Experimental investigation and empirical modeling of the set and reset kinetics of Ag-GeS$_2$ Conductive Bridging Memories

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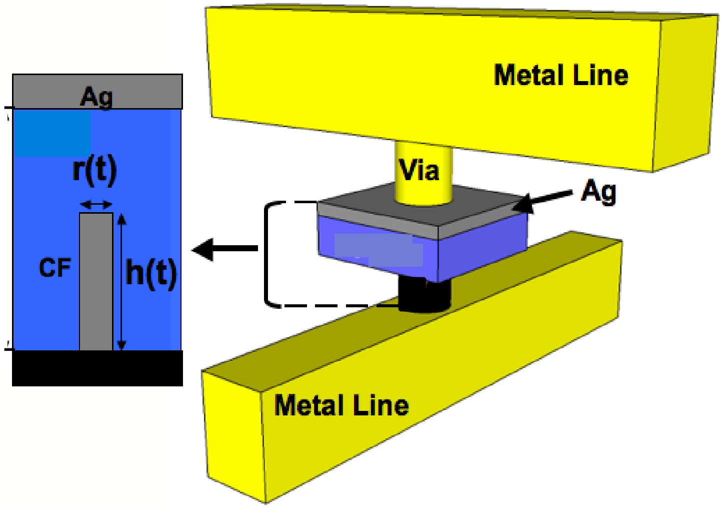
Altis Semiconductor

Basic concept of Conductive Bridge Memory

Conducting paths between the device's two terminals in a reversible process that changes electrical resistance by order of magnitudes

- electrochemical growth and dissolution of metallic filament
- small applied voltage levels and energy
- large non-volatile resistance changes
- simple, high scalable structure



active electrode (**Ag**, Cu)

solid electrolyte:

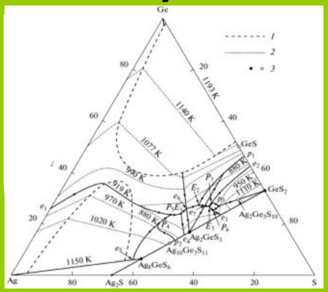
- Chalcogenides (**Ge_xS_y**,Ge_xSe_y, GeTe, GST,…)
- high-k (HfO_2, Al_2O_3, Ta_2O_5,…)

inert electrode (**W**, TiN, Pt,…)

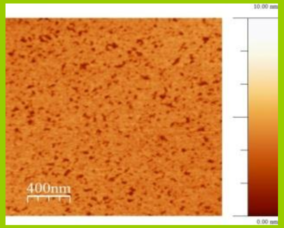
CBRAM LETI Workplan

Material research and characterization

New materials, new alloys



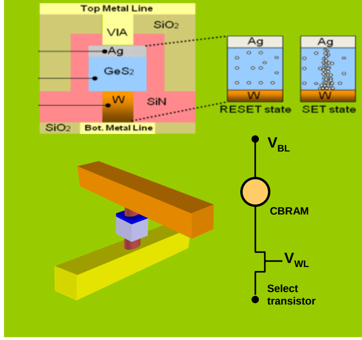
Physico-chemical characterizations



Device integration

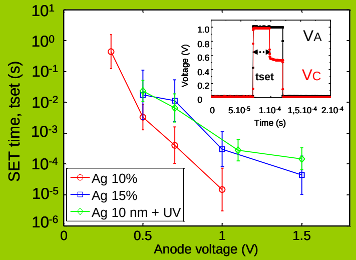
PVD & CVD deposition tools

Integration flows

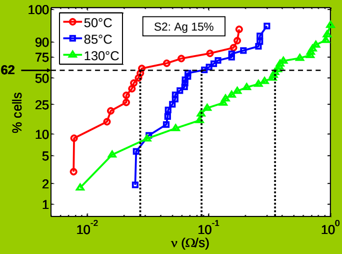


Electrical characterization

Memory performances…



… Specific characterization techniques

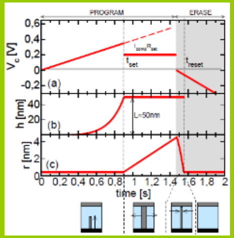


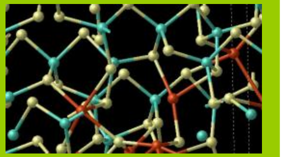
Modeling and simulations

Physical understanding

Physical modelling

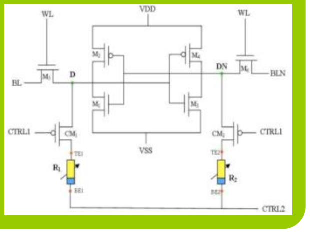
Ab initio calculations





Compact modeling

Design

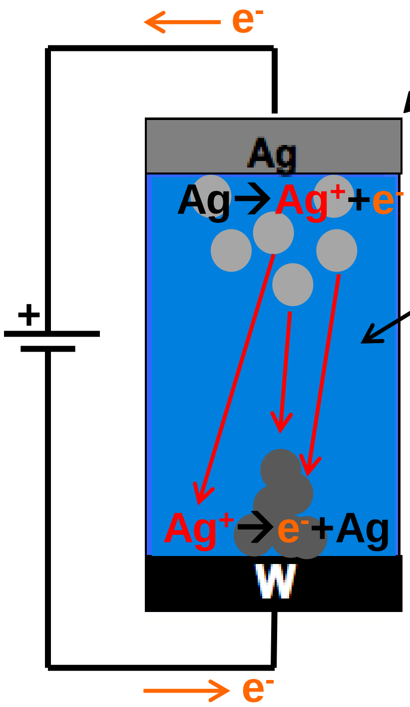


Outline

- Introduction
- Device physics and modeling
- Operations
- Compact ‘non-volatile’ logic
- Conclusions

Reaction environment

SET PROCESS

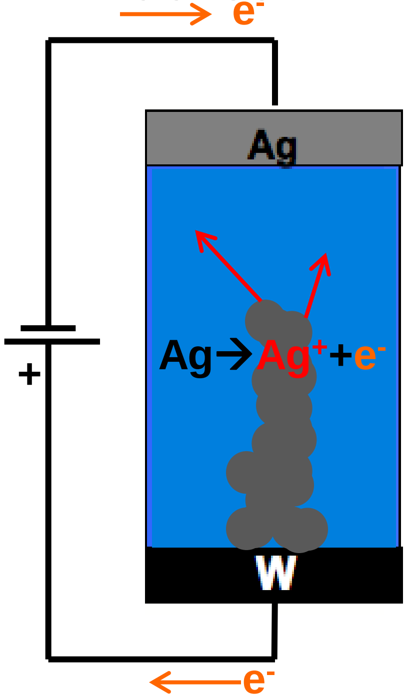


Anodic dissolution
electrochemical electron transfer (Butler-Volmer)
no overpotential, fast reaction
→ not taken into account in the model

