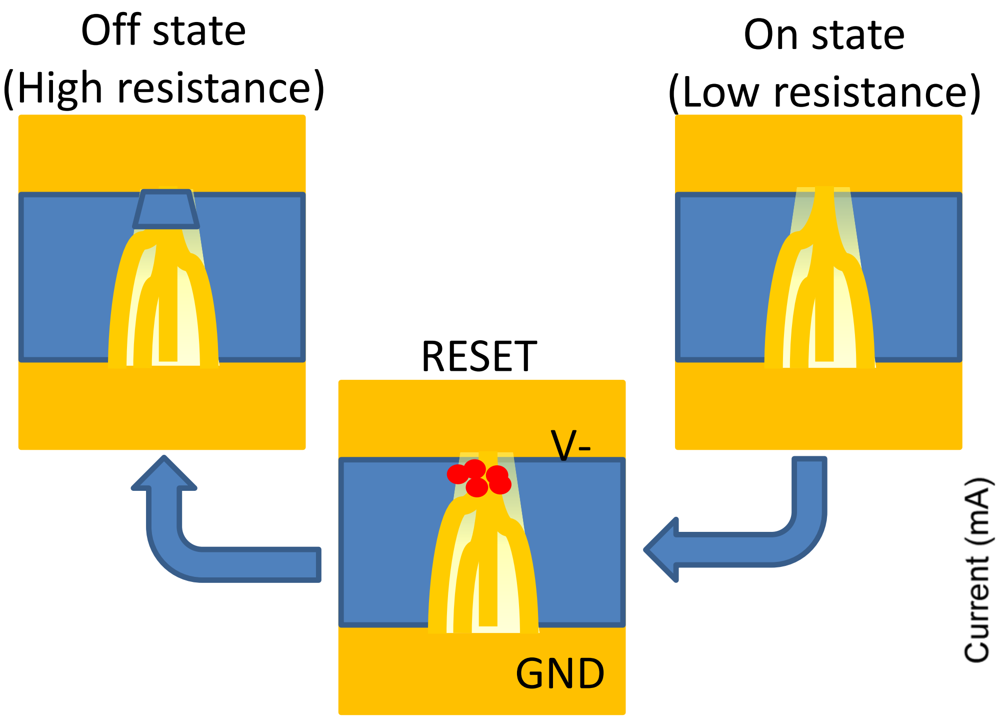
- Fresh cell
- Forming

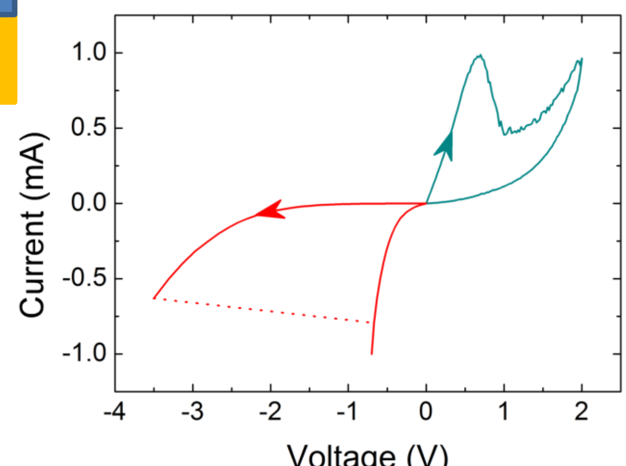




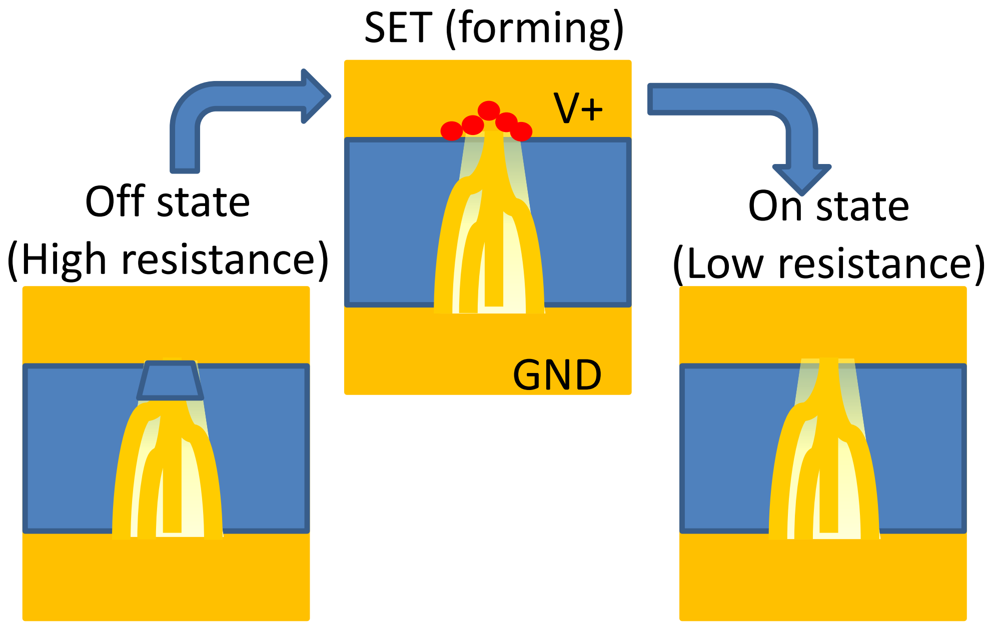
Resistive switching mechanism

- Fresh cell
