The performance materials business of Merck KGaA, Darmstadt, Germany operates as EMD Performance Materials in the U.S. and Canada.

ALD chalcogenide : a key player for next generation crosspoint memory

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EMD Performance Materials

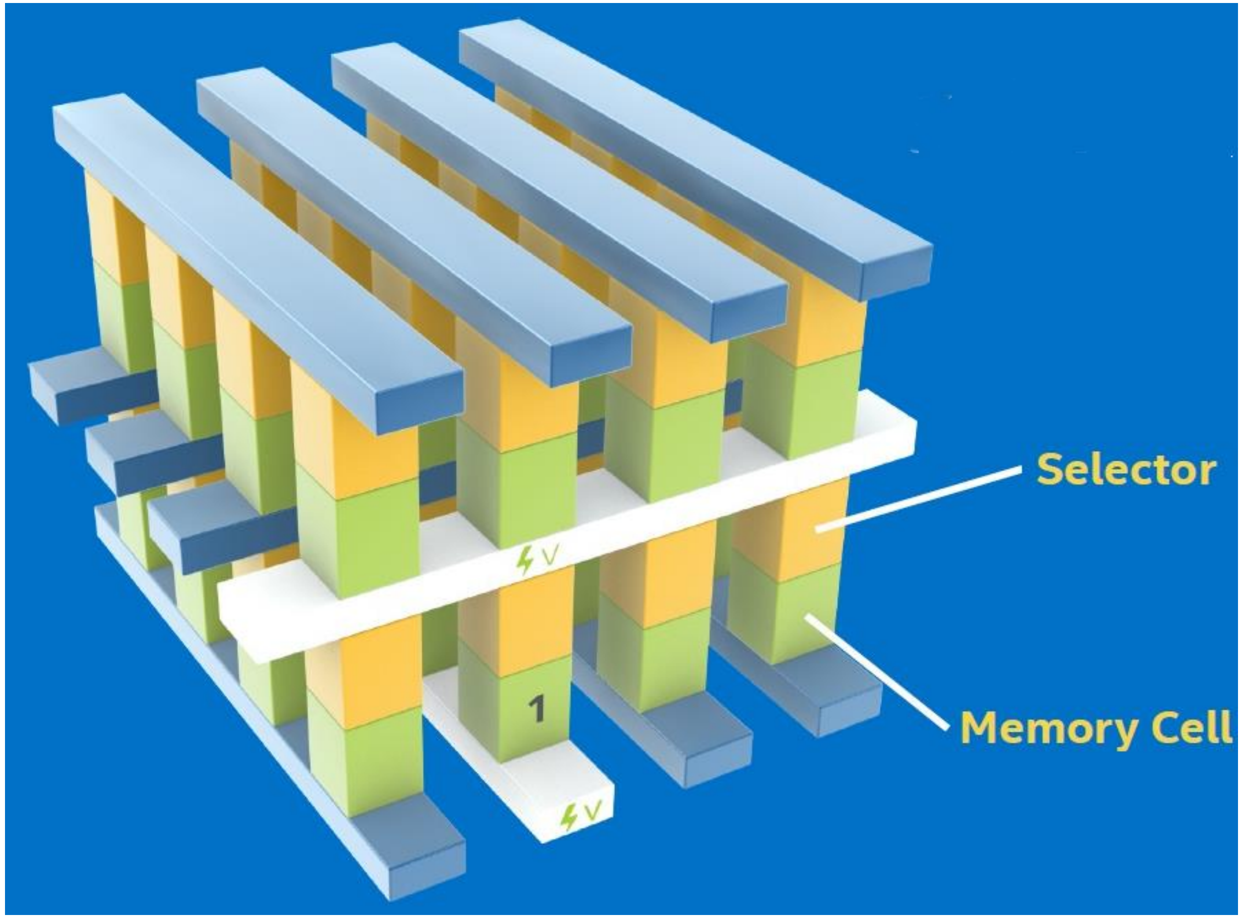
outline

- Introduction
  - 3D crosspoint memory architecture
  - Selector device requirements and challenges
  - Why do we need ALD chalcogenide?
- ALD PCM development with $Ge_2Sb_2Te_5$ (GST)
  - ALD of common PCM composition (GST) : conformality, composition, impurities
  - Integration of PCM device and electrical results
- ALD OTS development in the GeSe-GeTe space
  - ALD of common OTS compositions ($GeTe_4$ and GeSe) : conformality, roughness
  - Integration of OTS devices and electrical results
- Summary and conclusions

Proprietary and Confidential

Introduction: the 3D crosspoint architecture

Why a **thin film crosspoint** architecture?



The Selector Device is required for ***high density low cost*** **memories**

- **True Cross Point Array**
  - Cell dimension: $4F^2$
  - Strapless to simplify routing and process
- **Stackable**
  - Low temperature process
  - CMOS under the memory
  - Multiple decks feasible

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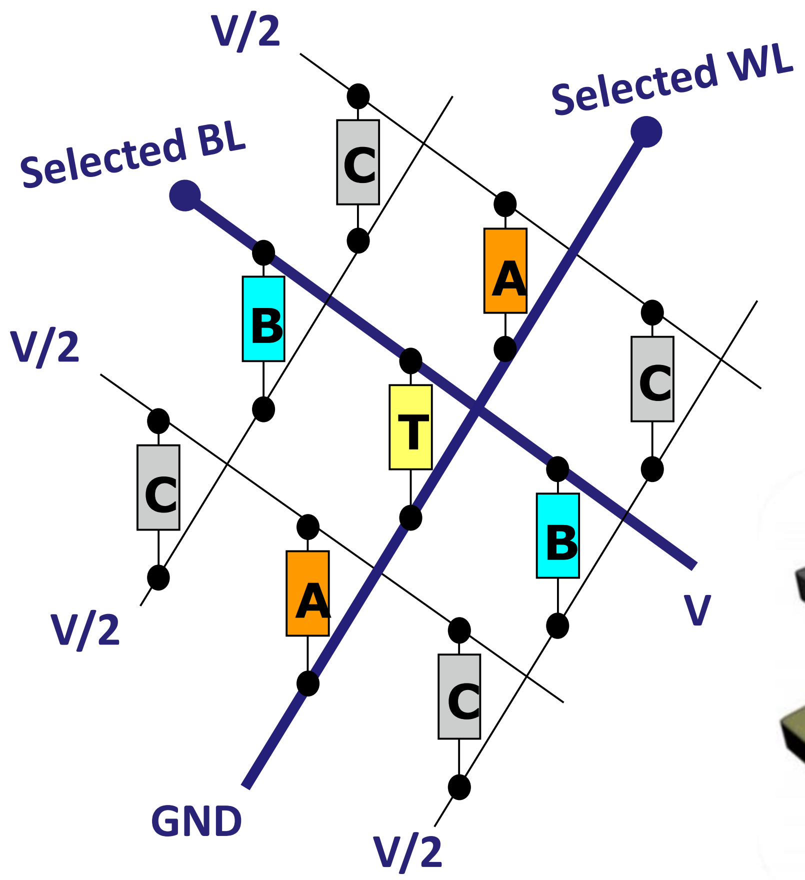
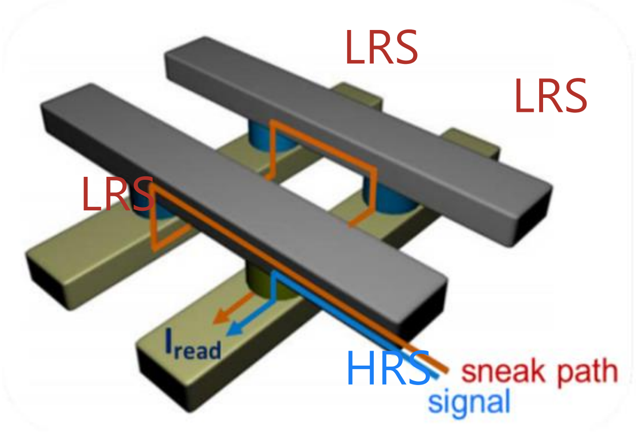
Requirements for a crosspoint selector



Cell	ΔV	
T	VSEL-GND	V
A	VB-GND	V/2
B	VSEL-VA	V/2
C	VB-VA	0



Access device requirements:

- High I_{ON}/I_{OFF} ratio (strong Non-Linearity)
- High J_{ON} → to allow programming
- Fast switching speed
- Bipolar
- Low temperature process → 3D Stackable