Ionic current
field driven migration process
→ model: Mott Gurney ionic hopping current

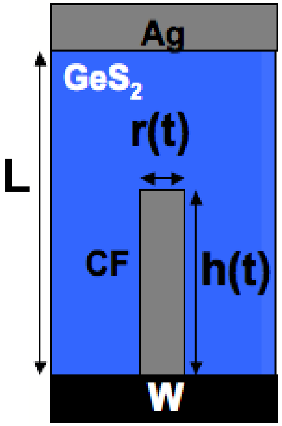
Cathodic deposition
electrochemical electron transfer (Butler-Volmer)
crystallization overpotential
→ taken into account by an empirical parameter (Δ)

RESET PROCESS



Model description

- cylindrical conductive filament: radius *r(t)*; height *h(t)*
- CF vertical and lateral time evolution are assumed to be proportional to the ion current density (Mott Gurney ionic hopping current)



$$\frac{dh}{dt} = \frac{J_h(t)}{qN_i} = v_h \overbrace{\exp\left(\frac{-E_A}{k_BT}\right)}^{\text{thermally activated}} \overset{\&}{\,} \overbrace{\sinh\left(\alpha q \frac{V_c(t) - \enclose{circle}{\Delta}}{k_BT}\right)}^{\text{field driven}}$$

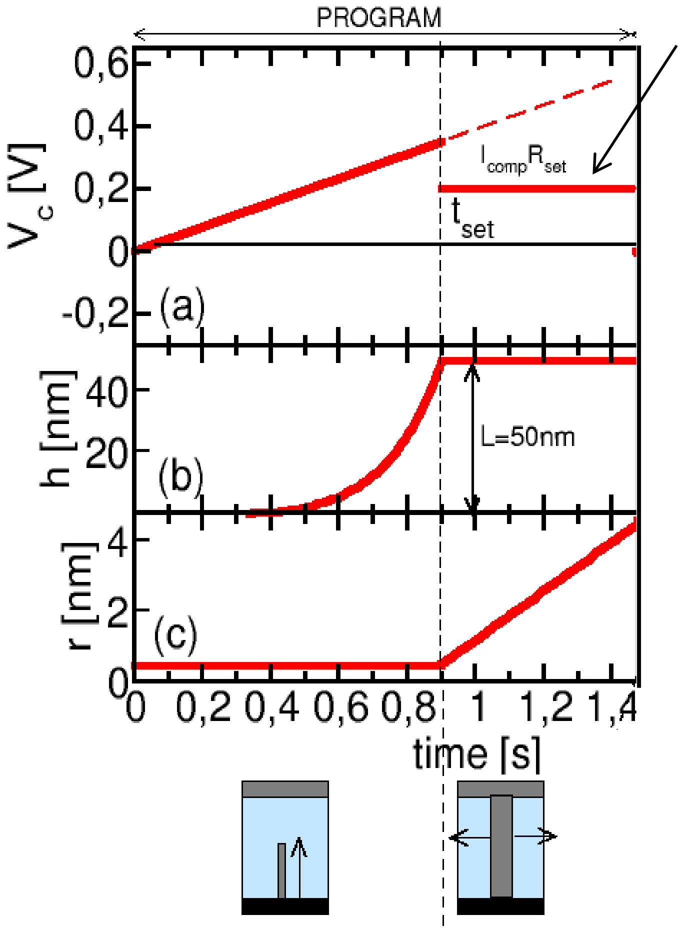
$$\frac{dr}{dt} = \frac{J_r(t)}{qN_i} = v_r \exp\left(\frac{-E_A}{k_BT}\right) \sinh\left(\beta q \frac{V_c(t) - \enclose{circle}{\Delta}}{k_BT}\right)$$

empirical parameter linked to the overpotential that controls the cathodic reaction

cell resistance:
sum of two series resistors

$$R_c = \frac{\rho_{\text{on}} h(t) + \rho_{\text{off}}(L - h(t))}{\pi r^2(t)}$$

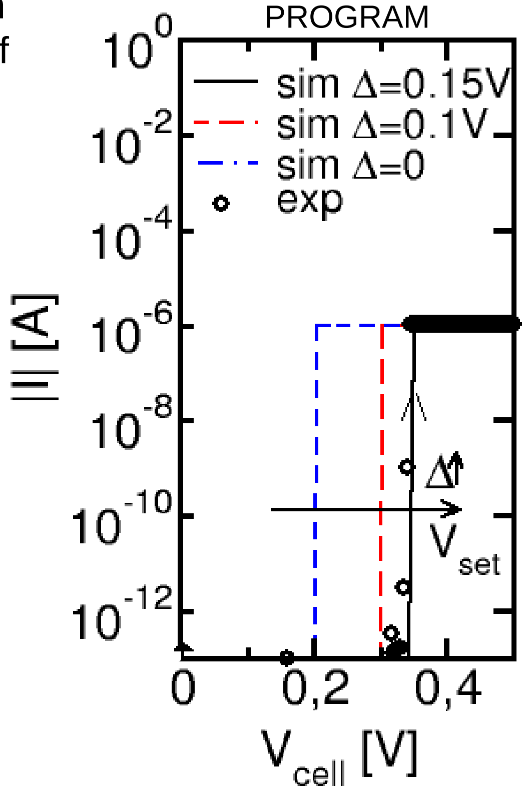
Quasi static program and erase transients



1.vertical growth

2.lateral growth

constant voltage at the end of the SET due to de voltage regulation in a feedback loop in presence of the current compliance



G. Palma et al., « Experimental investigation and empirical modeling of the set and reset kinetics of Ag-GeS_2 Conductive Bridging Memories », IMW 2012

