TowerJazz

The Global Specialty Foundry Leader

Nonvolatile memories for IoT applications

Yakov Roizin

21 September 2017

TowerJazz - the world largest Analog Foundry: 7 Fabs; >2.5 million wafers/year; revenues ~ 1.5 billion US $, ~4500 employees

TOWERJAZZ

Midgal HaEmek, Israel

6″, 150mm, 16k w/m
CMOS, CIS, Power, Discrete
1µm to 0.35µm
Planarized BEOL,
W and Oxide CMP

Midgal HaEmek, Israel

8″, 200mm, 43k w/m
CMOS, CIS, Power, Discrete, MEMS
0.18µm to 0.13µm
Cu and Al BEOL
EPI, 193nm Scanner

Newport Beach, USA

8″, 200mm, 24k w/m
CMOS, CIS, MEMS, RF Analog
0.5 µm to 0.13µm
Al BEOL, SiGe , EPI

San Antonio, USA

8″, 200mm,
Power, RF Analog
• 0.18µm , 36k w/m
Al BEOL

TPSCo

Tonami, Japan

8″, 200mm, 51k w/m
Power Discrete, HVCMOS, CMOS, PMIC, NVM, CCD
0.5µm to 0.13µ

Uozu, Japan

12″, 300mm, 20k w/m (8" equiv.)
CMOS, CIS, RF CMOS
65nm to 45nm

Arai, Japan

8″, 200mm, 14K w/m
Analog, CIS
0.13µm to 0.11µm
Thick Cu RDL

TOWERJAZZ
The Global Specialty Foundry Leader

Outline

- Semiconductor technologies for IoT and M2M
- NVM for Big Data storage
- Demands to embedded NVM for IoT motes
- Candidates for IoT memory:
  - FG solutions (small size modules)
  - MRAM, CBRAM, FeRAM and Beta-voltaic enabled SRAM
  - ReRAM
- Conclusions

Semiconductor technology and IoT

Two pronounced technological directions in the IoT:

- **Deeply scaled down semiconductor technologies for Big Data storage and analyses**

  Applications: base stations and data heavy IoT systems, like intelligent wearable devices.

  Currently: 14nm technology node Flash NAND and processors in mass production; fabrication mostly by IDMs (Intel, Samsung..) and digital foundries (TSMC, GlobalFoundries..).

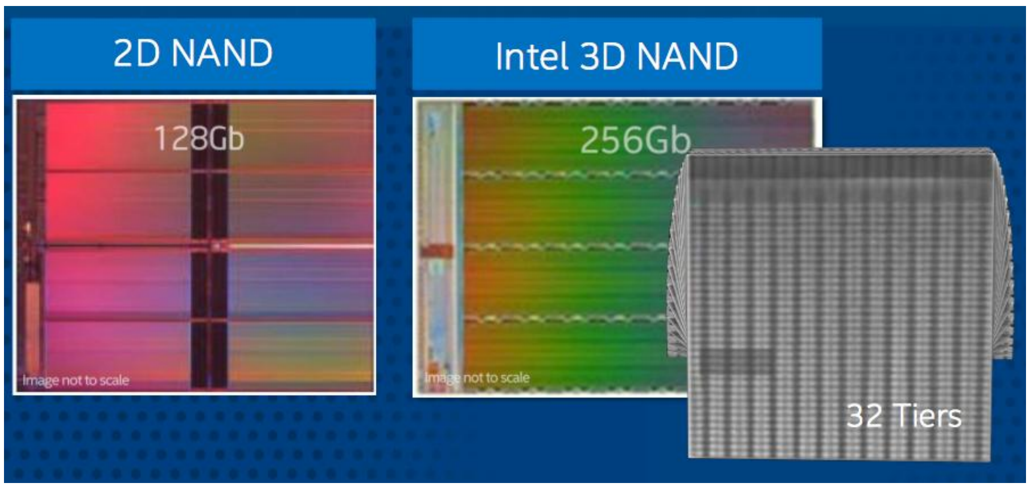
- **180nm to 65nm technologies for IoT motes: sensing devices with registration circuits and wireless communication means (fabricated mostly in foundries)**

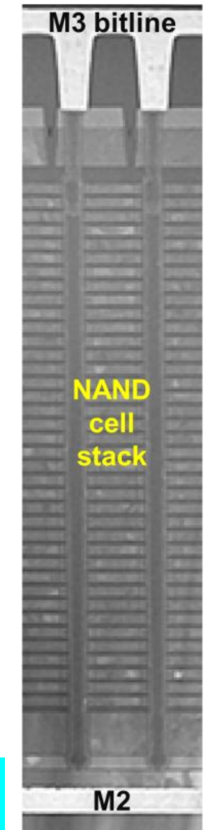
Special demands to IoT semiconductor technologies:

ultra-low power , low-cost, security , highly flexible design based on specialized IPs, reliability