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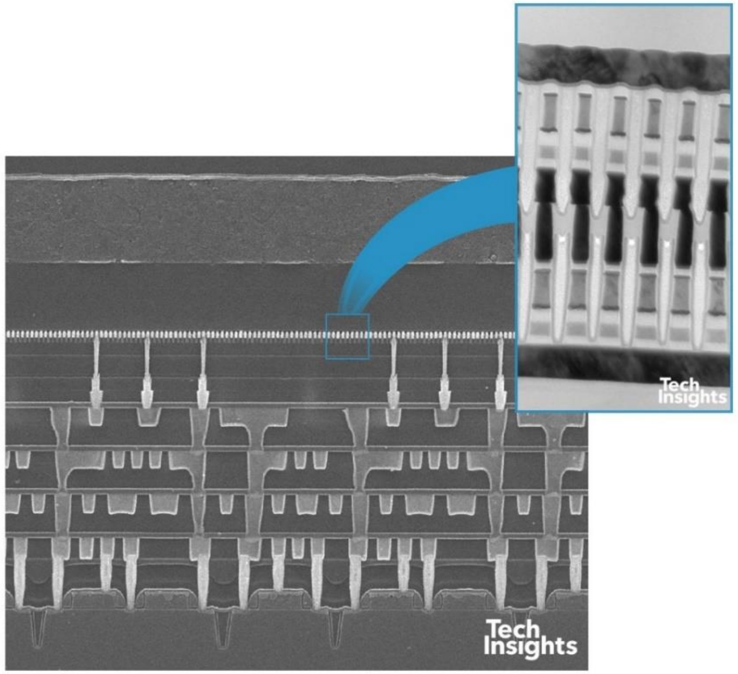
where is crosspoint technology now?

Intel 3D Xpoint

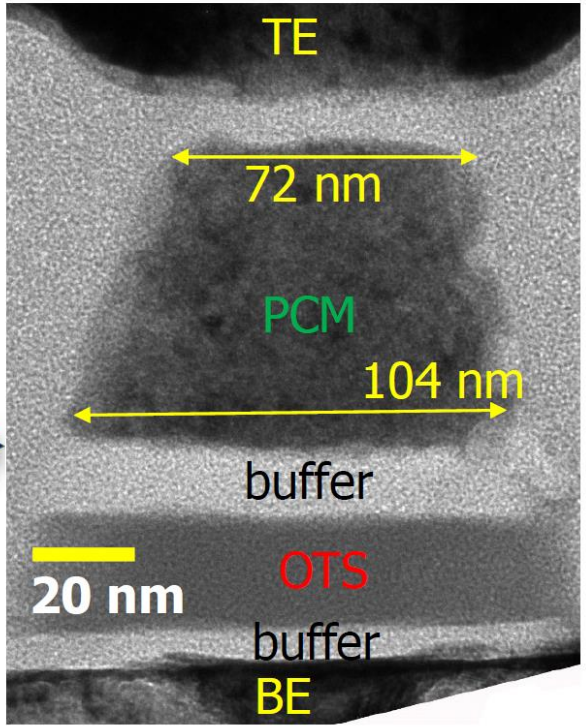


Techinsights report on Intel Optane Technology, May 2017

Micron 3D Xpoint

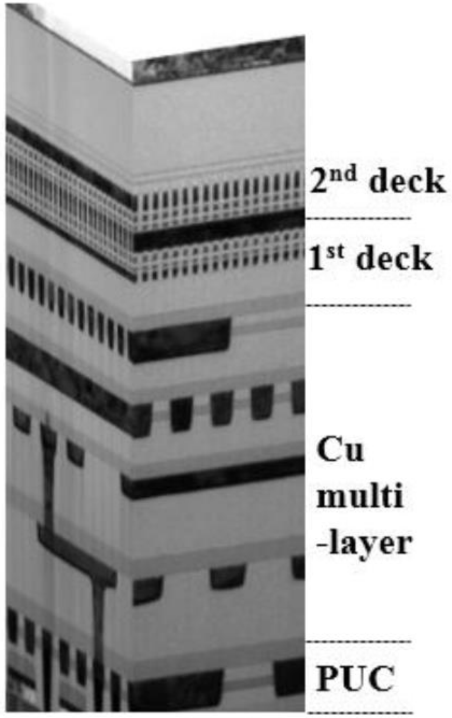
X100 NVMe SSD product just released

IBM



H.Y. Cheng et al., IEDM18

SK Hynix



T. Kim et al., IEDM18

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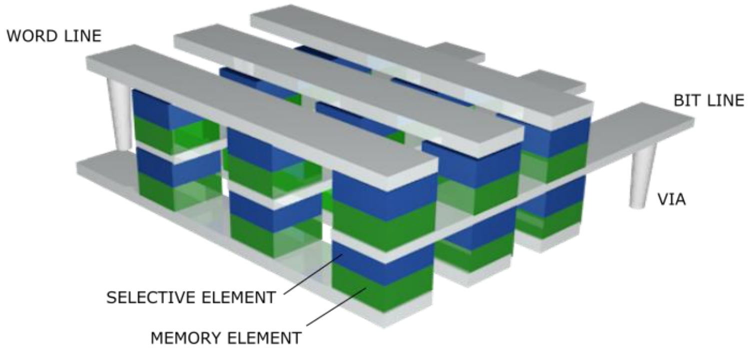
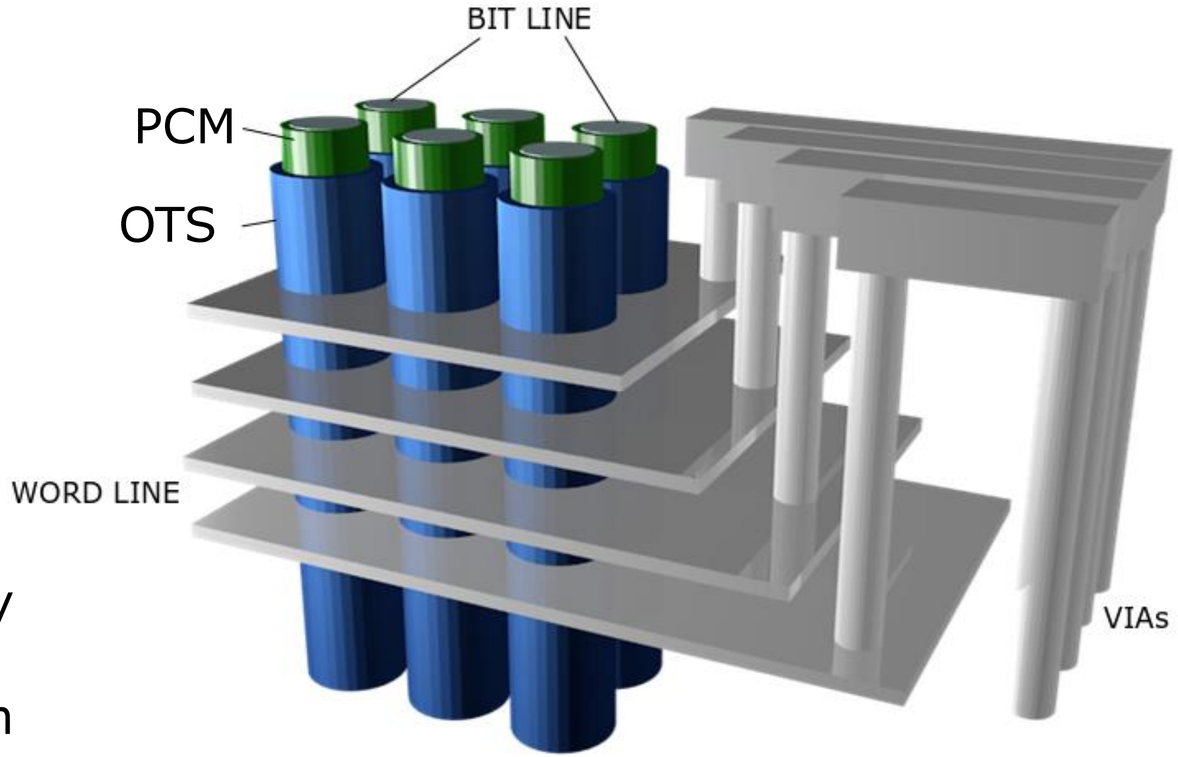
Why do we need ALD chalcogenide?

