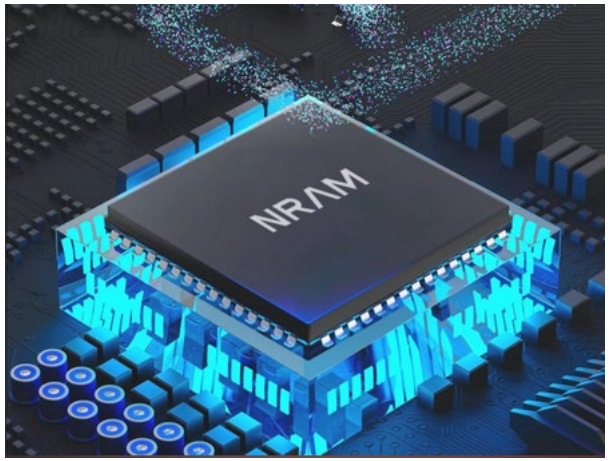
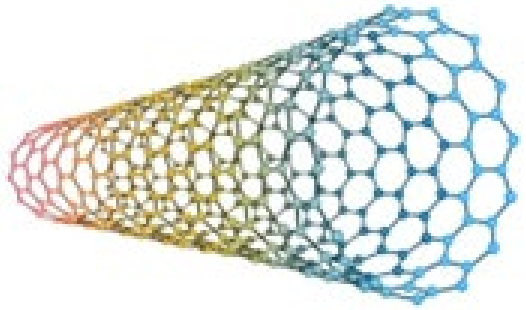
Carbon Nanotube Memory Device (NRAM®): A Green Technology



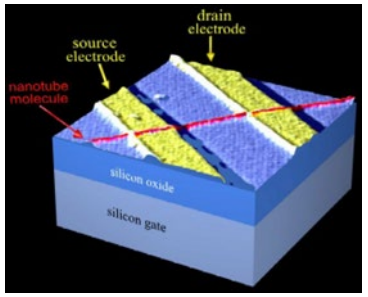
NANTERO

Presented by:
Rahul Sen
rahul@nantero.com

Carbon Nanotubes (CNTs)

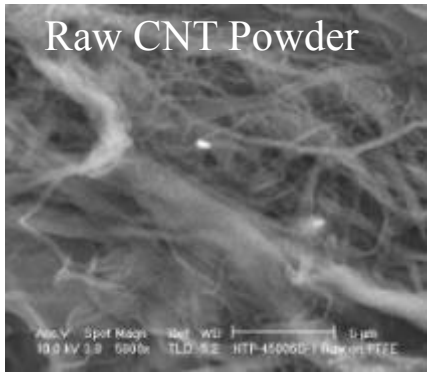


Individual CNTs: Unique properties
- Semiconducting or metallic (with ballistic conductance)
- Strength
- Thermal conductivity

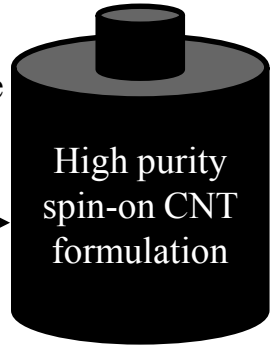


Making devices with single CNTs
Not scalable or commercially viable

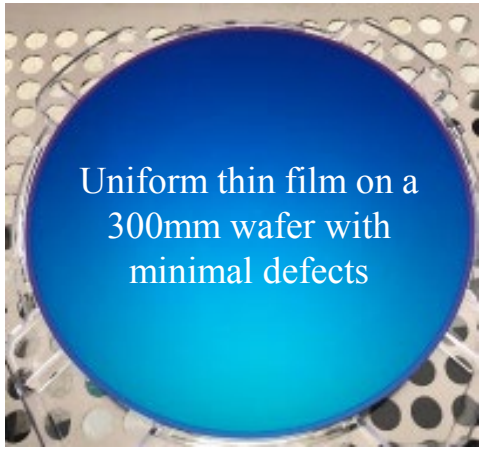
Nantero's Approach: use assemblies of CNTs in thin film form
- Scalable
- 300mm Fab Compatible



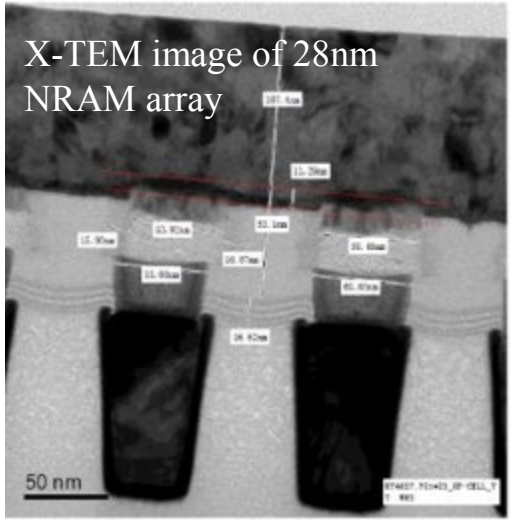
Highly engineered and scalable chemical processes



