Versatile RRAM Technology and Applications

Hagop Nazarian

Co-Founder and VP of Engineering, Crossbar Inc.

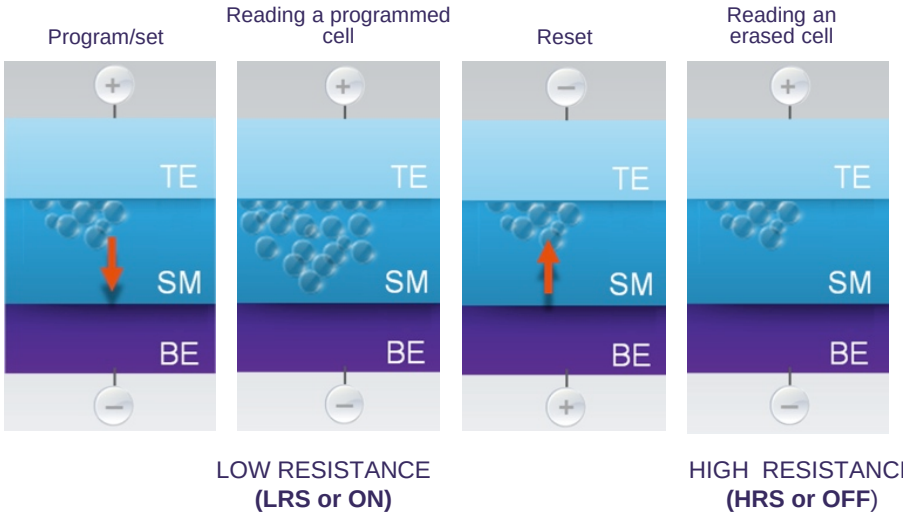
Agenda

- **Overview of RRAM Technology**

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

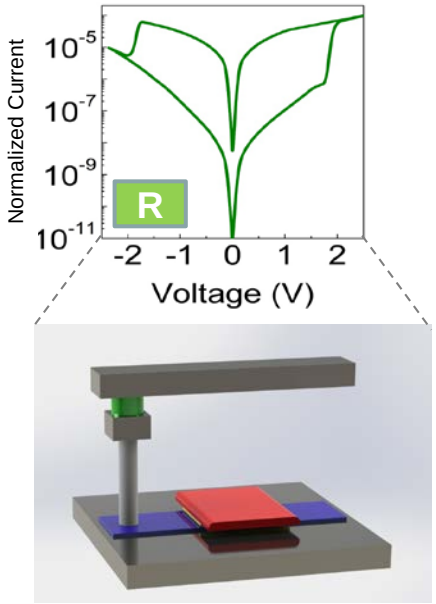
Crossbar's RRAM Technology

- 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



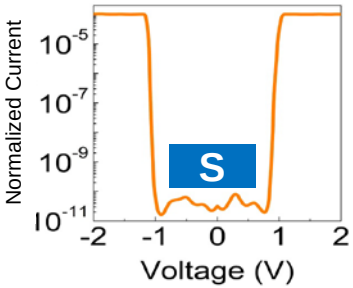
Crossbar Technology

Crossbar **RRAM** Cell

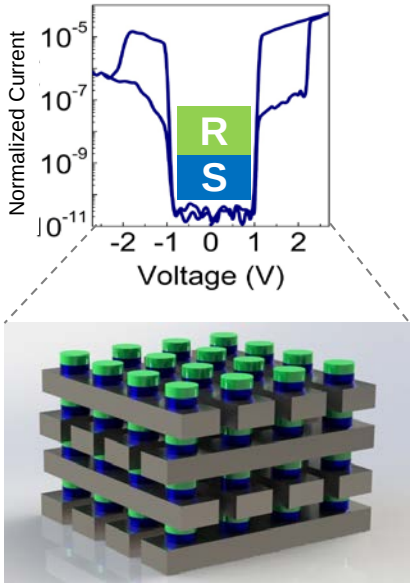


