Versatile RRAM Technology and Applications

Hagop Nazarian

Co-Founder and VP of Engineering, Crossbar Inc.

Agenda

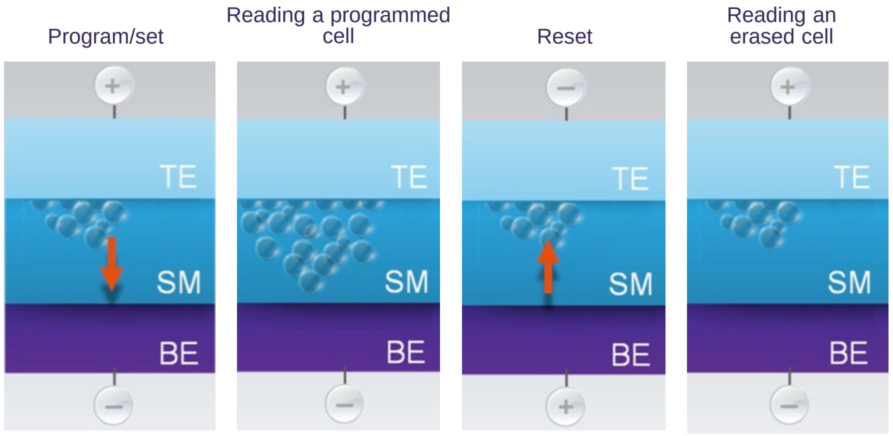
- **Overview of RRAM Technology**

- **RRAM for**
  - Embedded Memory
  - Mass Storage Memory
  - Storage Class Memory
  - FPGA Configuration, NVRAM,
    State Retainer
  - Monolithic system integration

Flash Memory Summit 2015
Santa Clara, CA

Crossbar’s RRAM Technology

- Simple device structure using fab friendly materials and process
- Information is stored in the form of metallic nano-filament in a non-conductive layer
- Filamentary-based switching by electric field

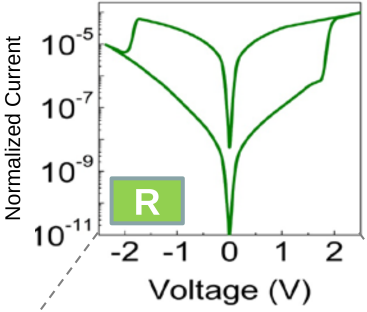


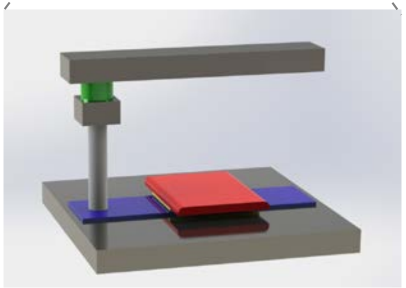
LOW RESISTANCE
(LRS or ON)

HIGH RESISTANCE
(HRS or OFF)

Crossbar Technology

Crossbar **R**RAM Cell

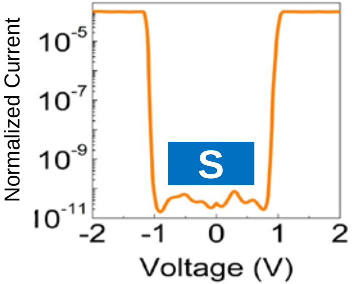




Suited for low latency, high speed embedded memory

+

Crossbar **S**elector



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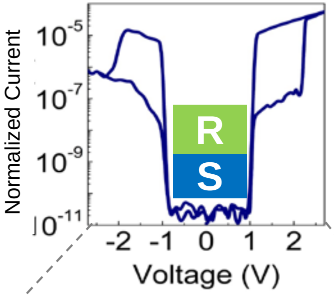
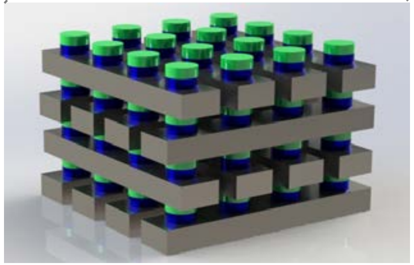
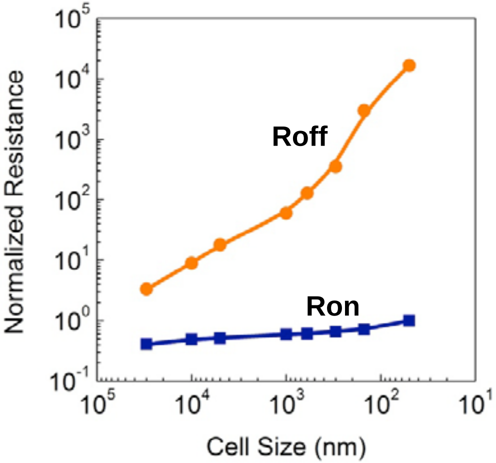
Crossbar **SR** Cell