PVD 3D X-Point ➤➤➤ ➤ **ALD vertical 3D X-Point**



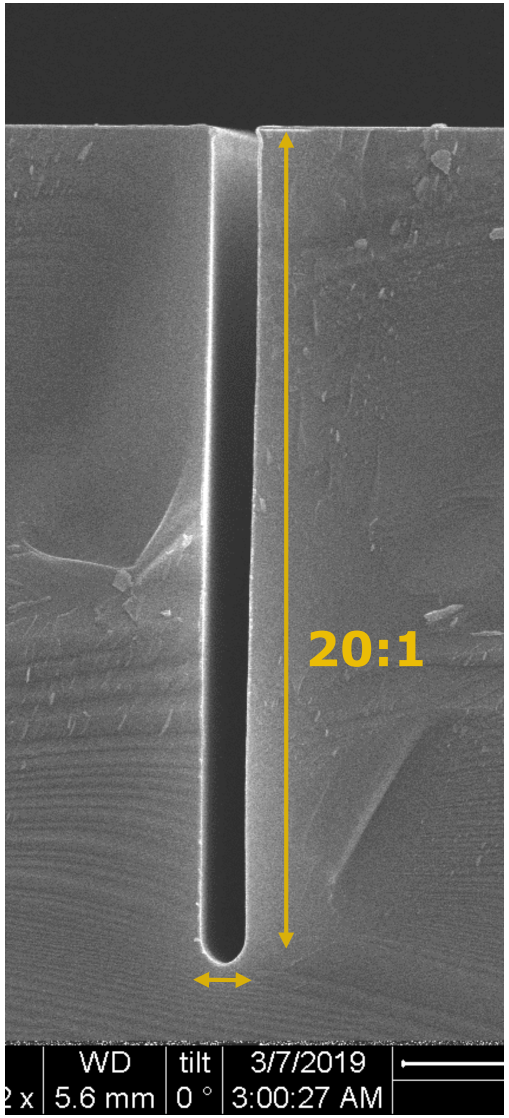


Key challenges:

- ❑3D Vertical NVM architecture requires highly conformal deposition processes (e.g. ALD)
- ❑Layered architecture require uniform composition and interface control
- ❑ALD chalcogenide chemistry is complex and not well understood especially for OTS compositions

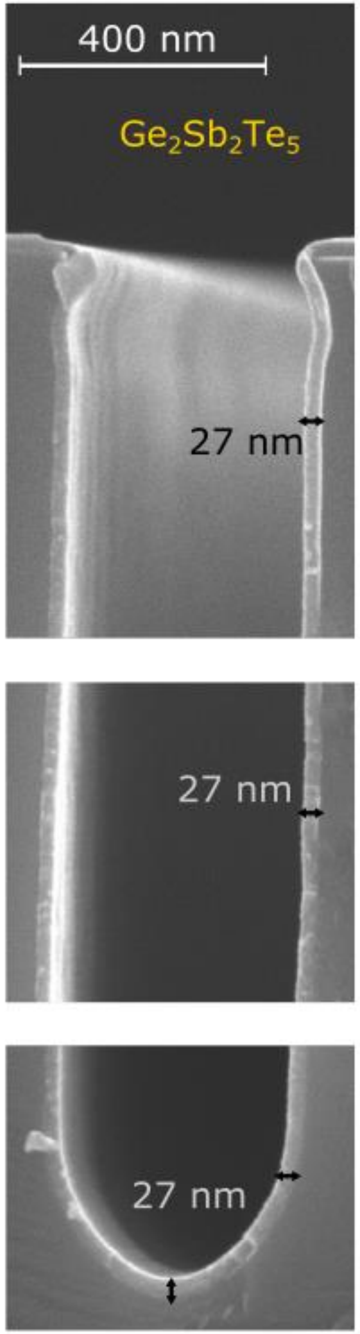
IMI developed ALD films for PCM and OTS applications

ALD $Ge_2Sb_2Te_5$: conformality



Cross-sectional TEM of trench structures reveals excellent conformality.

The film appears compact and smooth; the top/bottom thickness ratio appears to be very close to 1



Top

Center

Bottom

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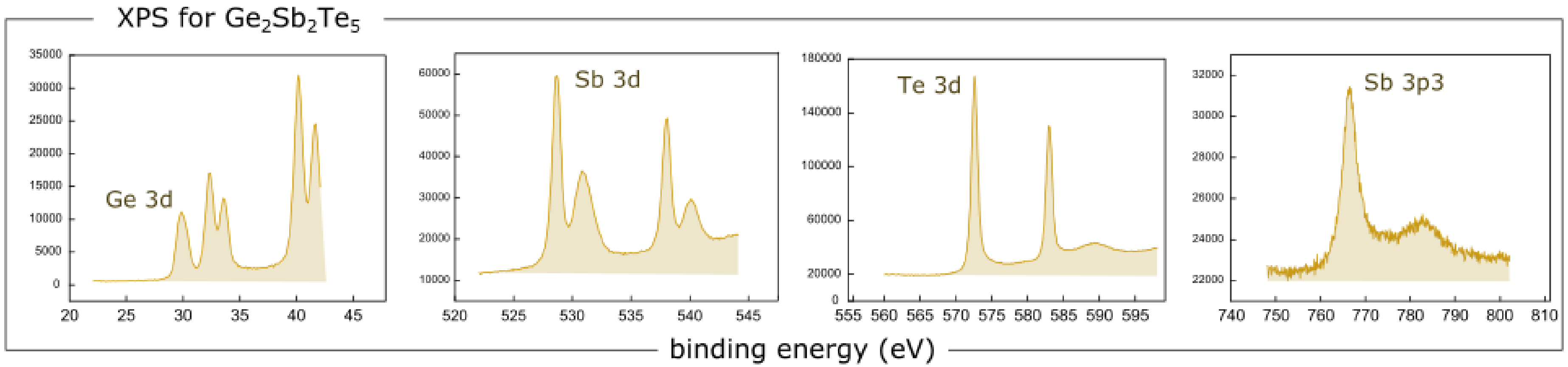
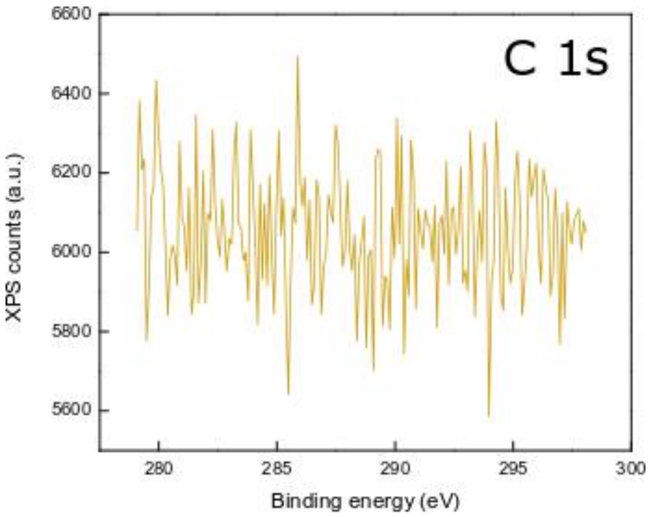
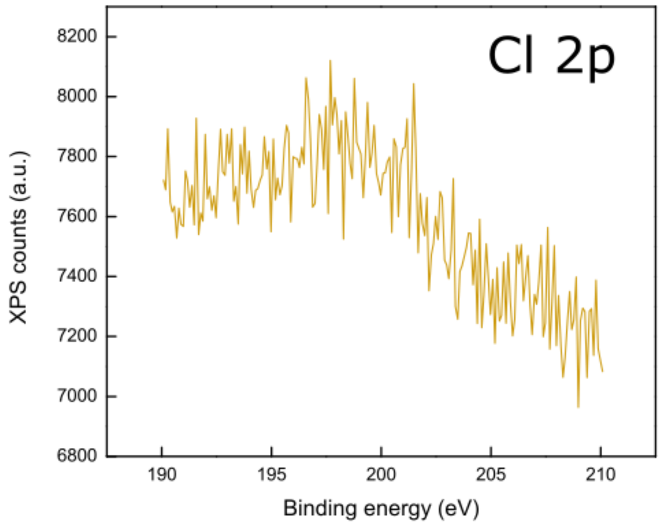
composition and impurities

XPS analysis confirms a $Ge_2Sb_2Te_5$ composition







The level of impurities such as Cl and C is buried in noise revealing a concentration comprised between 0 – 1%

