NON VOLATILE MEMORY :
A WIDE SPECTRUM OF POTENTIAL SOLUTIONS

Etienne NOWAK, Head of Advanced Memory Lab
etienne.nowak@cea.fr

OUTLINE

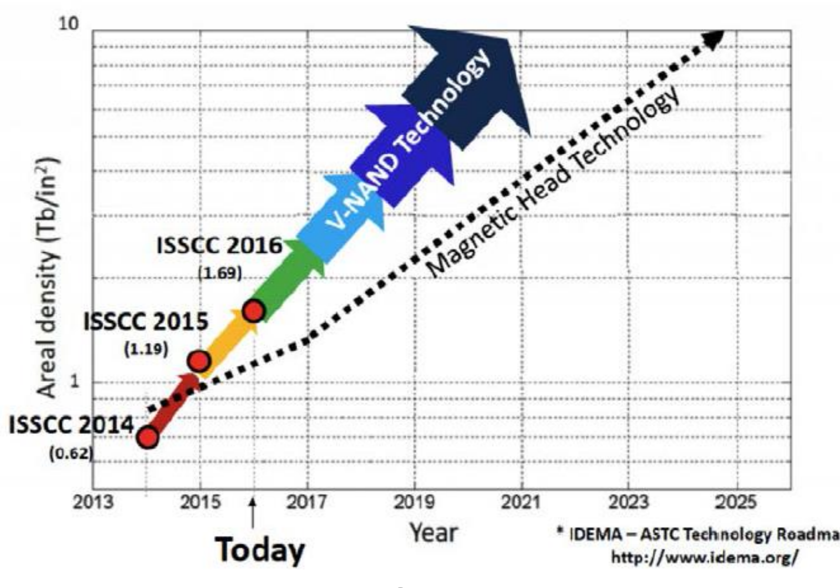
3D in Memory Product

What about Emerging Non Volatile Memory ?