NVM for Big Data storage: 3D roadmap

- **In the last decade , NAND flash was scaled by a factor of two every two years (faster than logics).**
- **At present , there is a slow down in NAND scaling (15nm MLC-multilevel Hynix Flash s probably the most deeply scaled EEPROM in production; 256Gbit chips in iPhone 7)**
- **3D NAND: Toshiba, Hynix ,Samsung and Intel-Micron stack Flash cells (32 layers in IMFT; 256Gb MLC ; Poly FG ; ~1.5 Gb/mm2 density ; 2.5 inch SSDs > 10TB volume,).**





Poly channels and Poly (W replacement) gates

40nm process is used in Samsung V-Flash (CT Flash) due to superior data retention and endurance compared with 20nm range FG Flash

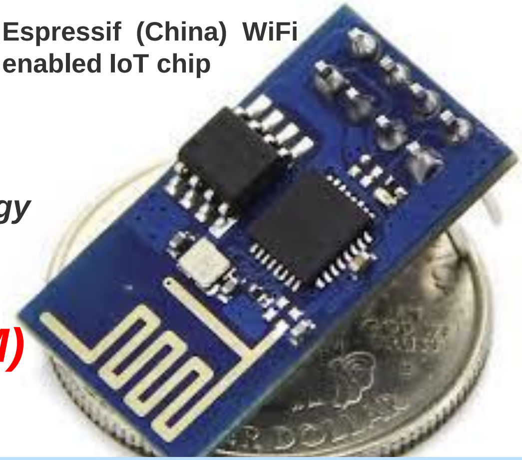
Toshiba : 3bit/cell 256Gb x3 48 layers BiCS in iPhone8 : 256Gbit 3D chips

New players: Optane/3D X-point, Nantero 2nd Gen --??

IoT motes

A typical IoT integrated sensing node includes :

- Sensors (*temperature, vibration, gases, humidity, pressure, altitude, acceleration, proximity…)*
- Energy source and power management electronics (*battery, or/and energy harvesting: solar, vibrational, Seebeck, betavoltaic …)*
- Low power MCU
- **Embedded Memory *(ultra-low power SRAM and NVM)***
- RF-Connectivity (*GSM/LTE, Bluetooth , Zigbee, WiFi…*)



Espressif (China) WiFi enabled IoT chip

General IoT mote strategy: -

Higher functional integration and lower power consumption

In silicon foundries :

- **IoT CMOS platforms (e.g. low power SOI based CMOS) as a foundation.**
- **Sensors and NVM married to RF and PM to create wireless sensor motes**
- **Both monolithic integration on one crystal and 3D/2.5D (on an interposer) integration**

Most of leading IDMs and foundries announced their IoT roadmaps (Intel, TSMS, GF, UMC, SMIC..) and opened IoT business units and divisions

Demands to the NVM in IoT motes

Different projections of spec numbers , but general agreement is that the advanced mobile applications (IoT; M2M..) will need various types of embedded memories (both OTP and MTP) , mostly small or middle sized (< 0.5Mb) modules :

Currently , small volume NVM modules (up to 16 kbit) are of the greatest demand today (calibration, offsets, IDs, security..)-different demands to endurance
When IoT and M2M would expand, larger volume/high endurance/high speed MTP would be needed to support :
(i) gathering information by intelligent sensors ,
(ii) advanced communication protocols
(iii) enhanced security

Demands to NVM in IoT motes:

- **low power consumption**
- **low cost**
- **field programmability**
- **high security**
- **high reliability**

Mobile devices have limited energy sources. Devices connected to the Internet of Things ran on small batteries.
***Main technical demand*:**
Low Voltage and Low Power

E.g., CR1225 Lithium battery is used : ~12.5 mm, 3.3V, stores ~ 50 J.
To re-program 1 bit of FG Flash, one needs ~ 20nJ for F-N programmed devices
Cycling of 16 kbit data array to 200k cycles will need 62 J….

Alternative solutions are needed ….

What do NVM IP vendors consider for IoT?

NVM IP vendors advertise the **existing** offering as suitable for IoT

Antifuse OTP IP vendors, (*Sidense, Kilopass..*) : low-power design , though typically power consumption for programming is ~**1uJ/bit**

Cypress licensed 40/55nm Embedded SONOS to UMC for IoT and Wearable Applications
+3 masks to core CMOS (w/o HV).
Included into UMC IoT production platform.
Power in programming
10nJ range

Cypress bought in 2016 Broadcom IoT division (W-Fi, Zigbee and Blootooth IPs)