- Forming
- Reset

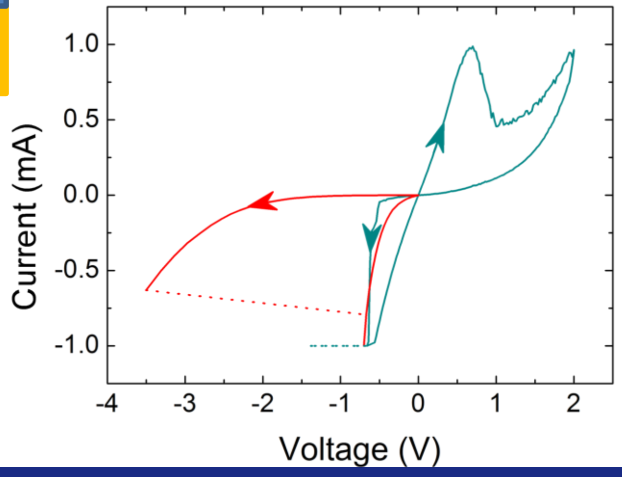




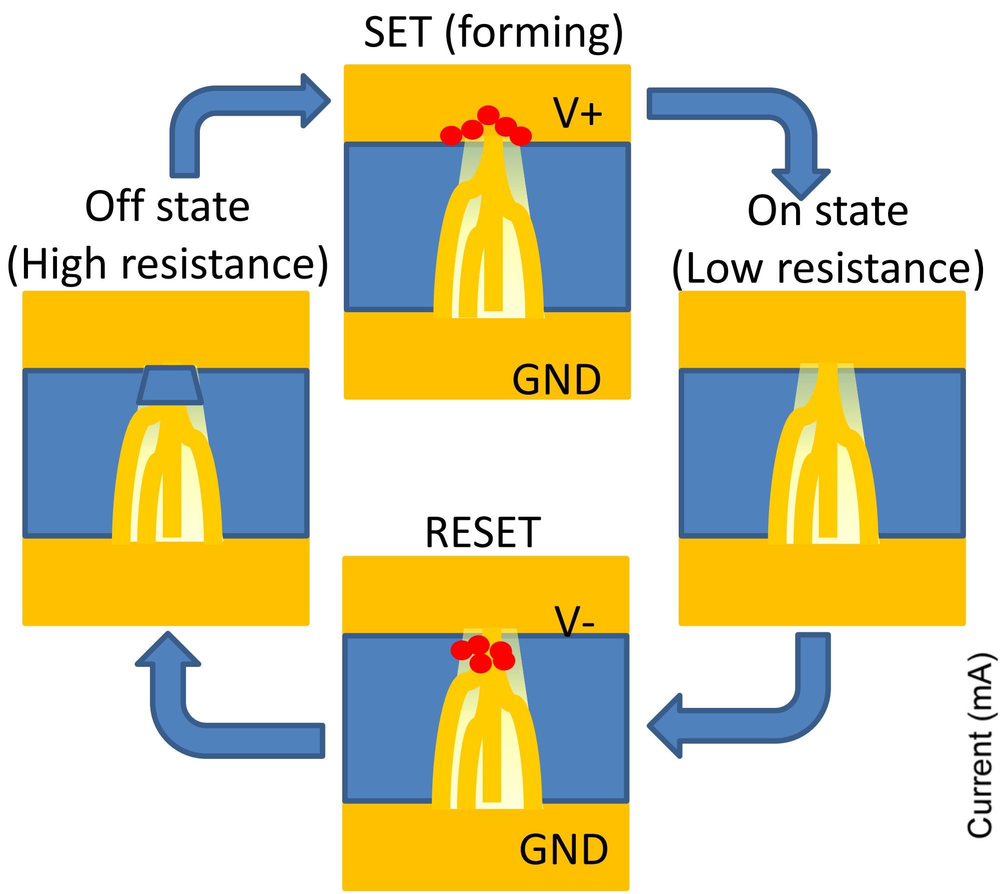
Resistive switching mechanism



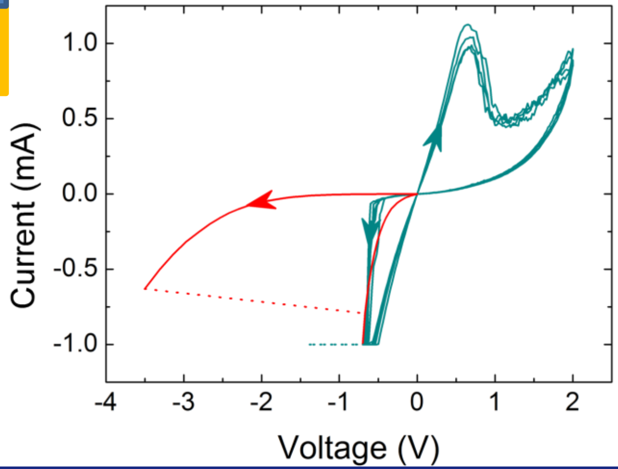