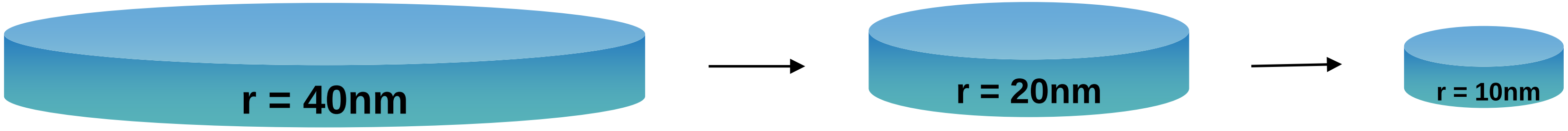


Suited for high density high performance NAND or SCM memory

Scaling Improves Crossbar RRAM



- **Scaling RRAM device**
  - Roff increases by $\frac{1}{Cell\ Area}$
  - Ron Stays nearly constant
- **Roff/Ron ratio improves**
- **Sensing window improves**
- **Improves BER**
- **Provides additional margin for MLC/TLC**

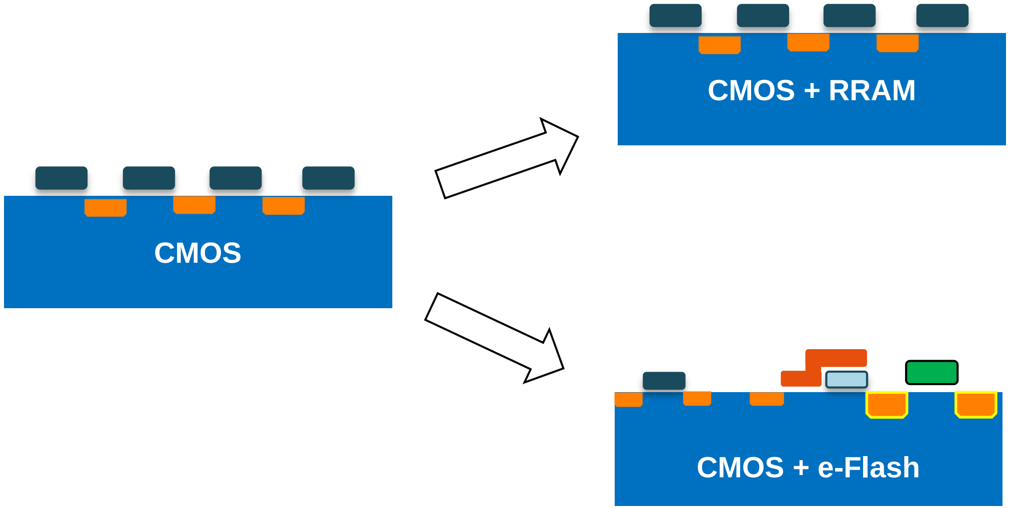


Ioff=1uA
Roff=1MΩ

Ioff=0.25uA
Roff=4MΩ

Ioff=62nA
Roff=16MΩ

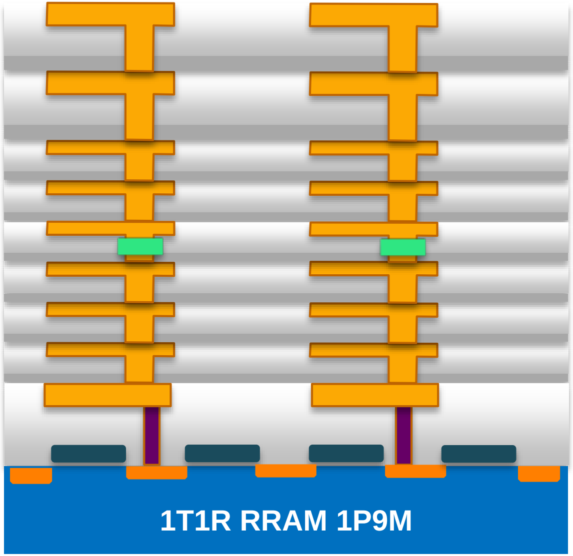
Benefits of Crossbar Embedded RRAM



- No Change to Front-end

- Major changes to Front-end
  - Complex cell
  - High voltage transistors
- Adds 6+ Masks & 40 steps

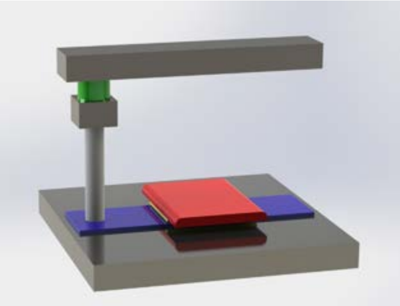
Benefits of Crossbar Embedded RRAM



- Back-end process – minimum impact
- RRAM located between metal layers
- Adds only 2 masks & 8 steps
- 32% lower cost
- Smaller die size

Advantages of RRAM for Embedded Memory

Scales with advanced nodes



Reduced Manufacturing Complexity

- CMOS compatible material
- Back-end process - No change in front-end

Cost

- Reduced masking steps

Performance

- Byte/Page Alterability
- Write operation – no need for block erase

RRAM for Mass Storage

Performance

- Latency reduction
- Byte/Page alterability
- Smaller page sizes
- Write - no need for block erase

