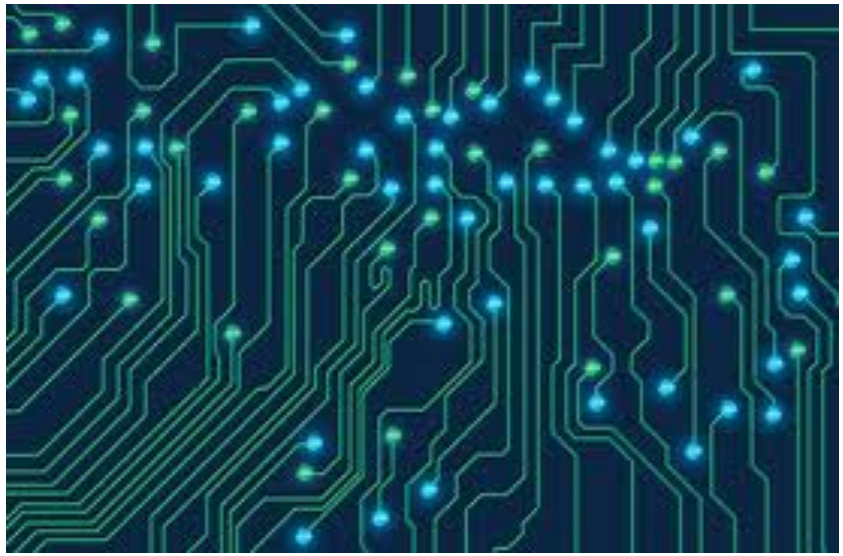


4D-S Ltd

May 15th 2013

Abstract

- **4DS has developed a robust ReRAM material system, MOHJO™:**
  - High cycle life
  - Low power dissipation
  - Good data retention
  - Reduced manufacturing time and cost
- **MOHJO™ is implemented as a back end process atop standard CMOS flow**
- **MOHJO™ has a low current reset state that enables large blocks of memory to be erased enabling a number of interesting applications**
- **MOHJO™ can be particularly useful in SSD where it can result in a 100x reduction of energy consumption.**