- Fresh cell
- Forming
- Reset
- Set



Resistive switching mechanism



- Fresh cell
- Forming
- Reset
- Set
- Many cycles



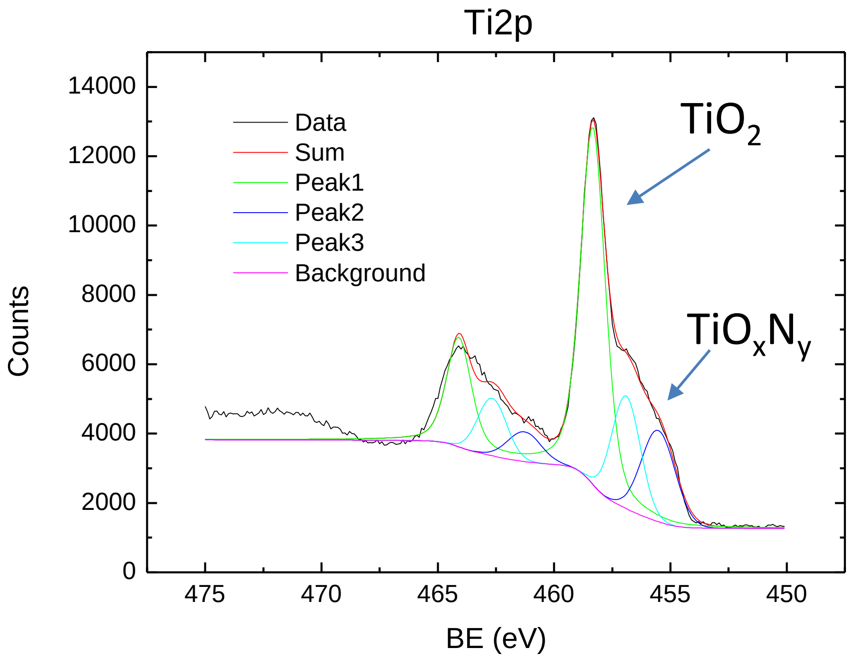
Experimental results