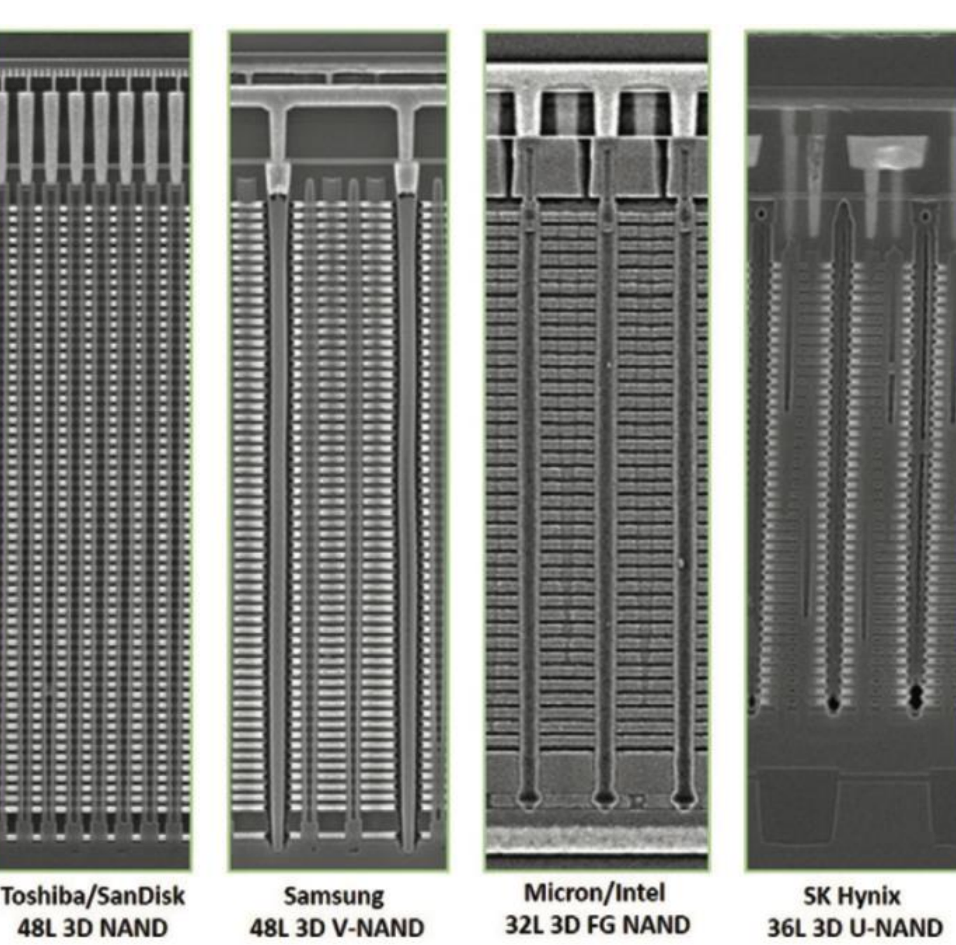
Emerging Non Volatile Memory at Leti

NAND FLASH IS A 3D TECHNOLOGY

- All NAND memory players have 3D memory product
- NAND Product transition from 1Ynm to 3D (48-64 layers)
- NAND density has surpassed HDD density



[H. Meinhard, 2016 ECFA Workshop]



[Techinsight]

Images not at same scale

NAND FLASH IS A 3D TECHNOLOGY

- Ultimate 3D architecture ?
- Layers are composed of
  - Transistor
  - Memory layers
  - Interconnection

3-4um

Toshiba/SanDisk 48L 3D NAND

Samsung 48L 3D V-NAND

Micron/Intel 32L 3D FG NAND

SK Hynix 36L 3D U-NAND

[Techinsight]

Images not at same scale

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Memory
Dummies memory
Transistors

3-4um

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[Techinsight]

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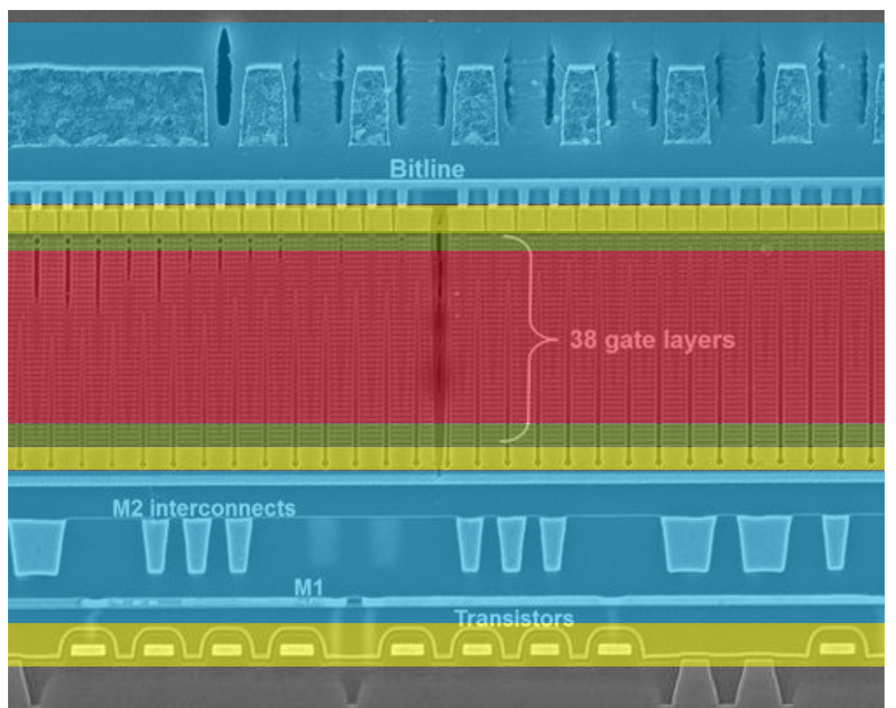
[Techinsight]

Images not at same scale

3D NAND FLASH PERIPHERY

- **NAND memory = Periphery + Memory array**
- **« Periphery under CMOS » improve array efficiency from 70% to 85%**

