RRAM – The Next “Flash”

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Non-Volatile Memory Trends

Storage capacity (Mb)

100,000
10,000
1000
100
10
1

Cond. 1Mb
ISSCC, VLSI Circuits, ASSCC
IEDM, VLSI Tech.

NAND flash
128Gb
32Gb
RRAM
8Gb
PRAM
FeRAM
128Mb
MRAM
64Mb

2001 2003 2005 2007 2009 2011 2013

Year

K. Zhang, Intel, ISSCC 2013

Non-Volatile Memory Trends

Write bandwidth (MB/s)

10,000
1000
100
10
1

Cond.>1Mb
ISSCC, VLSI Cir.,
ASSCC 2001-2011

Emerging NVRAM

eRAM
(ASSCC'07)

FeRAM
(ISSCC'09)

MRAM
(ASSCC'06)

FeRAM, MRAM
(ISSCC'06)

RRAM
(ISSCC'11)

NAND
(ISSCC'08)

PRAM
(ISSCC'07,'10)

Better

PRAM
(ISSCC'11)

NOR
(ISSCC'07, 05)

eNOR
(ISSCC'07)

Flash

100
1000
10,000

Read bandwidth (MB/s)

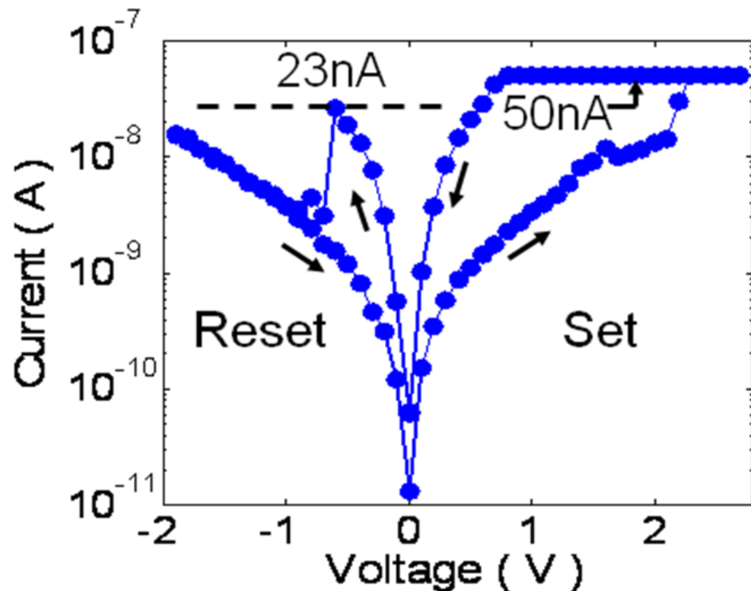
K. Zhang, Intel, ISSCC 2013

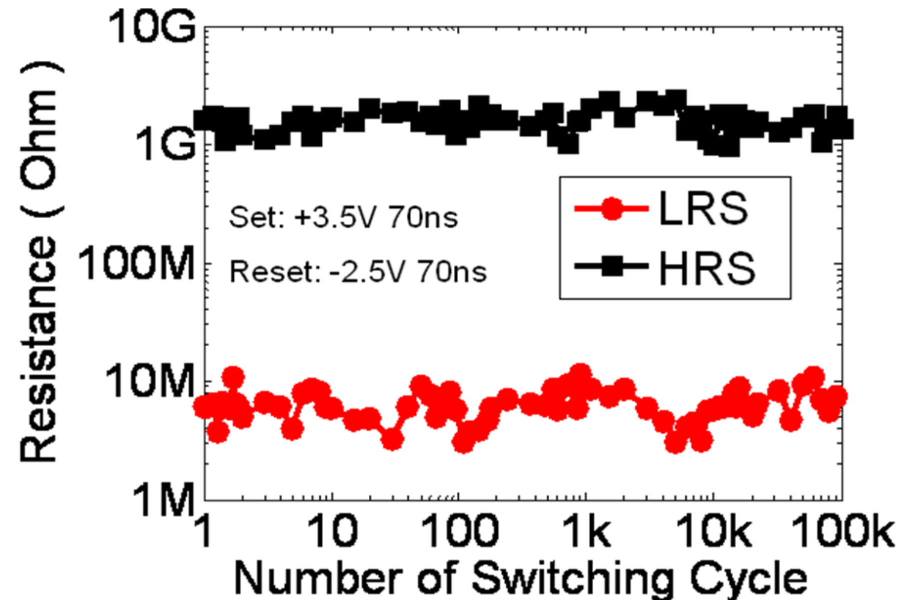
RRAM Benchmarks

	TaO_x IEDM 2008	HfO_x IEDM 2008	HfO_x IEDM 2009 &2010	$N:AlO_x$ VLSI 2011	TaO_x/Ta_2O_5 VLSI 2011	Hf/HfO_x IEDM 2011	Hf/HfO_x IEDM 2012	Ni/HfO_x IEDM 2012	$TaO_2O_{5-\delta}/TaO_x$ VLSI 2012	$Al_2O_3/HfO_2/Hf$ VLSI 2012	Nb_2O_5/NbO_2 VLSI 2012