Cypress bought Ramtron with an outlook of FeRAM for IoT

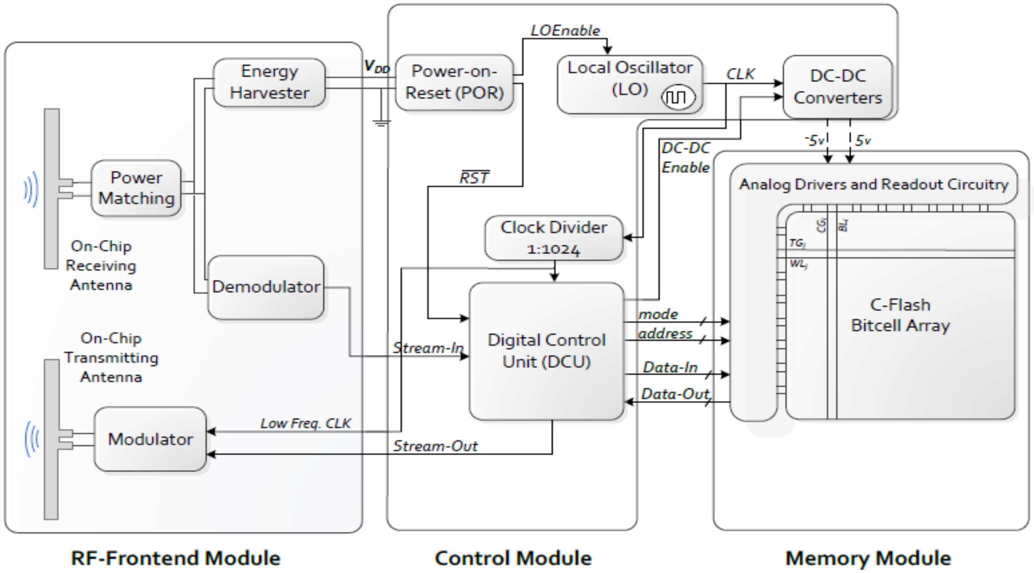
Even a specialized company **IoTFlash** appeared
(SINGLE BUTTON BATTERY TO OPERATE NOR FG FLASH)

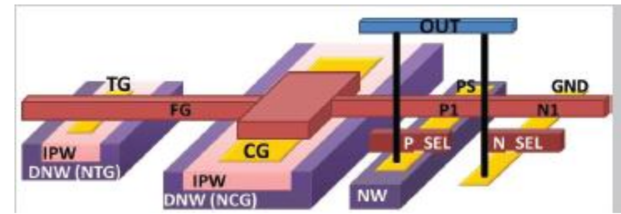
Synopsys offer Novea and AEON as ultra low power solutions
10nJ range

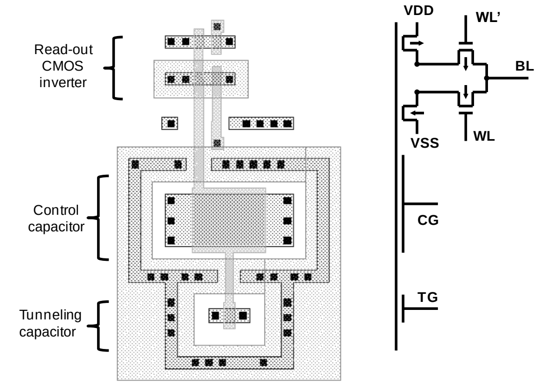
ULP		
TSMC 180G	TSMC 152G	SilTerra 180G
128 -> 1k	128 -> 1k	128 -> 1k
-40 -> 85	-40 -> 85	-40 -> 85
100,000	100,000	100,000
1.4 -> 2.0	1.4 -> 2.0	1.4 -> 2.0
0.9 -> 2.0	0.9 -> 2.0	0.9 -> 2.0

Only very few solutions comply with specific demands to IoT motes !!

Small EEPROM modules for IoT
TowerJazz C-Flash 256bit Module for RFID (an example)







24GHz RFID tag comprising the on-the-chip 24GHz antenna and embedded C-Flash ultra-low power consumption/low cost NVM module (256bit). Fabricated in TowerJazz 0.18um CMOS process flow. The total read power 13uW

(IEEE Journal of Solid State Circuits, V.49, No.9, 2014).

Joint project with several Israeli universities (BIU, BGU, TAU)

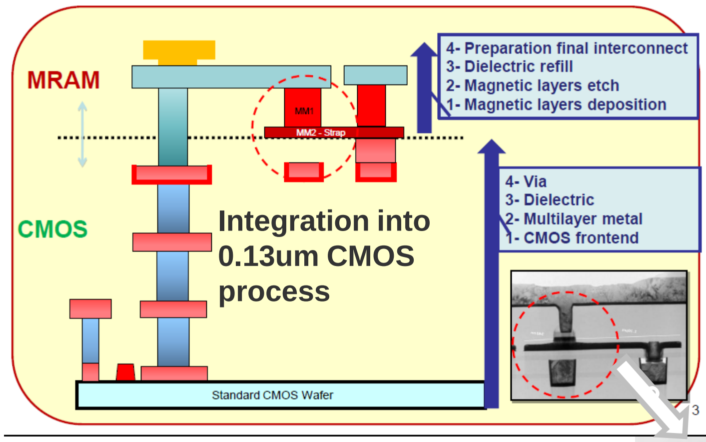
C-Flash memory cell, Fowler-Nordheim programming and erase. CMOS inverter for read-out. NVM drivers with <50pW static power in read.