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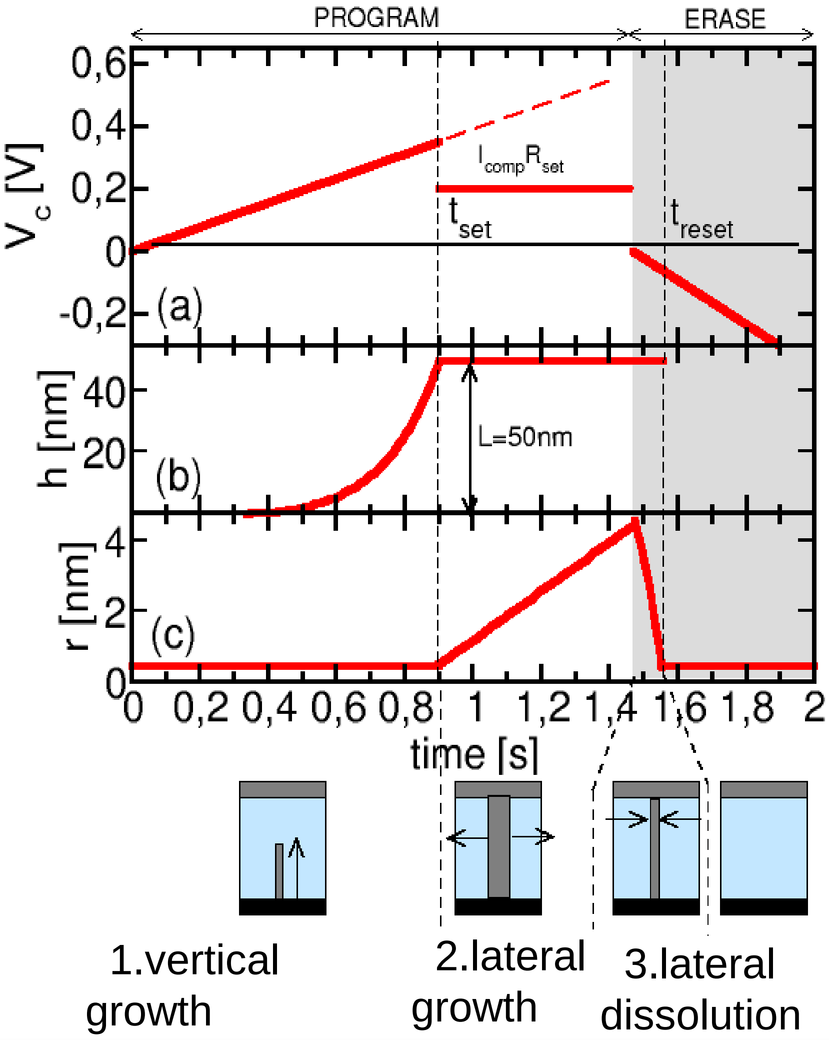
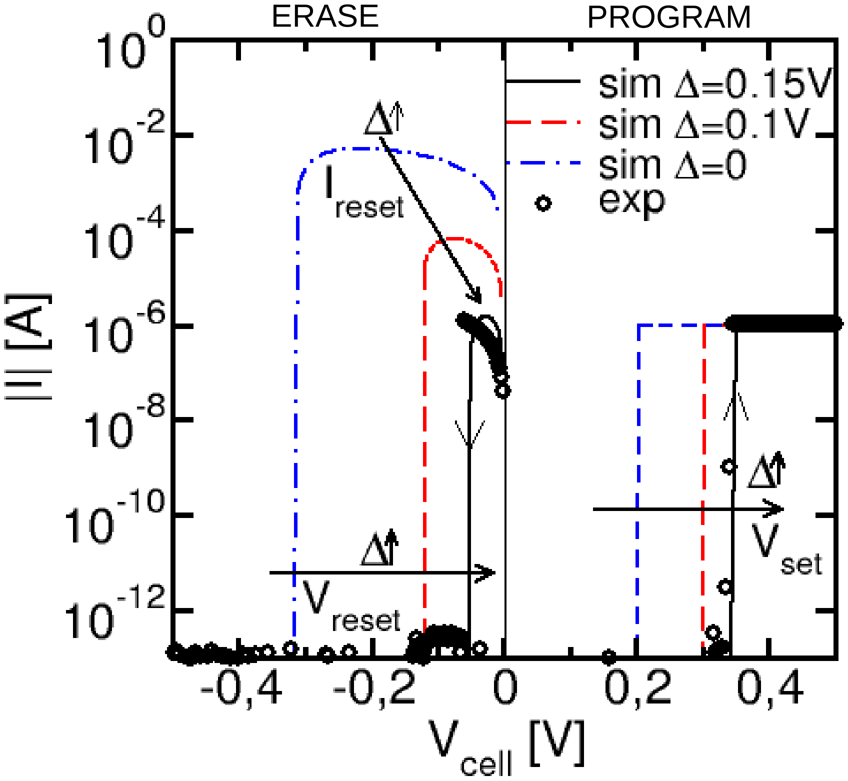
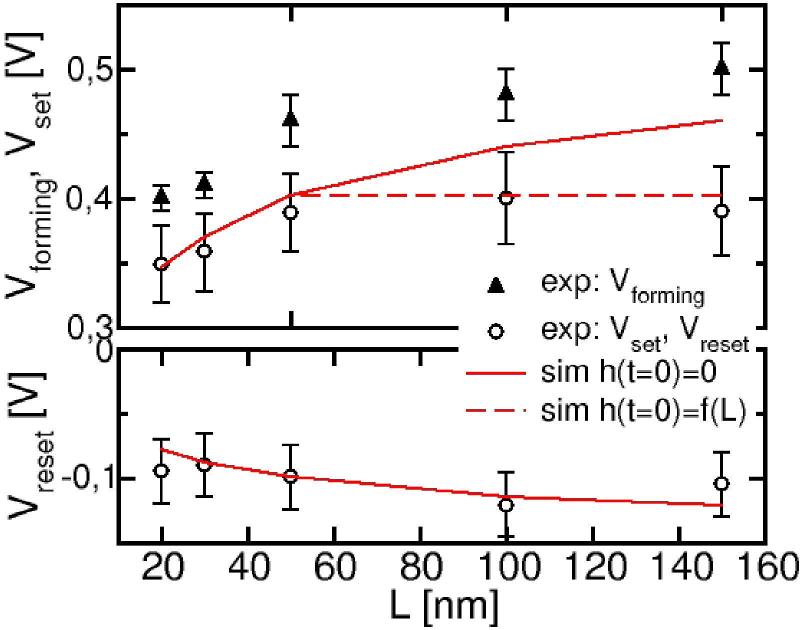
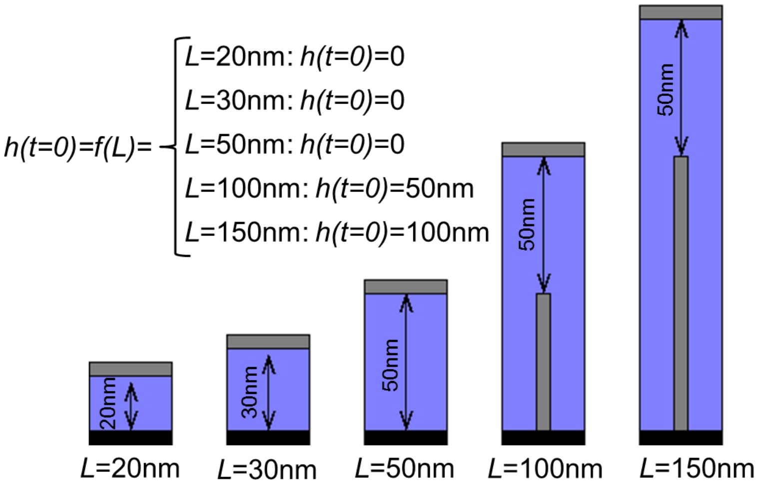