Memory **Transistors**
Dummies memory **Interconnection**



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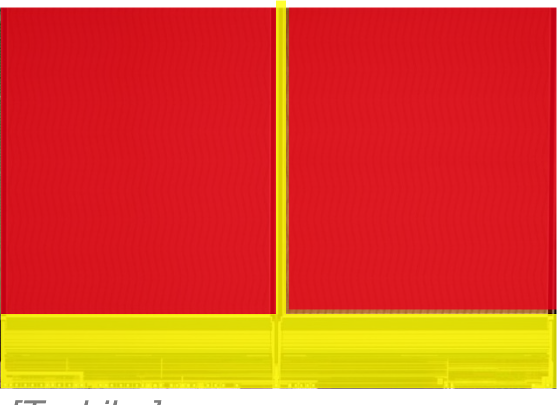
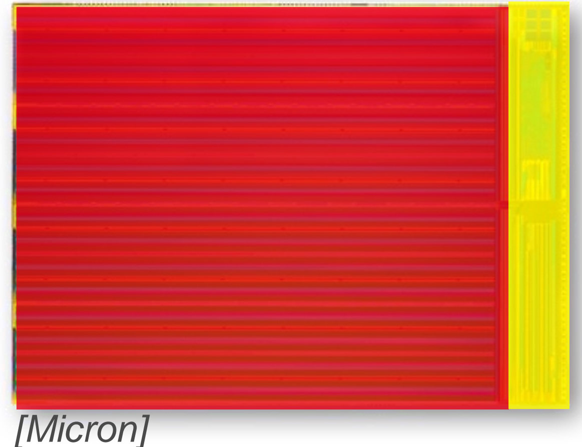
Toshiba/SanDisk 128Gb
Array efficiency ~70%



[Toshiba]

Micron Intel 256Gb
Array efficiency = 85%

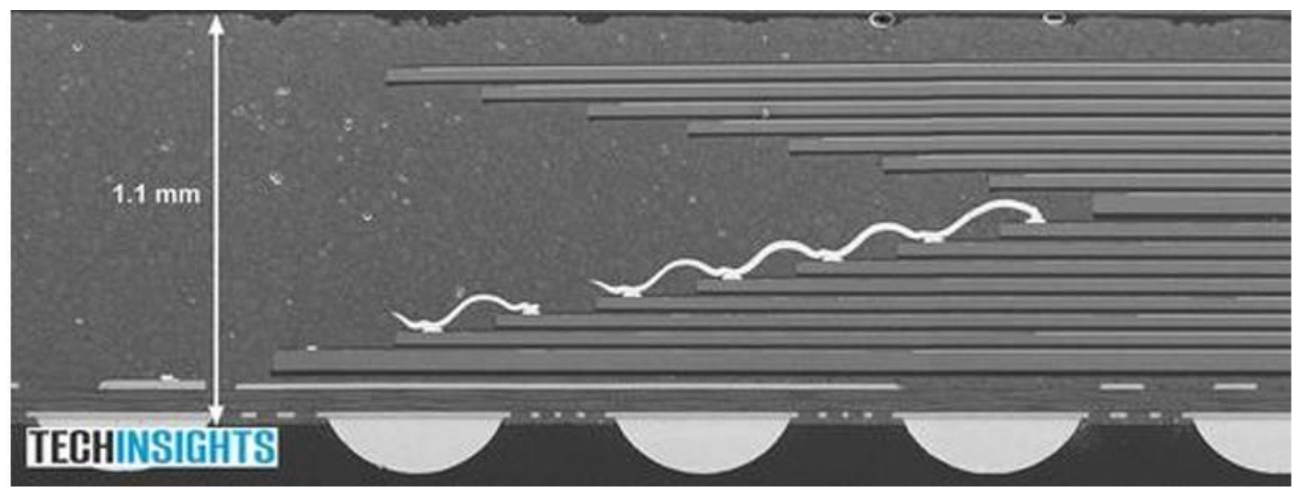


[Micron]

TYPICAL NAND PACKAGE

- Thinned die that are wire bonded
- Flash has high latency (10's of us)