Optimized 300mm Spin Coating Process

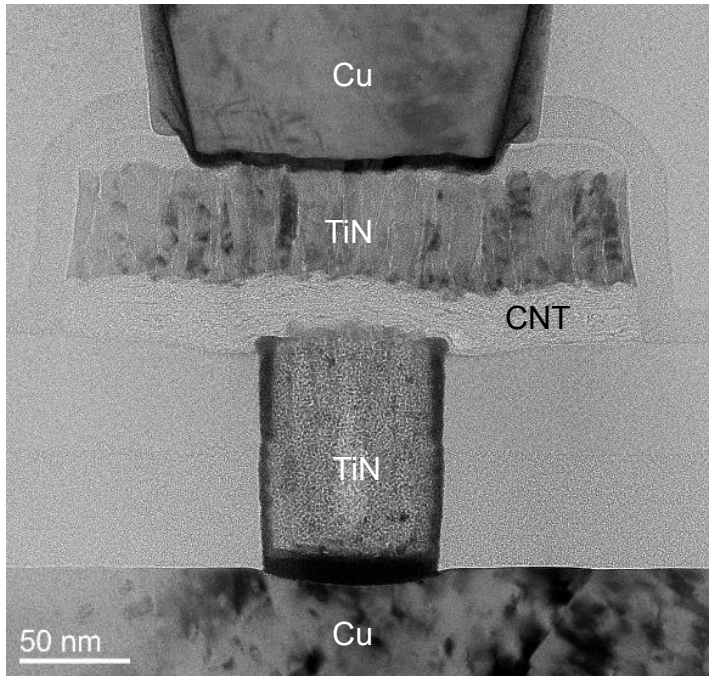


Device fabrication: standard lithography and etch processes in 300mm wafer fabs

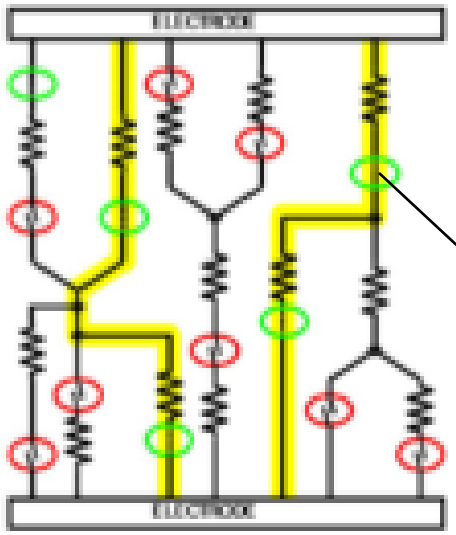


NANTERO

CNT-based Nonvolatile Memory (NRAM®)



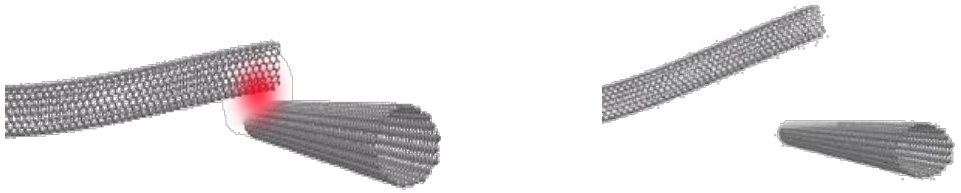
A Random CNT Network Sandwiched between top and bottom electrodes



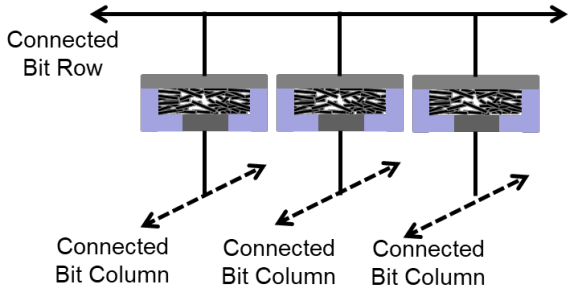
RESET
+V applied to top electrode

ON Low Resistance	⇄	OFF High Resistance

SET
+V applied to bottom electrode



ON ('1') **OFF ('0')**

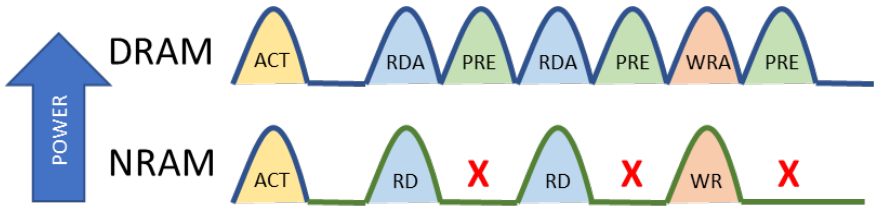


- Non-volatile (DRAM is volatile)
- Fabricated in back-end of line (BEOL) 300mm fab process (no new tooling required)
- Cross-point arrays with 3D scaling
- Intrinsically faster and lower power than DRAM