G. Palma et al., « Experimental investigation and empirical modeling of the set and reset kinetics of Ag-GeS$_2$ Conductive Bridging Memories », IMW 2012

Effect of the active layer thickness



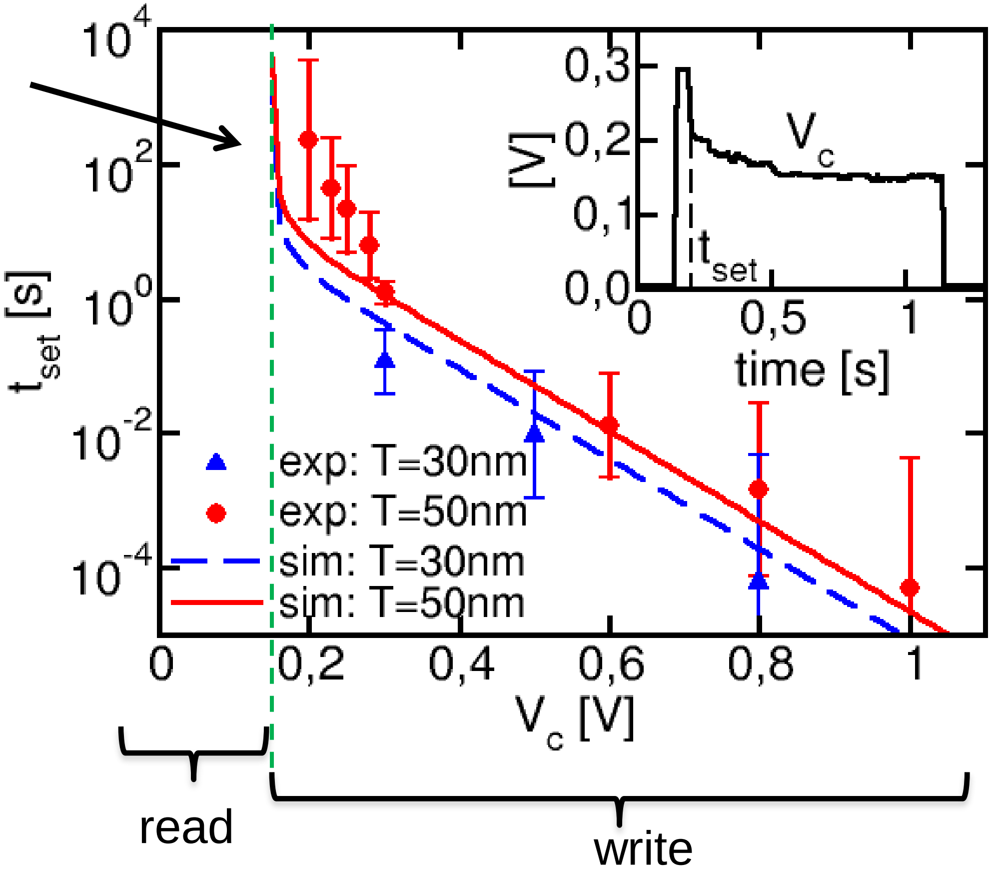


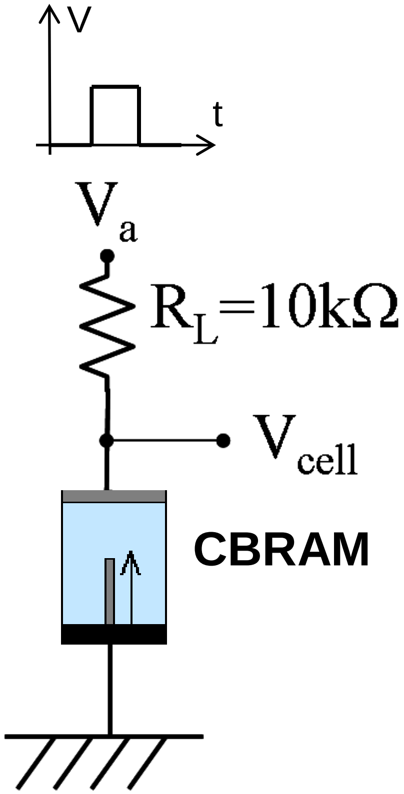
G. Palma et al., « Effect of the active layer thickness and temperature on the switching kinetics of GeS_2-based Conductive Bridge Memories », submitted to SSDM 2012

- ***L*<50nm**: the CF in the OFF state is almost completely dissolved → increasing *L*, V_{set} increases
- ***L*>50nm**: a portion of the filament might subsist on the W electrode (*h*(t=0)≠0) acting as a cathode → V_{set} almost independent of L

Programming in pulsed mode

Saturation at
low voltage
(nucleation
overpotential
Δ=0,15V)





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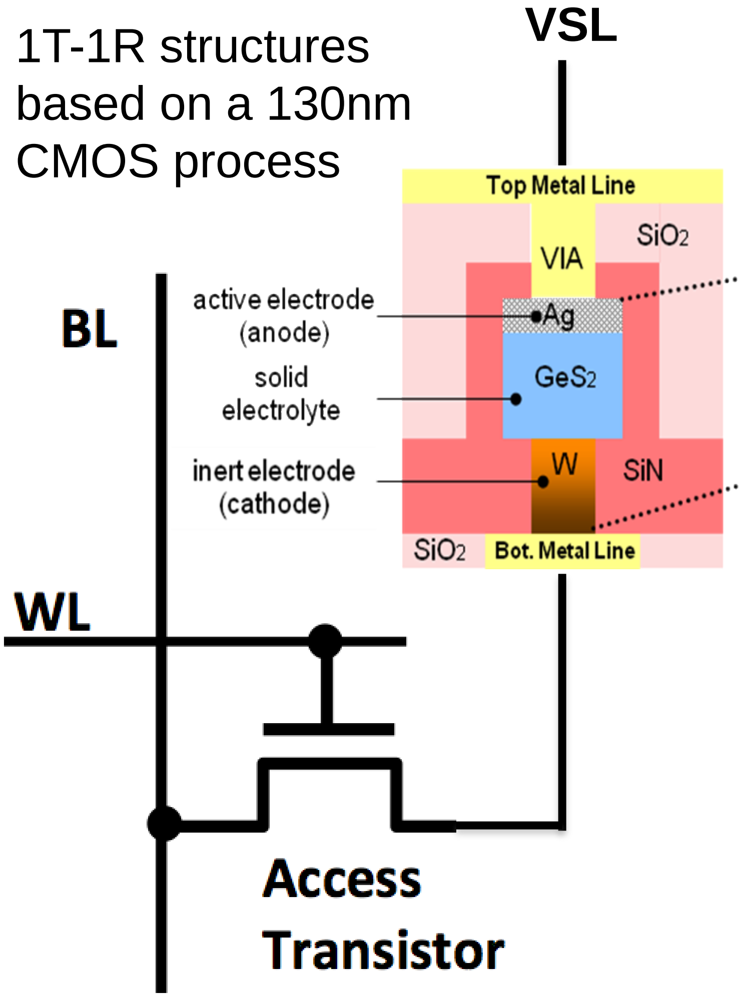
Studied samples