SOI based cell area about 10um2

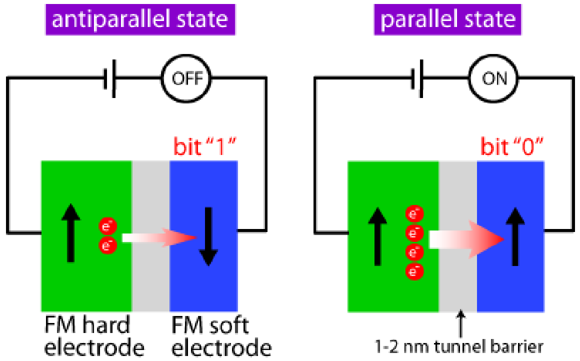
Challenges: power consumption, cell size

MRAM as a NVM candidate for IoT/sensor applications

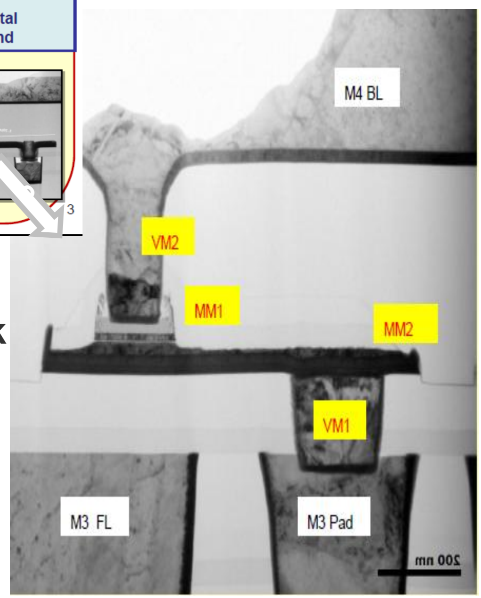
TAS MRAM TowerJazz-Crocus



Arrays of up toseveral Mbit demonstrated.



MTJ stack



~ 60pJ/bit in programming.
Programming energy is higher than for STT MRAM.

Challenges:

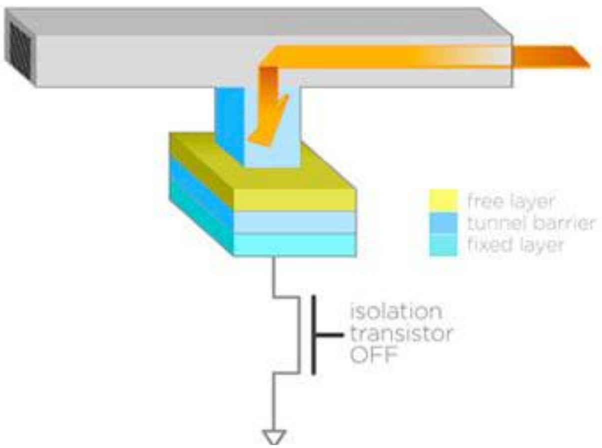
-compromise between array size and reliability (endurance) Qbd issues (like in most MRAMS employing MgO tunnel oxide)

- cost issues (relatively expensive magnetic stack)

Medium density modules (1-64 kbit) are suitable for many IoT applications

STT and SOT MRAM for IoT
(currently running projects)

STT MRAM



STT MRAM (currently developed within GREAT H2020 EU consortium: cooperation of TowerJazz with CEA/Spintec , Singulus and European Universities)

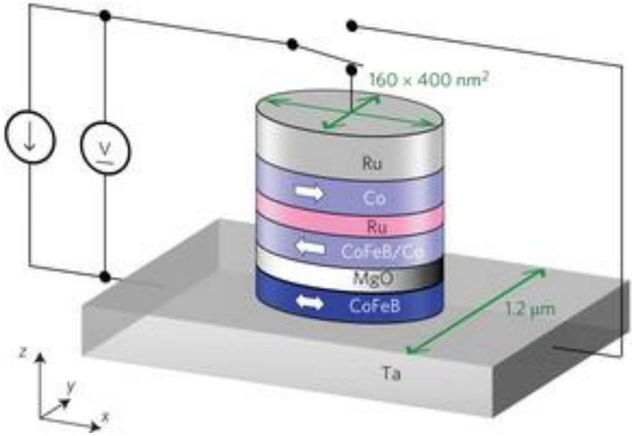
The aim is to integrate memory , MTJ magnetic field sensors, and RF elements based on MTJ with 0.18/0.13um CMOS.

