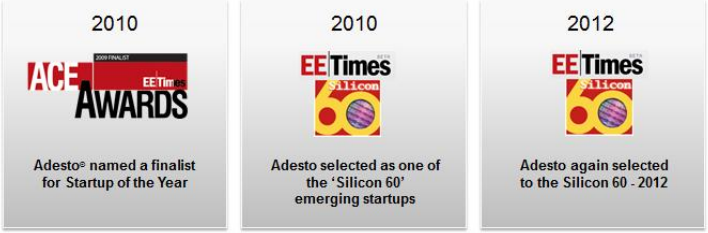
Conductive-bridge Memory (CBRAM®) with Excellent High-temperature Retention and Tolerance to High Levels of Gamma Radiation

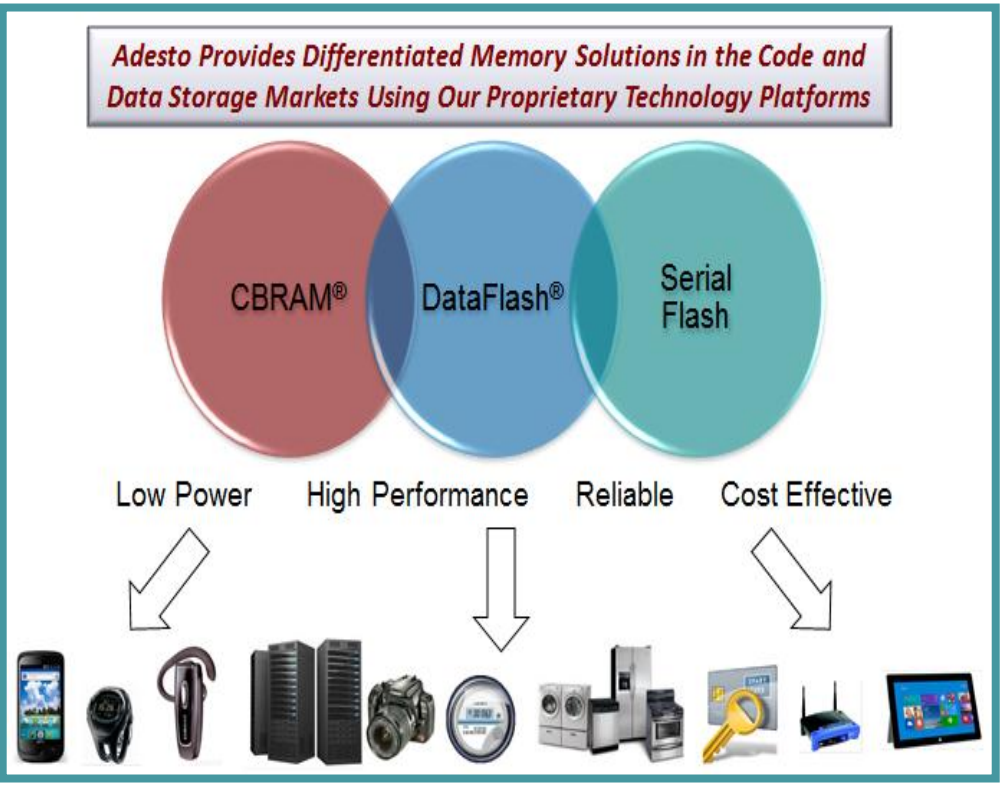
Dr. Venkatesh P. Gopinath,
V.P. of CBRAM Technology
Adesto Technologies



Outline/Contents

- **Introduction to Adesto Technologies**
- **Introduction to CBRAM**
- **CBRAM from Adesto®**
  - General characteristics
  - High-T retention
  - Radiation tolerance
- **Conclusions**

Adesto Technologies Corporate Overview



Overview:

Private company founded in 2007 by semiconductor industry veterans

Locations:

Headquarters in Silicon Valley, California / Offices in Asia, Europe

Employees:

100 (Engineering=70, Sales/Marketing=20, Other=10)

Status:

$50M+ profitable business, supporting over 100 tier 1 customers

Business Model:

Discrete product manufacturing and technology licensing

Technologies:

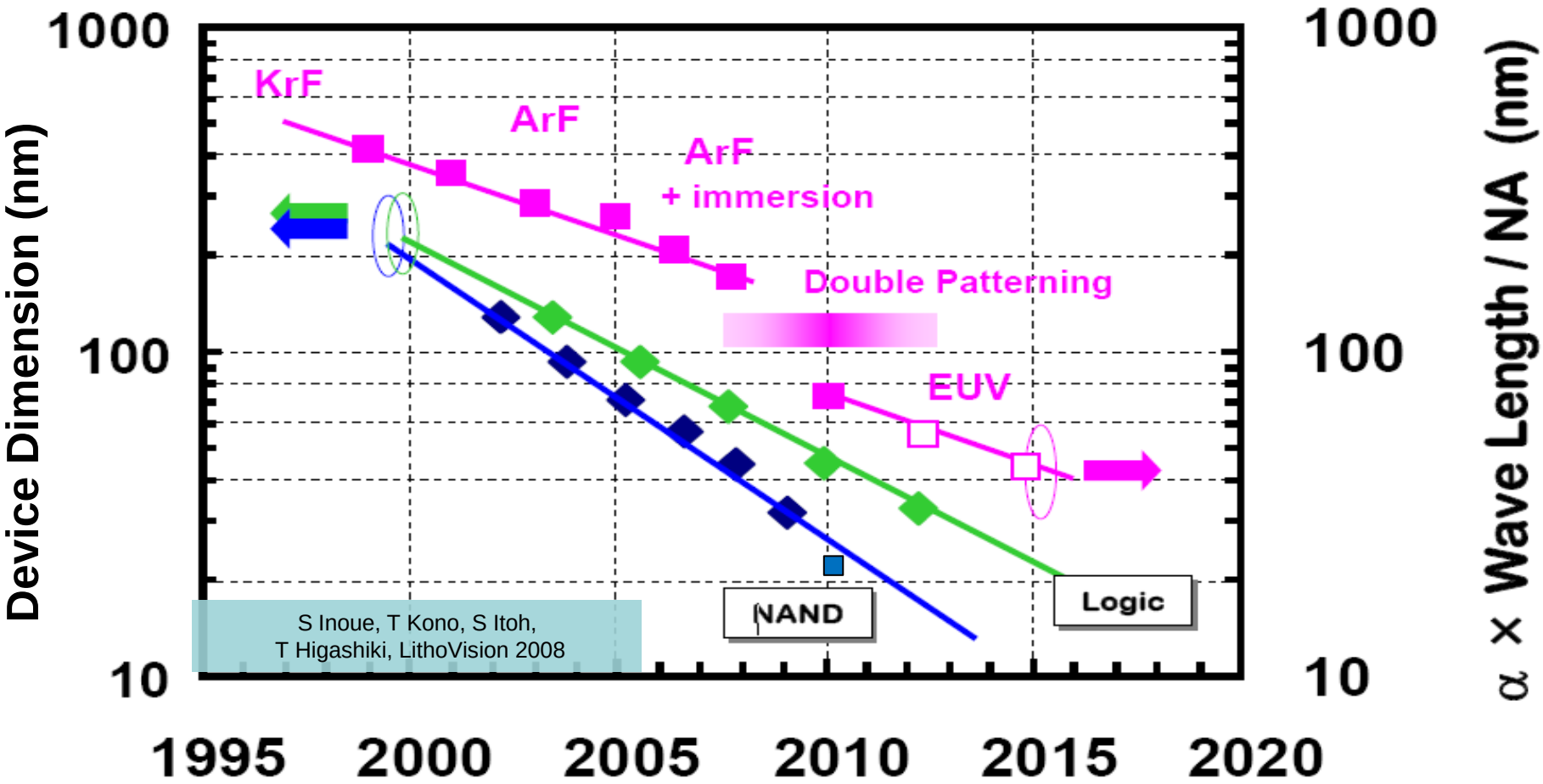
Serial Flash / DataFlash® / CBRAM®

Solid Intellectual Property Position: Over 100 patents granted or filed

Outline/Contents

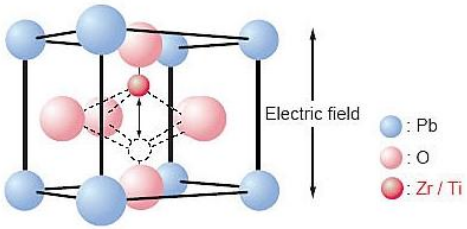
- **Introduction to Adesto Technologies**
- **Introduction to CBRAM**
- **CBRAM from Adesto**
  - General characteristics
  - High-T retention
  - Radiation tolerance
- **Conclusions**

Moore's Law

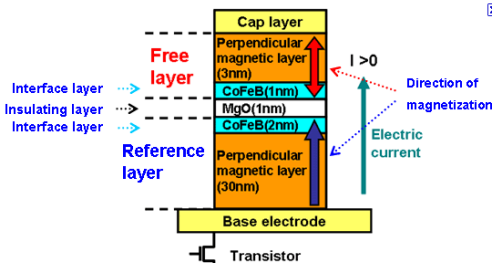

1000
100
10
Device Dimension (nm)
KrF
ArF
ArF
+ immersion
Double Patterning
EUV
NAND
Logic
S Inoue, T Kono, S Itoh,
T Higashiki, LithoVision 2008
1995
2000
2005
2010
2015
2020
1000
100
10
α × Wave Length / NA (nm)