Switching type	bipolar	bipolar	Bipolar	bipolar	bipolar	bipolar	bipolar	bipolar	bipolar	bipolar	bipolar
Structure	1T-1R	1T-1R	1T-1R	1T-1R	1R	1T-1R	1T-1R	1T-1R	1T-1R	1T-1R	1S-1R
Cell Area (μm^2)	~0.25	~0.1	0.0009 (30nm)	1	~9000	0.0001 (10nm)	0.0016(40nm)	0.0014	0.0324	0.0035	0.0225
Speed	~10ns	~5ns	~300ps	N/A	~10ns	~10ns	~10ns	~50ns	N/A	~10ns	~10us
DC Peak Voltage	<2V	<1.5V	<2.5V	<2V	<2.5V	<1.5V	<1.5V	<4.5V	<3V	<2V	<2V
DC Peak Current	~17μA	~25μA	~200 μA	~50nA	~30μA	~50 μA	~25μA	~200pA	~80μA	~500nA	~800μA
HRS/LRS Ratio	>10	>1,000	>1000	>100	>100	>10	>10	>10	>1000	>10	>10
Endurance	10^9	10^6	10^{10}	10^5	10^{12}	$5x10^7$	10^7	10^5	N/A	10^7	10^6
Retention	3000h @ 150℃	10h@ 200℃	28h@ 150℃	28h@ 125℃	3h@ 200℃	30h@ 250℃	3h@ 200℃	10yr@85℃	100h@ 150℃	3h@250℃	N/A

Low Programming Energy, High Endurance Cycles

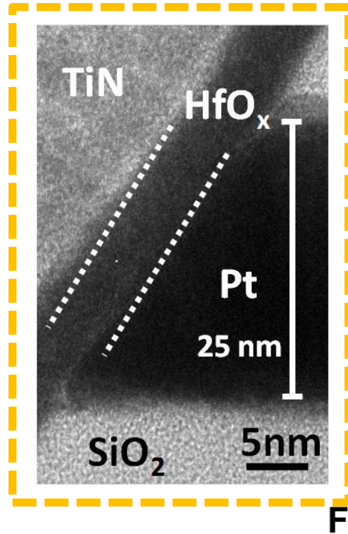
Nitrogen doped AlOx

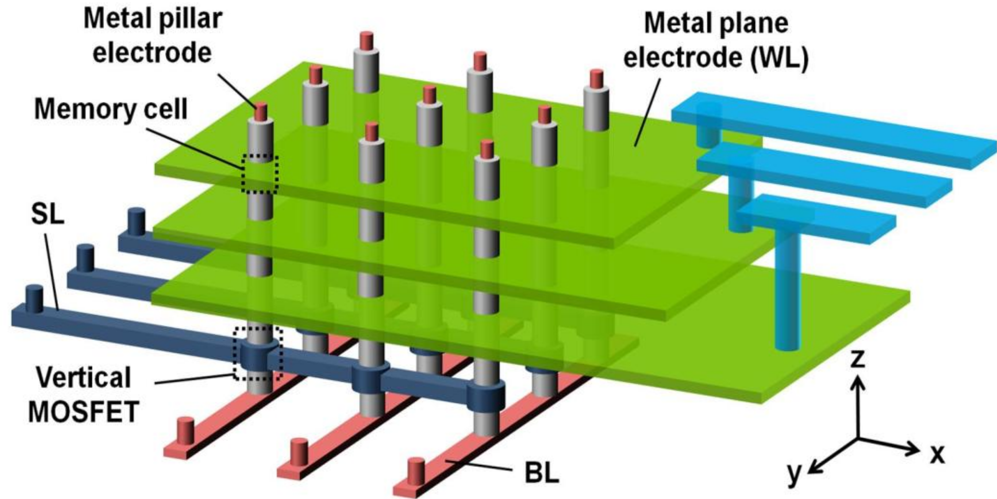




W. Kim…S.S. Wong, *Symp. VLSI Technology,* June 2011

3D RRAM





H.-Y. Chen … H.-S. P. Wong, IEDM 2012
S. Yu … H.-S. P. Wong, Symp. VLSI Tech. 2013