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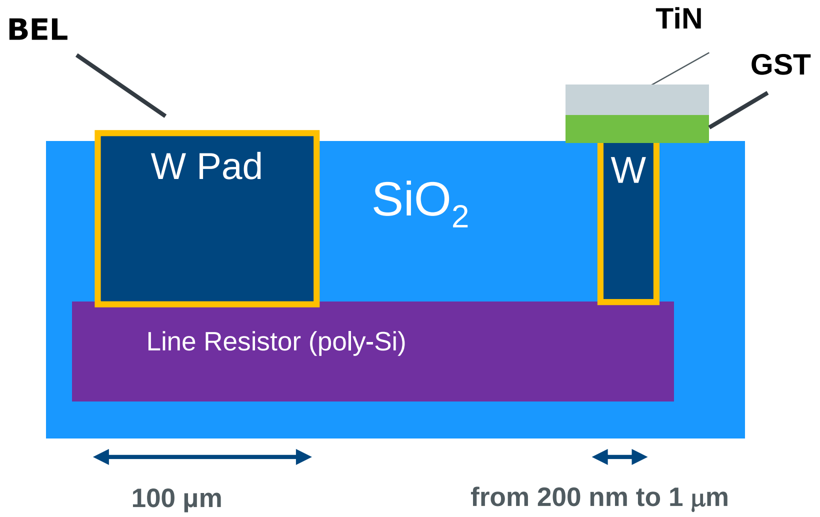
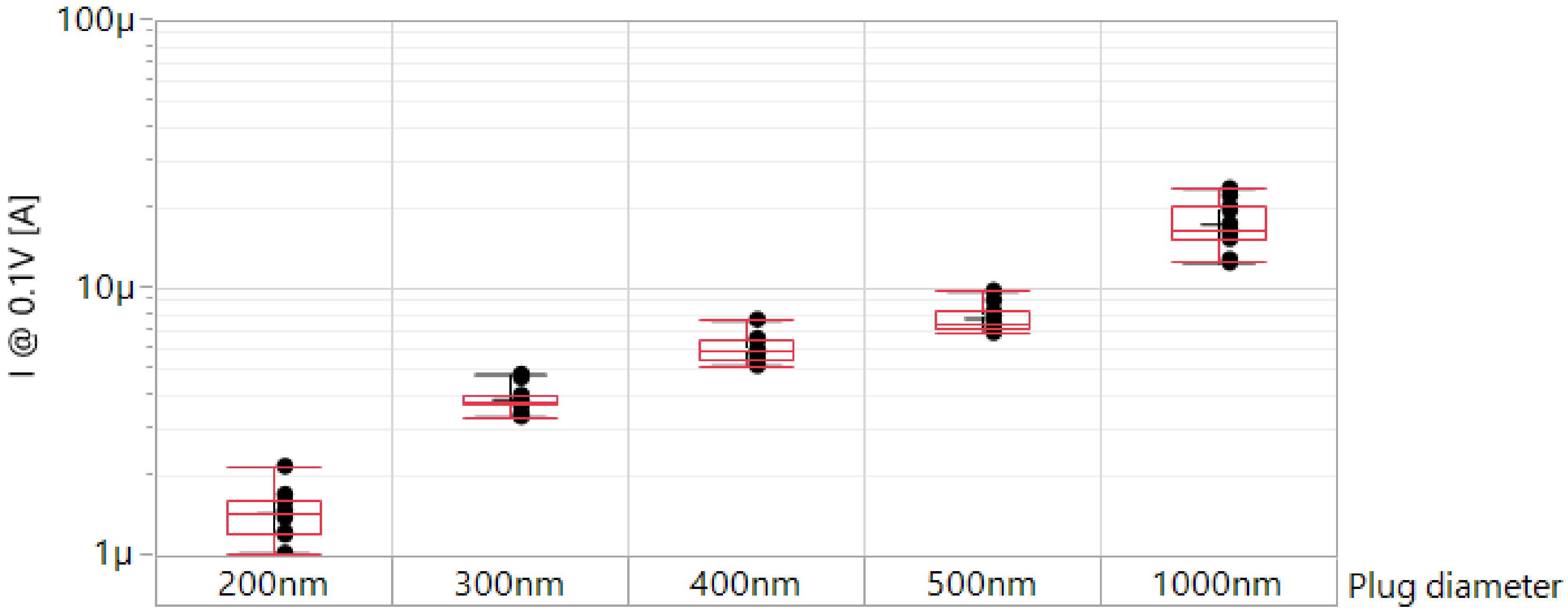
PCM device integration

Device structure



Leakage as-deposited



- ❑ Clear dependence of the as-deposited GST leakage on the plug diameter
- ❑ Tight distribution confirming good uniformity of our ALD film

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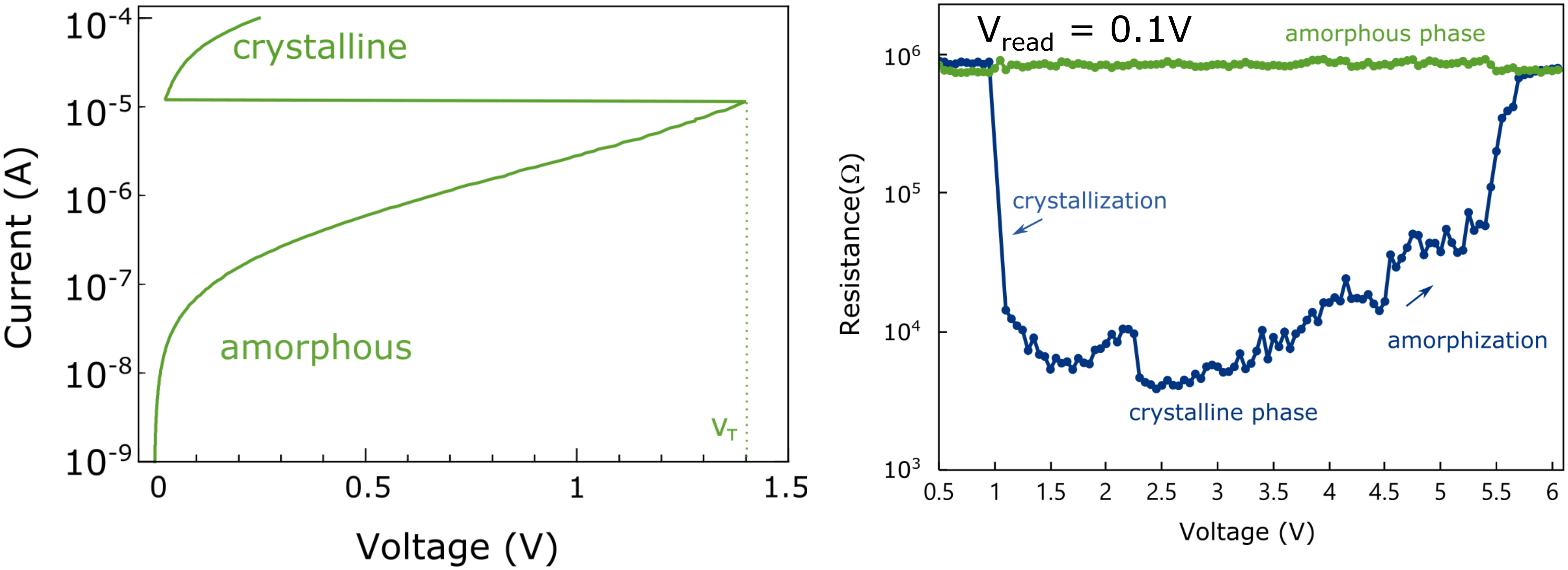
PCM IV and RV characteristics



V. Adinolfi et al., ACS Nano, 2019

- ❑ IV characteristics shows the characteristic ‘snap-back’ at a threshold voltage V_T = 1.4 V
- ❑ RV characteristics shows crystallization at ~ 1 V and full reset close to 6 V
- ❑ Amorphous and crystalline phases result in resistance window exceeding two OoM