Candidates for Next Generation NVM

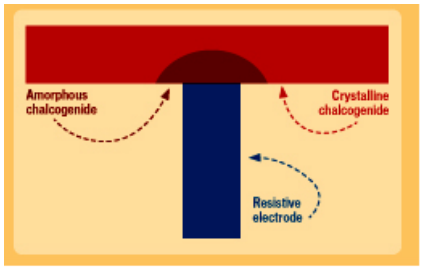
- **Ferroelectric RAM (FeRAM)**



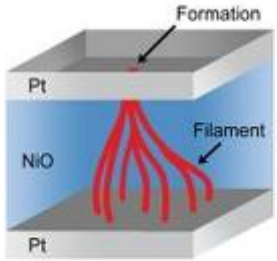
- **Magnetic RAM (MRAM)**



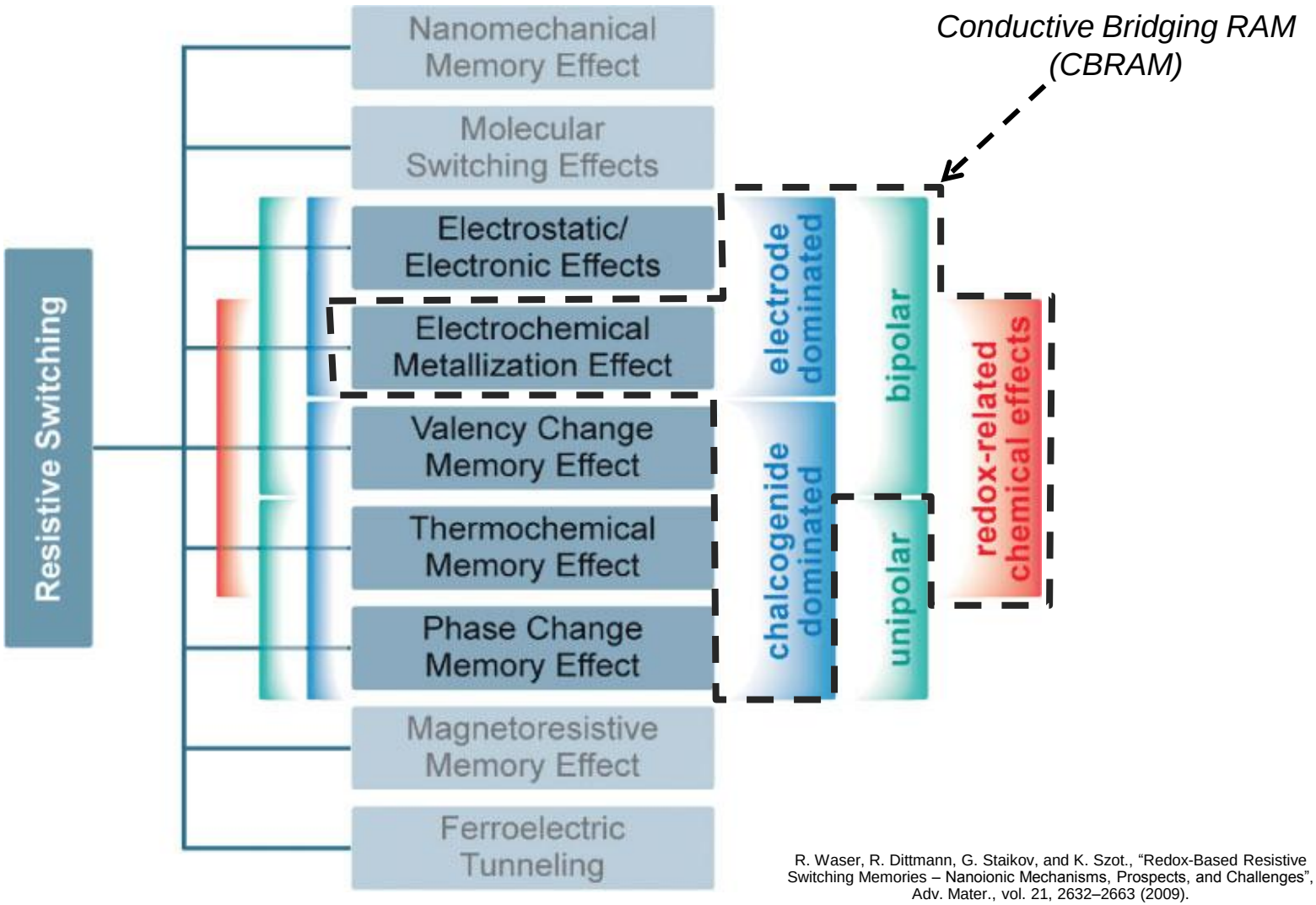
- **Phase Change Memory (PCM)**



- **Resistance Change RAM (RRAM)**
  (metal oxides)



Resistance Change Memory Taxonomy



R. Waser, R. Dittmann, G. Staikov, and K. Szot., "Redox-Based Resistive Switching Memories – Nanoionic Mechanisms, Prospects, and Challenges", Adv. Mater., vol. 21, 2632–2663 (2009).

Example of Electrochemical Memory Implementations

Table I. Summary of reported electrochemical metallization cells employing either Ag or Cu as an active electrode (AE) metal and various electrolytes and counter electrode (CE) metals.

Electrolyte	Active electrode (AE) metals	
	Ag	Cu
Ge_xS_y	W[11–19]	W[15]
Ge_xSe_y	W[11,16,20–23] Pt[24] Ni[16,25–27]	W[15]
Ge-Te	TiW[28]	TaN[29]
Ge-Sb-Te	Mo[30]	
As-S	Au[31]	
$Zn_xCd_{1-x}S$	Pt[32,33]	
Cu_xS		Pt[34,35] Ti[36,37]
Ta_2O_5		Pt[38–40] Ru[41]
SiO_2	Co[42]	W[43,44] Pt[10] Ir[45]
WO_3	W[43]	W[43,46]
TiO_2	Pt[47,48]	
ZrO_2	Au[49]	
MSQ	Pt[50,51]	
GdO_x		W[52]
a-Si	Poly-Si[53–55] Cr[56]	
Ge_xSe_y/SiO_x		Pt[57]
Ge_xSe_y/Ta_2O_5		W[58]
Cu_xS/Cu_xO		Pt[59]
Cu_xS/SiO_2		Pt[59]

Electrolyte and CE materials are indicated in each row. For bilayer electrolytes, AE would be placed to the left of the electrolyte (e.g., Cu/A/B/Pt for a cell with a Cu AE metal and A/B bilayer electrolyte). Information compiled by John R. Jameson, Adesto Technologies Corp. Reprinted with permission from Reference 9. ©2011, IOP Publishing.

Table II. Summary of key performance data reported to date in electrochemical metallization arrays.

Material Systems	$Cu/Cu_2S/Ti$	$Cu\text{-}Te/GdO_x/W$	$Ag/Ge_xS_y/W$	Ag/Ge_xS_y or Ge_xSe_y
Reference	Kaeriyama et al.[37]	Aratani et al.[52]	Gopalan et al.[19]	Dietrich et al.[53]
Array Size Tested	1 kbit	4 kbit	384 kbit, 1 Mbit	2 Mbit
Technology Node	250 nm	180 nm	180 & 130 nm	90 nm
SET Condition	1.1 V/5–32 μs	3 V/5 ns/110 μA	1.5 V/250 ns/30 μA	≥0.6 V/≤50 ns/10 μA
RESET Condition	1.1 V/5–32 μs	1.7 V/1 ns/125 μA	0.6 V/12 ms/20 μA	≤0.2 V/≤50 ns/20 μA
Endurance	10^2–10^4	10^7	10^5	10^6
Retention (measured)	10^2 s @ 35 mV	100 hours @ 130°C	24 hours @ 110°C	10^5 s @ 70°C
Retention (projected)	3 months	10 years	10 years @ 70°C	10 years

All arrays utilized 1T1R (one transistor for device selection and one resistive switching element) architecture. Compiled with information from Chen[62] with the addition of data recently reported for $Ag/Ge_xS_y/W$ cells.[19]

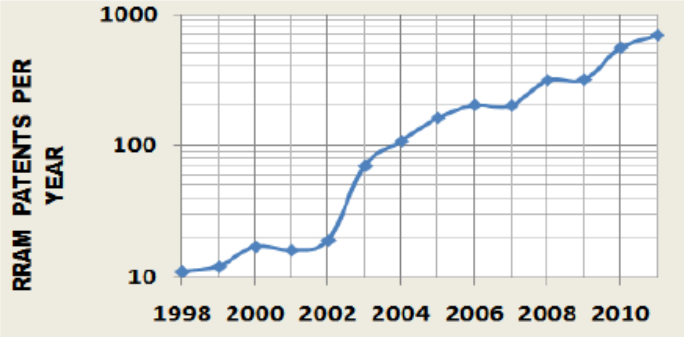


Figure 4 RRAM Patents per year [13]

Patents by Category:

Ionic/Electrolytic	204
Metal Oxide	169
Molecular/Polymer	74
Phase Change	961
Other/Unknown	1256

What is it Made Of?