16 Stacked Samsung 48L V-NAND Dies



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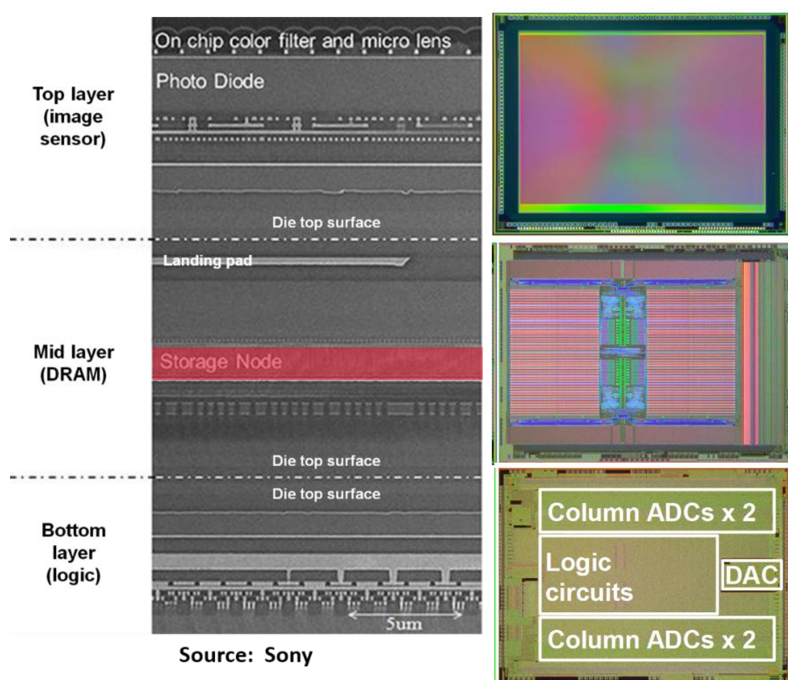
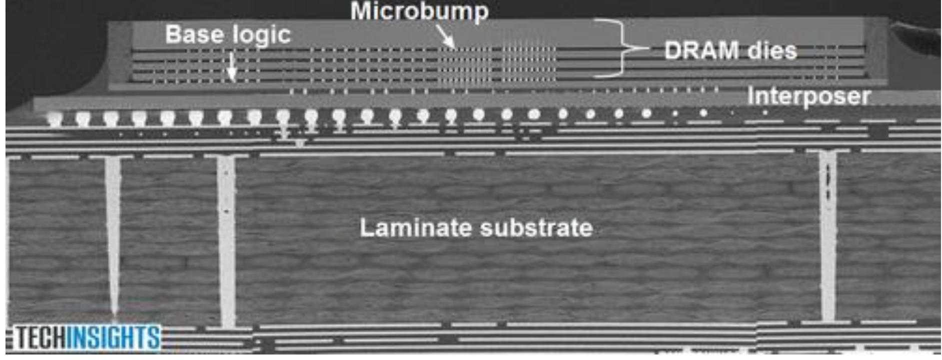
DRAM AS A COMPLEMENTARY APPROACH OF 3D

- DRAM continue « classical scaling » but used advanced packaging (TSV/ Micro bump)
- DRAM has a low latency (< 100’s ns)



[T. Haruta, ISSCC 2017]

[AMD/Hynix] HBM assembly
Radeon Fury X



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OUTLINE

3D in Standalone memory

What about Emerging Non Volatile Memory ?

Emerging Non Volatile Memory at Leti

GENERAL MARKET TREND FOR EMERGING NVM

- **Scaling at constant performances**
  - Density
  - Latency

➔ **Higher Density or Speed**

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NAND

DRAM

GENERAL MARKET TREND FOR EMERGING NVM

- **Scaling at constant performances**
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➔ **Higher Density or Speed**

NAND DRAM

- **Low/No energy consumption**
  - Cost of Si ownership due to power (Server)
  - Battery based system (IoT/VR/AR)