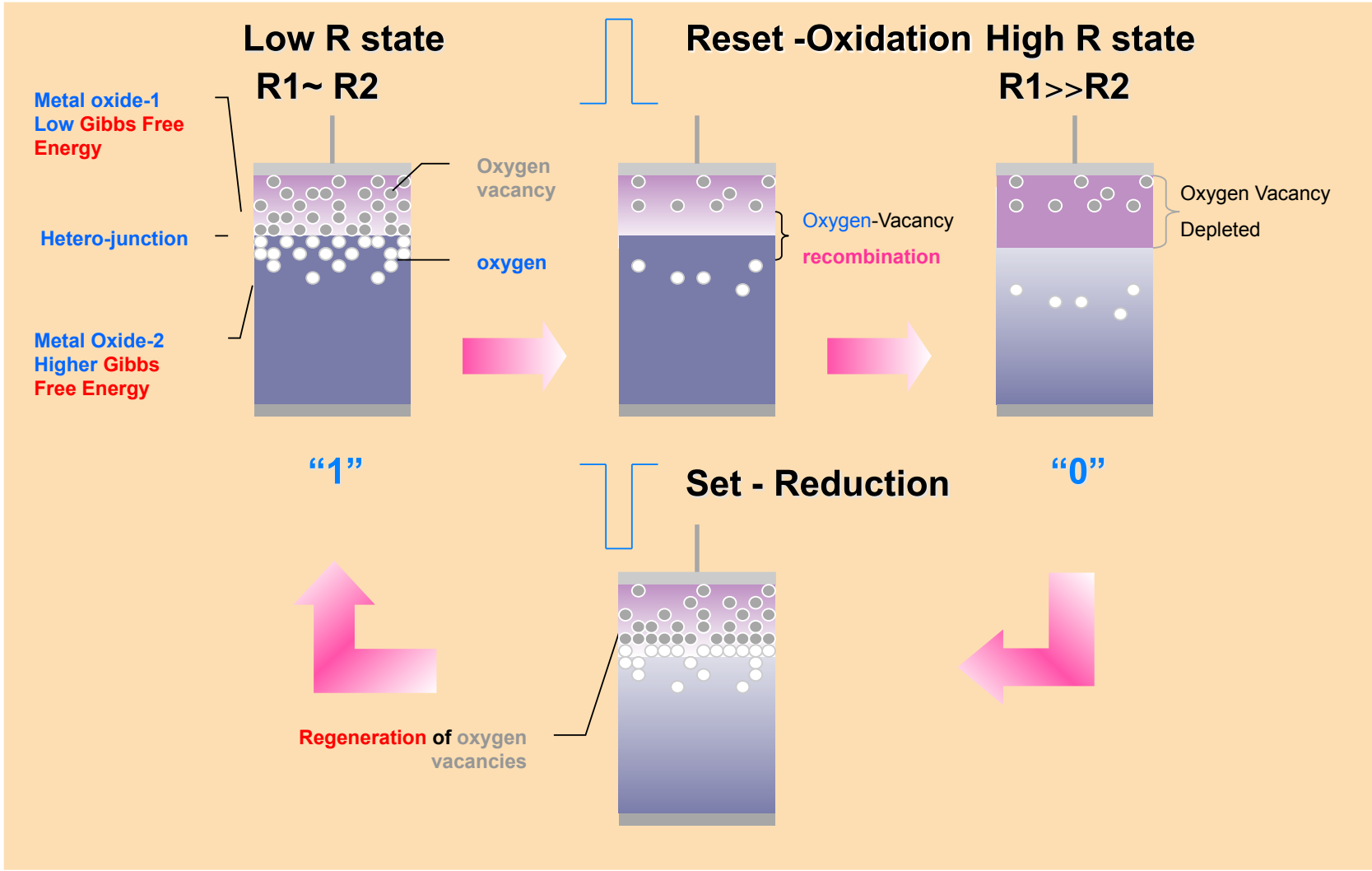
Technology – Key Attributes

4DS' MOHJO™ memory is high speed, non-volatile, low power, low cost and is able to be produced using existing semiconductor manufacturing equipment

LOW COST	• Produced using +1 to 4 mask steps when combined with standard CMOS process (as compared to +16 to 20 mask steps for FLASH) for the memory core. • Scalable and repeatable proprietary wafer process for mass production.
LOW POWER	• Low voltage operation and low current, making it attractive for a variety of applications
LOW TEMPERATURE	• Memory is formed with a proprietary low temperature process similar to CMOS back end of line (BEOL) temperatures.
HIGH SPEED	• Fast Read/Write
SCALABILITY	• Tested at 30nm, project down to 10nm and below.

EXISTING FAB EQUIPMENT / PROCESSES	• Simple integration into fabs, process steps utilizes established fabrication equipment and processes. • Proprietary process is implementable as customized module on existing fabrication tools.
DENSITY	• High density $4F^2$ with diode/$6F^2$ with transistor
LONG CYCLE LIFE	• 10^9
RELIABILITY	• 10 year data retention
CMOS COMPATIBLE	• Process is CMOS compatible.

Metal Oxide Hetero-Junction Operation (MOHJO™)



Technology – Relative Comparison

4DS' MOHJO™ memory compares very favourably to the best characteristics of competing solutions

	Flash	STT	PCM	MOJHO
Density (F^2)	1-4	20-60	4-16	4/(# layers)
Energy per bit (pJ)	100	0.1-2.5	2-2.5	0.2-3
Read Time (ns)	100000	10-35	10-50	10-50
Write Time (ns)	100000	10-90	50-500	10-50
Endurance	10^4	10^15	10^9	10^9
Retention	Years	Years	Years	Years