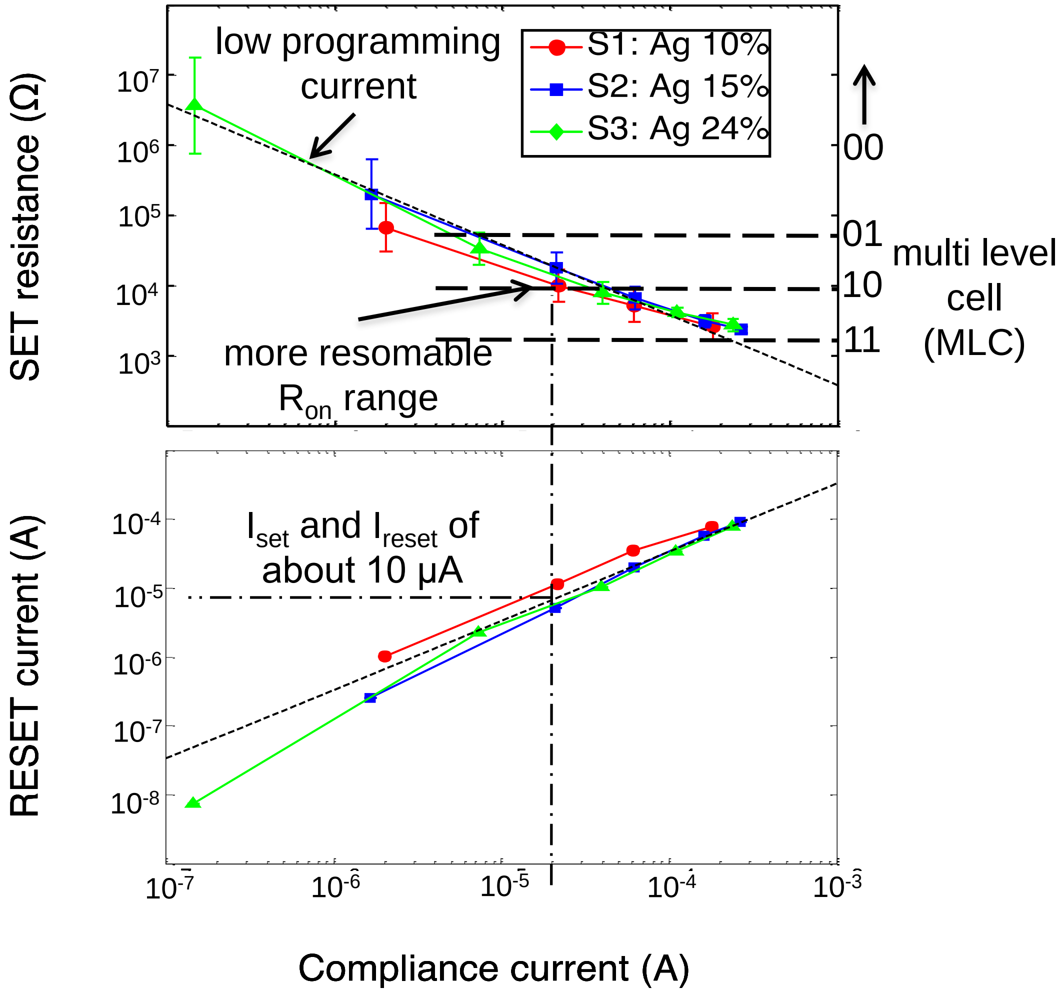
1T-1R structures based on a 130nm CMOS process



Sample	***%at Ag in the GeS_2 layer (RBS)***
S1	10.7
S2	15.2
S3	24

RBS measurements show a constant Ge/S ratio of 0.64-0.66 with different Ag concentrations

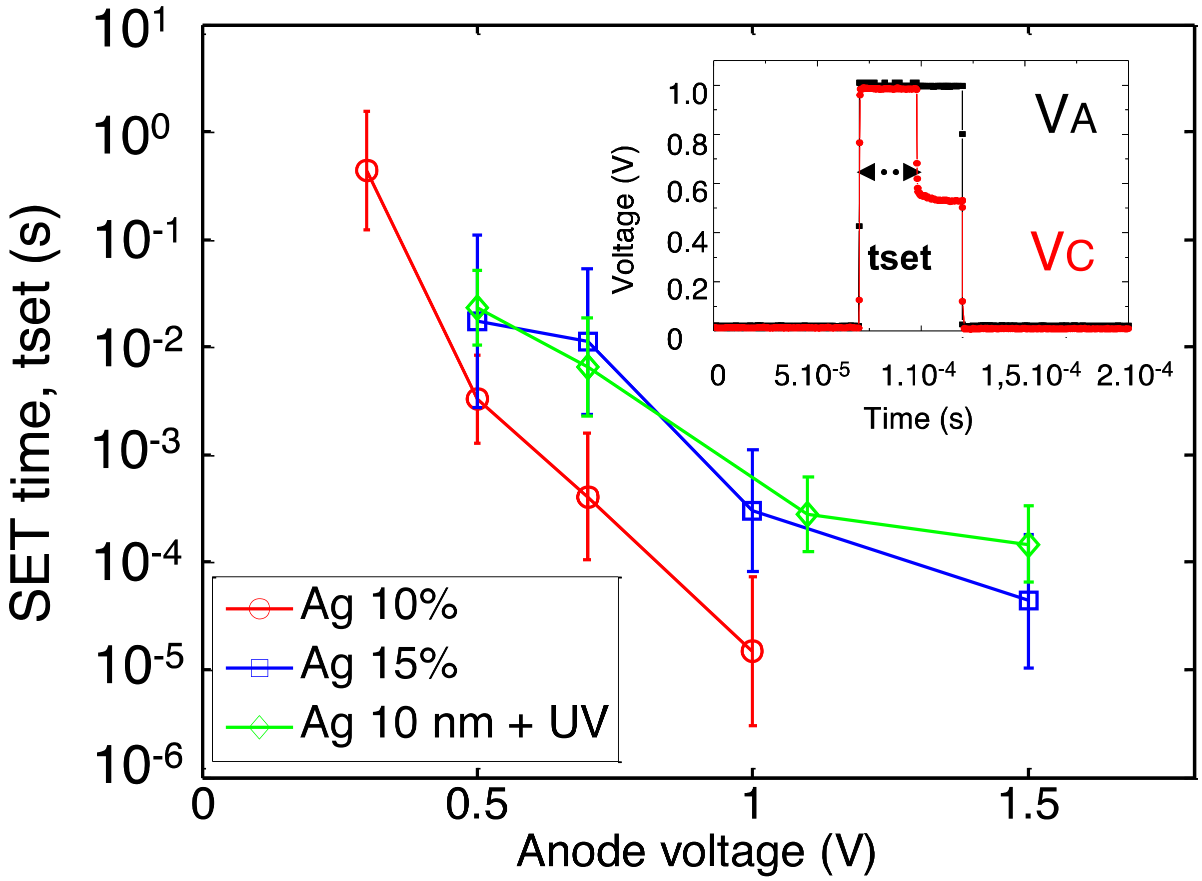
On state resistance vs SET/RESET current



