

Architecture for Carbon Nanotube Based Memory (NRAM)



Bill Gervasi Principal Systems Architect



- Carbon nanotube basics
- Making & breaking connections
- Resistive measurements
- Write endurance, Timing, & Temperature
- When DRAM fades away
- The universe of Storage Class Memories
- NRAM: Memory Class Storage
- Standard modules using NRAM
- Industry readiness for persistent memory



- Nantero is a technology development and intellectual property licensing company
- This presentation covers the technology we develop and license
- Details shown apply to a specific reference design
- Specific product details and introduction dates relate to availability of the technology
- Customers & partners control actual product details and dates
- We'd be thrilled to license to YOU, too 😳

CNT Nonvolatile Memory



Van der Waals effect keeps CNTs apart or together

Data retention >300 years @ 300° C (more likely >1000 years)

Stochastic array of many nanotubes per each cell

No Dielectric -> No Known Failure Mechanism 5 |



CNTs switch in a void

No dielectric

Wear-out has not been observed

→ Unlimited write endurance expected

Resistance Measurements, 0 and 1



Greater than 10X difference between '0' and '1'... No calibration required across the wafer Smooth SET curve: MLC has been tested as well

Pulse Width Timing, Reset \rightarrow 0, Set \rightarrow 1



Consistent operation from 40 ns down to 5 ns read/write per cell



No Apparent Temperature Sensitivity



Similar set & reset curves at any temperature CNT operation and retention seen at 300°C, > 300 years Limited by underlying silicon circuit reliability

NRAM Capacity Scaling





NRAM is a "Memory Class Storage"



DDR4 NRAM Reference Internal Architecture



Crosspoint Tiles



Timing Impact of On-the-fly ECC



Timing	DDR4 SDRAM ns	DDR4 NRAM ns	DDR5 SDRAM ns
Row cycle	47.00	46.25	50.18
Access time	17.14	13.50	18.18
Row to column	15.00	23.00	18.18
Precharge	15.00	14.25	18.18
Write recovery	15.00	23.00	45.00
Activate to precharge	32.00	32.00	32.00
Refresh	350.00	0	350.00

Bus Efficiency Comparison at Same Frequency 15 |



128 GB NRAM LRDIMM or RDIMM



For Comparison, Industry NVDIMM-N



For Comparison, Industry NVDIMM-P



Power Fail Comparison



19

Software Increasingly Persistence Aware





- Electrostatic effects set & reset each bit
- Resistance delta of 10X allows reliable sensing
- Dielectric-free cell shows no wear-out
- DDR4 NRAM includes a DRAM-compatible front end
- Defines a new category "Memory Class Storage"
- NRAM per die capacity scales far beyond DRAM
- Fully deterministic timing better than a DRAM
- On-the-fly ECC incorporated for server class reliability
- Module level NRAM products are plug and play compatible
- Industry is ready for persistent main memory



Thank you for your time

Bill Gervasi bilge@nantero.com