Technology – Relative Positioning

- Table ERD9 Target Device and System Specifications for SCM

Parameter	*Benchmark* [A]			*Target*		*MOHJO™*
	HDD [B]	**NAND flash** [C]	**DRAM**	**Memory-type SCM**	**Storage-type SCM**	
Read/Write latency	3-5 ms	~100µs (block erase ~1 ms)	<100 ns	<100 ns	1-10µs	10ns to 50ns
Endurance **(cycles)**	unlimited	10^4-10^5	unlimited	$>10^9$	$>10^6$	$>10^9$
Retention	>10 years	~10 years	64 ms	>5 days	~10 years	~10 years
ON power **(W/GB)**	~0.04	~0.01-0.04	0.4	<0.4	<0.04	<0.04
Areal density	~ 10^{11} bit/cm^2	~ 10^{10} bit/cm^2	~ 10^9bit/cm^2	~ 10^{10} bit/cm^2	~ 10^{10} bit/cm^2	~ 10^{10} bit/cm^2
Cost **($/GB)**	0.1	2	10	<10	<3-4	<1

Notes for Table ERD9:

[A] The benchmark numbers are representative values, which may have significant variations in specific products

[B] Enterprise class

[C] Single-level cell (SLC)

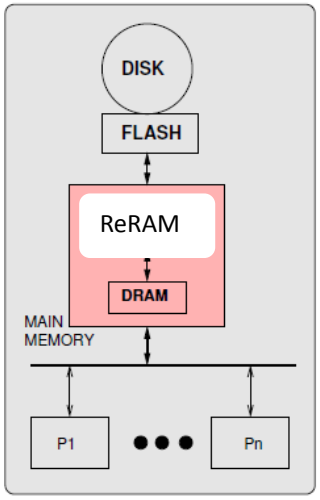
The International Technology Roadmap for Semiconductors, 2011 Edition (latest)

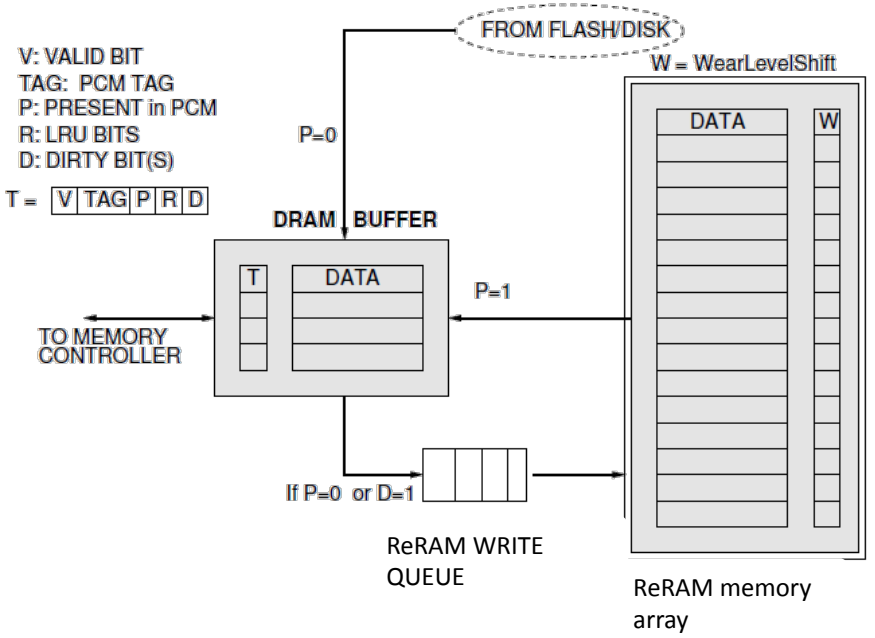
Advantages of Asymmetrical Hysteresis

- Extremely low power operation on the reset side
- Low power operation enables a bulk or block erase feature; which in Flash memory type applications would provide a drop in, higher performance replacement using current flash controllers.
- Low power bulk erase is also highly desirable feature in security applications where the data may need to be wiped out quickly.
- Of note the bulk erase is a feature not a requirement as in many current nonvolatile memories. Both the Set and Reset operations can be performed on a byte by byte basis.