- the SET resistance decreases and the RESET current increases while increasing the SET compliance current

- the SET resistances and the RESET currents are almost completely independent of the Ag doping concentration

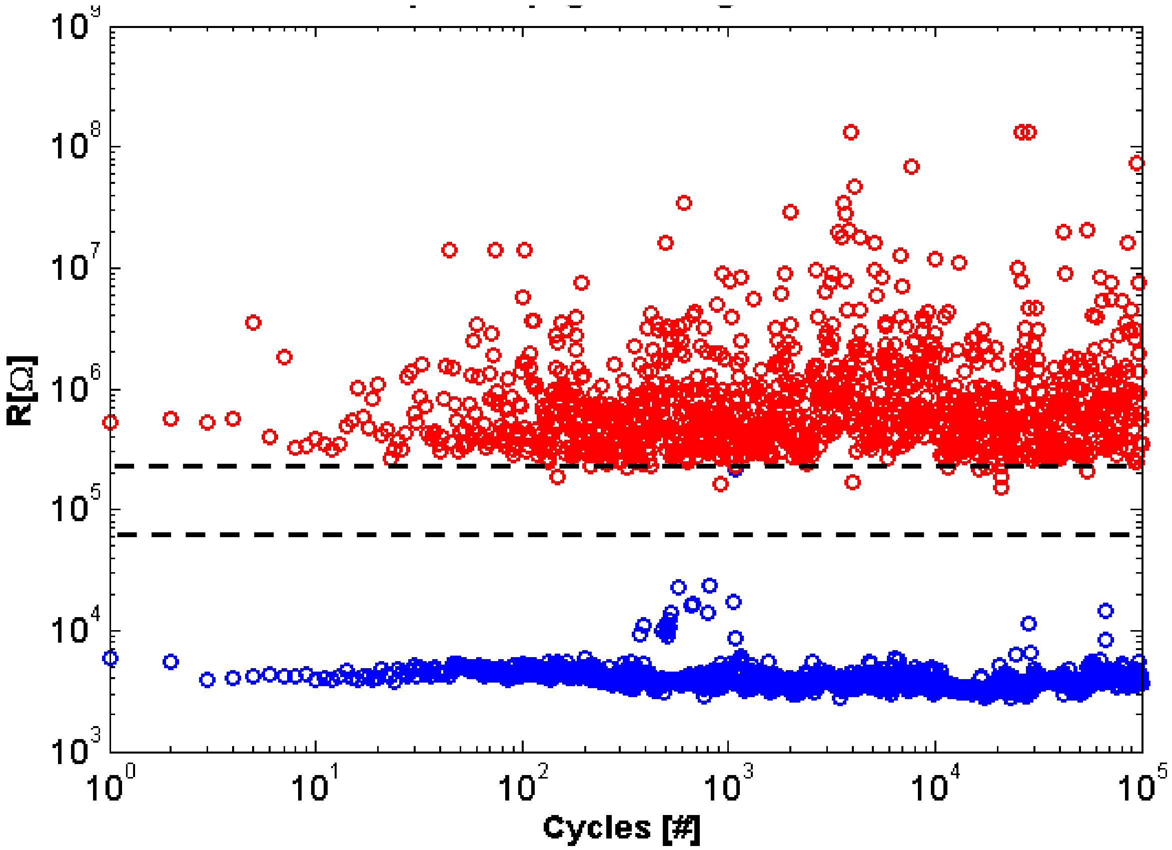
Program operation in pulsed mode



- the SET time increases slightly with the Ag concentration

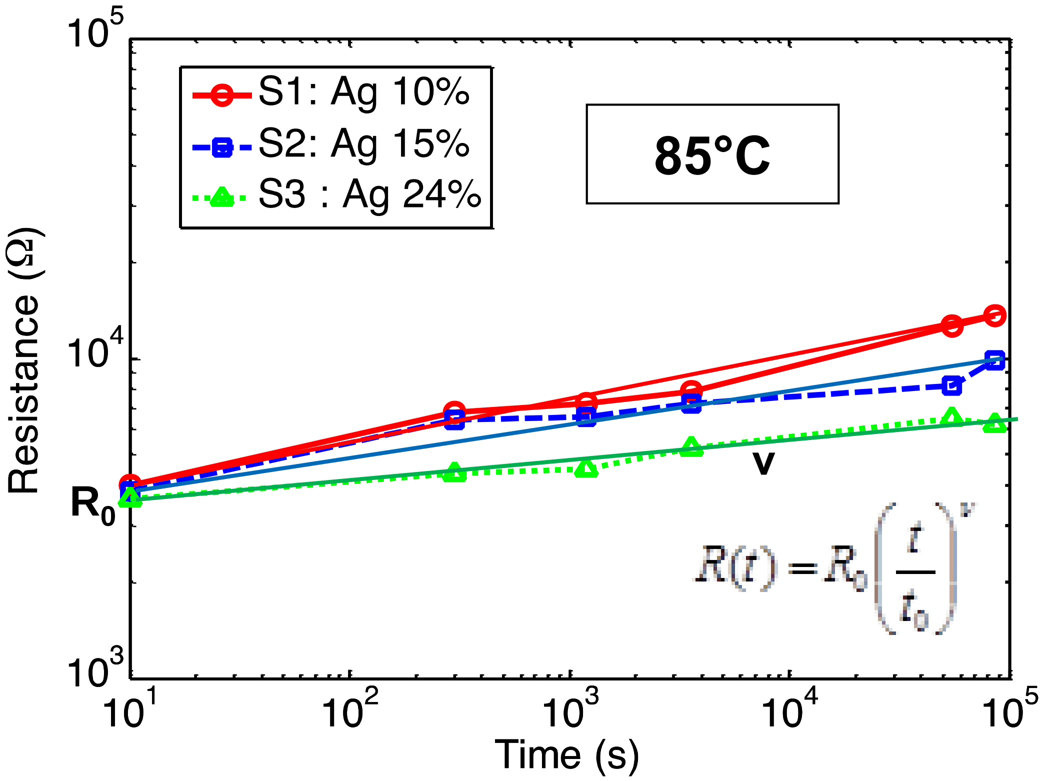
- **Compliance current in the order of 10µA gives programming energy in the orders of nJ !!**