STT MRAM Challenges:

i) High current required for writing damages MgO
ii) Read-out may cause switching (especially for scaled down MTJ)

SOT MRAM

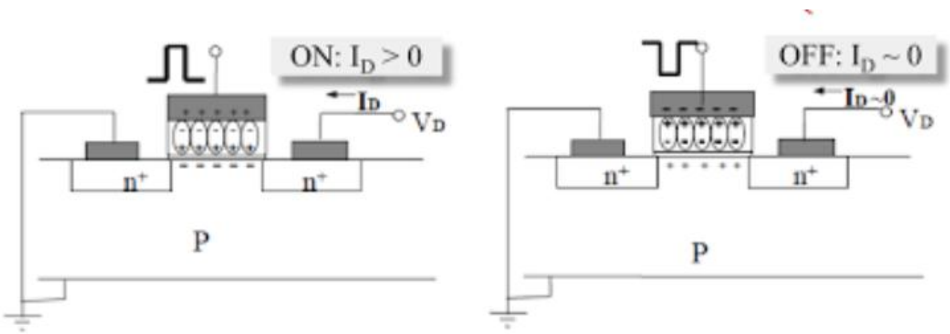
Three-terminal SOT MTJ with writing based on Spin-Orbit Torque approach revitalizes the hope of an "universal memory"

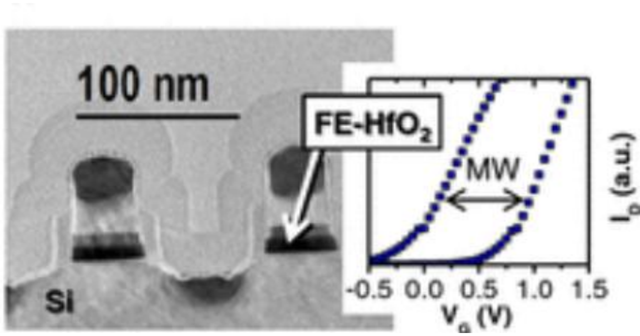


SOT is free from reliability issues since switching current is in horizontal plane and thus MgO Qbd issues are not relevant.

FeRAM for IoT (is there a niche for FeRAM in IoT applications?)

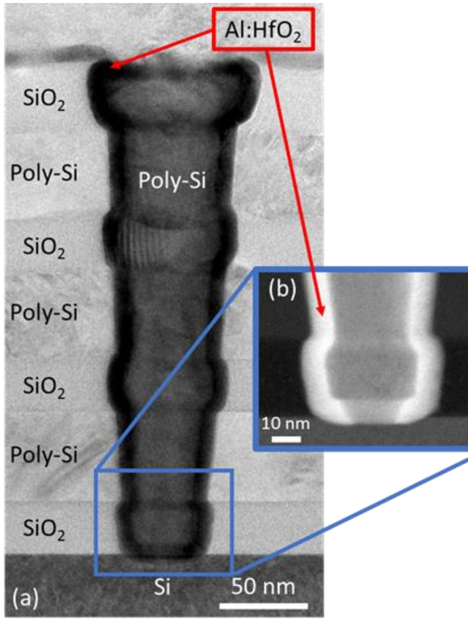
Some IoT applications, especially requiring high endurance and ultra-low power, can benefit from novel FeRAM approaches, like 1T based on doped with metals or Silicon HfO_2 gate oxides (FMC/Namlab ,Dresden)





Challenges:

