Challenges in Vertically Stackable Selectors for 3D Cross-Point Non Volatile Memories

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Outline

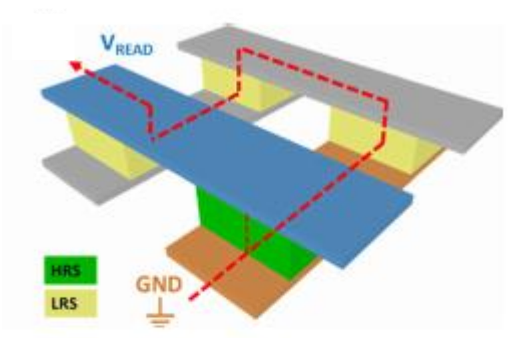
- Introduction and Background
  - 3D Cross Point Architecture – memory and selector
  - Selector Types
  - Challenge of 3D Integration
- Screening and Experimentation Methodology
  - Materials Deposition and Etest
  - ALD Chalcogenide Development
- ALD Selector
  - Electrical Evaluation
- Summary

3D Cross-point Memory – Selector Architecture

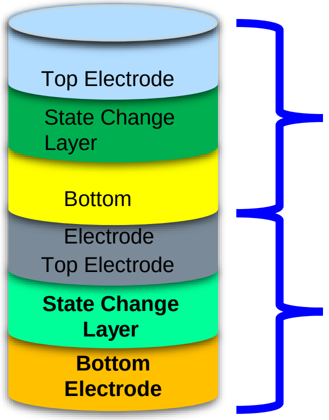
INTERMOLECULAR

Challenges with Sneak Current Paths for 3D Resistive Memory

Sneak current paths



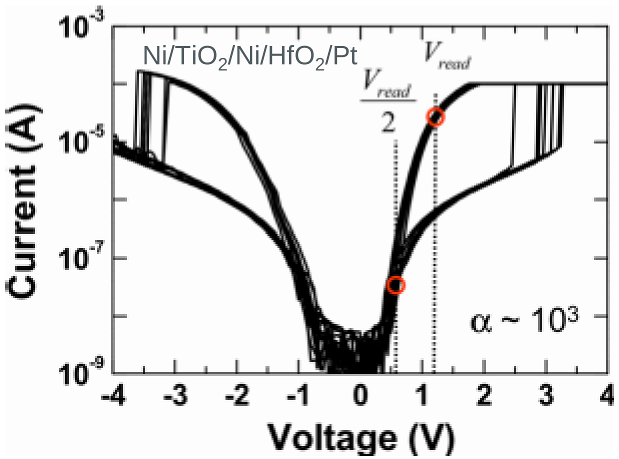
* Ref: Chen, et al. Journal of Electroceramics (2017): 1-18.



Memory Element
Eg: ReRAM, PCRAM, CBRAM

Selector Element
Eg: TMO, OTS, MSM, MIEC Diodes

Generic Two Terminal Memory Cell



J.J. Huang, et al, IEEE Int. Electron Devices Meet. (2011), p. 31.7.1–31.7.4

- ❑ Selector devices are critical to eliminating sneak current paths
- ❑ Selectors needed to address performance, density and reliability requirements

Survey of NVM Selector Current Options

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Type	MIEC	IMT	Tunnel barrier	FAST	OTS	Binary OTS
Material	Cu-based	NbO x	TaO /TiO /TaO	Unknown	AsTeGeSiN	SiTe
Source	IBM, 2012	POSTECH, 2015	POSTECH, 2014	Crossbar, 2014	SAIT, 2012	POSTECH, 2016
On. J [MA/cm^2]	0.08 (0.9 V)	4	>10 (2 V)	3	10	10
Off. J [kA/cm^2]	0.004	23	10	0.001	2	0.01
Selectivity	10^4	$>10^2$	10^2	$>10^6$	$>10^3$	10^6
SS [mV/dec]	100	<10	200	<5	<50	<1
Delay Time [ns]	50	?	20	30	20	10
Transition [ns]	15	<50	<20	5	5	2
Process T. [°C]	?	RT	300	300	?	RT

