Carbon Nanotube Memory

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NRAM: Carbon Nanotube Memory

**OFF (‘0’)**
- CNT-to-CNT are not in physical contact = high resistance

**ON (‘1’)**
- CNT are in physical contact = low resistance

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.
- **Low Cost**: Simple structure, can be 3D multilayer, can be MLC.
- **Low Power**: Zero in standby mode.
- **High Reliability**: Retains memory for >1K yrs at 95°C or 10+ yrs at 300°C.
- **Works in CMOS fabs**: No New Equipment Needed.
- **Limitless Scalability**: <5nm in future.
- **High Endurance**: Operates at orders of magnitude more cycles than flash, billions tested unlimited expected.
Flexible Add-On Process

Crossover around 8Mb or so

Scalable to multiple Gigabit densities and to Terabit stacking

Logic can be DDRx, LPDDRx, GDDRx, HMC, HBM, Custom…
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
- Half the memory capacity
- External power source needed
- Complex SAVE/RESTORE
- Complex controller

**NRAM RDIMM or LRDIMM**
- NRAM
- Register
- NRAM
- Full memory capacity
- No external power source needed
- No SAVE/RESTORE
- No controller: standard register
SAVE/RESTORE

Power fail

Many farads for many seconds, per DIMM

Power restore

Complete burst in process

Save all pending operations

Copy DRAM to NVM

Check save status

Copy NVM to DRAM

NRAM RDIMM

Complete burst in process

Nothing to do

Run

No energy required

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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

Ultra high performance NRAM-only drive enabled

SSD, NVMe, EDSFF, NGSFF, etc
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