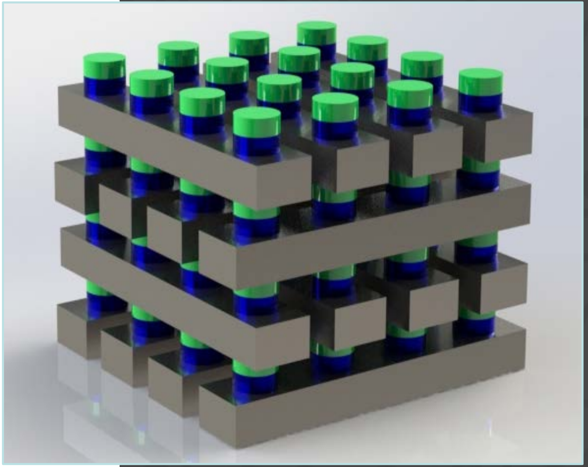
Superior endurance & retention

Density and Scalability

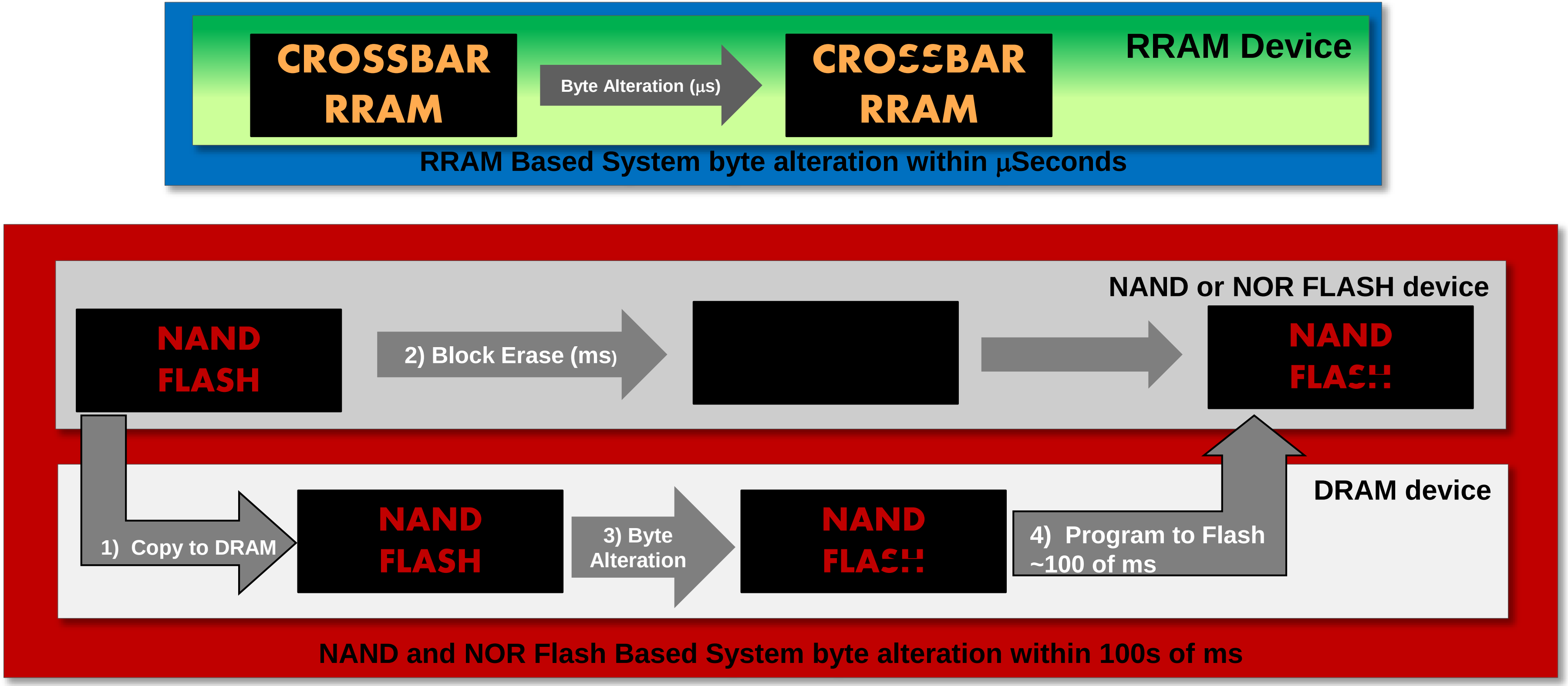
- 3D crosspoint array stackable at advanced nodes

Utilizes standard CMOS process

- Mass storage available to Fabless companies



Crossbar Memory Byte/Page Alterability Demonstration



RRAM Device

CROSSBAR RRAM