NANTERO

Energy Savings with NRAM®

- NRAM is non-volatile and persistent
  - ➢Eliminates pre-charge
  - ➢Eliminates refresh



DRAM destructive activate requires “precharge” writeback after every read or write operation on a row; NRAM non-destructive activate eliminates the need for precharge:

Power Savings = 21%

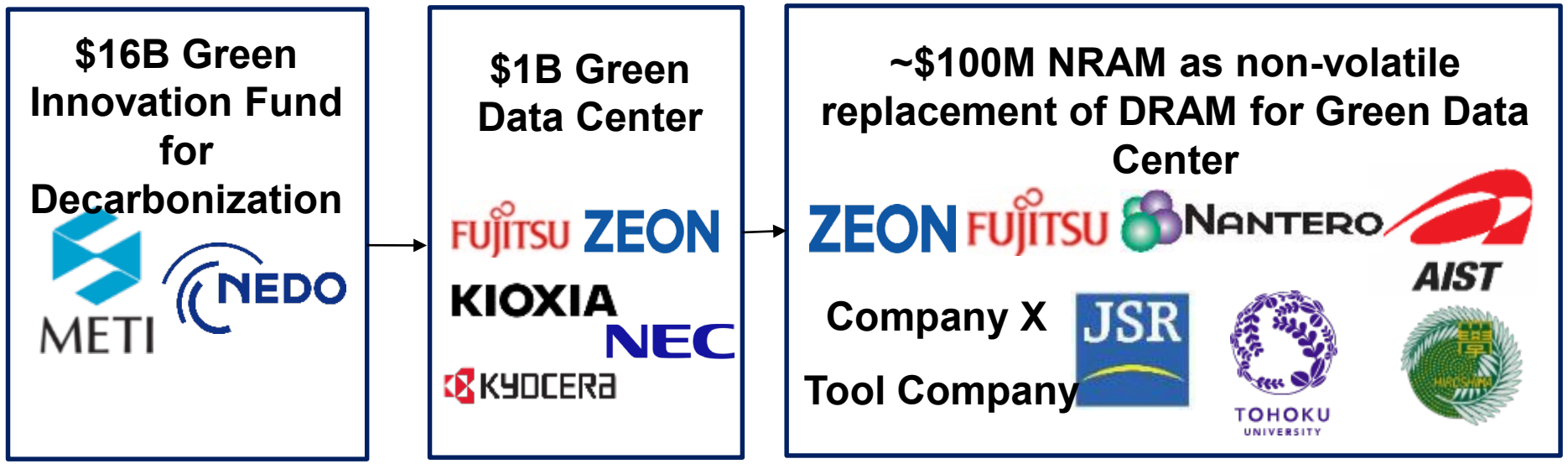
System Configurations				
Device	DRAM only	DRAM DIMM + NRAM CXL	NRAM only	
	2025	2025	2025	Year
CPU	Yes	Yes	Yes	540W
DRAM DIMM	Yes	Yes		208W
DRAM CXL	Yes			224W
SSD	Yes			100W
NRAM DIMM				148.16W
NRAM CXL		Yes	Yes	160
I/O	Yes	Yes	Yes	100
Server Power	1172	1008	800	W
Normalized (2)	100%	86%	68%	%
Percent of DC	43%	43%	43%	Per chart
Savings DC%	0%	6%	14%	Server
Savings Cooling%	0%	3%	6%	Cooling
Total savings	0%	9%	20%	Server+Cooling
Single 300 MWH Data Center				
Single DC	300	300	300	MWH
Savings DC	0	26	59	MWH

A 300 MWH Data Center can have energy savings of 59 MWH

NANTERO

Japan's Green Innovation Fund and NRAM Eco System

Japan already has invested in NRAM as Green Technology for DRAM replacement and Eco-System has been established



- Low power CPU
- Disaggregation / accelerator
- Fiber optic communication
- Optimized SSD
- Nantero's NRAM is the only emerging memory included (MRAM/FRAM too expensive/not scalable & PCM/RRAM too slow for nv-DRAM replacement). Target is nv-DRAM for server power reduction