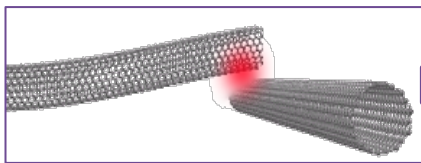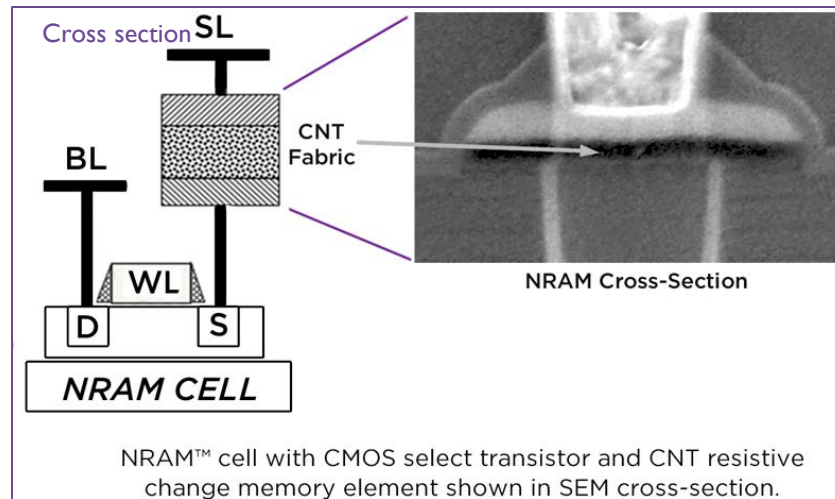# Carbon Nanotube Memory

Bill Gervasi
Principal Systems Architect
Nantero
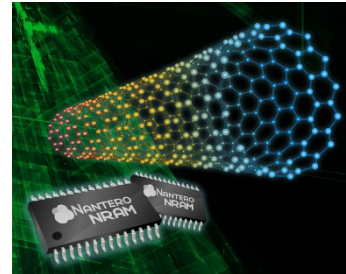
NRAM: Carbon Nanotube Memory

OFF ('0')

ON ('1')