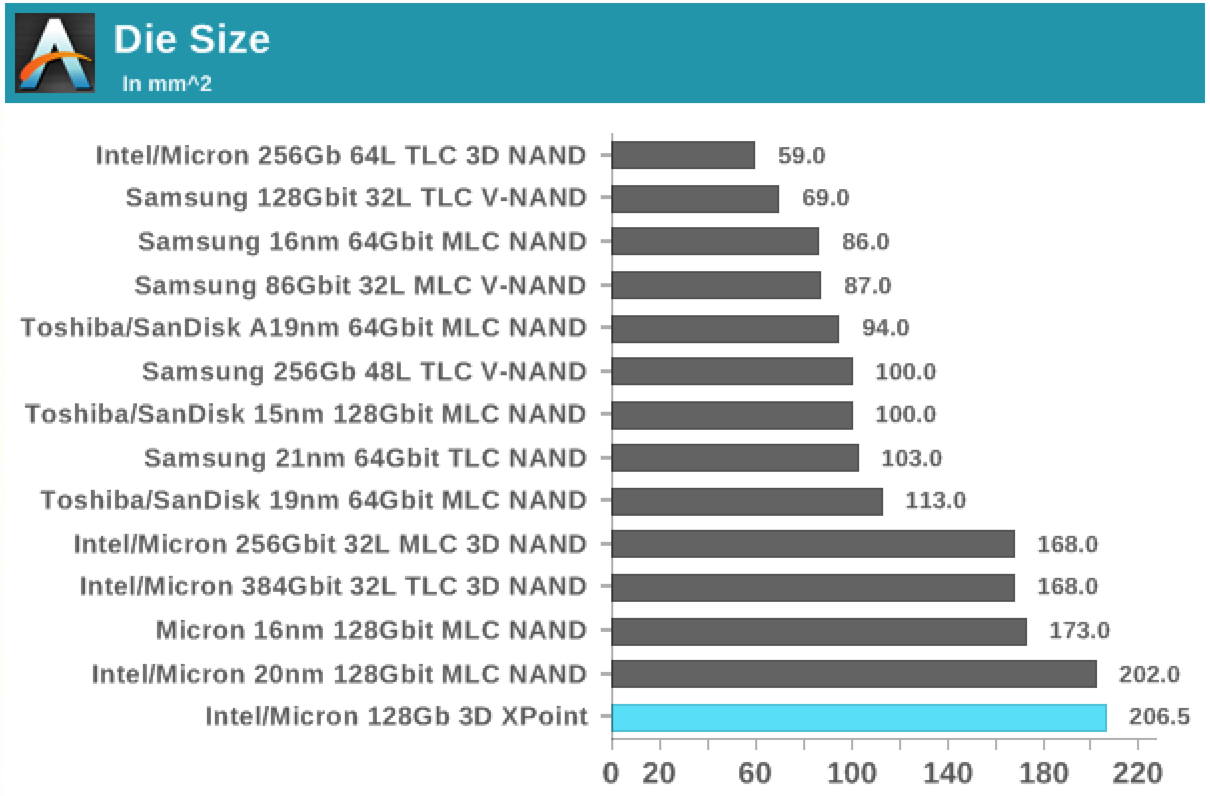
Ref: Chen, et al. Journal of Electroceramics (2017): 1-18.
Y. Koo, K. Baek, H. Hwang, In 2016 Symp. VLSI Technol. (2016)

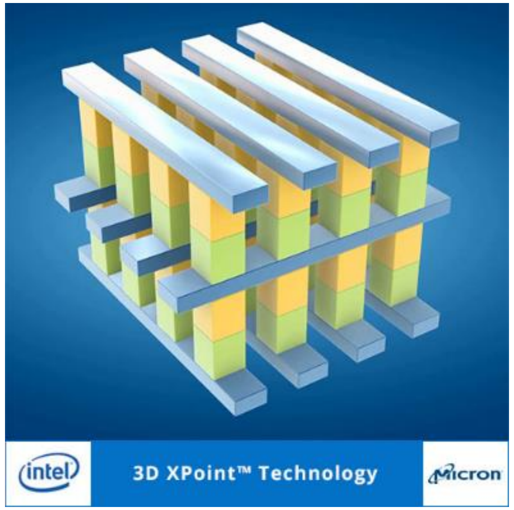
MIEC: Mixed Ionic Electronic Conduction
IMT: Insulator Metal Transition
FAST: Field Assisted Superlinear Threshold selector
OTS: Ovonic Threshold Switch