Metal/Oxide interface

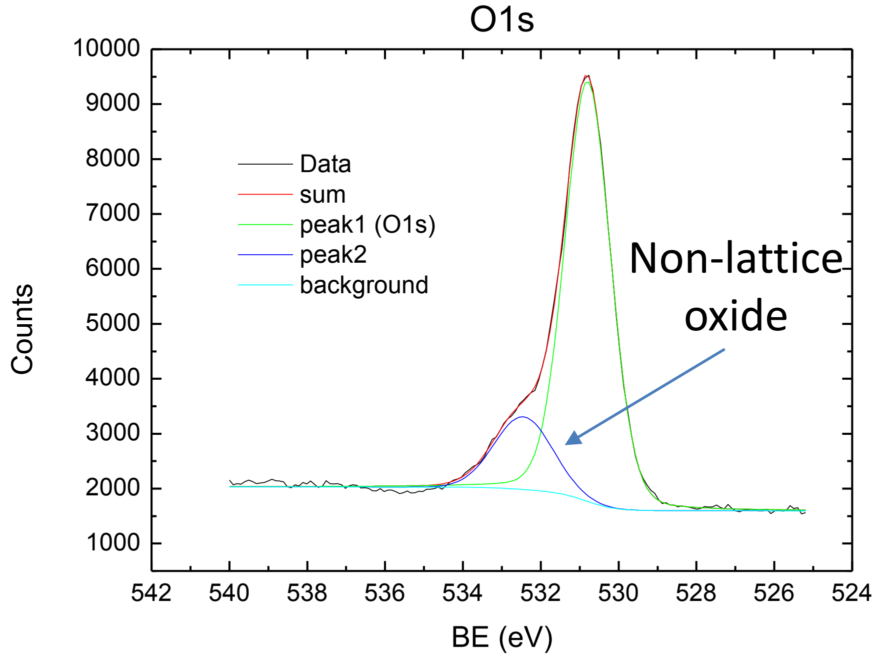
X-ray photoemission spectroscopy

- TiO_2/TiO_xN_y in serie with the HfO_2 film
- Significant percentage of non-lattice oxide