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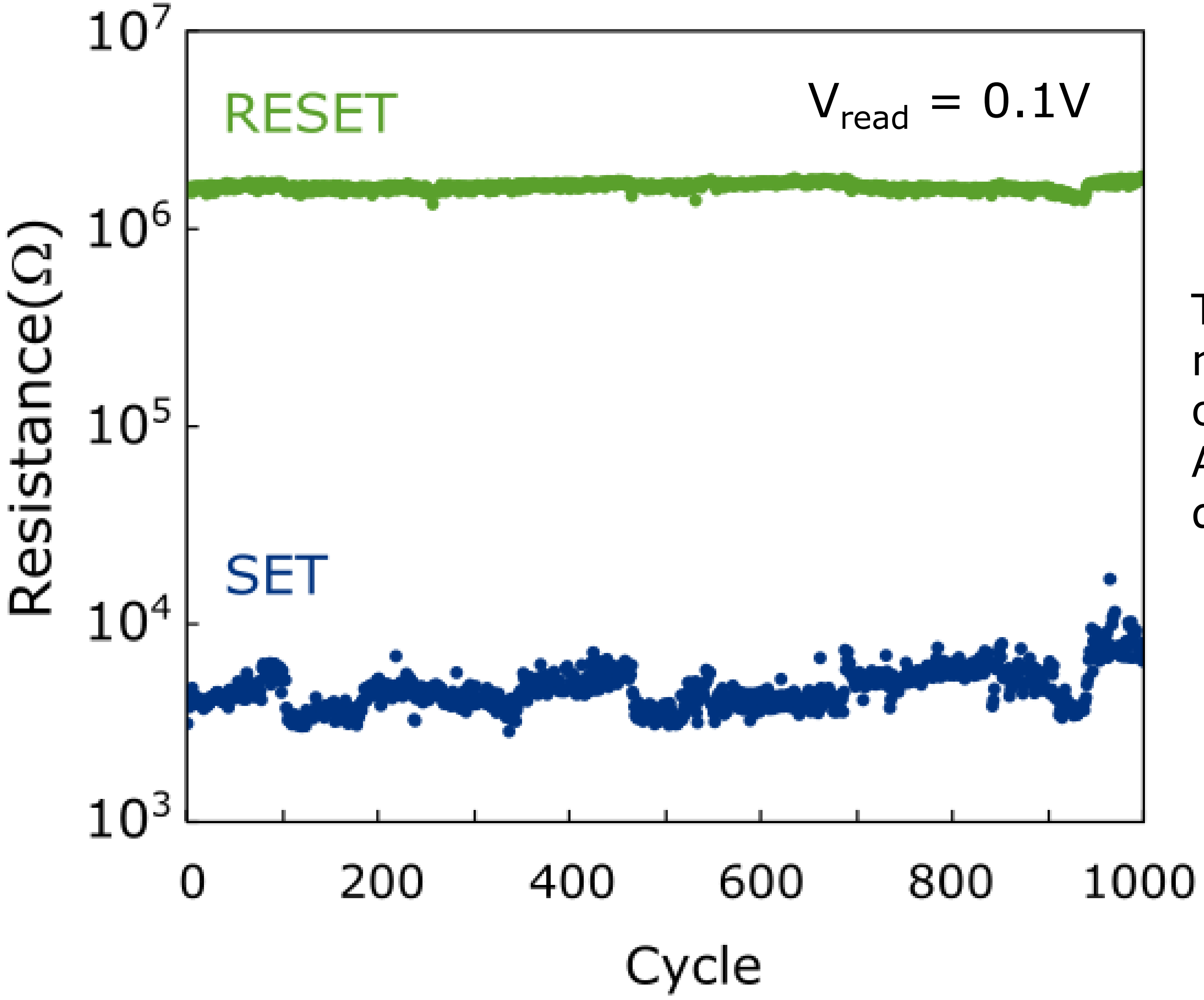
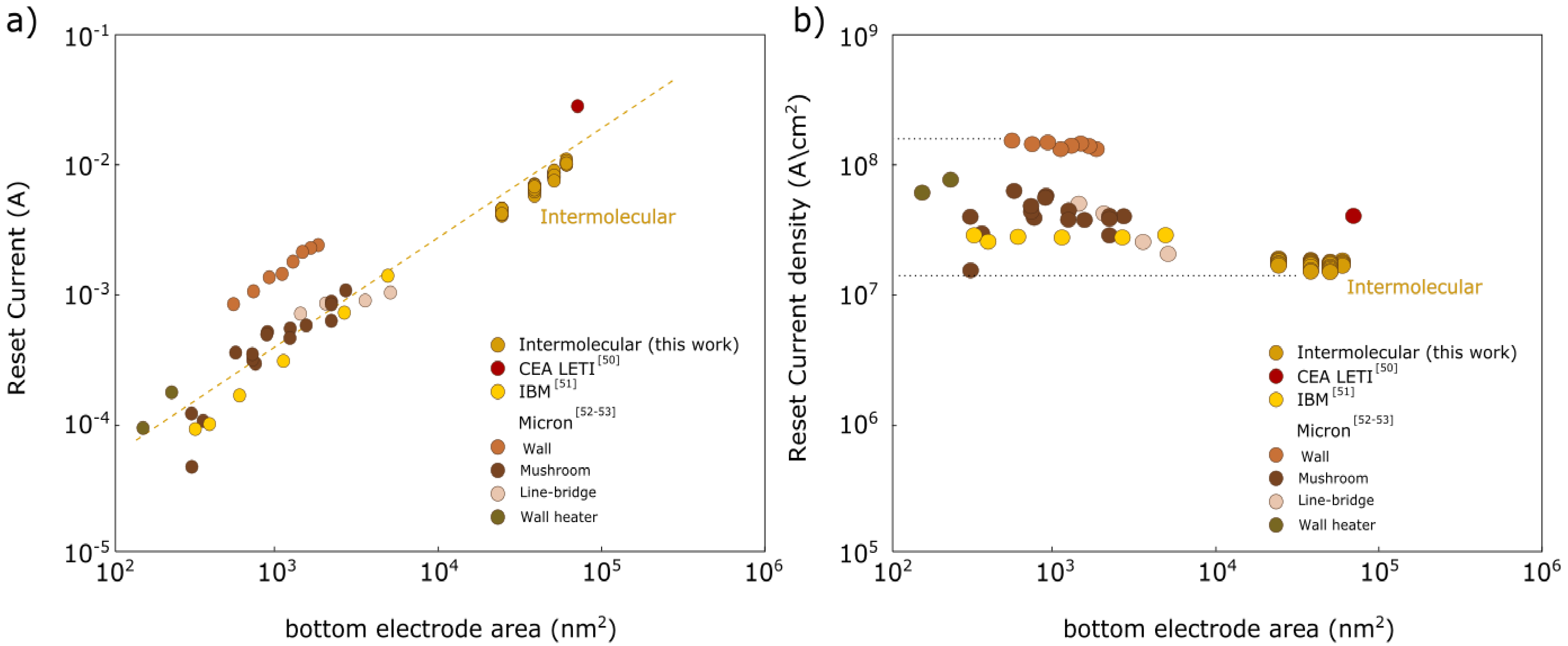
PCM cycling endurance



The PCM memory maintains > 2 orders of magnitude of resistance memory window over 1000 cycles → very promising result for ALD implementation of more scaled PCM device

V. Adinolfi et al., ACS Nano, 2019

PCM reset current scaling



V. Adinolfi et al., ACS Nano, 2019

The ALD PCM compares well with state-of-the-art devices showing comparable or better reset current density confirming the high quality of the ALD film

Perniola, L et al. *IEEE Electron Device Lett.* **2010**, *31* (5), 488–490.

Padilla, A.; Burr et al. *2010 International Electron Devices Meeting*; IEEE, 2010; p 29.4.1-29.4.4.

Boniardi, M. et al. *2014 IEEE International Electron Devices Meeting*; IEEE, 2014; p 29.1.1-29.1.4.

Pirovano, A et al.In *IEEE International Electron Devices Meeting 2003*; IEEE; p 29.6.1-29.6.4.