Byte Alteration (µs)

CROSSBAR RRAM

RRAM Based System byte alteration within µSeconds

NAND or NOR FLASH device

NAND FLASH

2) Block Erase (ms)

NAND FLASH

DRAM device

1) Copy to DRAM

NAND FLASH

3) Byte Alteration

NAND FLASH

4) Program to Flash ~100 of ms

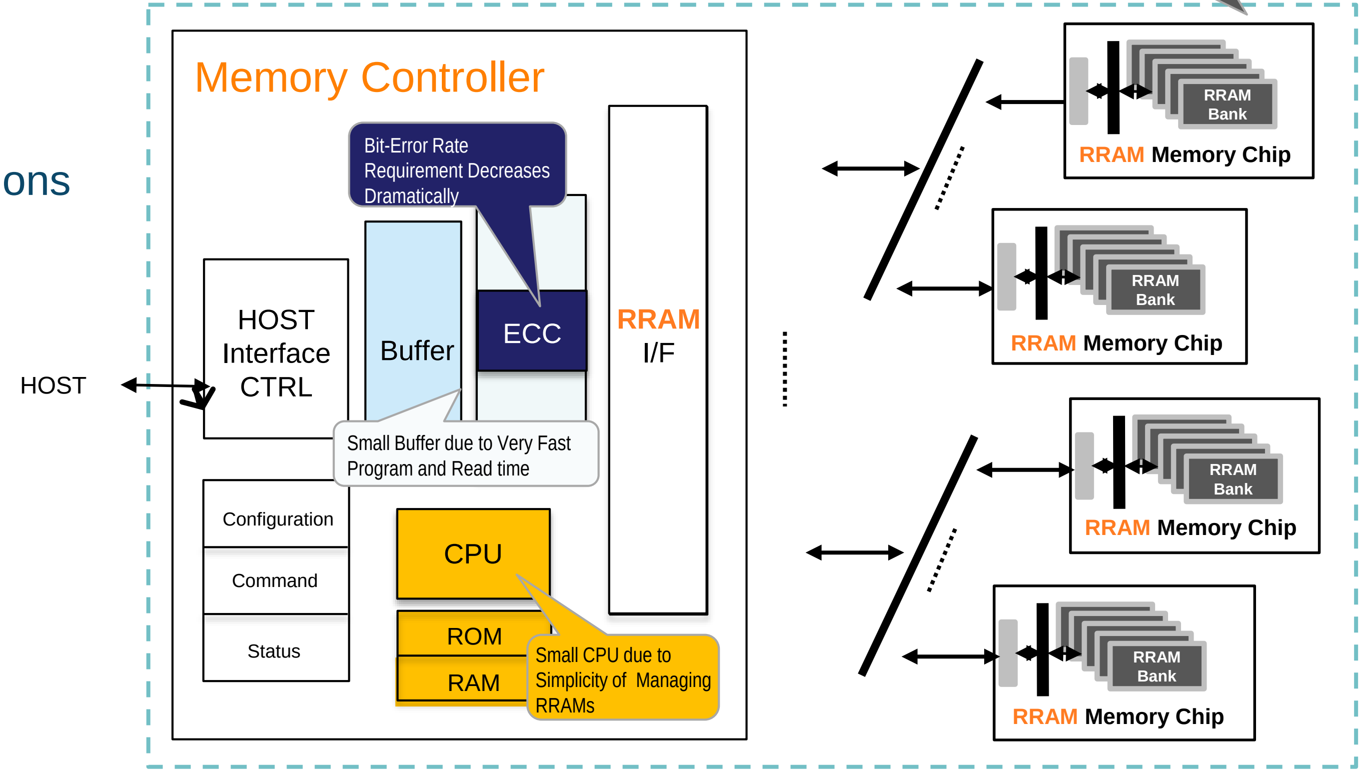
NAND and NOR Flash Based System byte alteration within 100s of ms