Implementation 1: Cache/Working memory

DRAM/ReRAM Hybrid Cache





Graphics borrowed from Qureshi HPAC 2009

Implementation 2: SSD File Storage

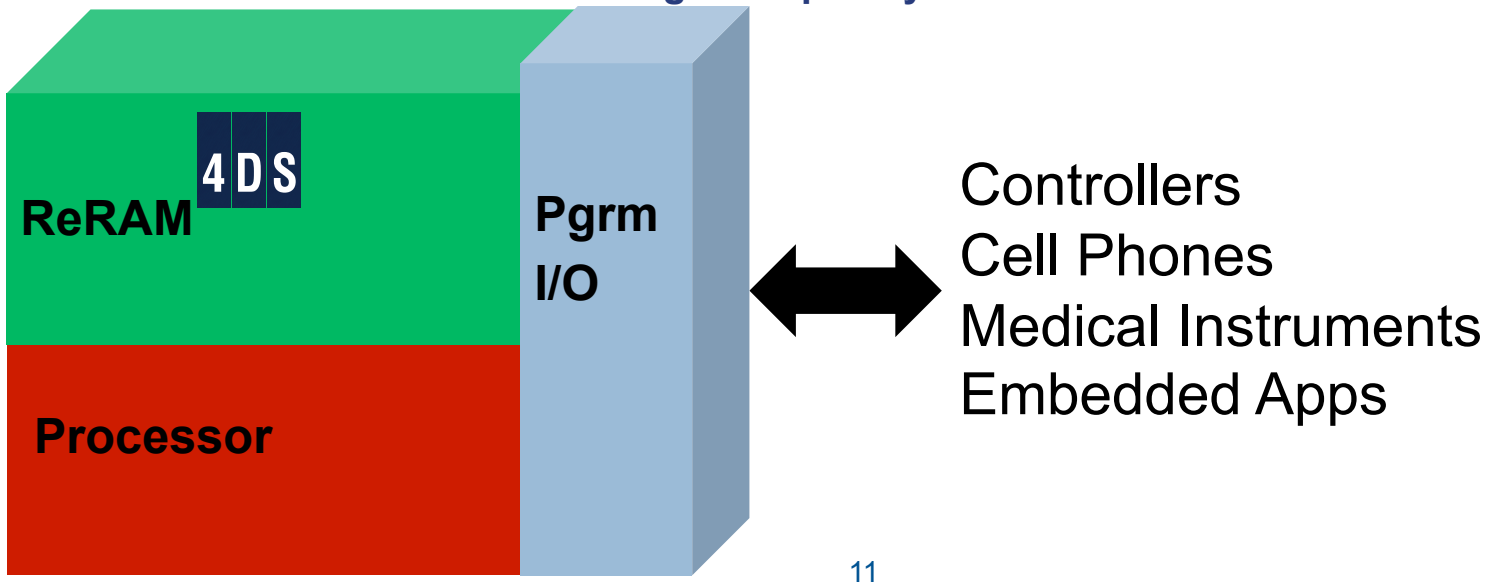
- Utilizing ReRAM to replace FLASH in SSD file storage
- 4DS ReRAM performance exceeds high end flash

	Flash	MOJHO™
1.Voltage:	< 15V	Better
2.Endurance:	> 10^4 W/E cycles	Better
3.Scalability:	< ~18 nm, 3D stackable	Comparable
4.W/E time:	< 100 µs	Better
5.Retention:	> 10 years	Comparable

- In spite of the excellent potential this transistion will take a while due to the billons invested in Flash infrastructure

4DS MOHJO™ Embedded Memory

- Lower cost and higher performance than embedded flash with the updating capability that OTP memories lack
- Optimizes processor speed and reduces power consumption of electronic devices.
- High Security applications
- The memory would be implemented in a 1T/1R configuration for embedded applications instead of 1D/1R to reduce the design complexity on the smaller embedded memories.



High Security in Embedded Configuration

- **One of the major advantages of embedding memory is improved security due to the elimination of external and easily accessible bus lines.**
- **Once the memory is embedded the next level of security is determined by how easily a hacker can determine what is inside the memory.**
- **The 4DS MOHJO™ memory is very secure.**
  - Extremely low power and high speed makes thermal detection extremely difficult.
  - No visible difference between 1's and 0's in de-processing
    - **No physical links or other features.**
  - Extremely low voltage contrast in the array.