Endurance



Endurance 10^5 cycles with no degradation evident for 15% Ag doped GeS_2 device (S2) (I_{comp}= 10 µA)

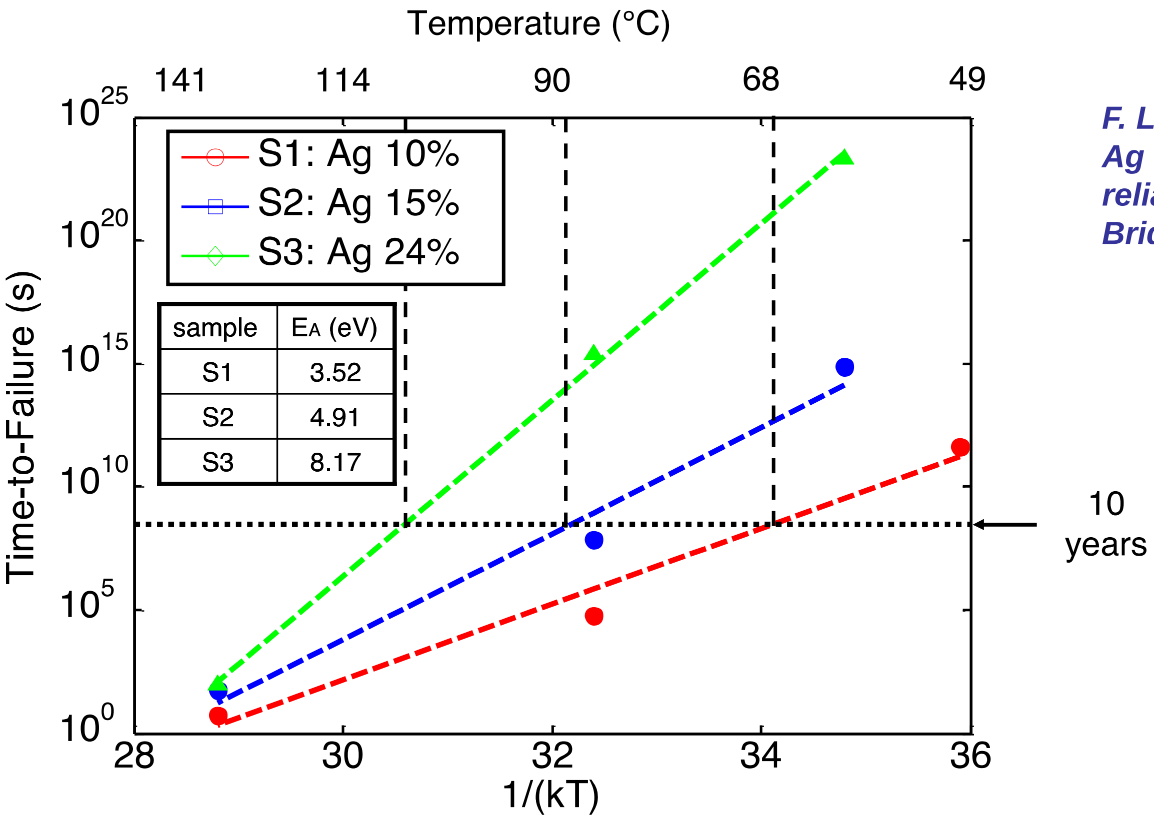
Retention



resistance evolution averaged on 30 cells

- slower resistance evolution for the highly Ag doped sample
- the resistance-time curves obey a power law → we can extrapolate a time-to-failure

Arrhenius plot of the time-to-failure

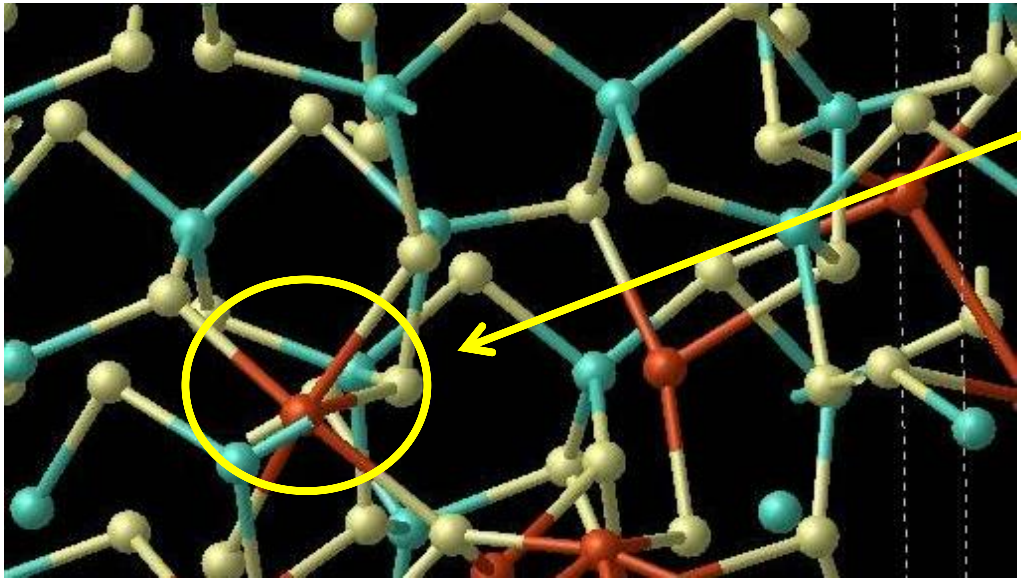


sample	E_A (eV)
S1	3.52
S2	4.91
S3	8.17

F. Longnos et al., « On the impact of Ag doping on performance and reliability of GeS2-based Conductive Bridge Memories », ESSDERC 2012