Anode

Electrolyte

Cathode

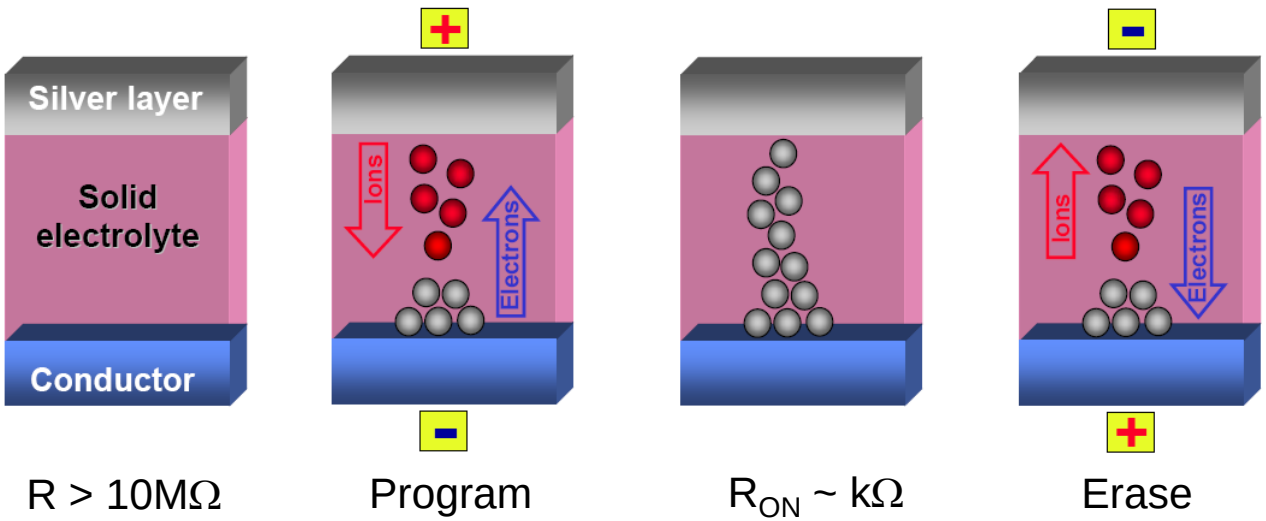
CBRAM uses 25% of all the elements

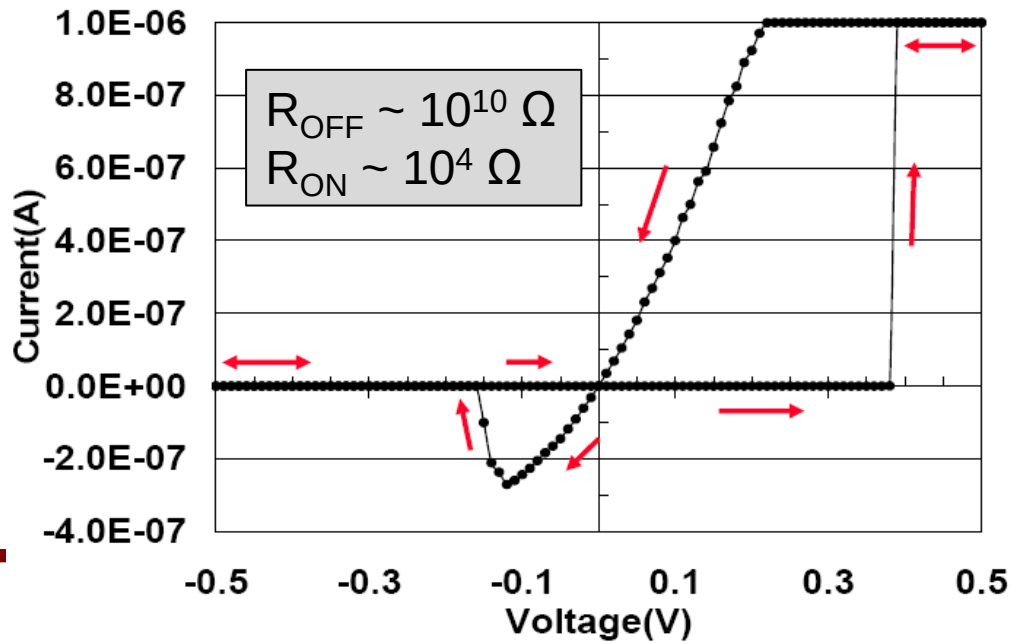
CBRAM / CMOS Build uses ~75% of all the elements ! More than Moore in action.

1 H 1.0079																	2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.065	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078		21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.468	38 Sr 87.62		39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc 98	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33		71 Lu 174.97	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po 209	85 At 210	86 Rn 222

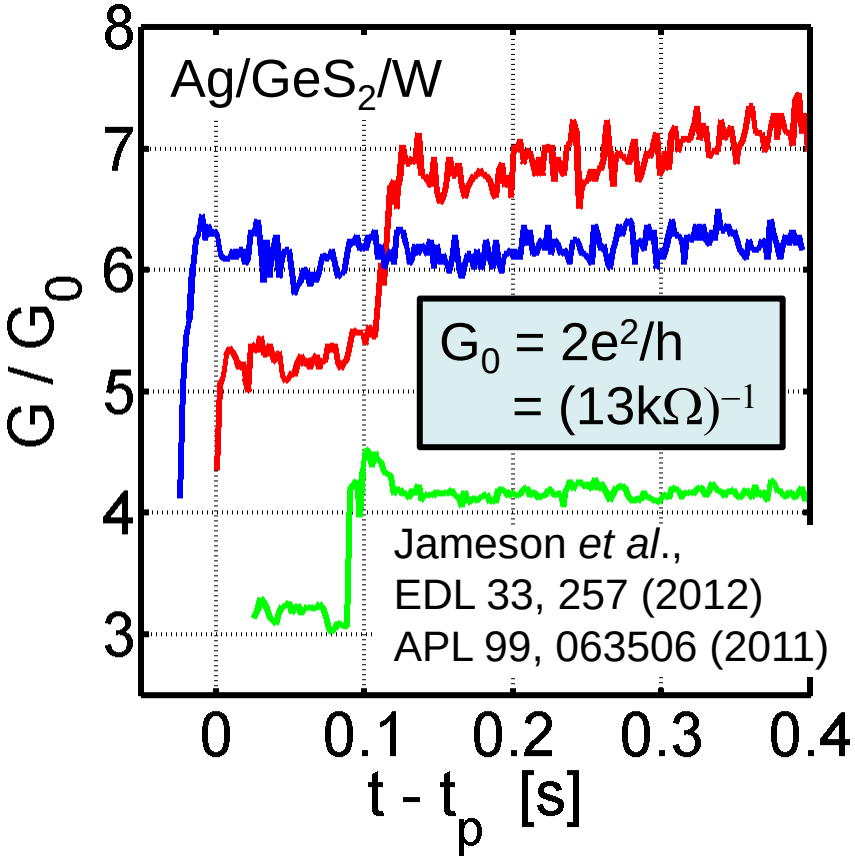
57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm 145	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04
89 Ac 227	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237	94 Pu 244	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 251	99 Es 252	100 Fm 257	101 Md 258	102 No 259

Operating Principle of a CBRAM Cell

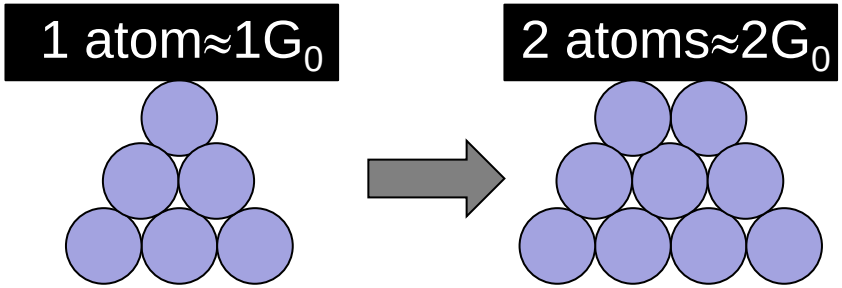




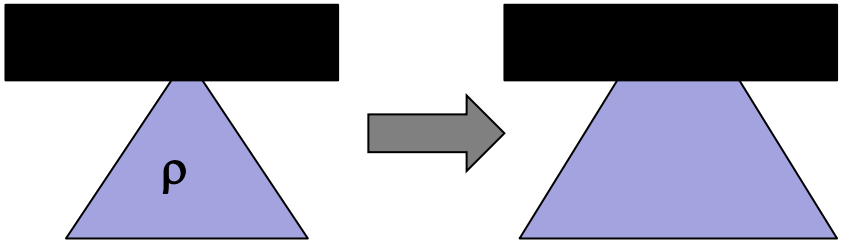
CBRAM cells as quantum point contacts (QPCs)



Physical picture is atomic:



Not continuum:



Similar observations in other systems:

Gap: Terabe *et al*., Nature 433, 48 (2005)
Non-gap: See paper for 8 refs from 2012/13

Summary of QPC-related device behavior:

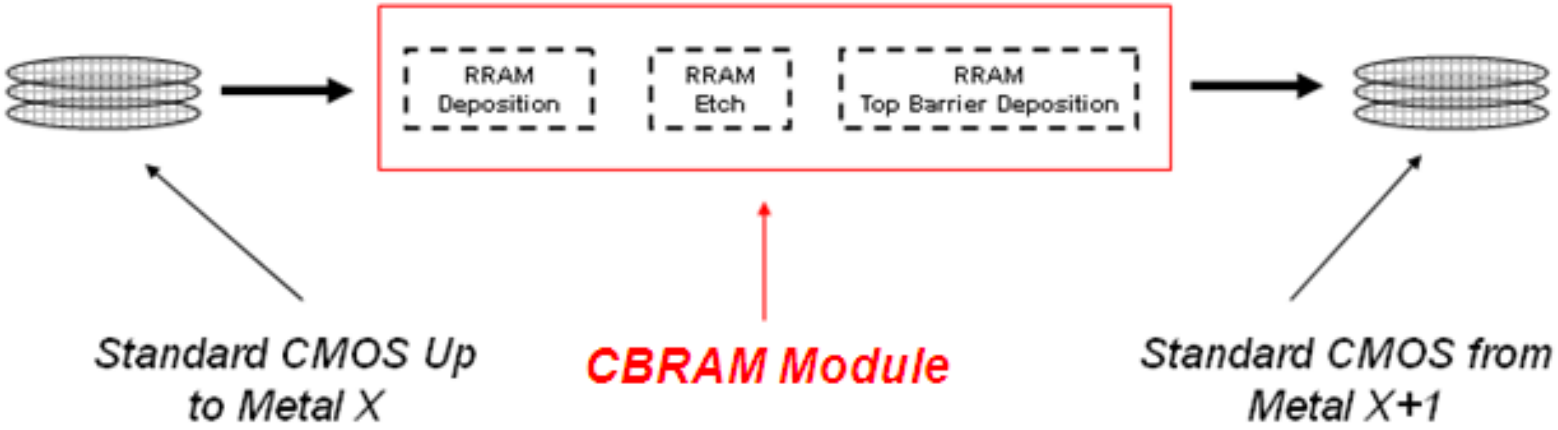
"Conductive bridge random access memory (CBRAM) technology", Jameson & Van Buskirk
- in -
Advances in nonvolatile memory and storage technology, ed. Y. Nishi, Woodhead Pub.