➔ **Deeper integration of Non Volatile Memory in computing**

- **New Market forces**
  - Deep Learning / Artificial Intelligence

➔ **Blurred Computation/Memory frontier**

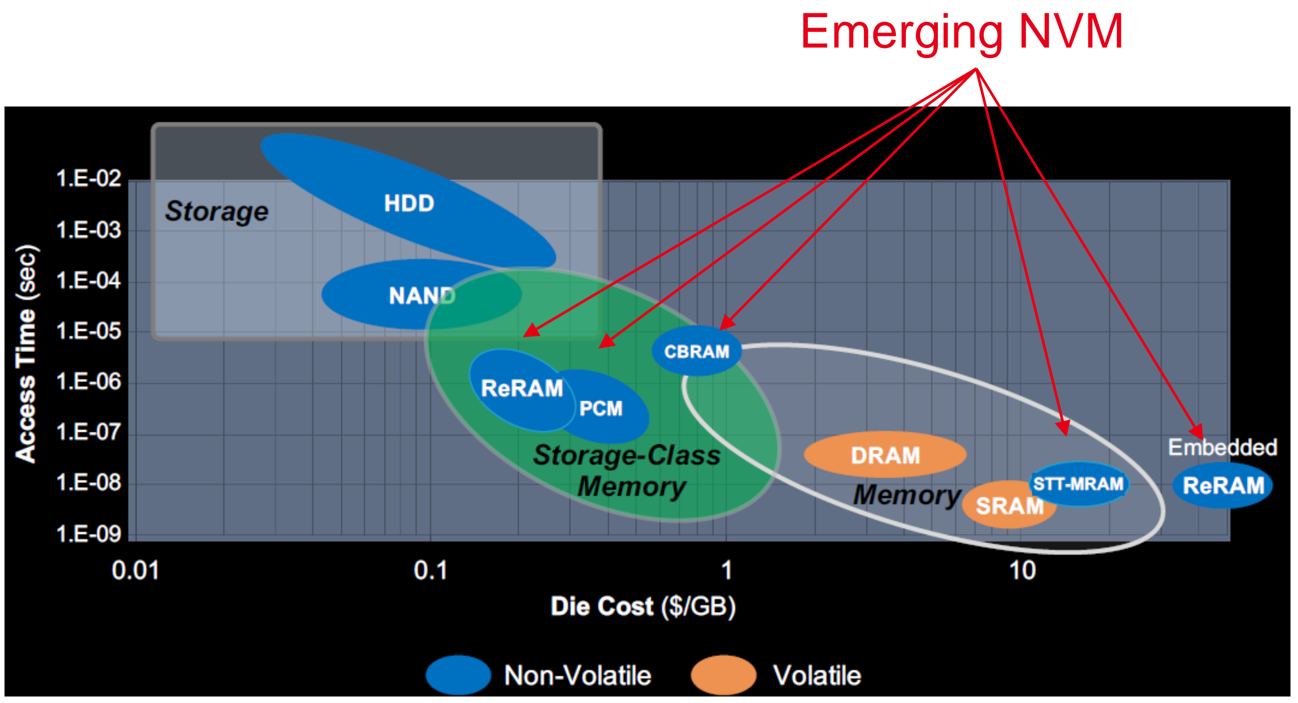
2016 MEMORY MARKET DIRECTION

- **PCM revival**
  - Intel/Micron : 3D XPoint 128Gb product
  - ST : 28nm annouced
- **MRAM confirmation**
  - Everspin : 256Mb product (1Gb annouced)
  - GF : embedded on 22nm
  - Samsung : embedded on 28nm
- **OxRAM/CBRAM continue**
  - Panasonic 0,18um product
  - UMC : 40nm annouced
  - Adesto: 512kb product
  - Crossbar/SMIC : 40nm annouced
- **FeRAM**
- **Mott memory, …**

→ **All emerging memories are going to market**

→ **Emerging memories are complementary, no clear winner**

2016 MEMORY HIERARCHY



[Siva Sivaram, Western Digital, Flash memory summit 2016]

2016 MEMORY HIERARCHY

Emerging NVM

Storage
HDD
NAND
CBRAM
ReRAM
PCM
Storage-Class Memory
DRAM
Memory
SRAM
STT-MRAM
Embedded ReRAM