NRAM™ cell with CMOS select transistor and CNT resistive change memory element shown in SEM cross-section.
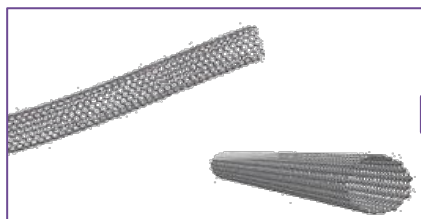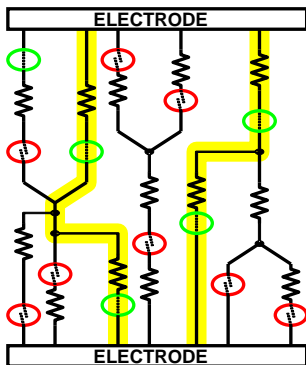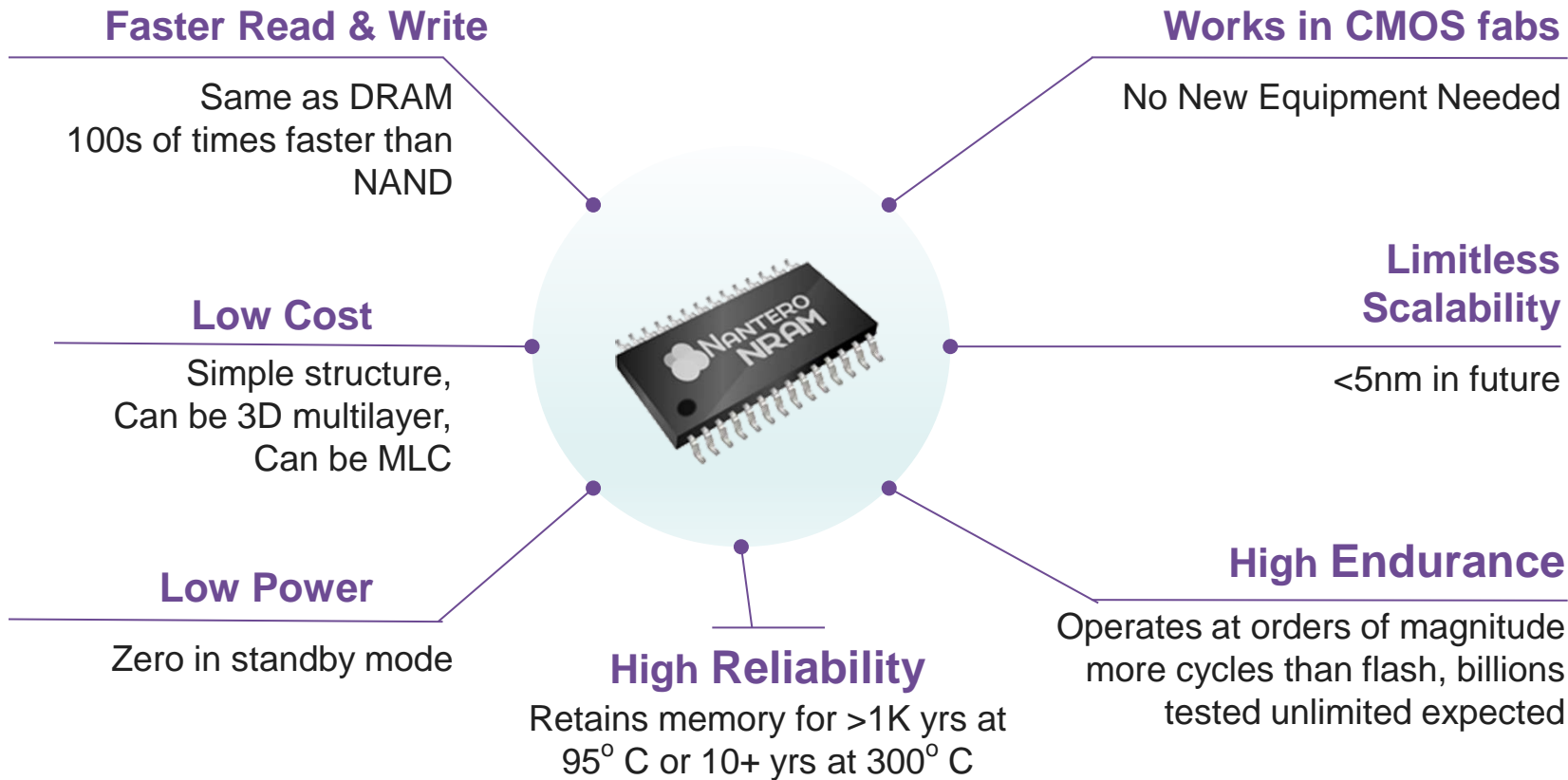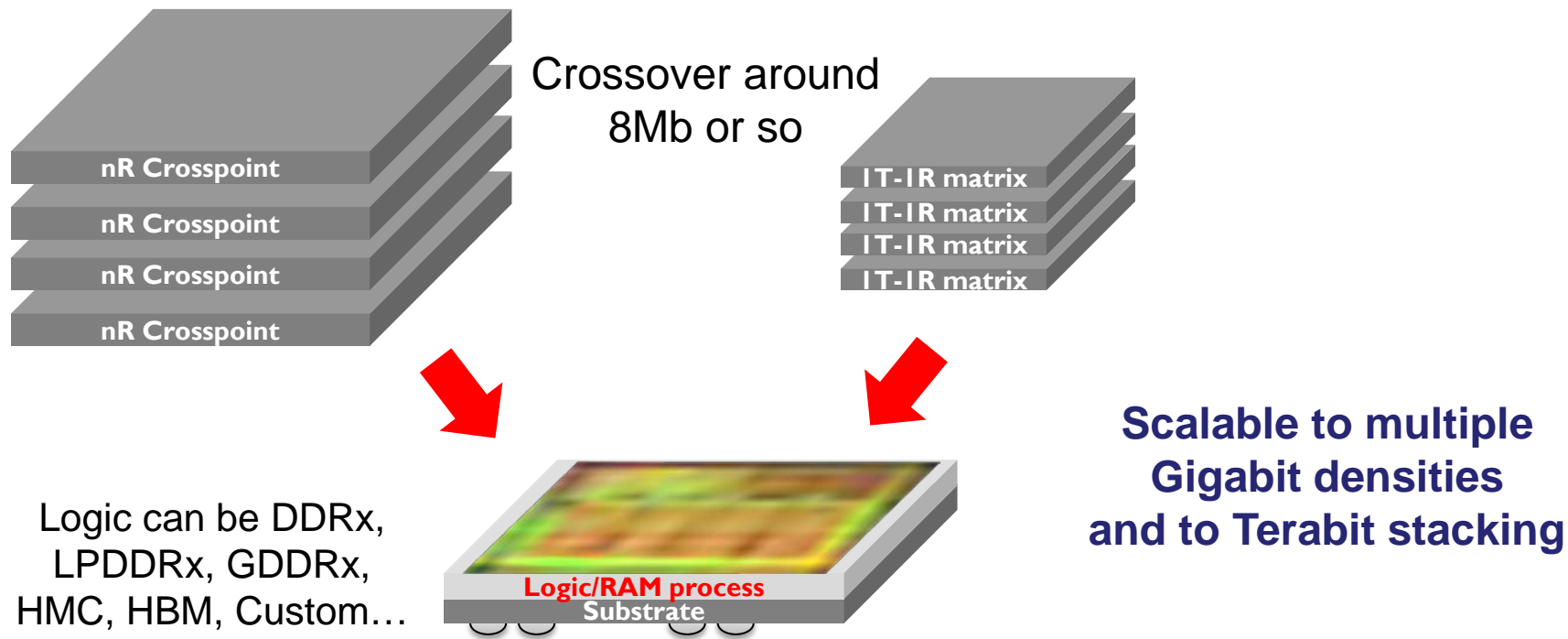
- RESET (ON → OFF): CNT-to-CNT are not in physical contact = high resistance
- SET (OFF → ON): CNT are in physical contact = low resistance