Suited for low latency, high speed embedded memory

Crossbar **Selector**

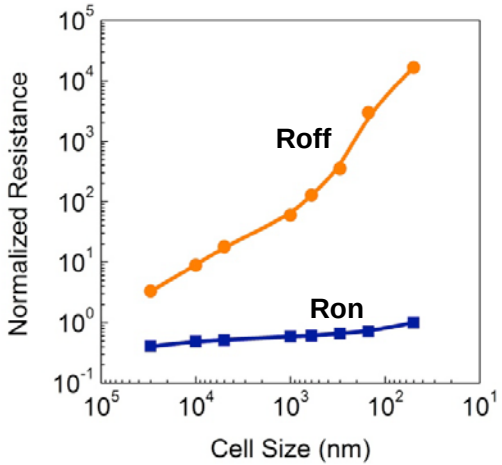


Crossbar **SR** Cell

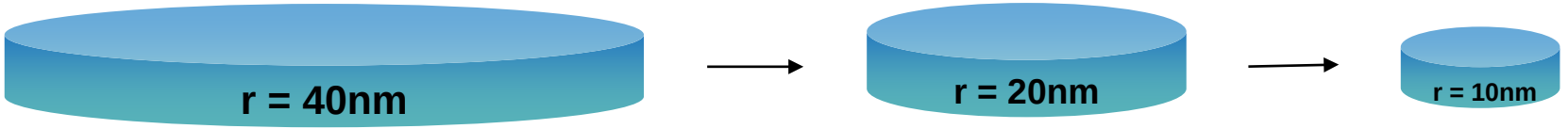


Suited for high density high performance NAND or SCM memory

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**

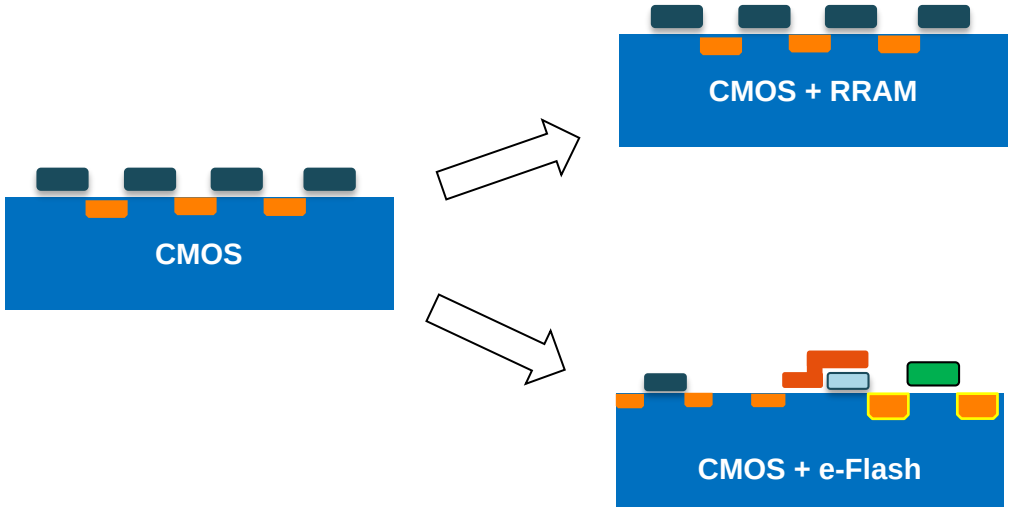


Ioff=1uA
Roff=1MΩ

Ioff=0.25uA
Roff=4MΩ

Ioff=62nA
Roff=16MΩ

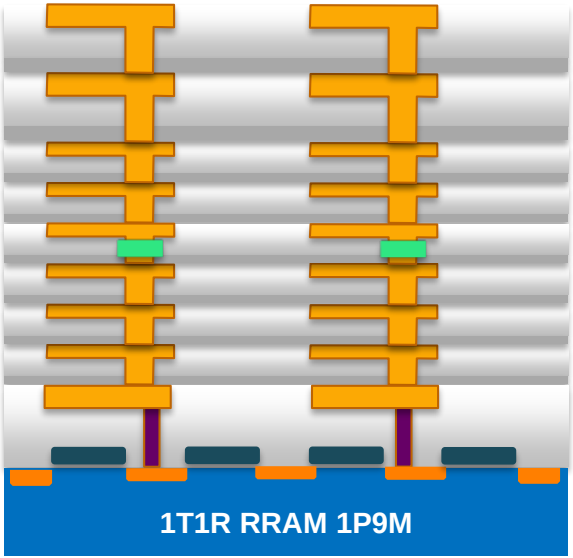
Benefits of Crossbar Embedded RRAM