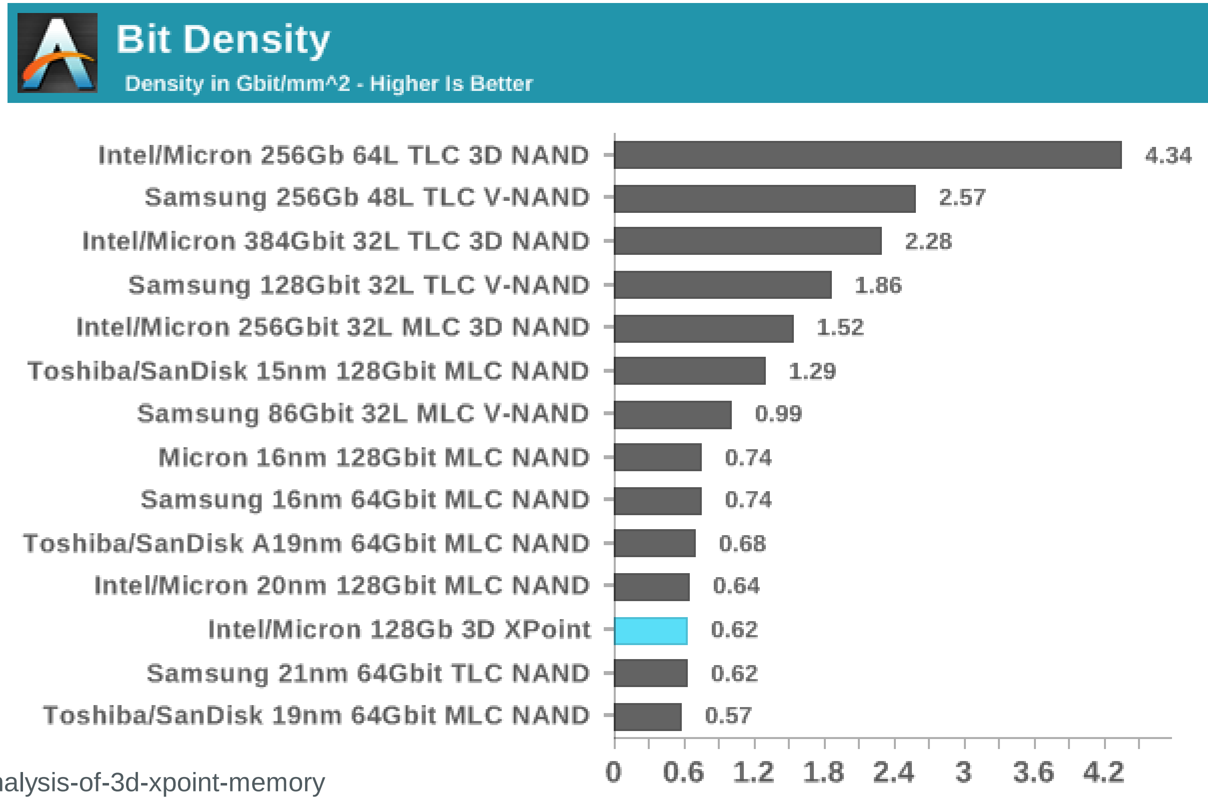
- Choice of selector materials & devices in 3D implementation requires concurrent evaluation for performance, reliability, cost and ease of integration