RRAM-Based Storage Card

Services
20X
More Transactions

Responds to
Transactions
30X Faster

Performance Increases Substantially



Nand Memories are Replaced with RRAM

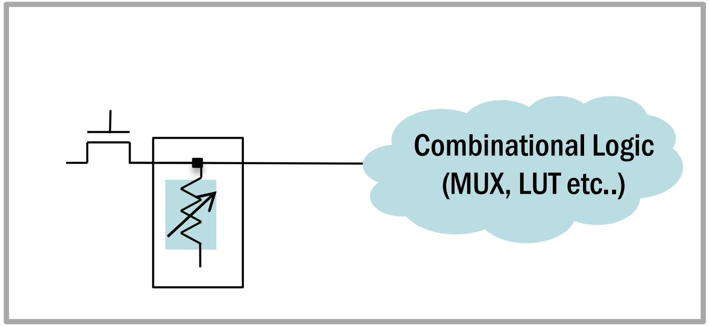
Bit-Error Rate Requirement Decreases Dramatically

Small Buffer due to Very Fast Program and Read time

Small CPU due to Simplicity of Managing RRAMs

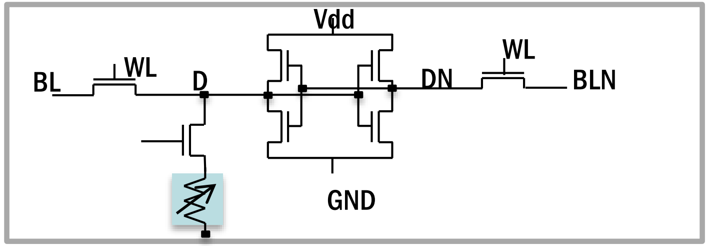
Crossbar Patented IP Libraries

FPGA Configuration Bit

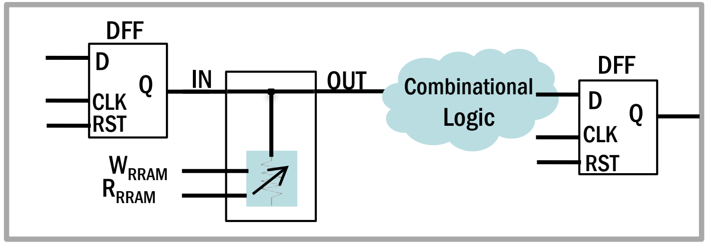


- Instant On
- Eliminates external non-volatile memory

NVRAM



State Retainer

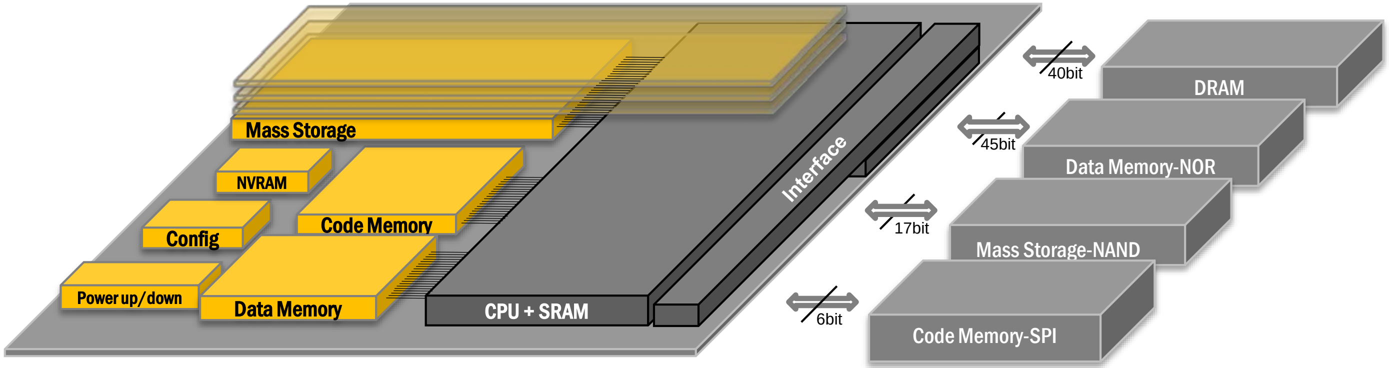


- Stores data at power down
- Recalls at power up