- No Change to Front-end

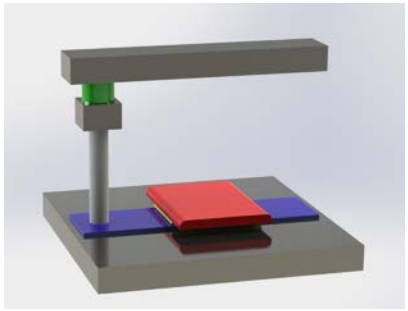
- Major changes to Front-end
  - Complex cell
  - High voltage transistors
- Adds 6+ Masks & 40 steps

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

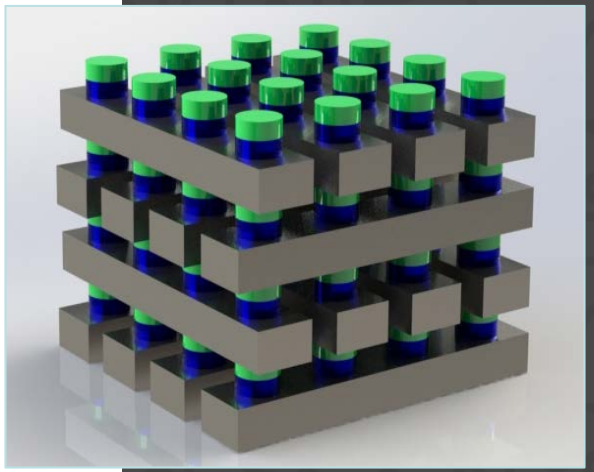
Scales with advanced nodes	Reduced Manufacturing Complexity	Cost	Performance
	▪ CMOS compatible material ▪ Back-end process - No change in front-end	▪ Reduced masking steps	▪ Byte/Page Alterability ▪ Write operation – no need for block erase