3D XPoint Size and Density

INTERMOLECULAR





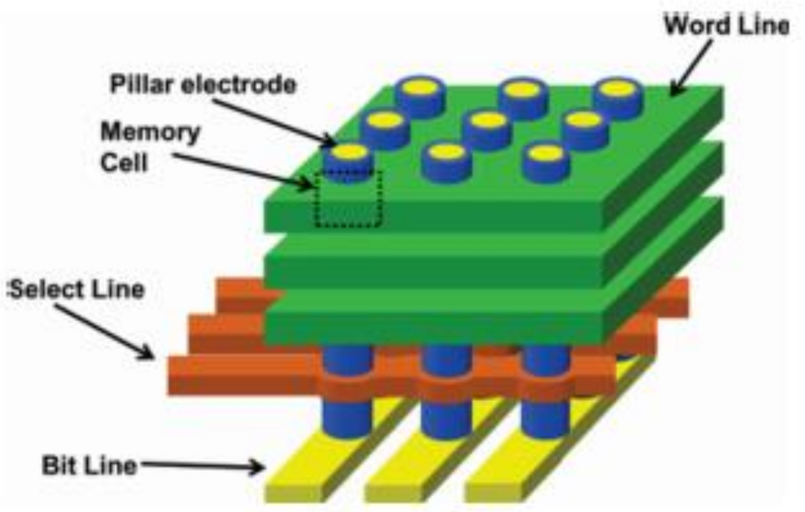


Size and density most similar to planar NAND

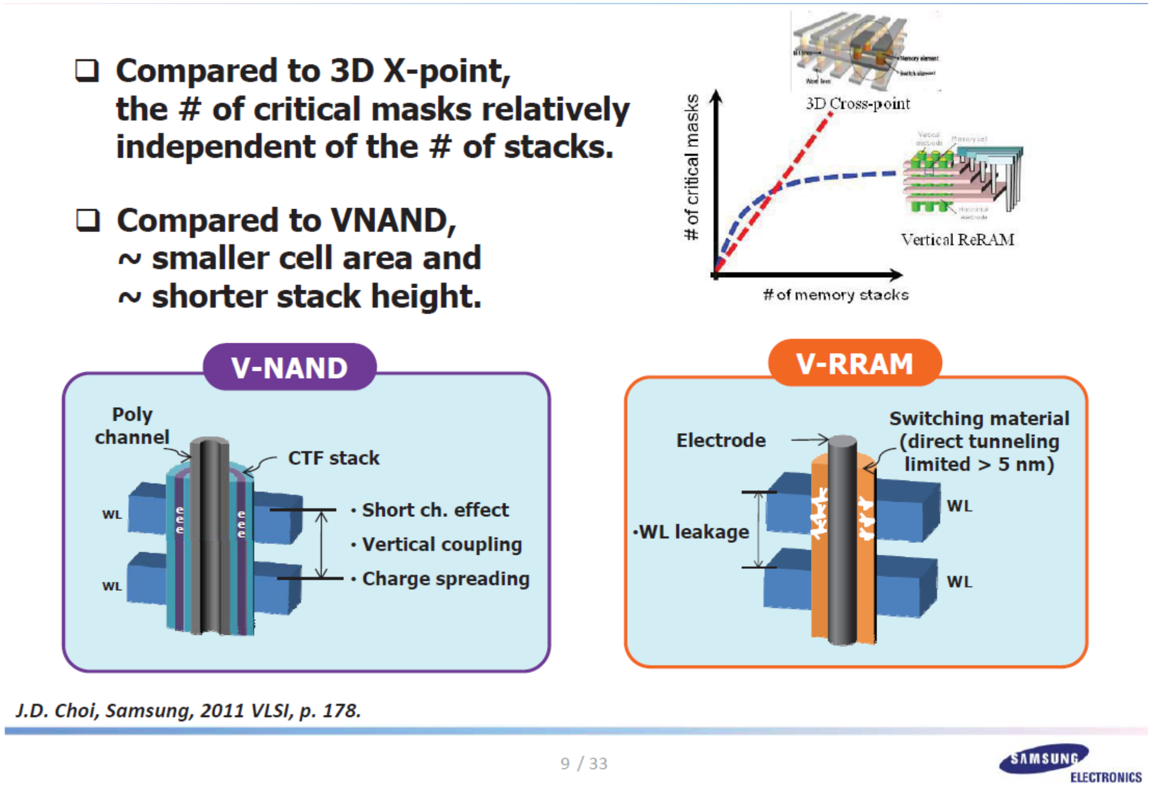
Critical litho for each layer may be cost disadvantage vs. 3D NAND type flow with increasing layer counts

Source: ANANDTECH http://www.anandtech.com/show/11454/techinsights-publishes-preliminary-analysis-of-3d-xpoint-memory

3D Vertical NVM – Conformal Selectors:



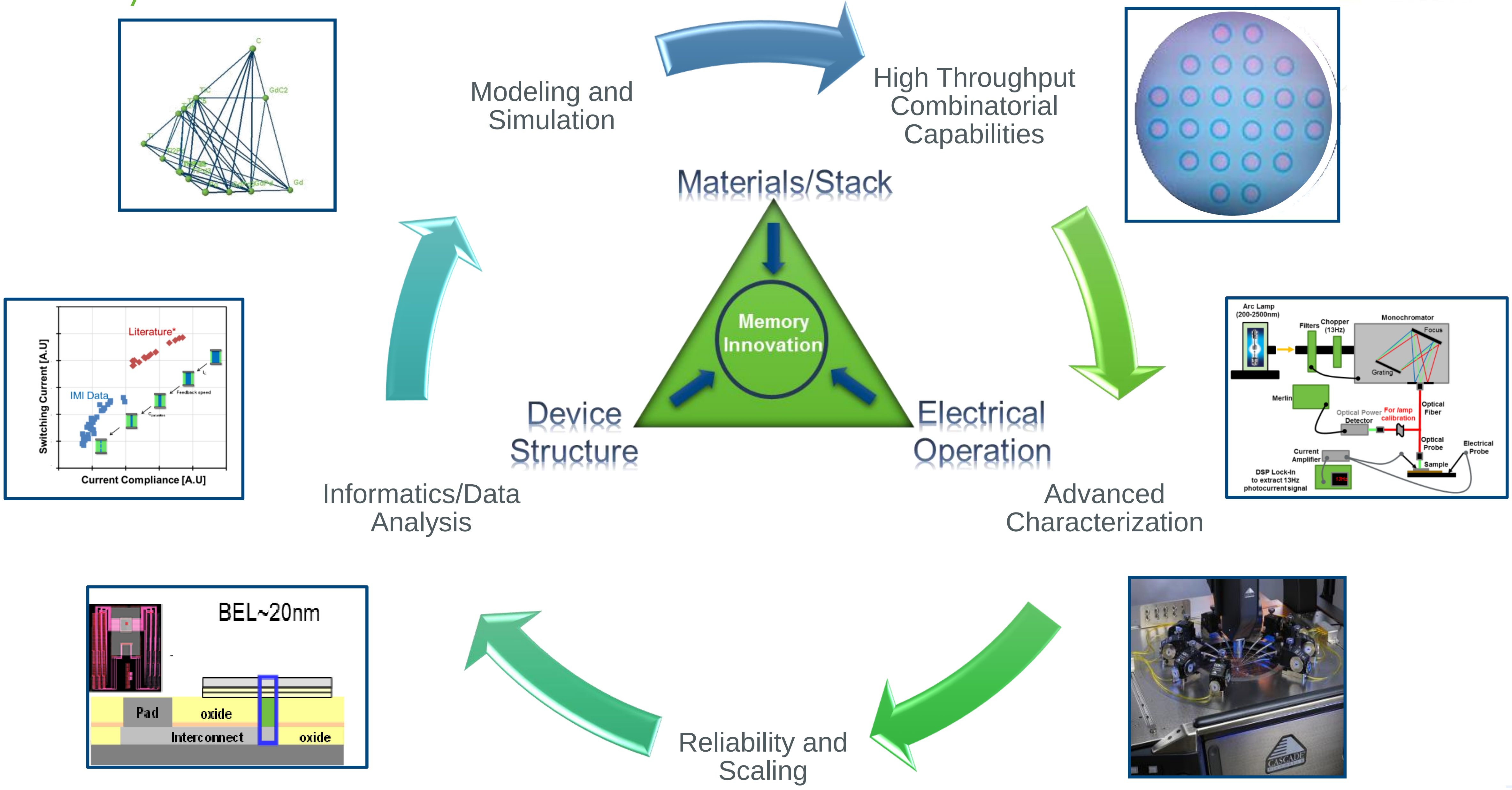
Y. Deng, et al, IEEE Int. Electron Devices Meet. (2013), p. 25.7.1–25.7.4.