- time-to-failure time defined by 10x increase in resistance
- 15%Ag doped GeS_2 extrapolated fail temperature @ 10 years ~ 100 °C

Ag-doped GeS_2 structure



Ag_2S compound

DFT, 200 atoms system
(Red=Ag, green=Ge,
yellow=S)

Ag is always chemically bonded: S atoms react with the Ag thus generating Ag_2S compounds → deficient of Ge-S bonds and unbonded S atoms, hindering the dissolution of additional Ag into the GeS_2

The Ag diffusion seems to obey the Fick's law → increasing the Ag doping, the GeS_2 matrix becomes saturated thus limiting the Ag diffusion during the memory operations

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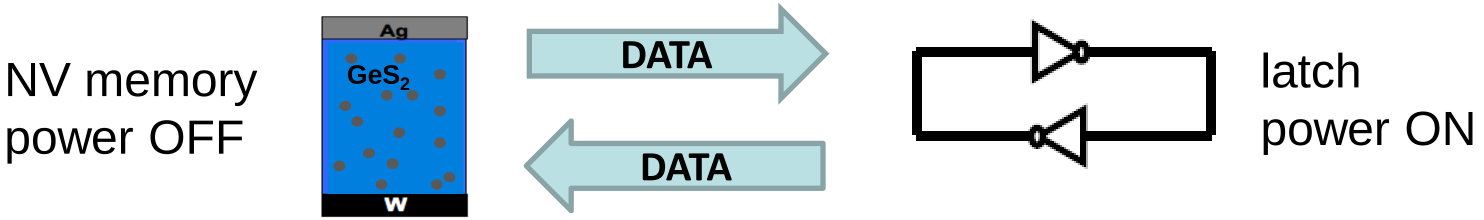
Study of hybrid “logic-NVM circuits”

- **ERD ITRS 2009:** « Nanodevices that implement both logic and memory in the same device would revolutionize circuit and nanoarchitecture implementation »



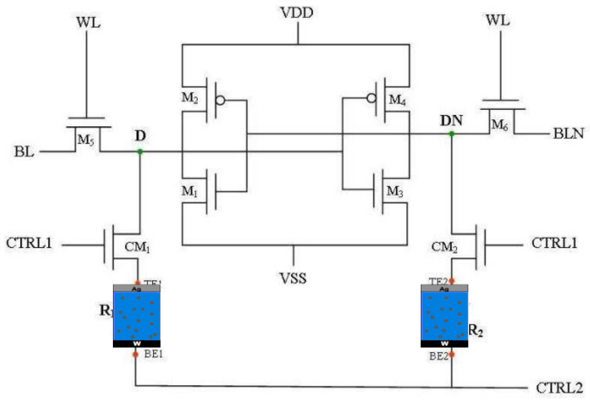
NV memory
power OFF

DATA

DATA

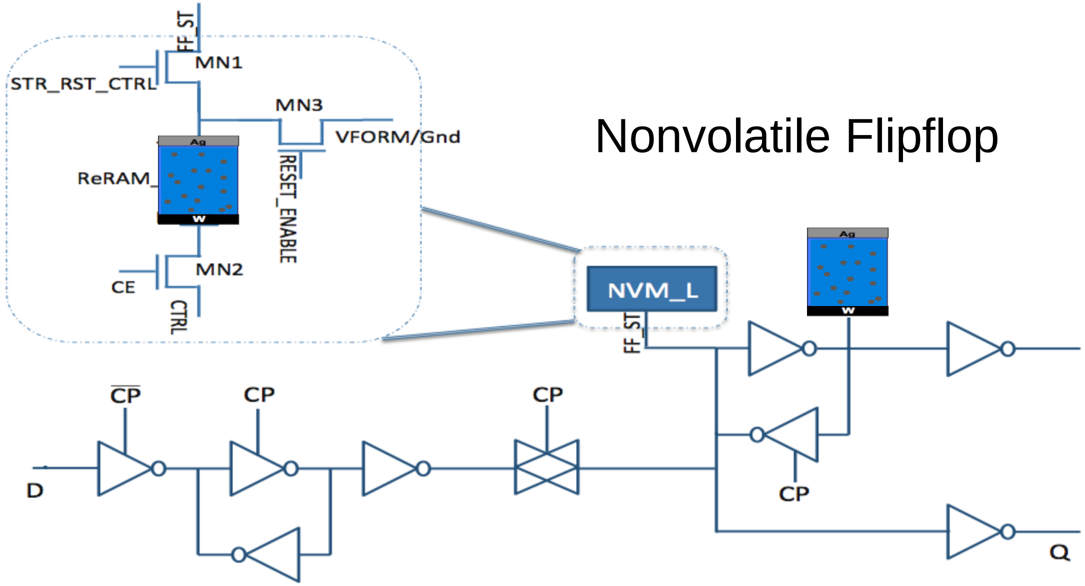
latch
power ON

Nonvolatile-SRAM



Hraziia et al., « Bipolar OxRRAM-based non-volatile 8T2R SRAM for information back-up », EuroSOI 2012

Nonvolatile Flipflop



S. Onkaraiah et al., « Bipolar ReRAM Based Non-Volatile Flip-Flops for Low-Power Architectures », NEWCAS 2012

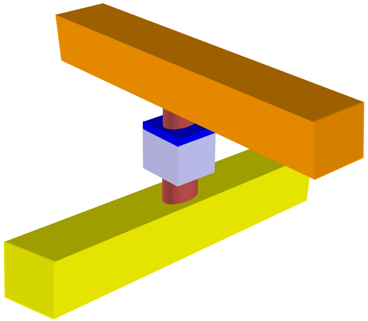
Conclusions and perspectives

- An empirical model able to well reproduce the set and reset kinetics in Ag/GeS_2 CBRAM cells has been developed
  →CBRAM compact model suitable for design implementation
  →design of hybrid Non volatile circuits

- Impact of Ag doping on GeS_2-based CBRAM performance
  → Ag doping leads to a saturated GeS_2 matrix thus limiting the Ag diffusion during the memory data-retention. Other paths of improvements to further to increase operating temperature are under investigation.

Conclusions and perspectives

- RRAM has excellent basic cell properties but scaling, reproducibility/uniformity, reliability, and mass-production issues should be cleared for commercialization



New materials to adress soldering issue

- Chalcogenide optimization
  - GeS_2 doping (Sb, Ag, SiO_2…)
- Oxyde based electrolytes
  - High-k (Al_2O_3, HfO_2)
  - Electrodes (Cu, …)

New architectures to study the cell scaling

- Electron beam scaled structures
- µ-trench structures

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Annual Review

Save the date now!

→ June 19-20, 2012

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Merci de votre attention