RRAM for Mass Storage

Performance

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

Superior endurance & retention



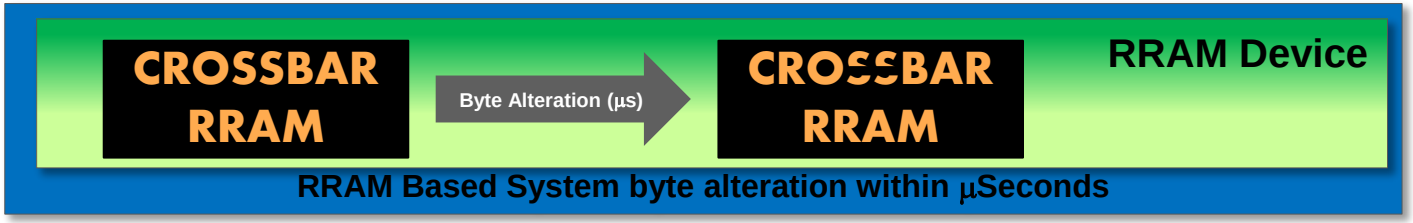
Density and Scalability

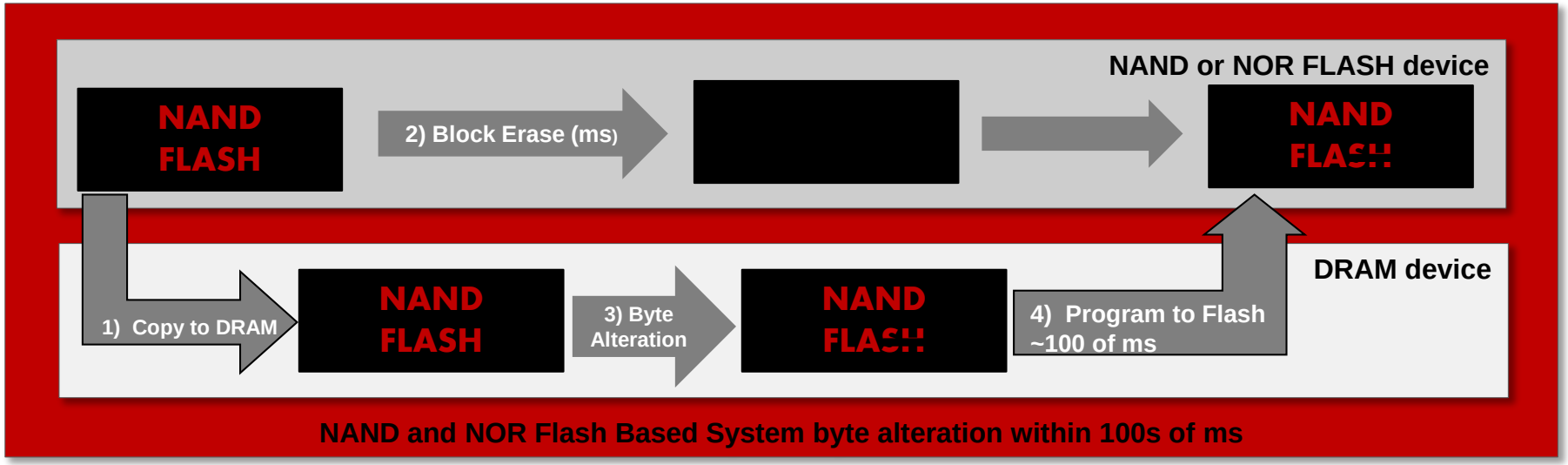
- 3D crosspoint array stackable at advanced nodes