Need a conformal selector or self regulating cell (perhaps difficult to realize)

IMI Capabilities:

Memory Materials and Device Innovation

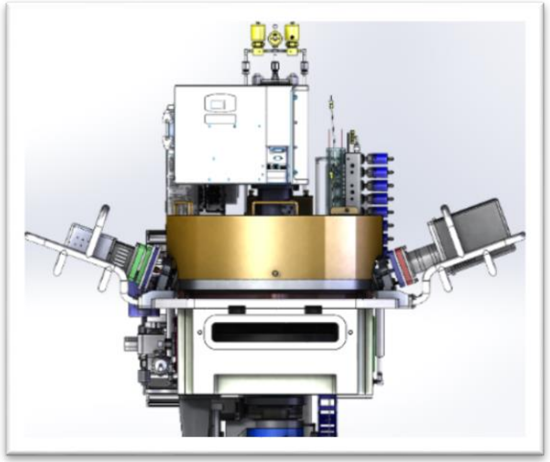


ALD Chalcogenides (ChG)

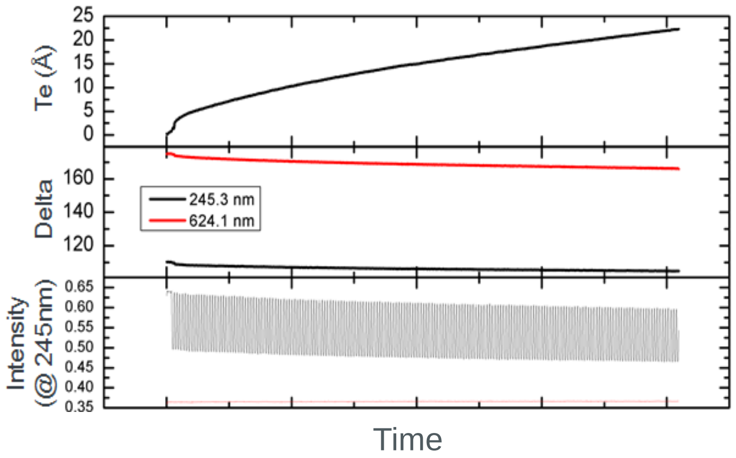
Key challenges

- Chalcogenides are used in advanced NVM applications
- 3D Vertical NVM architecture requires highly conformal deposition processes (e.g. ALD)
- Layered binaries require uniform composition and interface control
- ALD chalcogenide chemistry is complex and not well understood (i.e. not as simple as reactions with O_3 or NH_3)
- Elemental ALD is desirable to adjust stoichiometry of base system as memory/selector behavior is composition dependent
- Simplest chemistry is desired which also achieves performance requirements (e.g. stoichiometry, step coverage, thermal stability, electrical performance)