Outline/Contents

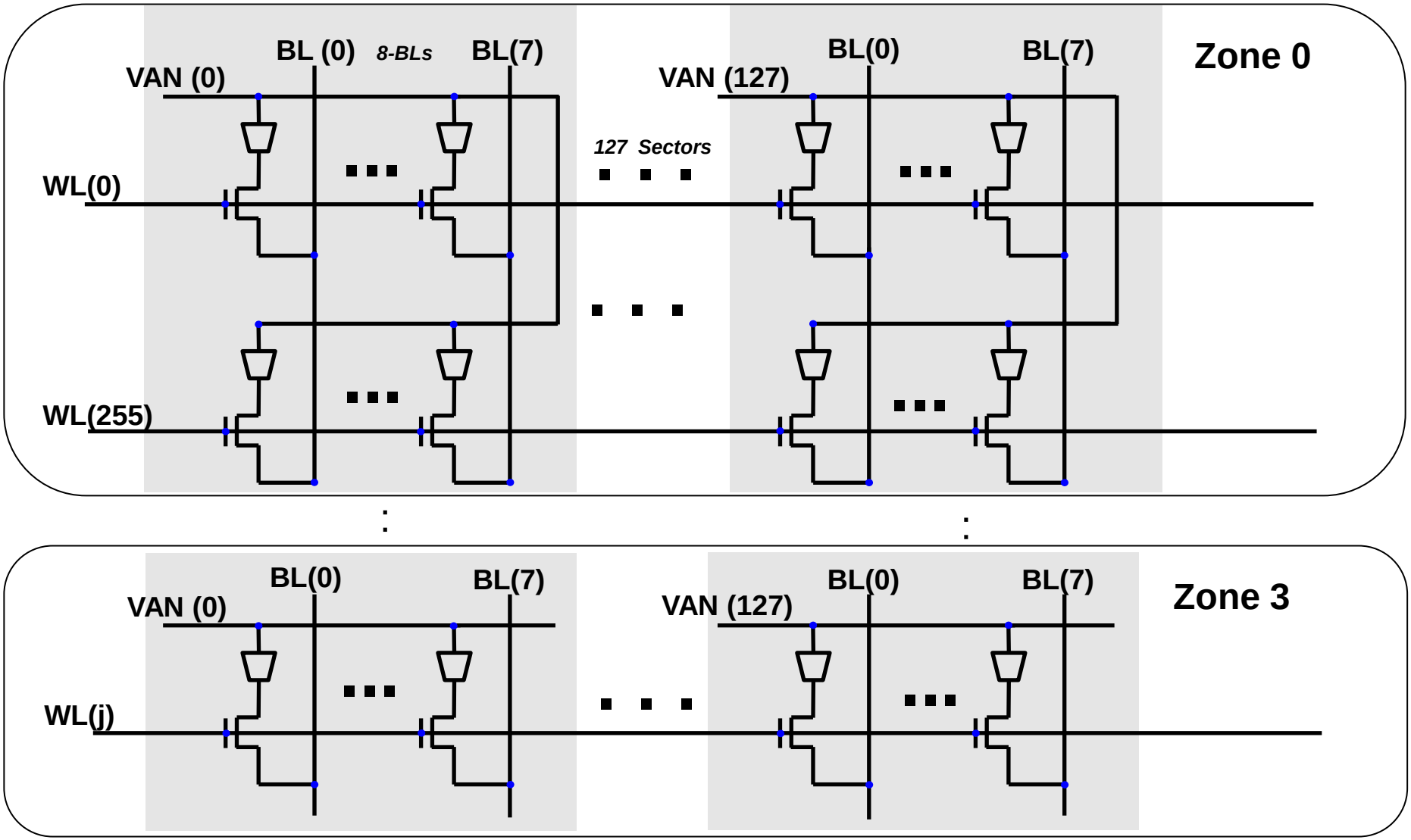
- **Introduction to Adesto Technologies**
- **Introduction to CBRAM**
- **CBRAM from Adesto**
  - General characteristics
  - High-T retention
  - Radiation tolerance
- **Conclusions**

CMOS Integration

- **Adesto has successfully completed baseline integration flow in a standard CMOS Logic fab**
- **Adesto's process integration enables the introduction of CBRAM memory stack into CMOS BEOL without affecting the line**
- **Over 8000 wafers processed so far without any issue on background CMOS process**

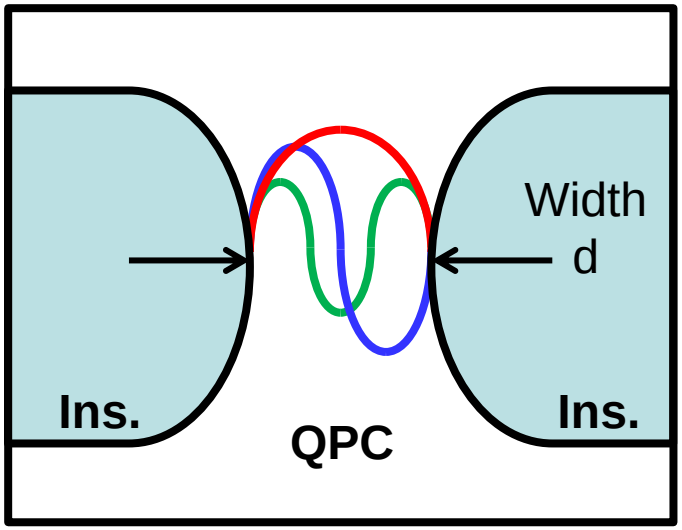


1Mb Array Architecture and Diagram



Importance of the Fermi wavelength in QPCs

To open first conductance channel ($R \sim 1/G_0$), need $d \sim \lambda_F$

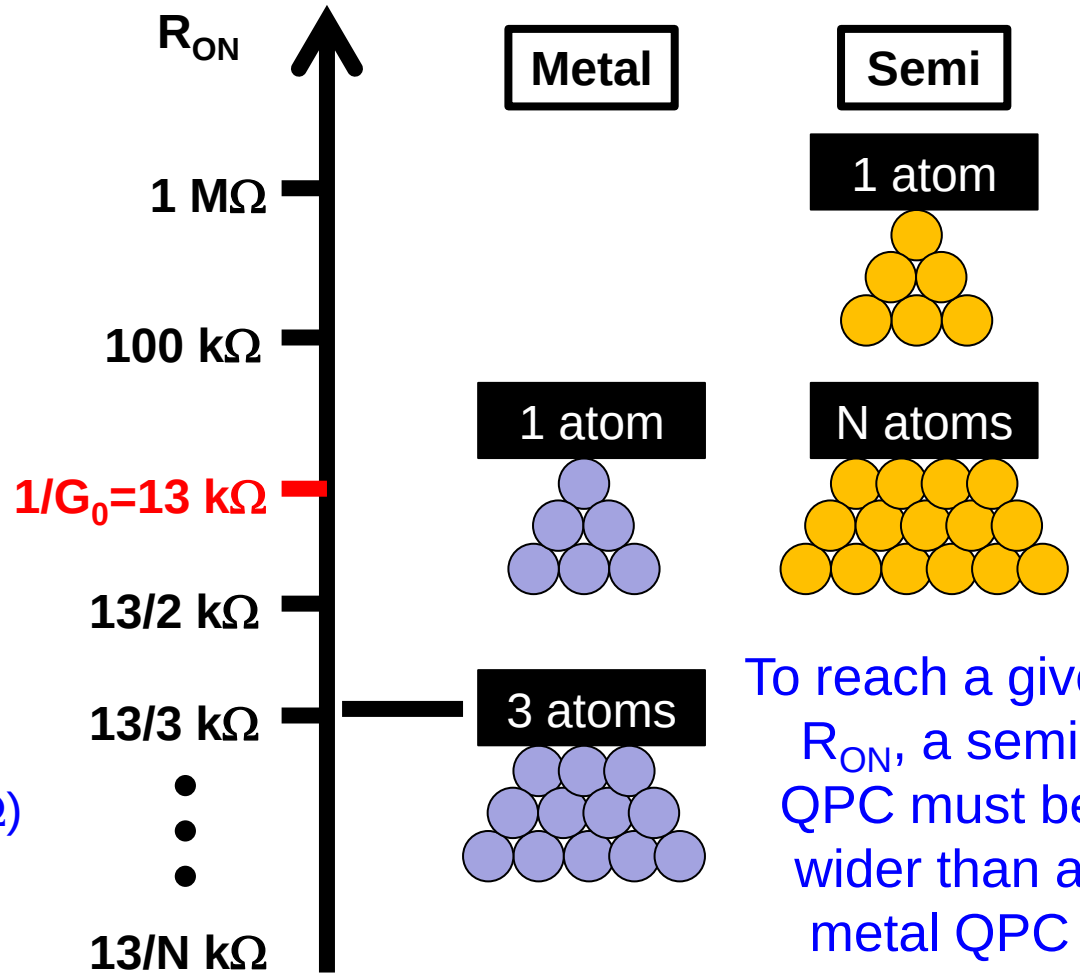


Metals:

$\lambda_F \sim 1$ Å ➔ 1 atom ~ 1 G_0 (13kΩ)

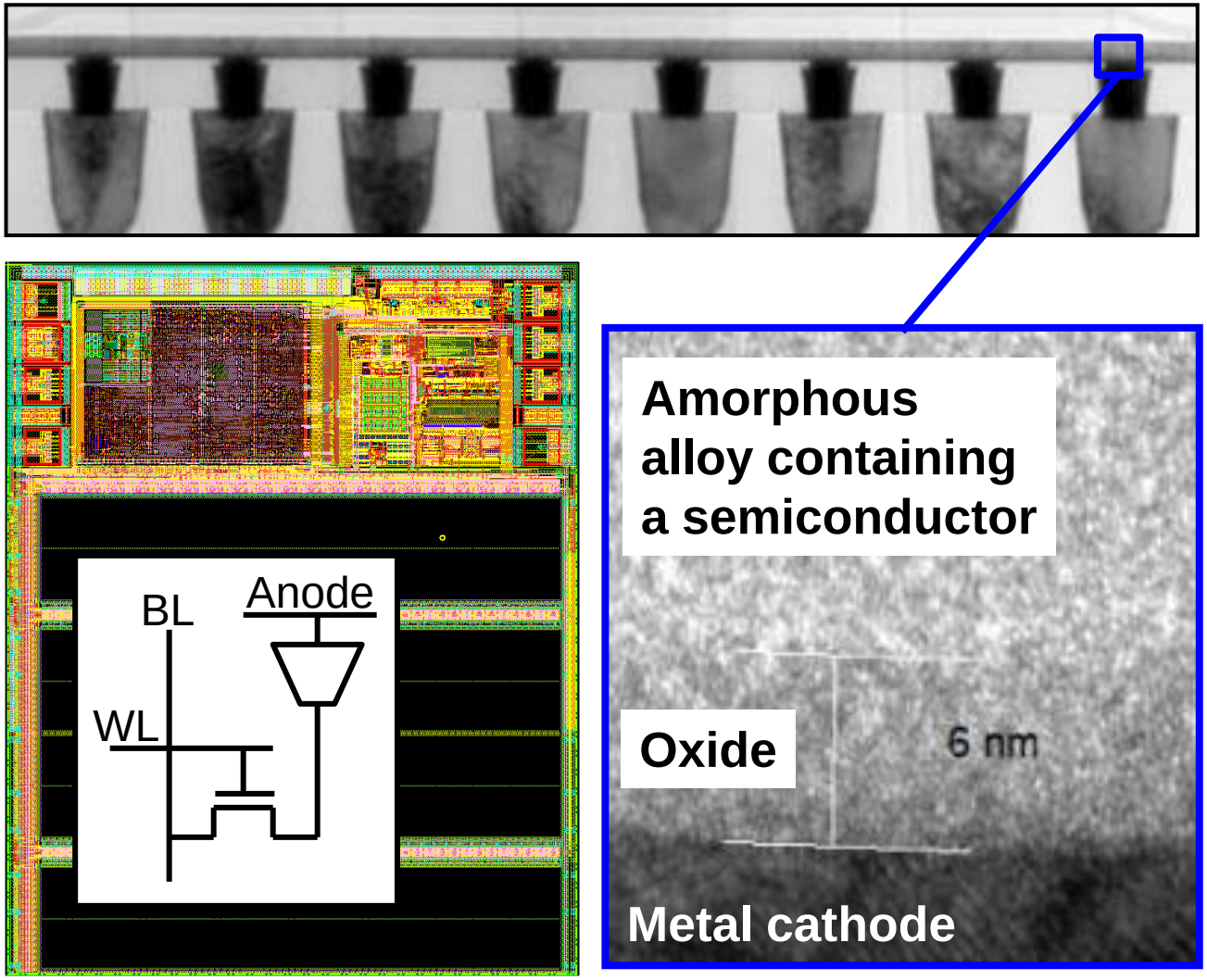
Semiconductors:

$\lambda_F >> 1$ Å ➔ 1 atom << 1 G_0



To reach a given R_{ON}, a semi QPC must be wider than a metal QPC

CBRAM: Cell Structure and Architecture

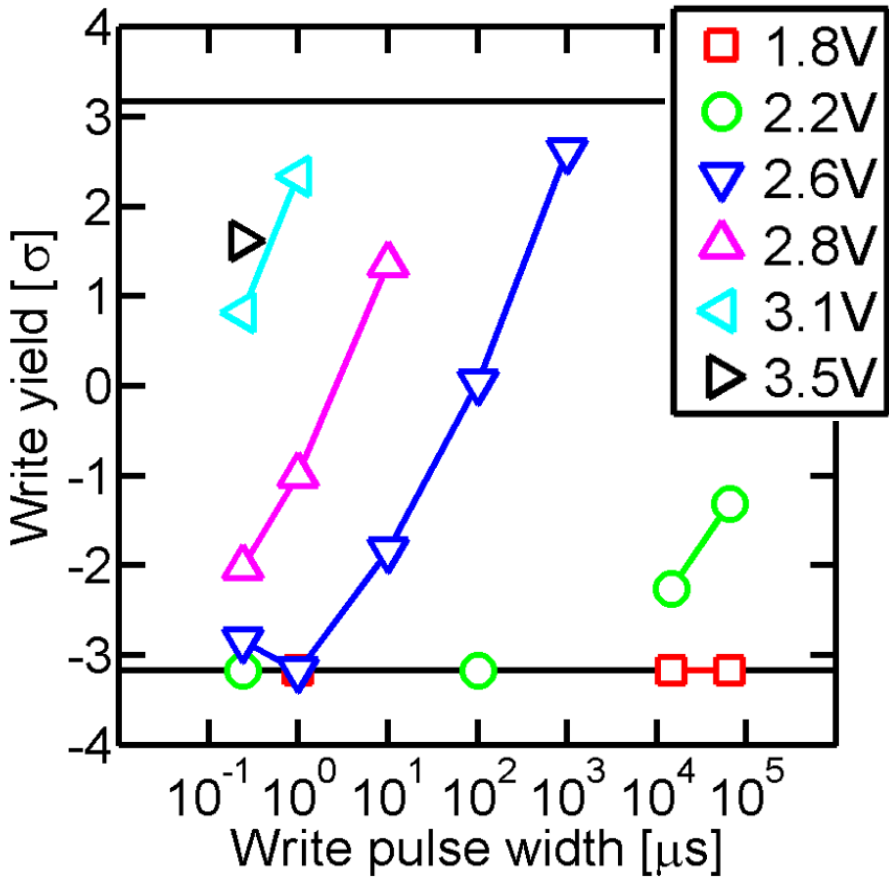


- 128kb–1Mb EEPROM-compatible products
- I^2C interface
- 1T1R
- 130nm Cu BEOL

Outline/Contents

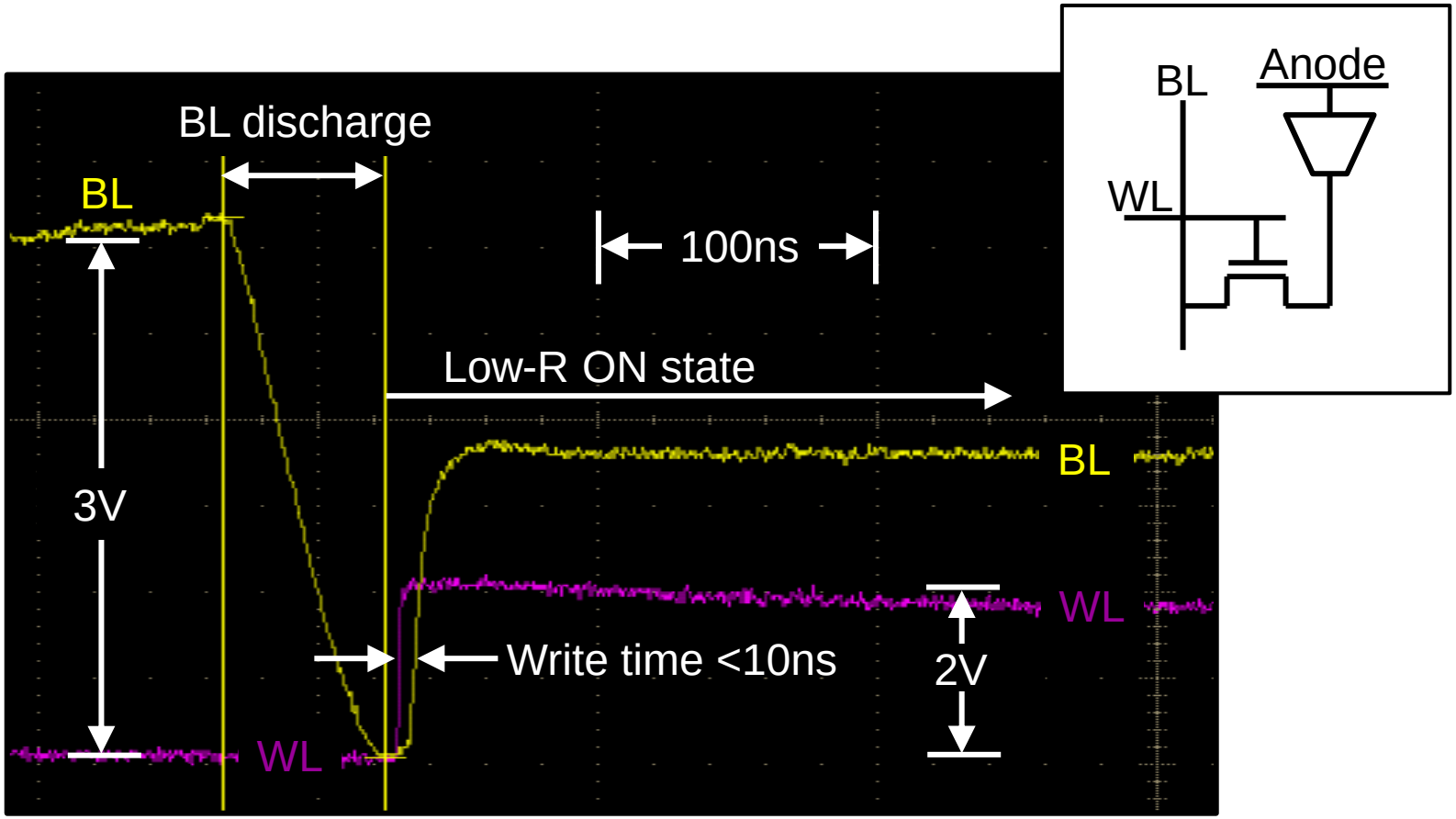
- **Introduction to Adesto Technologies**
- **Introduction to CBRAM**
- **CBRAM from Adesto**
  - General characteristics
  - High-T retention
  - Radiation tolerance
- **Conclusions**