- Power saving

RRAM for FPGA Configuration Bits, NVRAM, State Retainer

- **Major Advantages:**
  - NV Configuration bit
  - Area reduction
  - Performance improvement
  - Power reduction
  - Instant on
    - No need for external non-volatile memory
  - Embedded non-volatile memory for data/code/storage

RRAM for Monolithic Integration



- Elimination of large number of I/Os, and simplification of the external interface
  - Reduction of components
  - Power reduction due to elimination of large number of I/O

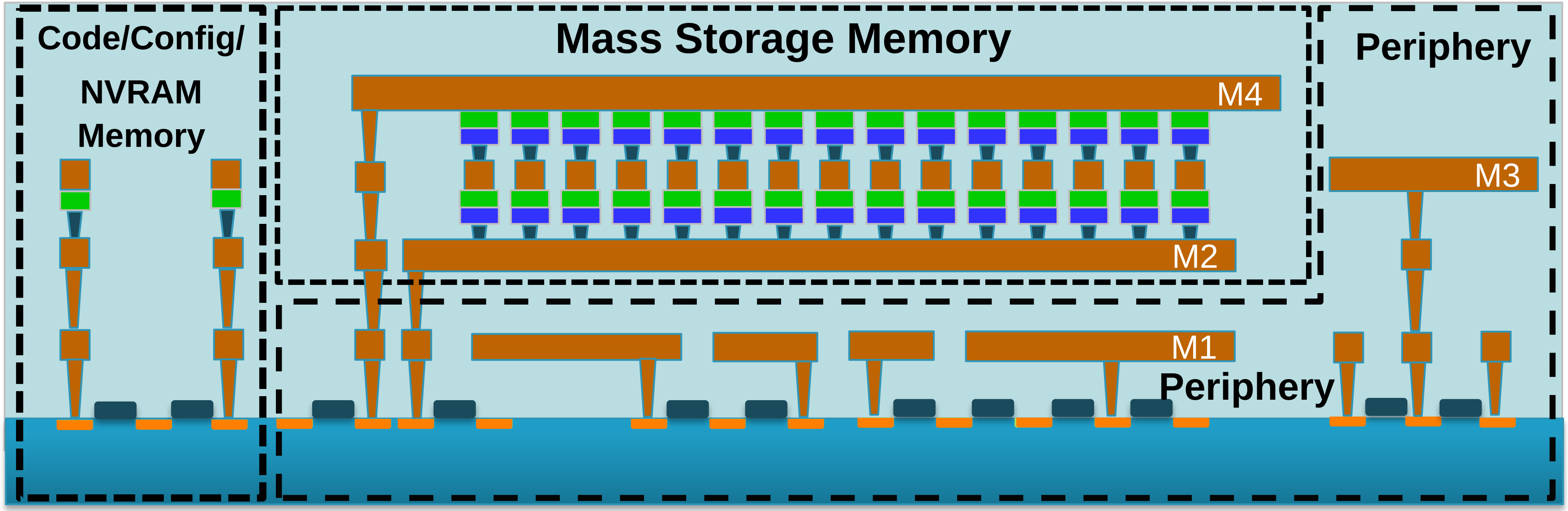
- Breakthrough performance
  - Direct wide bus connection between memory and CPU/peripheral devices