NRAM Characteristics

Faster Read & Write

Same as DRAM
100s of times faster than
NAND

Works in CMOS fabs

No New Equipment Needed

Low Cost

Simple structure,
Can be 3D multilayer,
Can be MLC

Limitless Scalability

<5nm in future

Low Power

Zero in standby mode

High Reliability

Retains memory for >1K yrs at
95° C or 10+ yrs at 300° C

High Endurance

Operates at orders of magnitude
more cycles than flash, billions
tested unlimited expected

Flexible Add-On Process

nR Crosspoint

nR Crosspoint

nR Crosspoint

nR Crosspoint

Crossover around 8Mb or so

1T-1R matrix

1T-1R matrix

1T-1R matrix

1T-1R matrix

Scalable to multiple Gigabit densities and to Terabit stacking

Logic can be DDRx, LPDDRx, GDDRx, HMC, HBM, Custom…

Logic/RAM process
Substrate

How Does NRAM Appear to Host?

◆ NRAM is like a DRAM minus the D (*not* Dynamic)

◆ Fully deterministic

◆ Acts like a higher efficiency DDR4 device:

- No refresh required

- No tFAW (fifth activation) penalty

- No bank group timing penalties
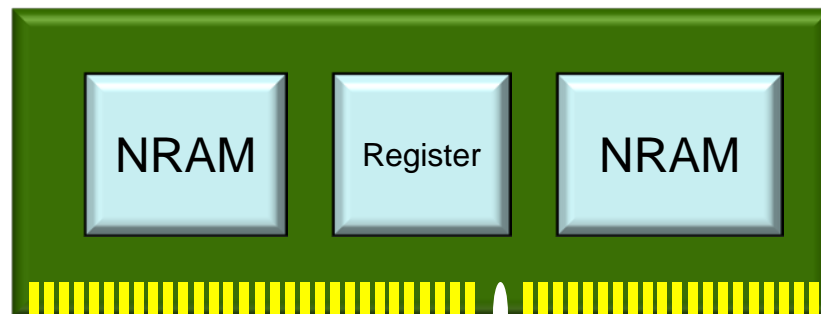
◆ Automatically non-volatile; only need to complete burst