CBRAM: Forming



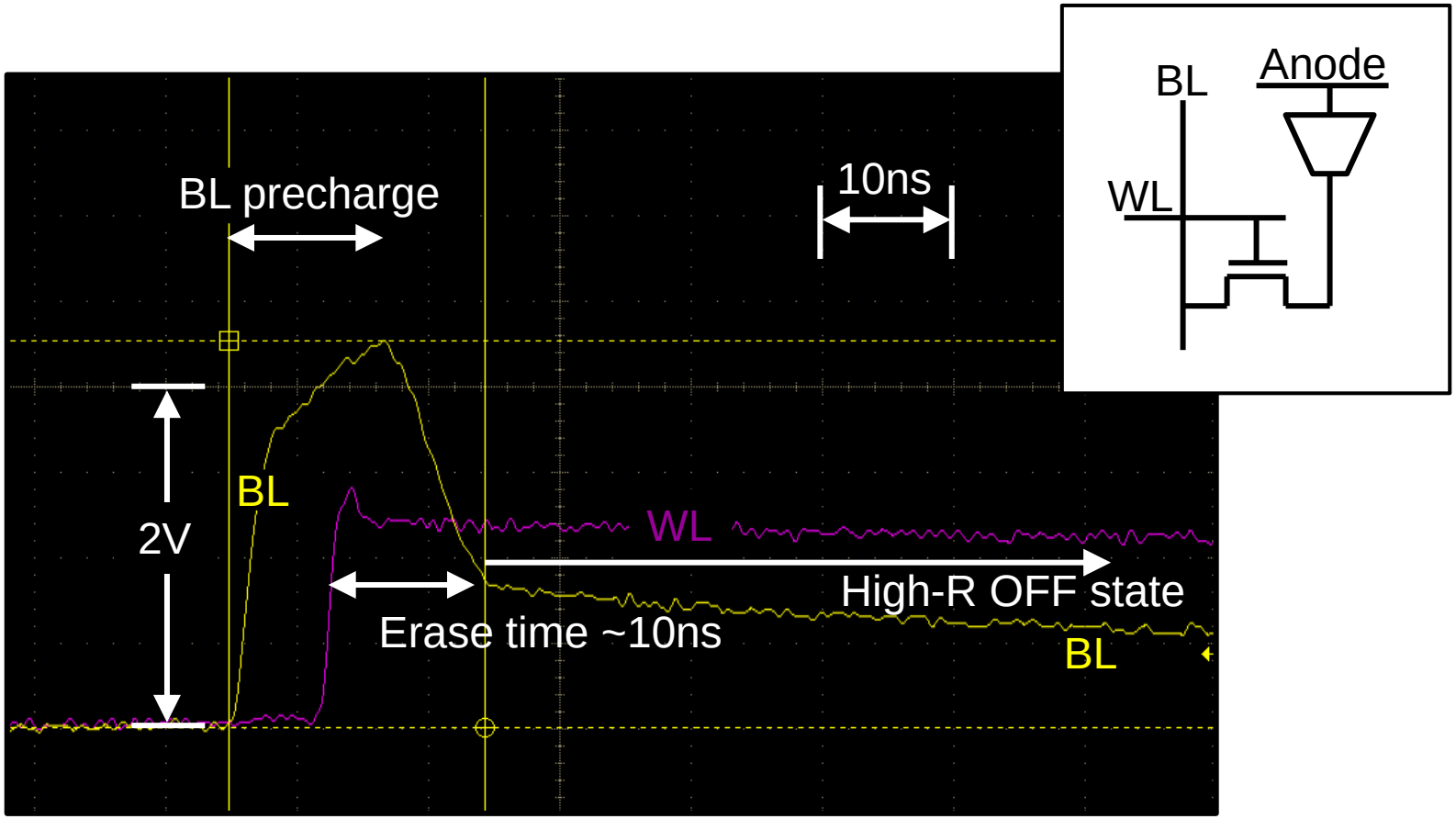
- In general, first write is slower than subsequent writes
- But, high yield still achievable with forming pulse of 10μs/3V

CBRAM: Write Speed



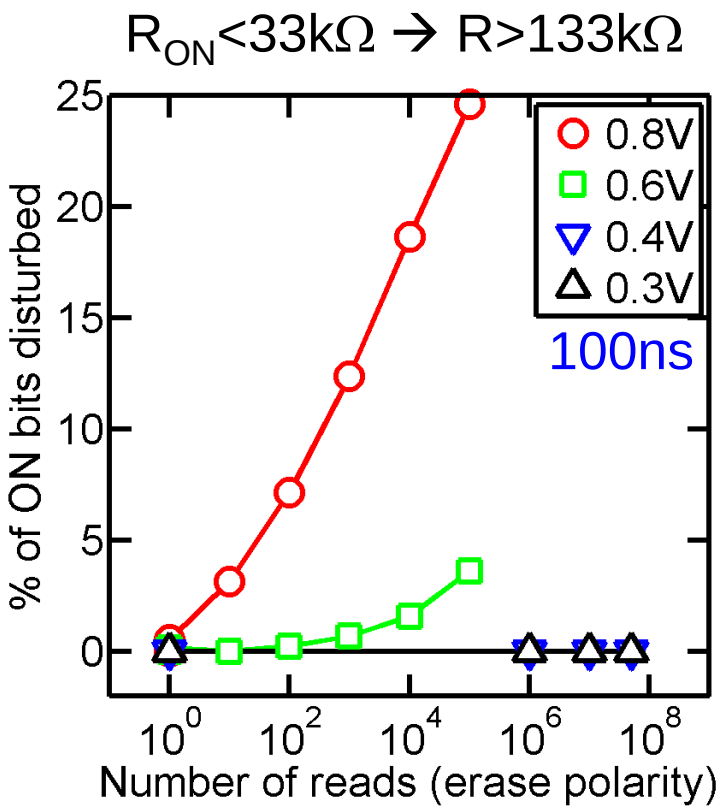
- Write speed depends “exponentially” on voltage
- At a write voltage of 3V, sub-10ns writes are possible
- Typical program uses ~2V/100ns-1us

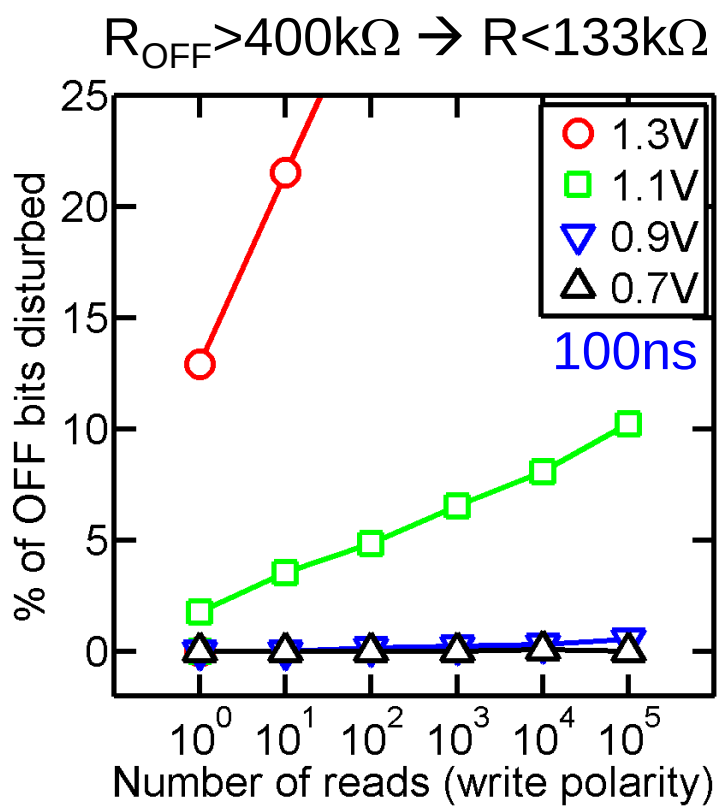
CBRAM: Erase Speed



- Above a voltage of ~2V, sub-10ns erases are also possible
- Typical erase uses ~1.5V/100ns-1us