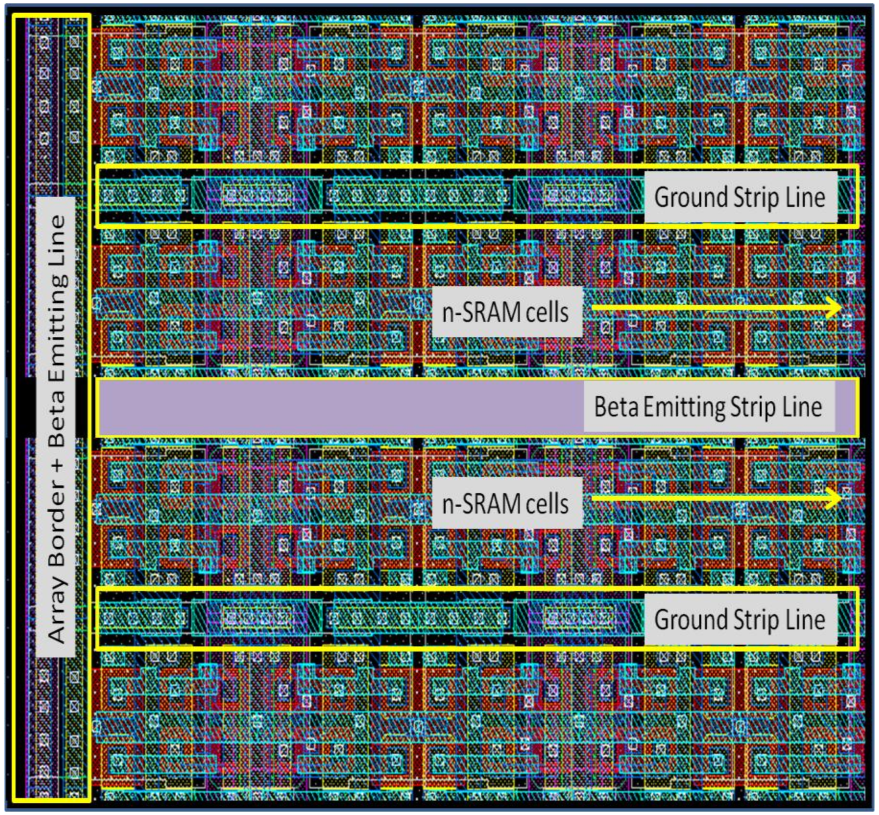
1) Trapping in Hafnia (Vt instabilities).
2) With cycling , large leakage currents are built-up in HfO2 due to trap generation. Currently, max 10k cycles are reported
3) Ferroelectric domain are easier in deeply scaled down processes. Probably, has an added value for technologies that already use Hafnia HfO2 as CMOS gate oxides

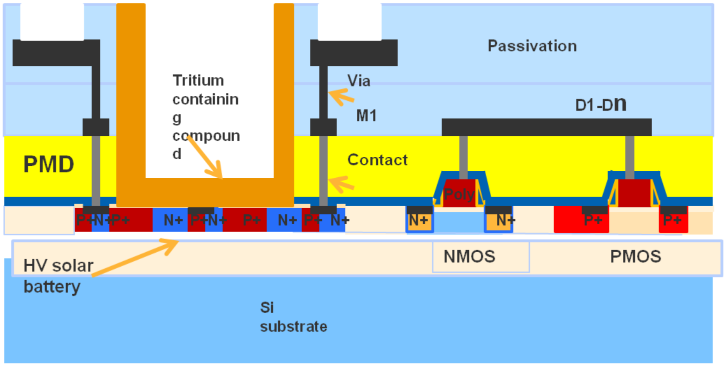


IMEC vertical HfO2 doped with Al FeRAM

SRAM enabled by Betavoltaic sources

Beta emitting areas are formed in the SRAM array. Tritium sources are used to convert the HV solar cells into beta voltaic sources continuously providing bias for the NVM arrays





An opening is etched through the stack of Back End dielectrics (Tritium containing film is introduced

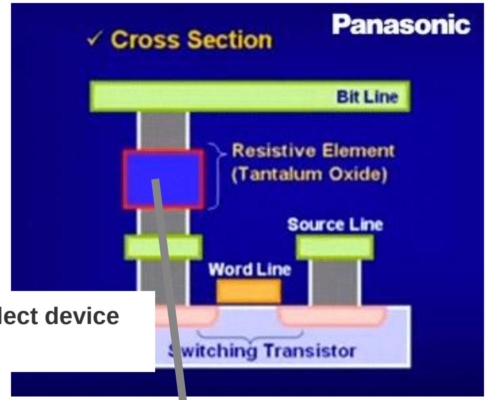
TowerJazz and RedCat , Italy

Based on several TowerJazz patents

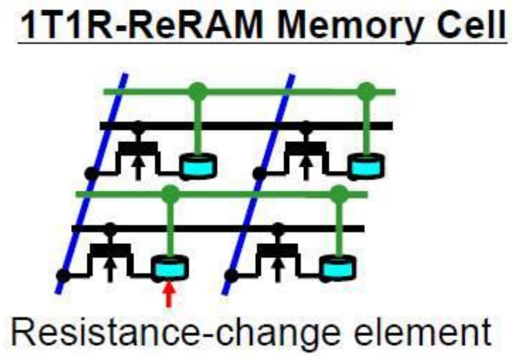
Challenge: cost connected with T (^{3}H) sources

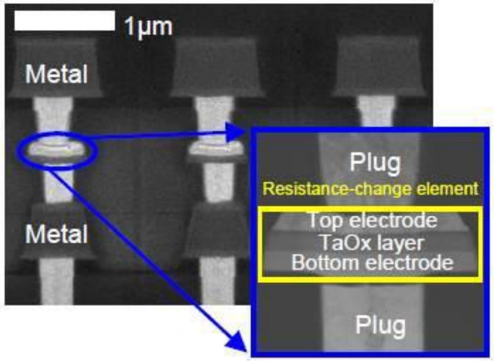
ReRAM (TowerJazz /TPSCo Tonami Fab)