Crossbar technology = True high performance integrated system

Monolithic Integration of NVMemory with Crossbar RRAM

Crossbar RRAM Technology Enables Monolithic integration of:

Embedded memory with **1T1R**	SCM with 1T1R or **1TnR**	Mass storage with **1TnR**	FPGA configurable logic, CPU with **1T1R**

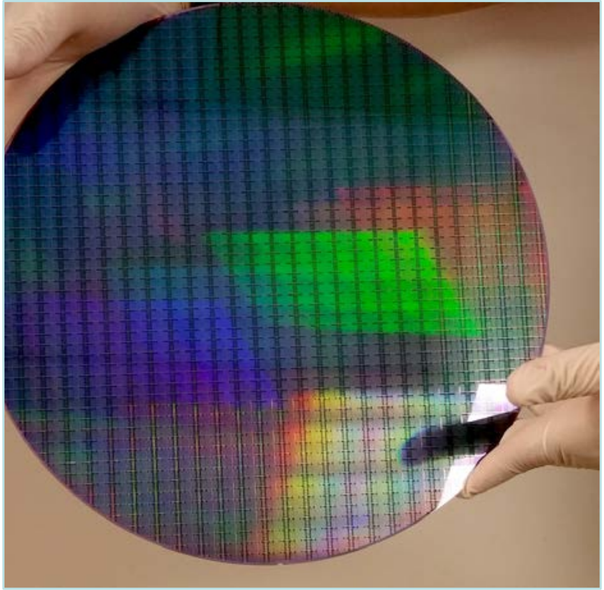


Crossbar Unique RRAM Versatile Technology

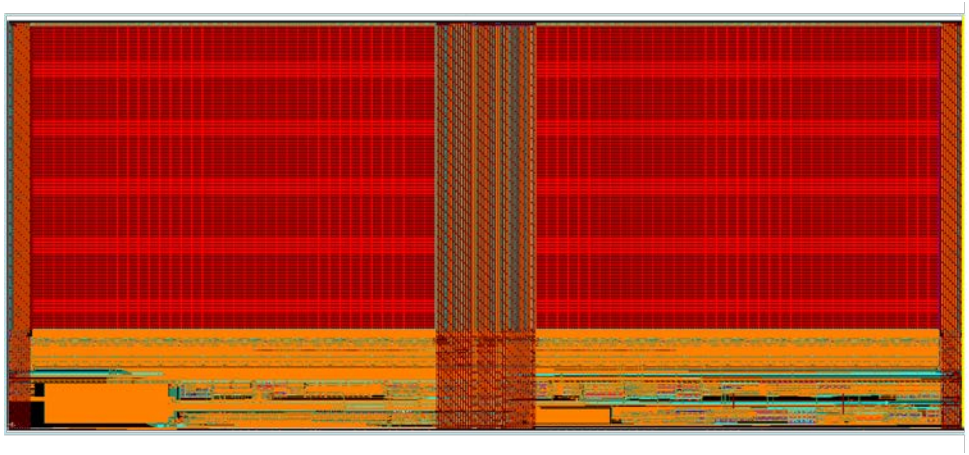
- Monolithic integration of Storage, Code, Data, FPGA configuration bit memories in one silicon
- Breakthrough system performance enabled with the monolithic integration of various memory architectures
- Fabless companies access IPs for a complete memory solution (storage, code, data, and FPGA configuration) from CMOS foundries

Ready for Business

Crossbar **RRAM 300mm Wafer**



Crossbar **RRAM Die**



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