A-30 300mm ALD chamber with in-situ spectroscopic ellipsometry

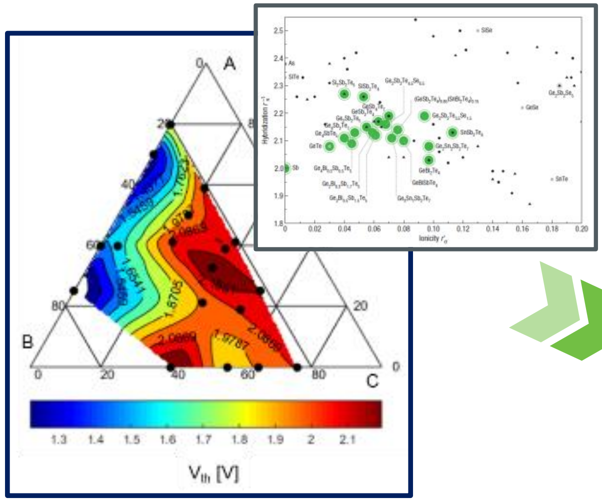


In-situ ALD Te growth monitoring on SiO2



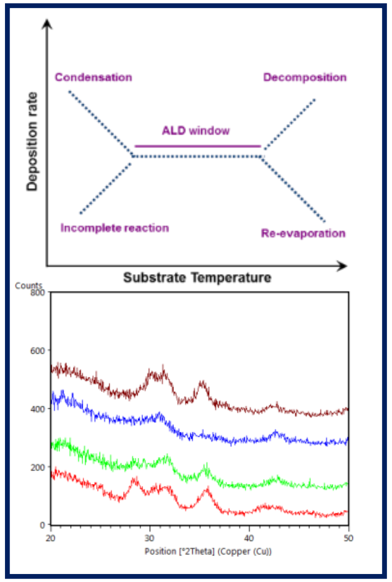
ALD Chalcogenide Selector Screening

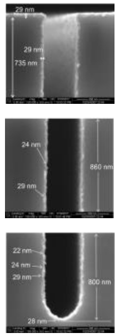
Material Selection



Select Promising Compositions (Leverage PVD Data/Modelling)

Process Development and Materials Characterization

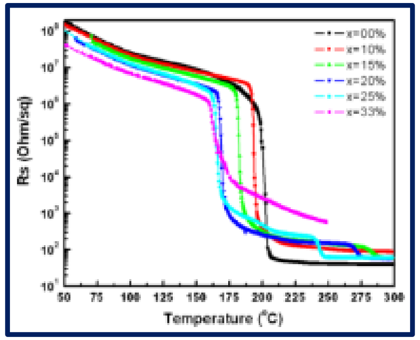




L(Se,Te) + R → (Se,Te) + RL ....etc.

Screen ligands/Develop ALD Unit Processes

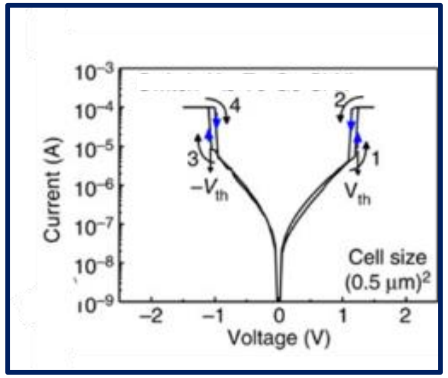
Thermal Stability & Resistivity



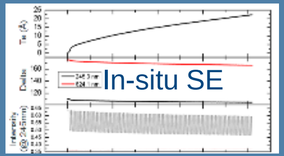
Test ALD Stacks and Nanolaminates

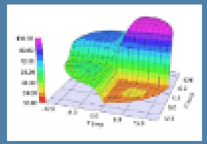
Parameter
Non-linearity
Threshold Voltage
Leakage (I_{off})
Switching time
Endurance