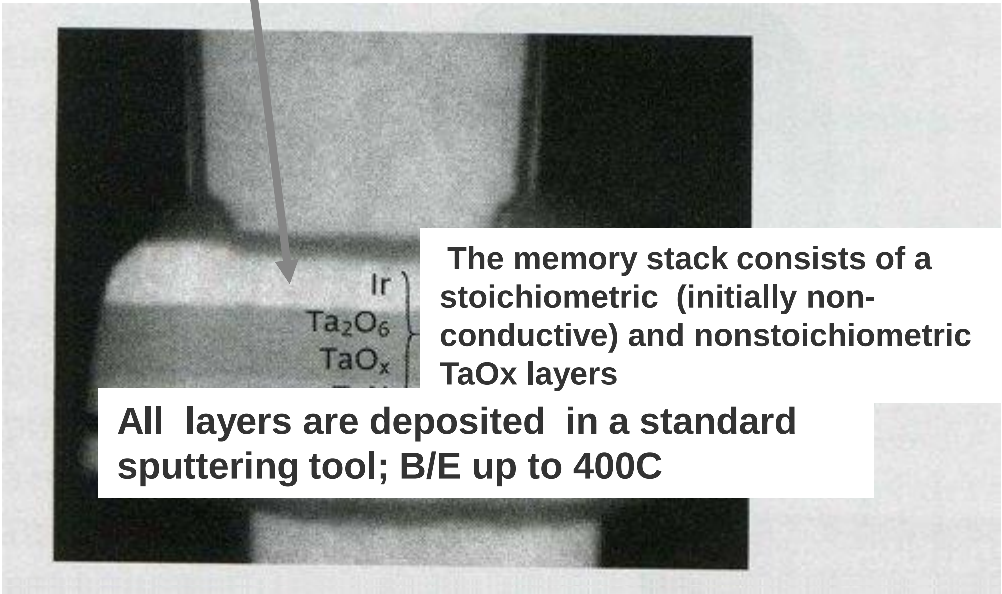
Developed by Panasonic



NMOS as a select device







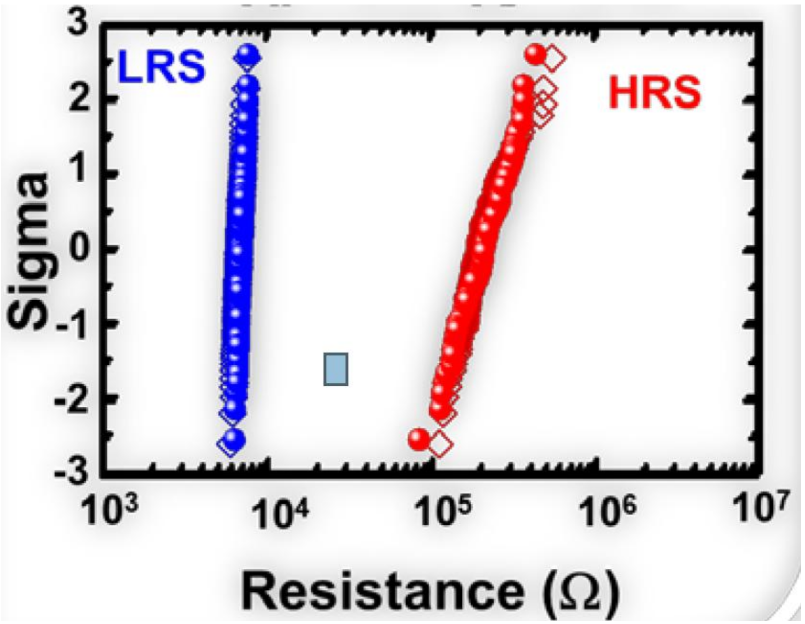
The memory stack consists of a stoichiometric (initially non-conductive) and nonstoichiometric TaOx layers

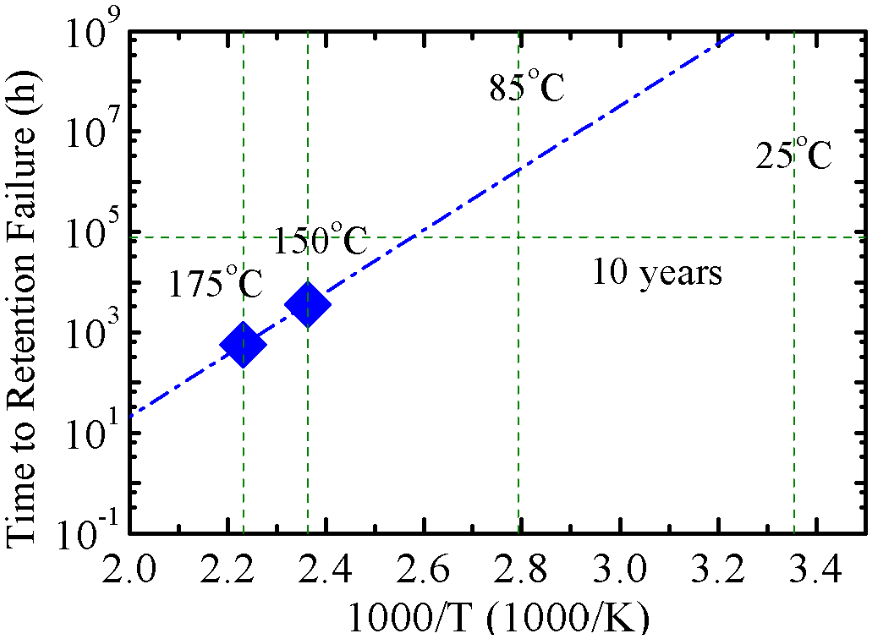
All layers are deposited in a standard sputtering tool; B/E up to 400C