Utilizes standard CMOS process

- Mass storage available to Fabless companies

Crossbar Memory Byte/Page Alterability Demonstration



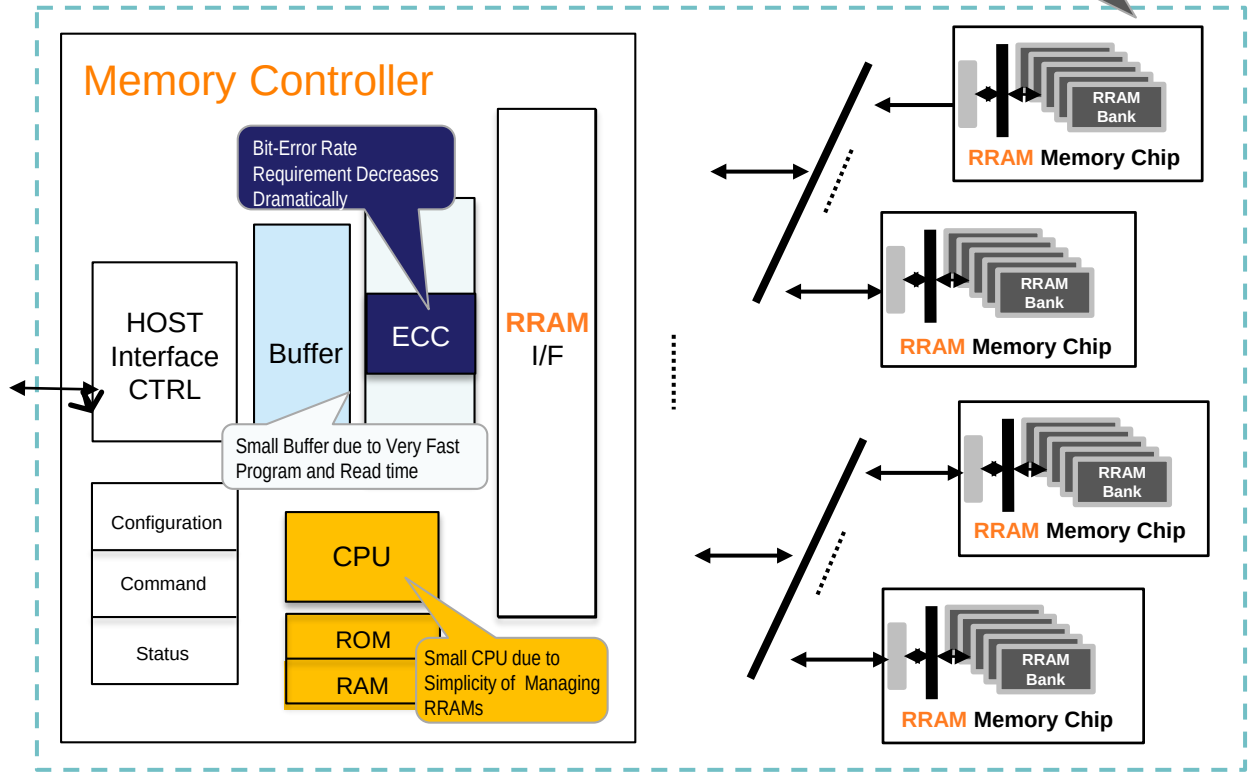


RRAM-Based Storage Card

Services
20X
More Transactions

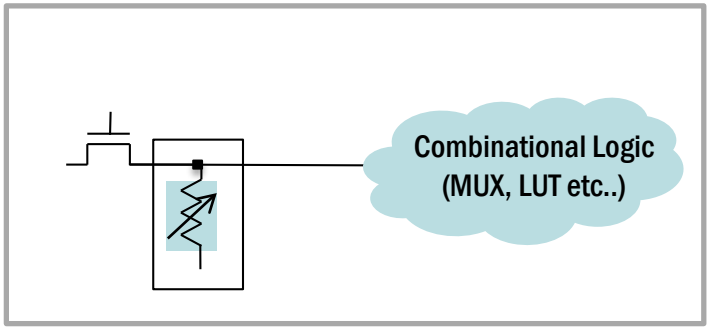
Responds to
Transactions
30X Faster

Performance Increases Substantially



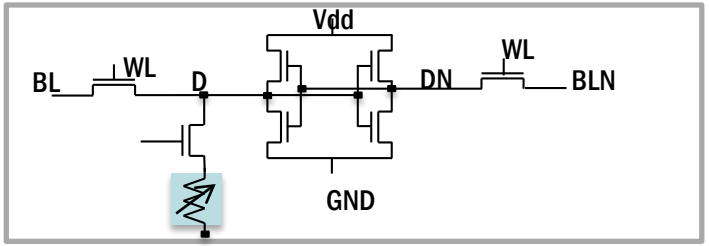
Crossbar Patented IP Libraries

FPGA Configuration Bit

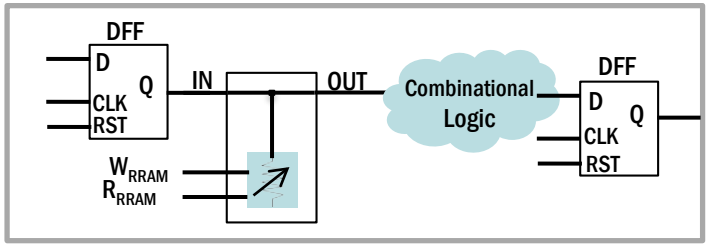


- Instant On
- Eliminates external non-volatile memory