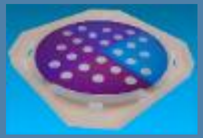
Electrical

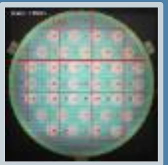


Electrical Response Feedback to Refine



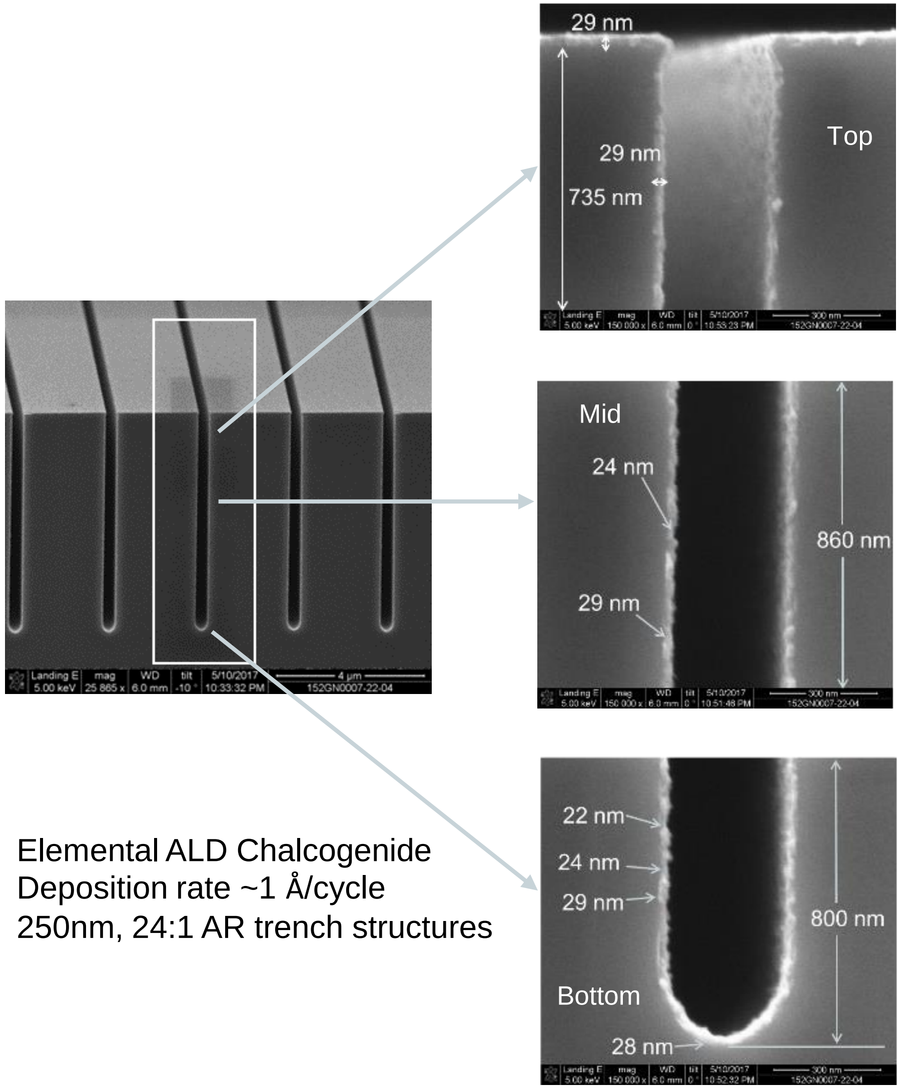




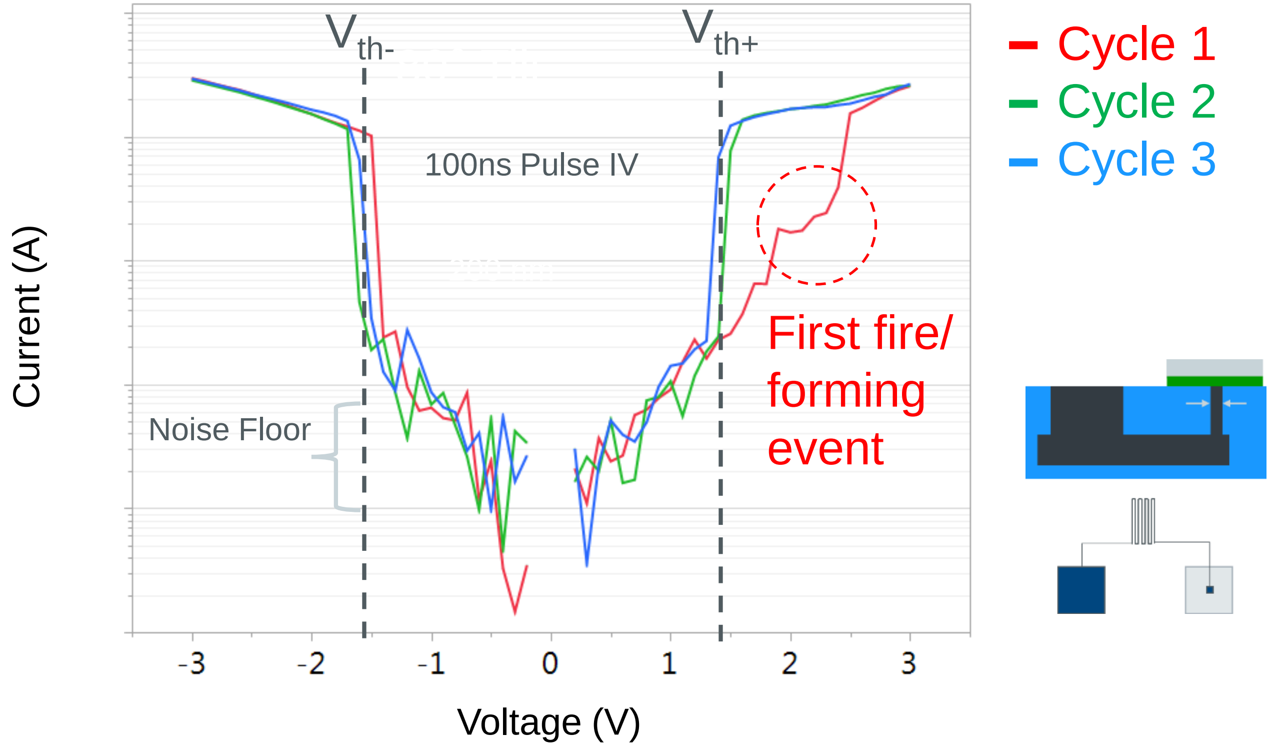


IMI A-30 ALD Chamber

ALD Chalcogenide Selector Initial Results



- Elemental ALD Chalcogenide
- Deposition rate ~1 Å/cycle
- 250nm, 24:1 AR trench structures