TiN film



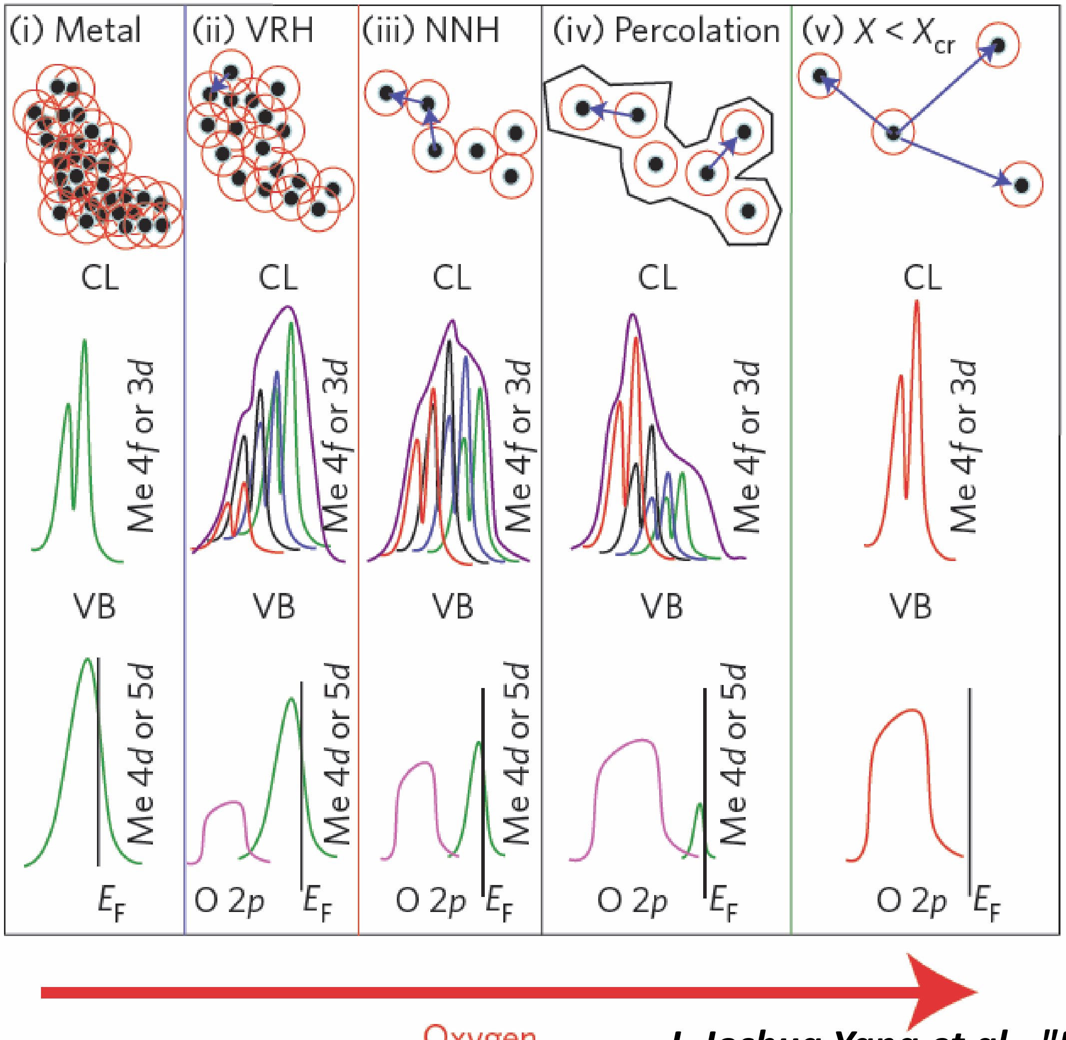
HfO_2 film



ITRS 2012 UPDATE - Winter Presentations

	Prototypical (Table ERD3)			***Emerging (Table ERD5)***					
Parameter	**FeRAM**	**STT-MRAM**	**PCRAM**	**Emerging ferroelectric memory**	**Nanomechanical memory**	**Redox memory**	**Mott Memory**	**Macromolecular memory**	**Molecular Memory**
Scalability	🙁	😐	🙂	😐	🙁	🙂	?	?	🙂
MLC	🙁	🙁	🙂	🙁	🙁	🙂	?	😐	🙁
3D integration	🙁	😐	🙂	🙁	🙁	😐	?	🙂	🙁
Fabrication cost	😐	😐	🙂	😐	🙁	😐	?	🙂	?
Endurance	🙂	🙂	😐	🙂	🙁	🙂	😐	🙁	?

Conduction in metal oxides



J. Joshua Yang et al., "Memristive devices for computing" Nature nanotechnology 8.1 (2012)