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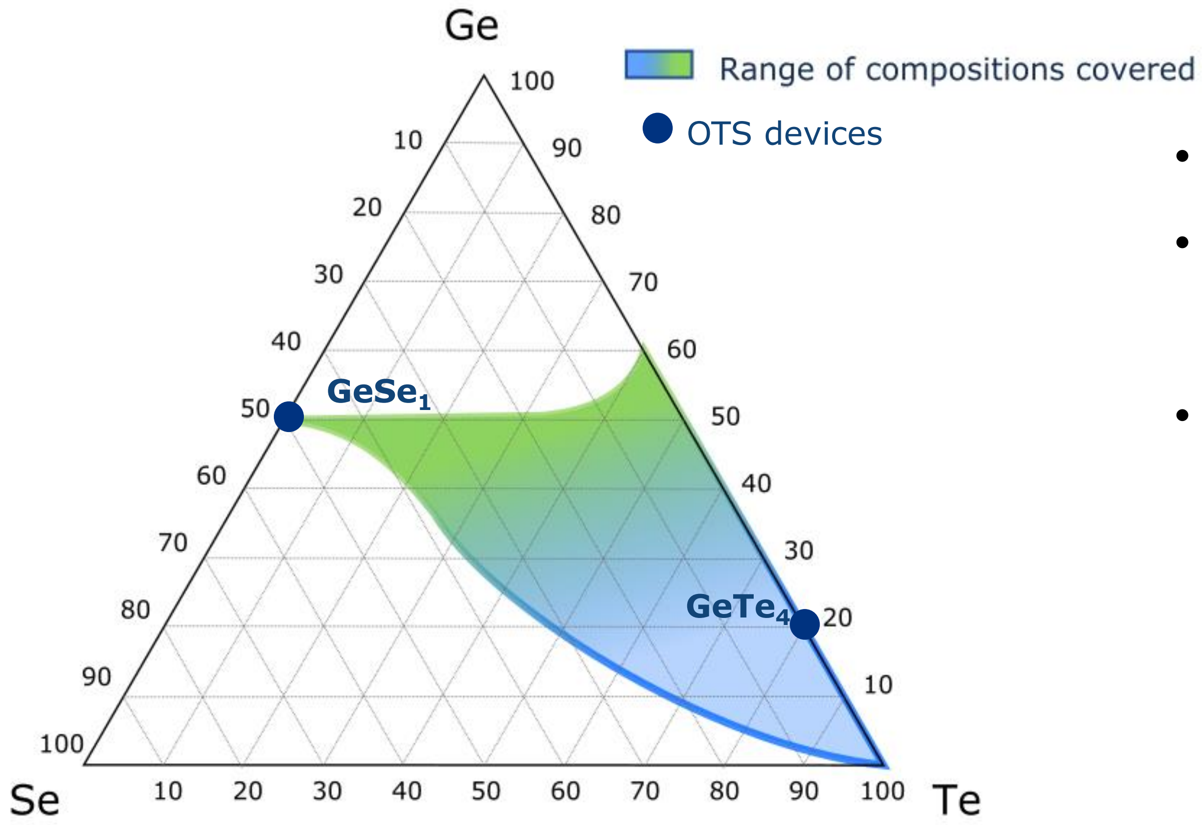
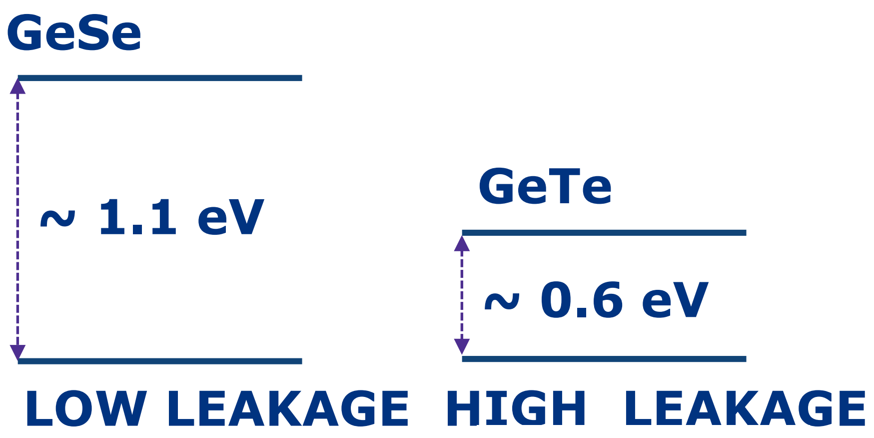
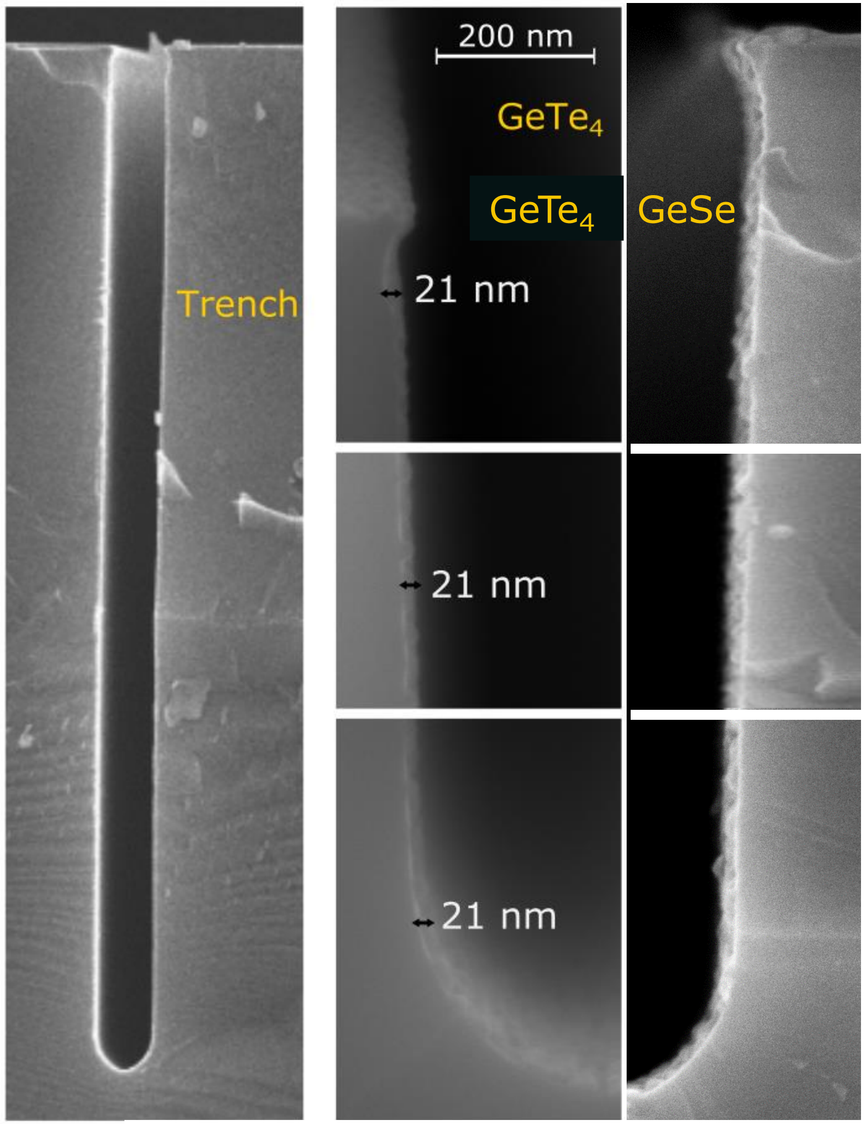
Range of composition explored for ALD OTS integration



- Opened a wide area of compositions
- Chose commonly referred material systems, with compositions expected to produce OTS
- We expect Se rich compositions to have higher bandgap → tunable V_T and subthreshold current



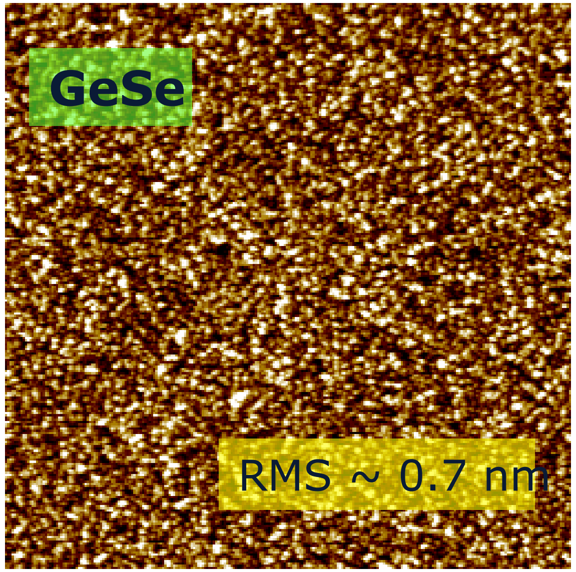
ALD $GeTe_4$ and GeSe conformality

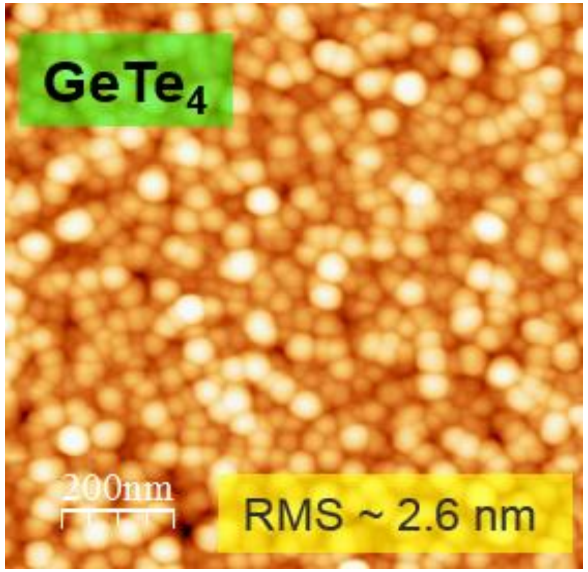


- Good conformality over a 20:1 Silicon trench for both ALD compositions coating uniformly the entire trench profile