CBRAM: Immunity to Read Disturbs





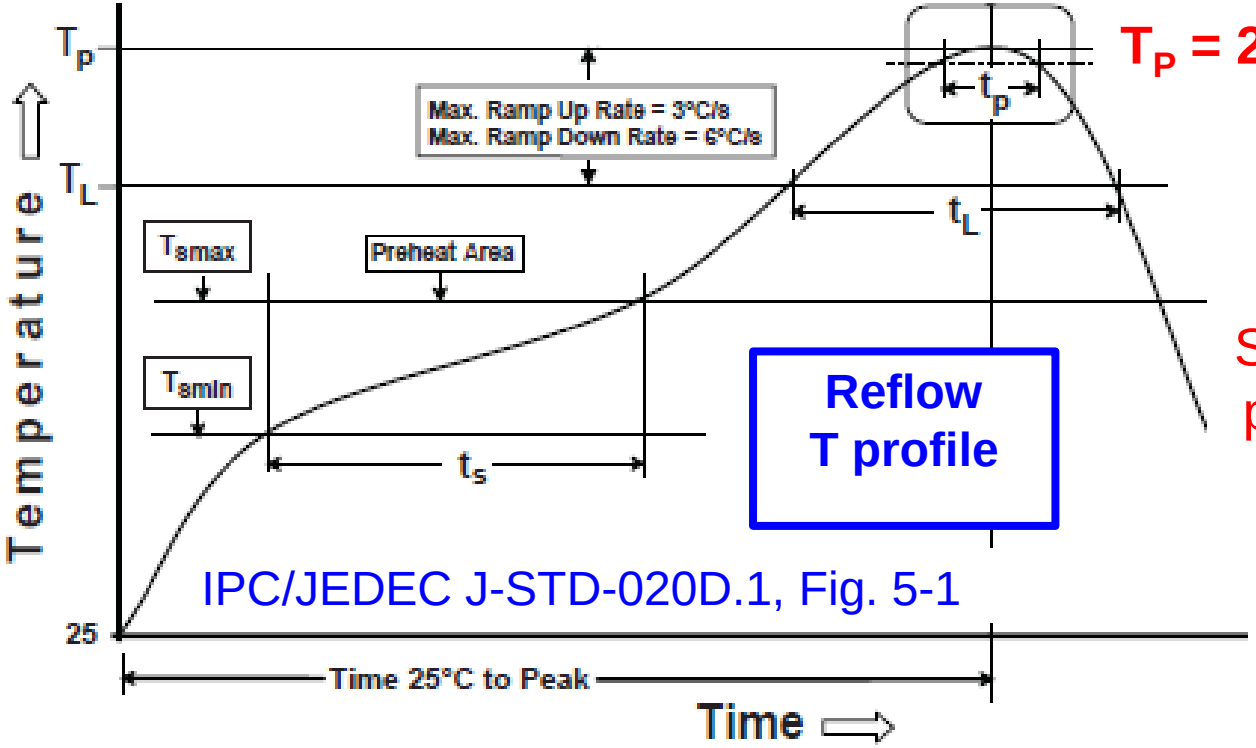
- The exponential dependence of speed on voltage allows read disturbs to be avoided
- Typical read uses ~0.2V/100ns

Outline/Contents

- **Introduction to Adesto Technologies**
- **Introduction to CBRAM**
- **CBRAM from Adesto**
  - General characteristics
  - High-T retention
  - Radiation tolerance
- **Conclusions**

The Need for High-T Retention in Emerging Memories

- Operational requirement for some applications (*e.g.*, automotive)
- Other applications (*e.g.*, code storage) utilize wafer-level or package-level programming, followed by solder reflow for board mount
- Low-density demonstrations to prove out new technology