NVRAM



State Retainer

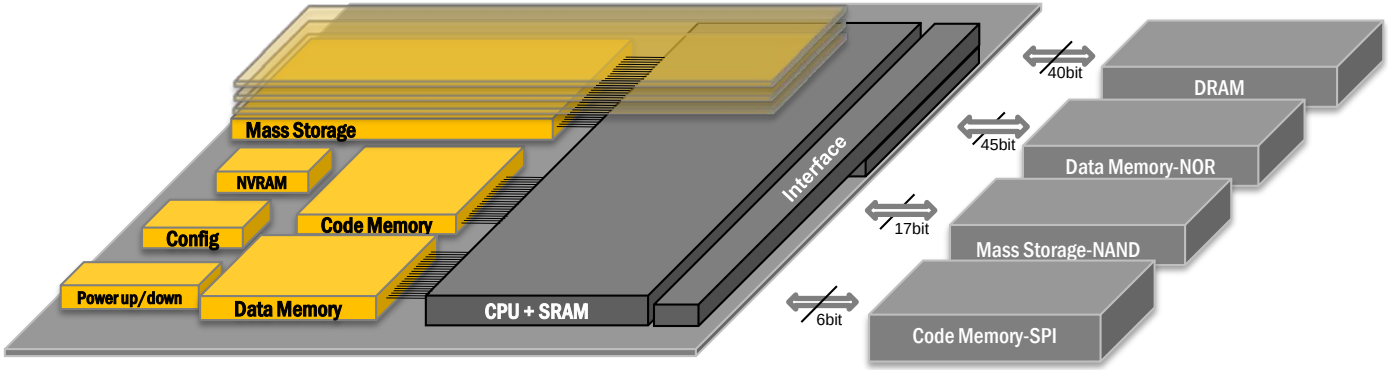


- Stores data at power down
- Recalls at power up
- Power saving

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



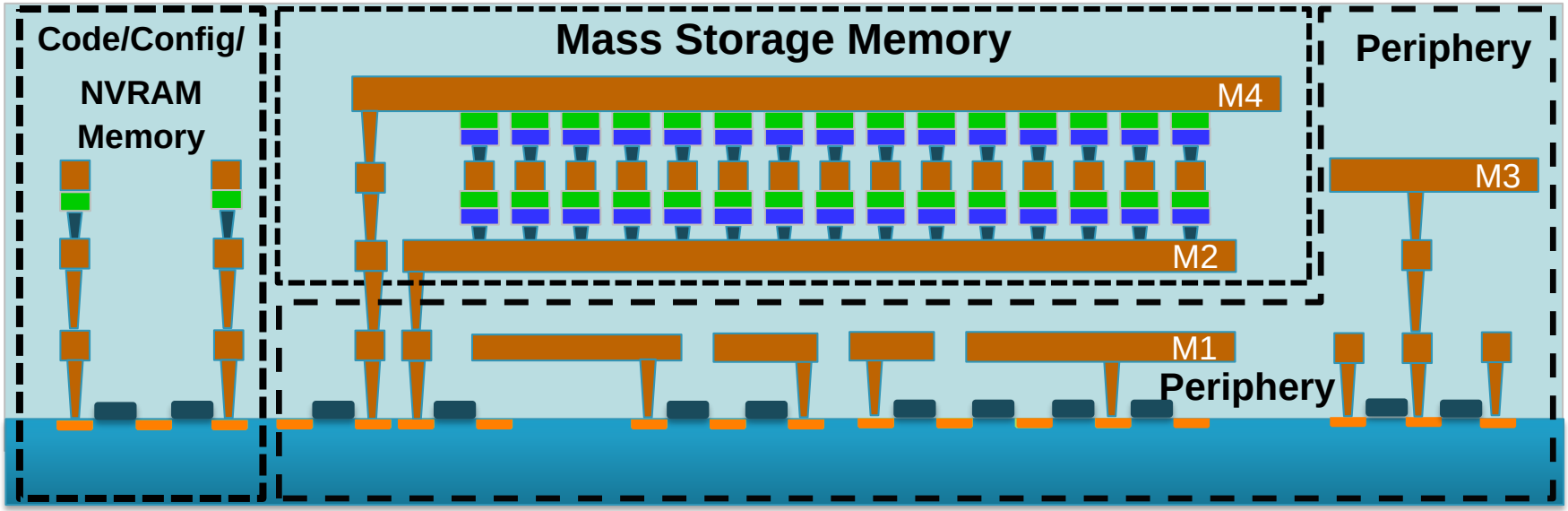
- Elimination of large number of I/Os, and simplification of the external interface
  - Reduction of components
  - Power reduction due to elimination of large number of I/O
- Breakthrough performance
  - Direct wide bus connection between memory and CPU/peripheral devices