Comparison with NVDIMM

NVDIMM-N

DRAM	FPGA/ Controller	Flash

NRAM RDIMM or LRDIMM
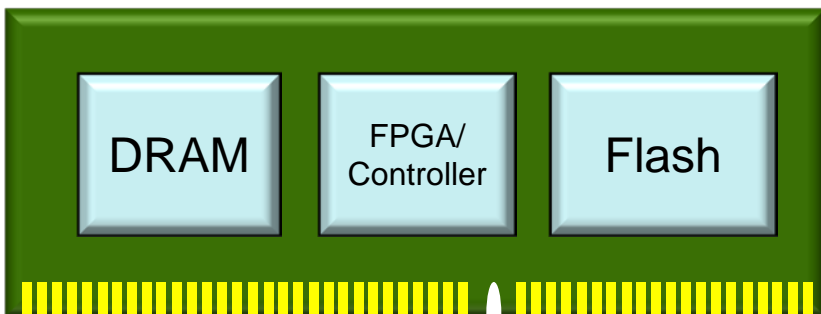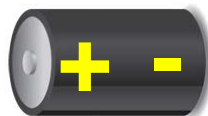
NRAM	Register	NRAM

Half the memory capacity
External power source needed
Complex SAVE/RESTORE
Complex controller

Full memory capacity
No external power source needed
No SAVE/RESTORE
No controller: standard register

SAVE/RESTORE

NVDIMM

Power fail → Complete burst in process

Many farads for many seconds, per DIMM

Save all pending operations

Copy DRAM to NVM

■ ■ ■

Power restore → Check save status

Copy NVM to DRAM

Run

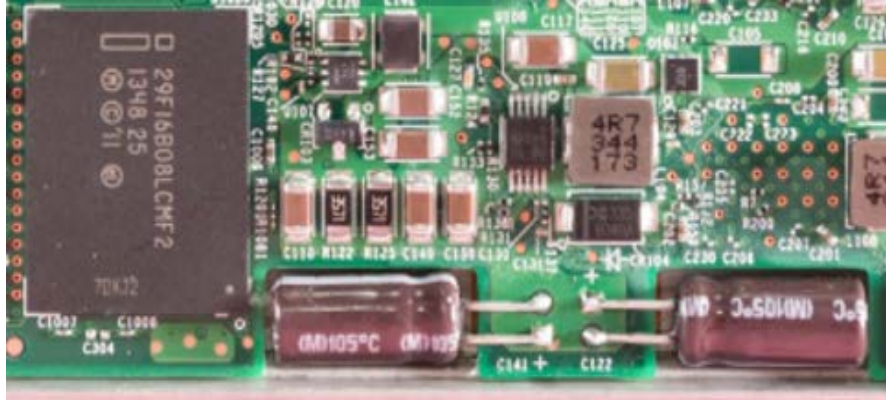## NRAM RDIMM

Complete burst in process

Nothing to do

No energy required

■ ■ ■

Run
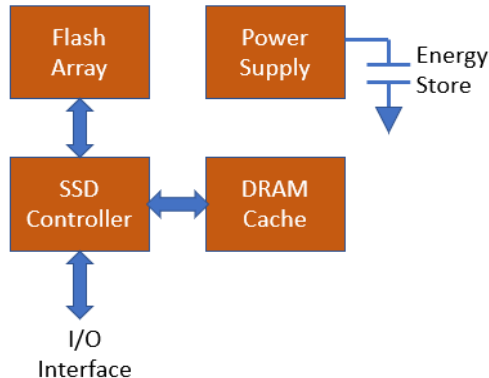
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New SSD Class Devices

Energy store no longer required
- Free up space used by capacitors
- Thinner form factor enabled

Cache size not restricted by amount of energy store

SSD, NVMe, EDSFF, NGSFF, etc

Ultra high performance NRAM-only drive enabled

Summary of NRAM

◆ Combines the best features of DRAM and NVM: high performance with non-volatility

◆ Flexible, stackable, configurable fundamental technology

◆ Eliminates the need for external power sources

"Have I mentioned to you how much I hate batteries?"
-- A Major Customer

Questions & Answers

Thank you for your time