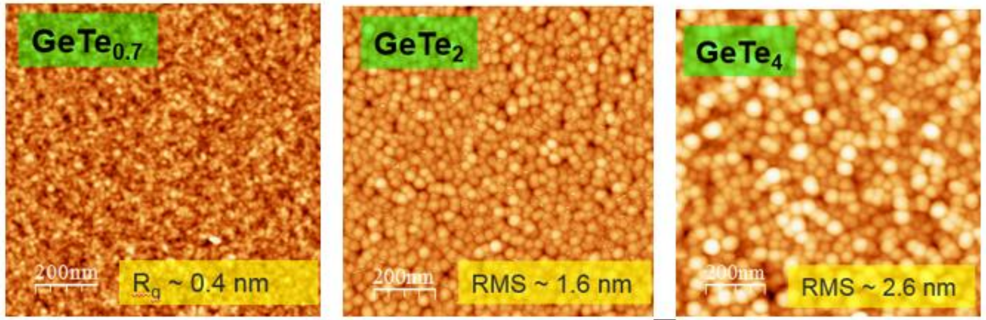
ALD $GeTe_4$ and GeSe Roughness - AFM

Film thickness ~ 20 nm





The role of tellurium



- Roughness as small as ~ 0.4 nm (GeSe and GeTe unit films)
- Tellurium tends to form crystallites and increase roughness

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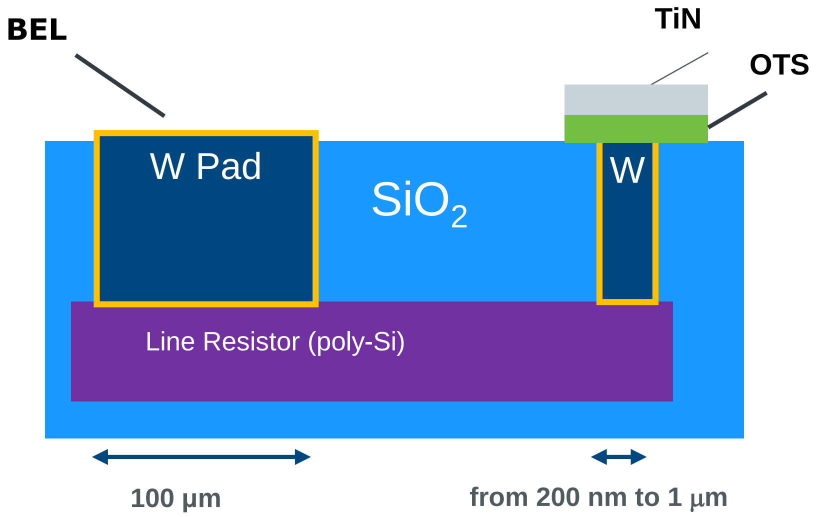
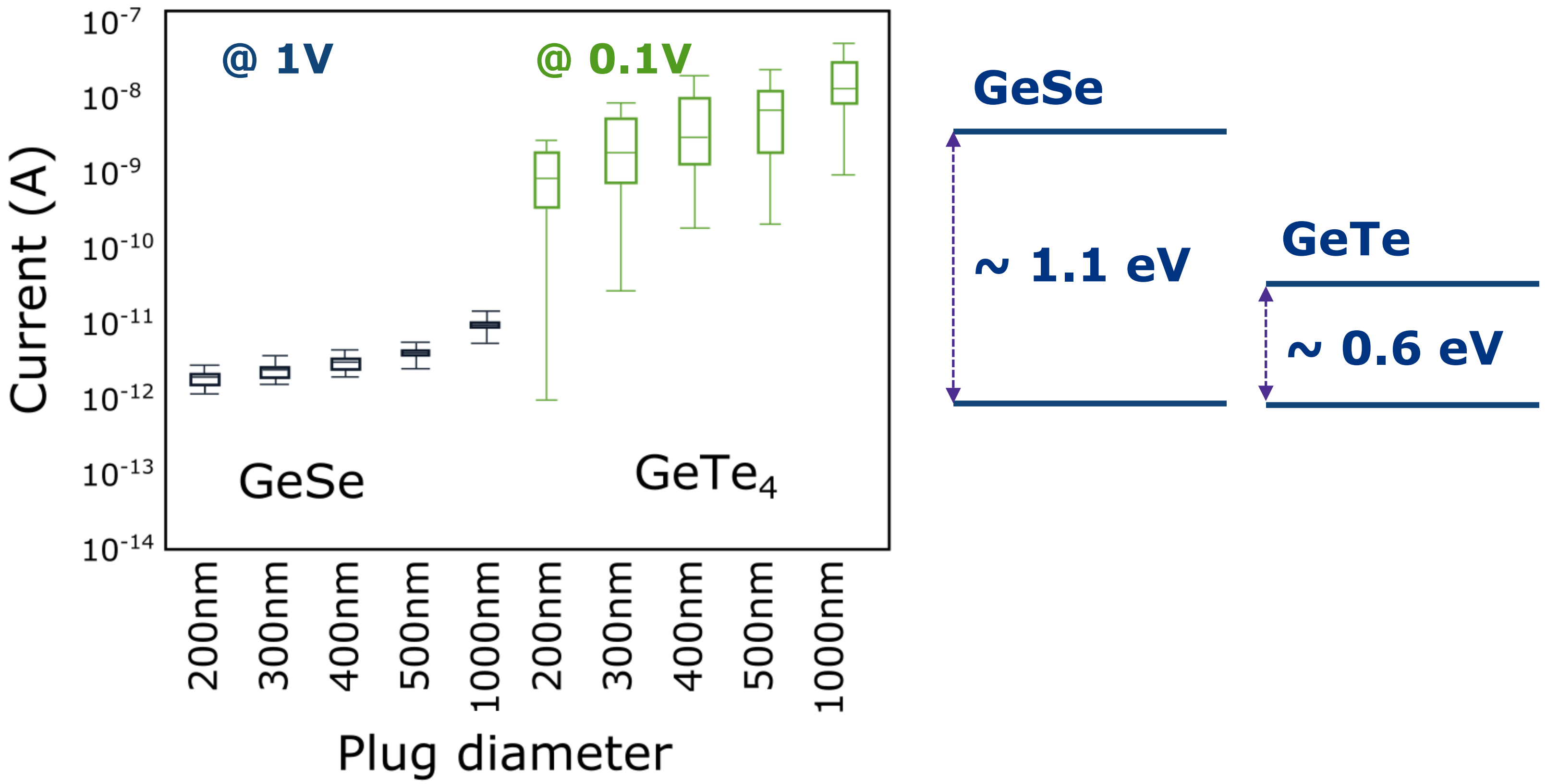
OTS device integration

Device structure



Leakage as-deposited



- ❑ Clear dependence of the as-deposited OTS leakage on the plug diameter
- ❑ Big change in the subthreshold transport depending on the Eg of the ALD material deposited