- ALD Chalcogenide Selector; elemental ALD to adjust composition of compound
- Conventional TiN Electrodes
- Pulse-mode electrical test (pulse width = 100 ns) shows clear, repeatable selector operation on 350 nm CD devices with forming event visible during first cycle
- Selector threshold voltage between 1.4-1.6V

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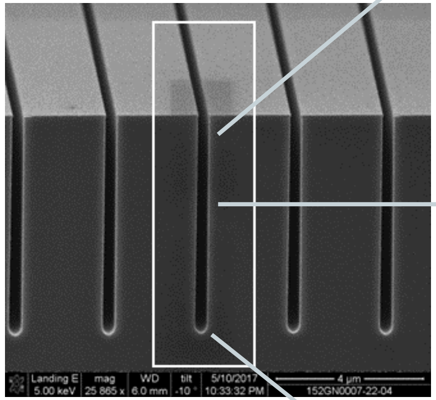

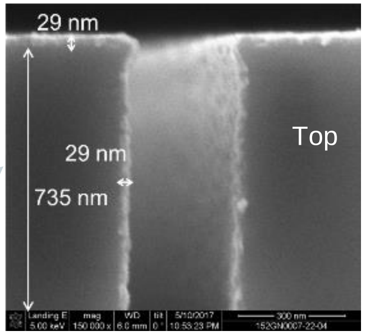

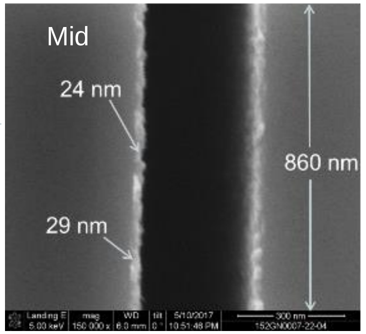

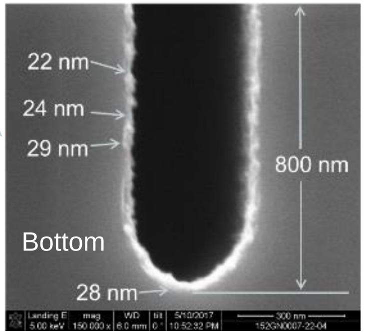

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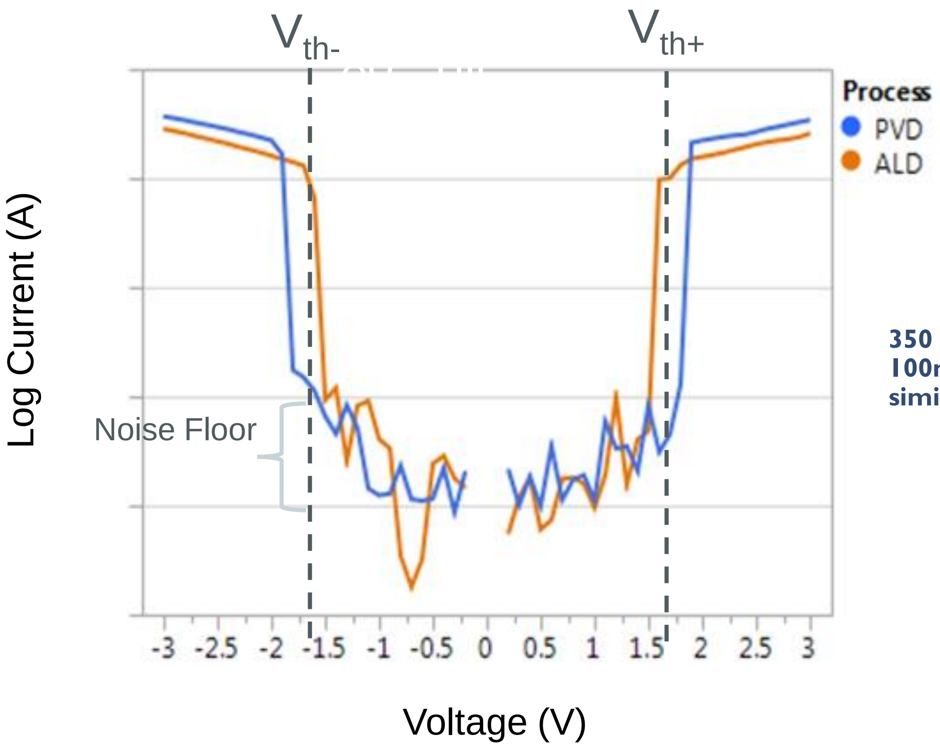

350 nm device size, 100ns Pulse IV, similar composition

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Summary

- 3D NVM architectures will require series connected non-linear selector elements
- Choice of selector materials & devices requires concurrent evaluation for performance, reliability, cost and ease of integration
- A conformal selector with layer by layer compositional control can open up potential integration schemes and provide additional materials engineering control
- Initial feasibility using ALD Chalcogenide selectors with good conformality and similar electrical performance to PVD demonstrated

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