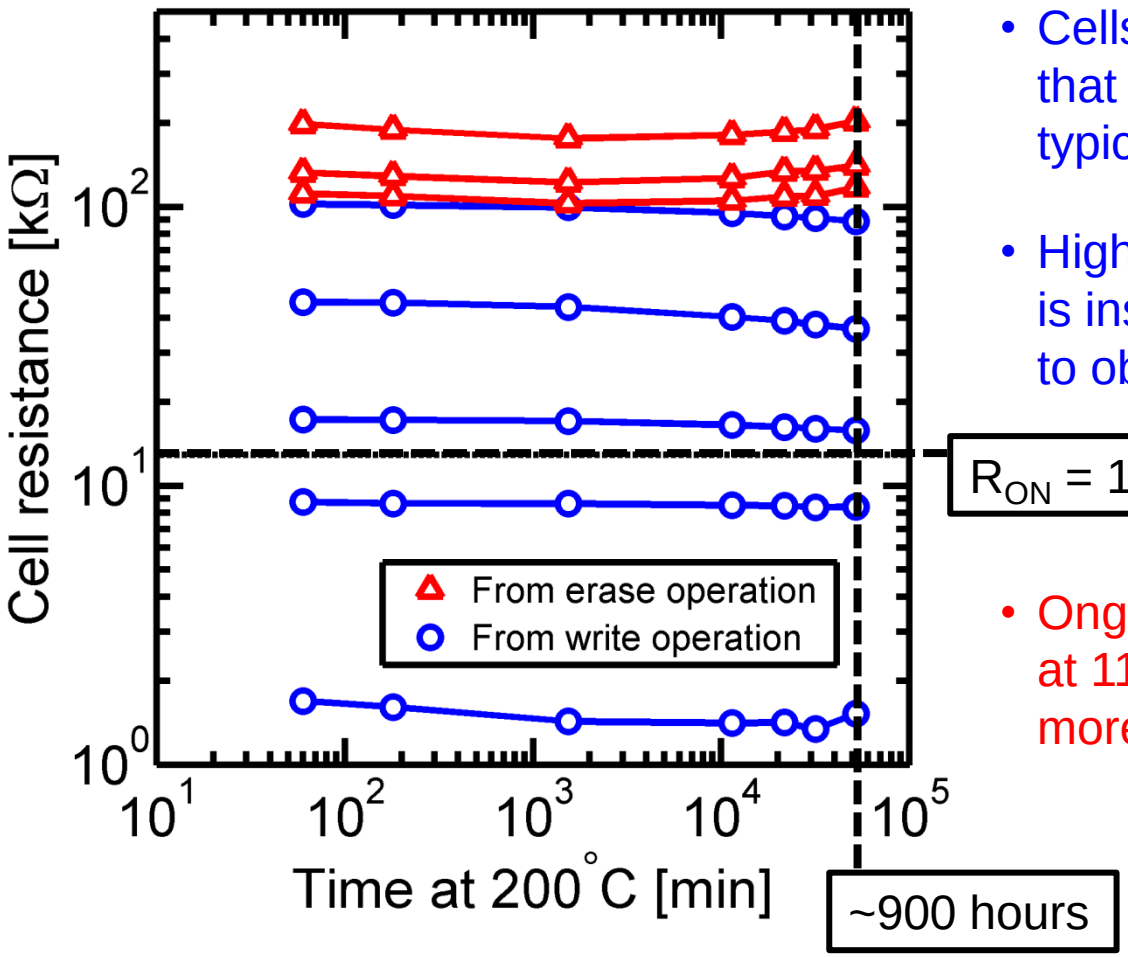


IPC/JEDEC J-STD-020D.1, Fig. 5-1

T_P = 260ºC, t_P = 30s

Worst case:
Surface mount of a thin package using Pb-free solder

CBRAM: Example of Long-term High-T Retention

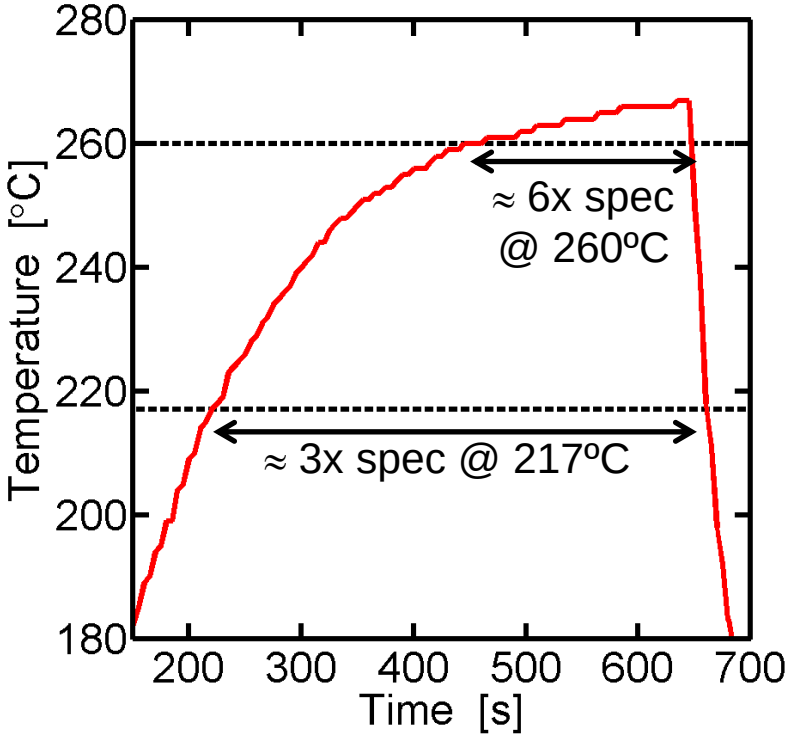


$R_{ON} = 1/G_0 = 13k\Omega$

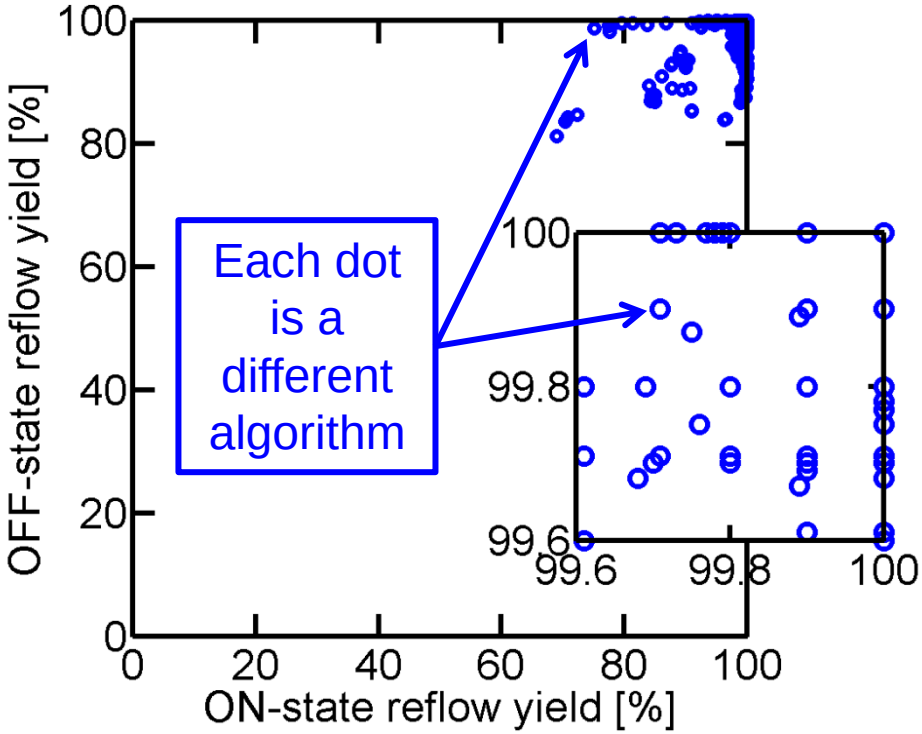
- Cells are stable at 10x greater R than that of a 1-atom point contact of a typical metal (*i.e.*, ~$1/G_0$)
- High-T retention of a given R state is insensitive to the operation used to obtain that state
- Ongoing product-level retention tests at 110ºC have shown no fails after more than 8 months

CBRAM: Retention through Simulated Solder Reflow

Anneal profile simulating high-T portion of multiple Pb-free solder reflows



Retention yields following simulated reflow



- Excellent retention is achievable at reflow-like times and temperatures
- Algorithm design is important, even with suitable materials system

Outline/Contents

- **Introduction to Adesto Technologies**
- **Introduction to CBRAM**
- **CBRAM from Adesto**
  - General characteristics
  - High-T retention
  - Radiation tolerance
- **Conclusions**

CBRAM – Robust in Extreme Environments

Recent News —

Collaboration with Adesto Technologies and Nordion Confirms Gamma Irradiation Tolerance of CBRAM® Non-Volatile Memory

Wednesday, October 16, 2013

Capability Opens New Market Opportunities to Ultra-Low Power Memory Products

Sunnyvale, CA, October 16, 2013 -- Adesto Technologies, a memory solutions provider delivering innovative products for code and data storage applications, and Nordion, with global expertise in the design and construction of commercial gamma irradiation systems, today announced the successful completion of gamma irradiation testing of Adesto's CBRAM non-volatile memory products. The results demonstrated CBRAM's tolerance for gamma testing with device function and data storage surviving gamma radiation exposure…

"Gamma irradiation is a proven technique for the sterilization of single use medical devices and other consumer products that require strict microbial decontamination." — Emily Craven, Manager of Sterilization Science at Nordion

CBRAM® Gamma Tolerance Study

Study 1: (vs. Conventional Flash)

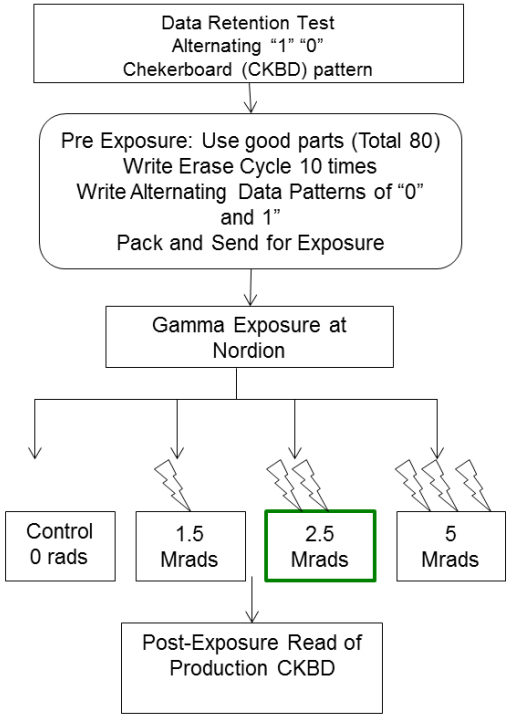
Device	Technology	DUT ID	Gamma Dose (krad Si)	Data Loss (# bit errors)	Result
AT25F512B	Floating Gate	1	447	859	FAIL
AT25F512B	Floating Gate	2	447	6519	FAIL
AT25F512B	Floating Gate	3	131	955	FAIL
AT25F512B	Floating Gate	4	131	4	FAIL
RM24EP128KS	CBRAM	1	447	0	PASS
RM24EP128KS	CBRAM	2	447	0	PASS
RM24EP128KS	CBRAM	3	131	0	PASS
RM24EP128KS	CBRAM	4	131	0	PASS

Conventional Flash Memory Devices

CBRAM Devices

- **Tests performed by ASU**

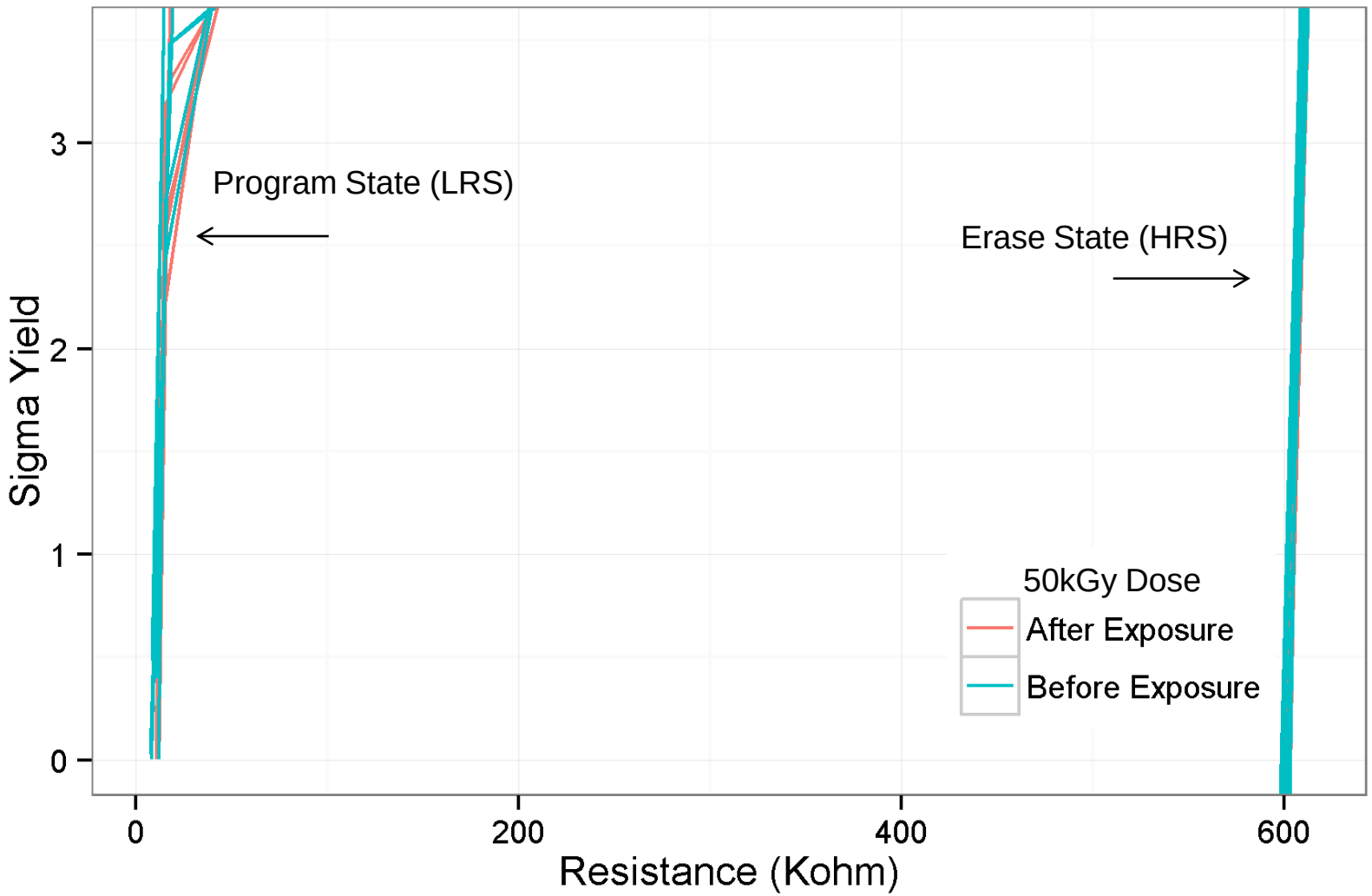
Study 2: (High Dose Gamma)



- **Tests performed by Nordion – Leading provider of isotopes and radiation therapy services to the medical and health care industry**
- **Results : CBRAM PASSED Data Retention Test**

CBRAM had no failure even at twice the normal dose used for Gamma Sterilization

CBRAM Cell Tolerance to Gamma Radiation – Resistance Distribution



Summary and Outlook for CBRAM

- **Field of emerging memory is diverse and vibrant**

- **CBRAM has been a leading candidate, and has recently made significant new advancements**

- **CBRAM has achieved high-T retention by using a combination of materials engineering & a properly designed algorithm**

  → Opportunities for apps w/ high-T operation or requiring solder reflow

- **Tolerance to gamma radiation has also been achieved**

  → Opportunities for medical or aerospace applications