Access Time (sec)
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
1.E-09

0.01
0.1
1
10

Die Cost ($/GB)

Non-Volatile
Volatile

[Siva Sivaram, Western Digital, Flash memory summit 2016]

3D Scaling

2016 MEMORY HIERARCHY

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Die Cost ($/GB)

Non-Volatile
Volatile

Advanced 3D Packaging with logic

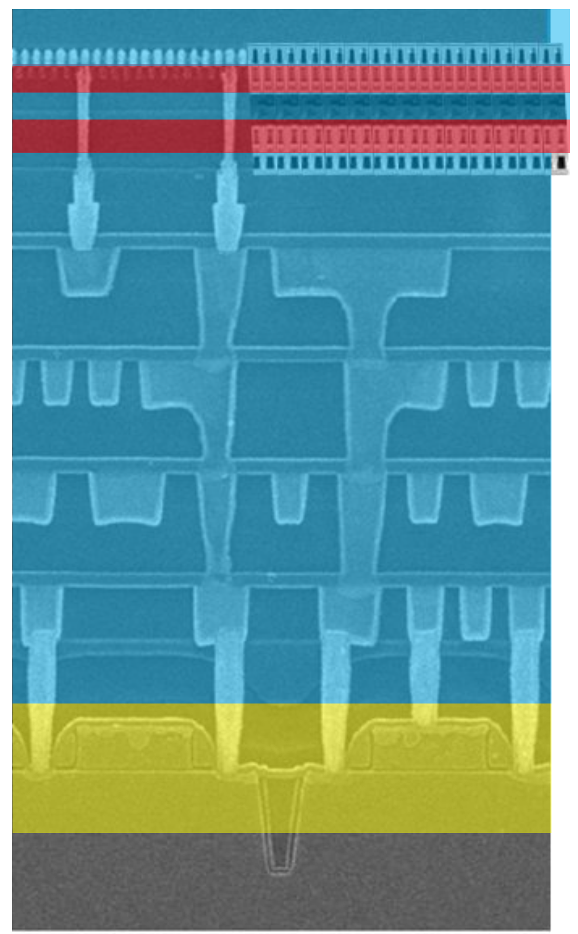
Embedded within logic

[Siva Sivaram, Western Digital, Flash memory summit 2016]

3D Scaling

« EMERGING NVM » IN PRODUCTION INTEL/MICRON 3DXPOINT

- 2 memory layers above CMOS
- NVM Memory layers above CMOS (91% Array efficiency)



[composed from TechInsights images]

Memory
Transistors
Interconnection

2016 MEMORY HIERARCHY

Emerging NVM

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[Siva Sivaram, Western Digital, Flash memory summit 2016]

3D Scaling

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LETI TECHNOLOGY SOLUTION FOR NVM
ASSESS TECHNOLOGY ON THE SAME PLATFORM

- MAD (Memory Advanced Demonstrators) test vehicule allowed to compare different technology on the same demonstrator

Leti BEOL memory

+

Foundry CMOS

ReRAM demonstrator
(1R, 1T1R, 4 Kb, 1 Mb)