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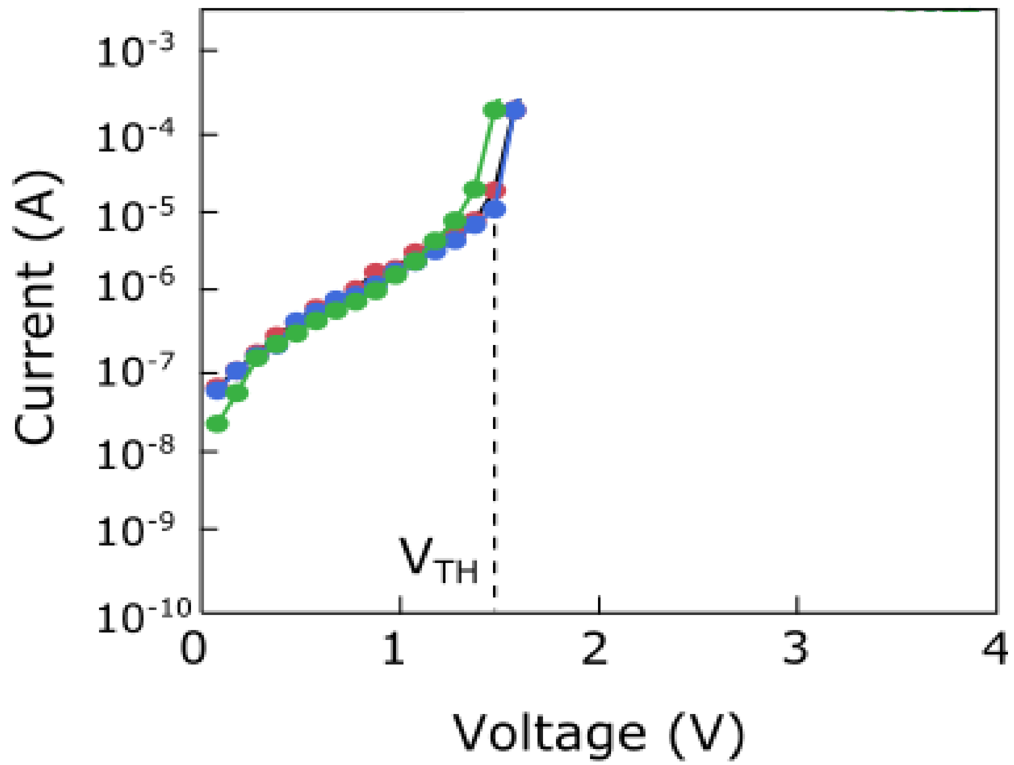
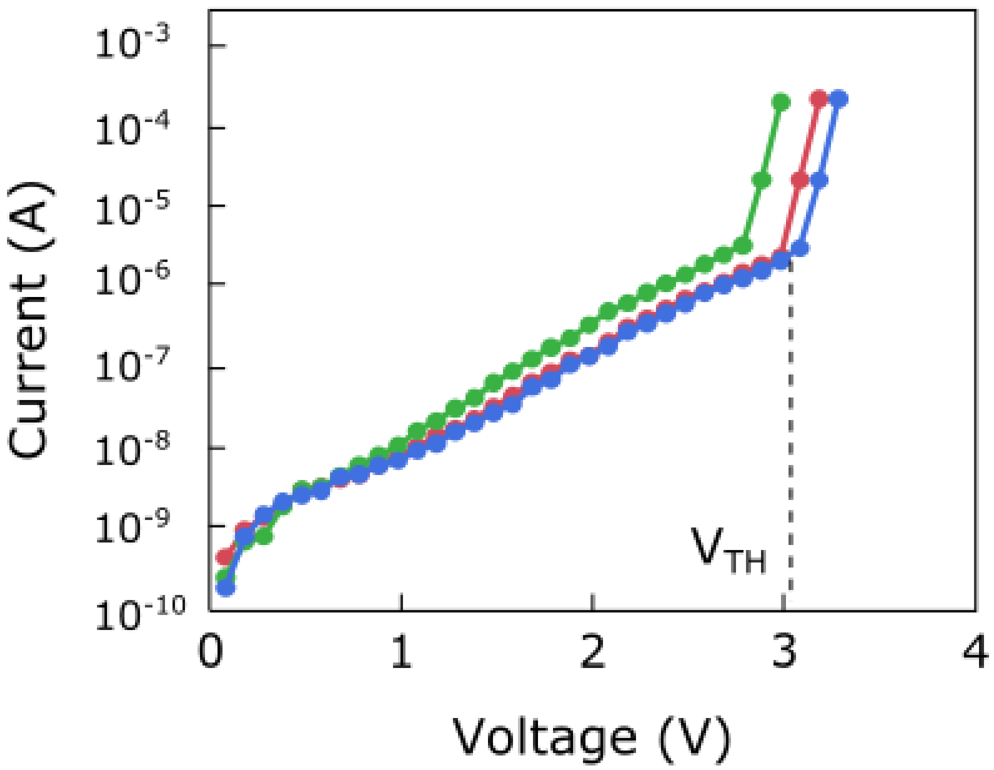
OTS P-IV characteristics

PW = 10 µs

$GeTe_4$



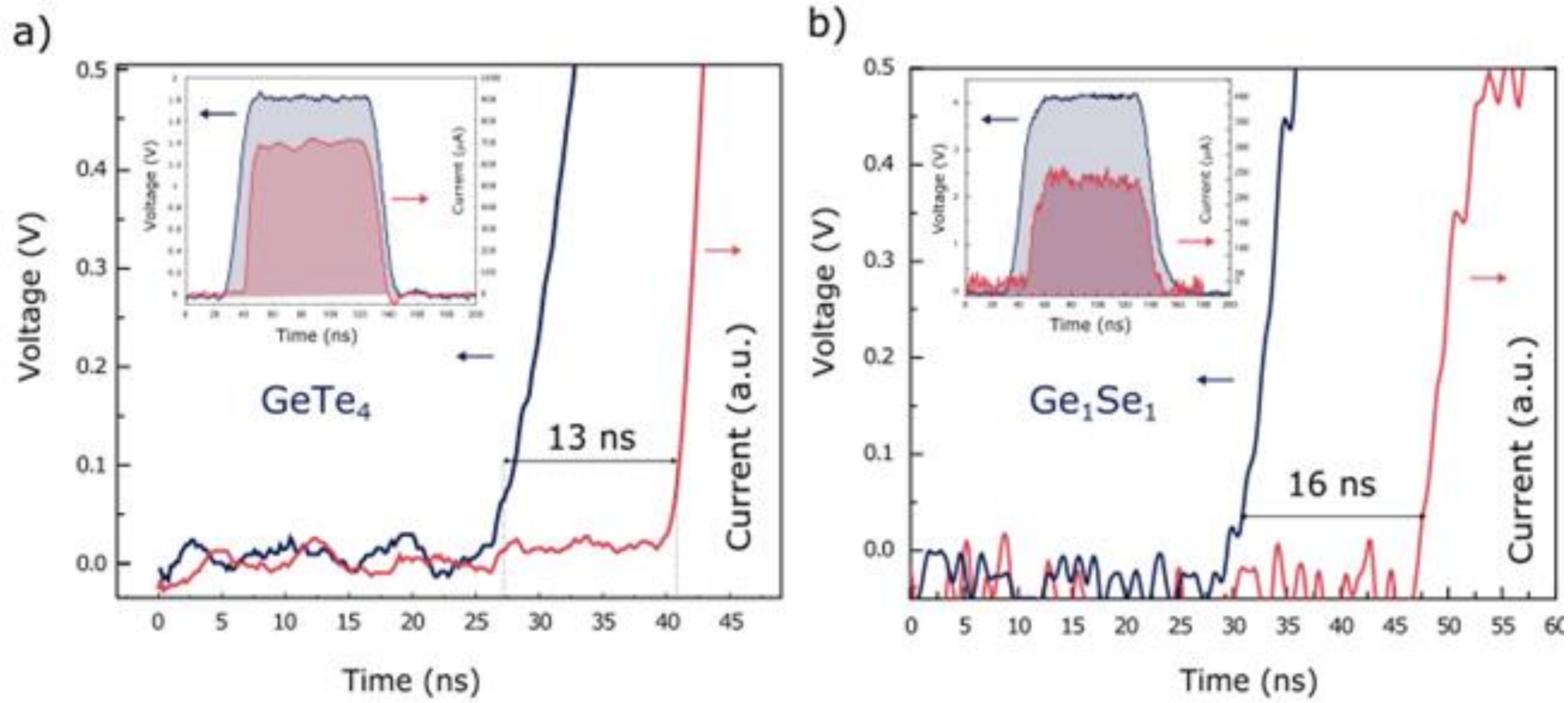
GeSe



CYCLE 1
CYCLE 2
CYCLE 3

- ❑ Through modulation of our ALD OTS composition is possible to efficiently tune V_{th} and subthreshold leakage allowing for higher selectivity and larger crosspoint arrays

OTS switching speed



- Switching speed of our ALD OTS devices between 10 and 20 ns in target with specifications of fast selector devices for crosspoint memory application

Summary

Next generation of 3D crosspoint memory needs ALD chalcogenide film

- ❑ 3D Vertical NVM architecture requires highly conformal ALD deposition processes
- ❑ Multi-layer architecture require uniform composition and interface control

Intermolecular ALD chalcogenide films allow for PCM and OTS integration

- Developed ALD GST deposition for PCM integration
- Covered GeSeTe space in order to tune OTS Vth and subthreshold leakage

Future steps

- Introduce As in ALD OTS composition in order to decrease subthreshold leakage and improve endurance and thermal stability of ALD OTS selector device

thank you for your attention