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**

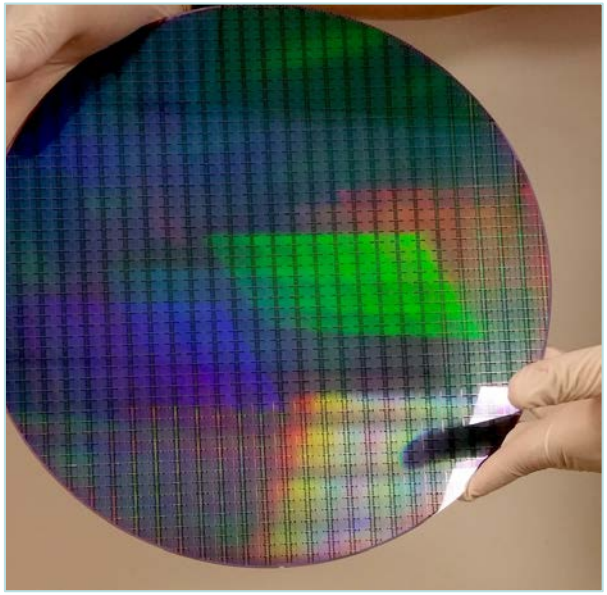


Crossbar Unique RRAM Versatile Technology

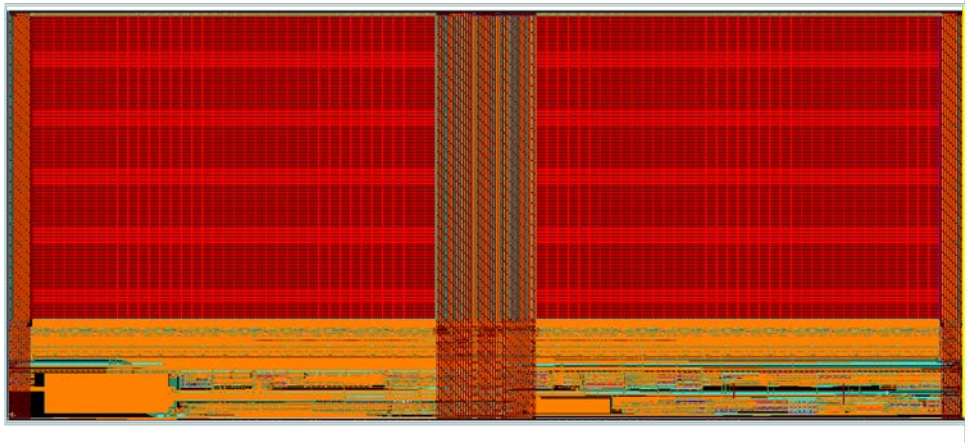
- Monolithic integration of Storage, Code, Data, FPGA configuration bit memories in one silicon
- Breakthrough system performance enabled with the monolithic integration of various memory architectures
- Fabless companies access IPs for a complete memory solution (storage, code, data, and FPGA configuration)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

Ready for Business

Crossbar **RRAM 300mm Wafer**



Crossbar **RRAM Die**



Crossbar-inc.com