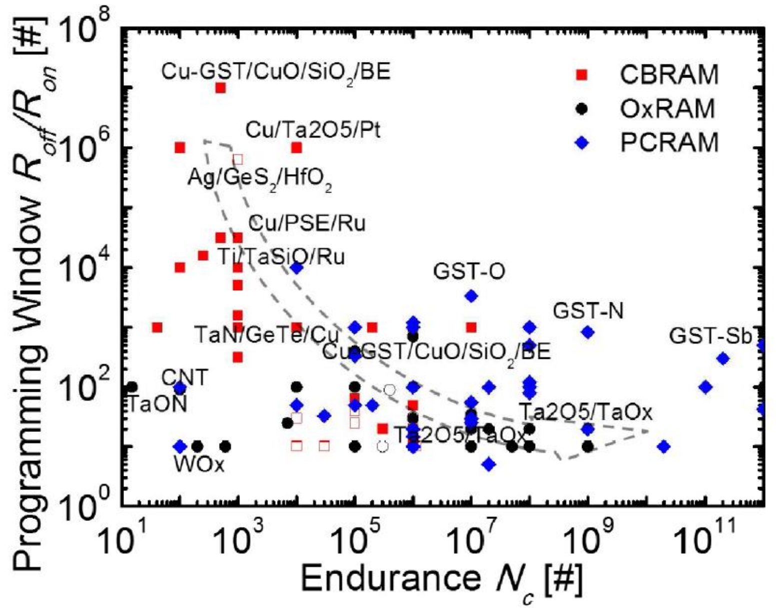
2016 LETI NVM ACHIEVEMENTS

- Test Vehicle MAD operational with most emerging memory integrated

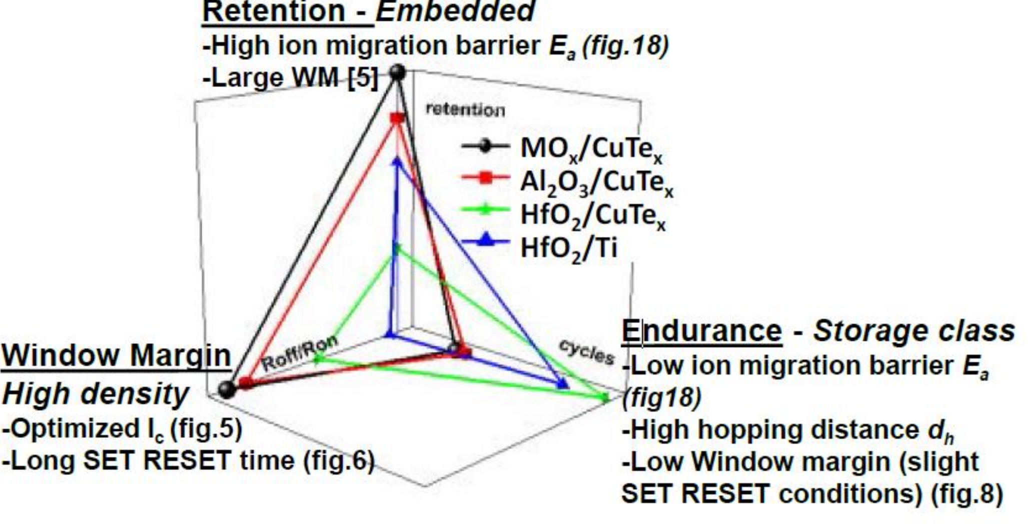
→ Leti knowledge upgraded from single cell to matrix and complex design while continuing integration of new materials

LETI NVM PERFORMANCES ASSESSMENT

- General tradeoff between endurance, retention and window margin trade-off is observed
- Emerging memories are complementary with no clear winner



[L. Perniola, IMW 2016]



[C. Nail, IEDM 2016]

What does 3D change for NVM in Leti

3D Customize materials

3D Innovative design

Material Analysis

eNVM

Future solutions

TCAD & modeling

Critical NVM module devlpmt 3D

Tailored electrical Test

- A wide toolbox enables **customized** research with **our partners** and a **benchmark** between different technological solutions

Conclusion

Conclusion

- Memories are 3D
  - 3D technologies are used in Flash for Cost (Highest Density)
  - 3D packaging are used in DRAM for Performance (Latency)
- Emerging NVM performance spaces are at the limits between 3D technology and 3D packaging
- Emerging NVM are complementary with no clear winner
- NVM consist of “Memory + CMOS+ interconnect” layers at state of the art lithographic pitch
- Leti technology able to assess most emerging NVM technology in order to choose the right “3D” that associated with it

Thank you for your attention

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LETI MEMORY WORKSHOP

MEMORY OF THE FUTURE
FROM CONCEPT TO MARKET

TUESDAY, JUNE 27, 2017
MINATEC, GRENOBLE

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Minatec Campus | 17 rue des Martyrs | 38054 Grenoble Cedex | France
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