Write/erase energy : 50 pJ/cell
Low voltage operation:
read @1.1 V; write @2.3-2.8 V
Write /erase times : 100ns
1.18um2 cell area
0.18um CMOS flow (+2-3 masks)

Example of qualified embedded module:
256 kbit program area: 1k cycles
8 kbit data area: 100k cycles

Switching performance and retention



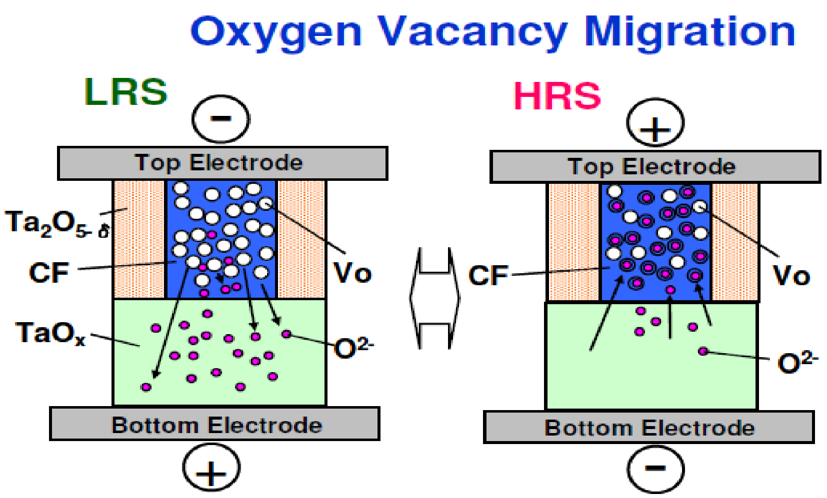


Retention after ~10^6 cycles

- **The main candidate for IoT memory**
- **Suitable both for sensor supporting platforms and neuromorphic computing applications (ultra-low power processors where part of execution is delegated to NVM).**

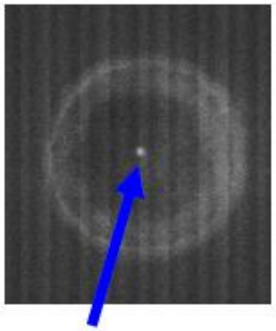
ReRAM operation physics

Switching



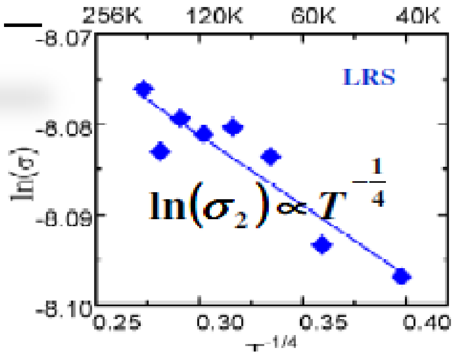
$$O^{2-} \Leftrightarrow O_0 + Vo + 2e$$

After forming



Filament

Low temperature



Switching Model for TaOx ReRAM:

•A filament in the Ta_2O_5 layer

Conduction :

• Hopping conductivity via Oxygen vacancies in Tantalum Oxide

Switching

•The change in the density of vacancies

Conclusions

- **Out of the existing embedded NVM, today only ReRAM and MRAM comply with the demands of the IoT motes. In case of high volume applications , ReRAM is advantageous because of lower cost.**
- **Beta-voltaic enabled SRAMs and 1T FeRAM are promising but not enough mature.**
- **Ultra-low cost (single Poly) MTP and OTP NVM already find extensive application in the design of simple IoT motes (low density/limited endurance , but high reliability modules)**
- **NVM for Big Data storage will follow the trends in the developing ultra-high volume memories (like those for SSDs, intelligent wearable devices: virtual reality, etc.)**

  3D solutions (3D NAND) currently have the highest business potential.

TOWERJAZZ

www.towerjazz.com