



Flash Memory Summit

Developing IoT-Based Factory Automation Using F-RAM

Douglas Mitchell





INDUSTRIAL SYSTEMS TODAY





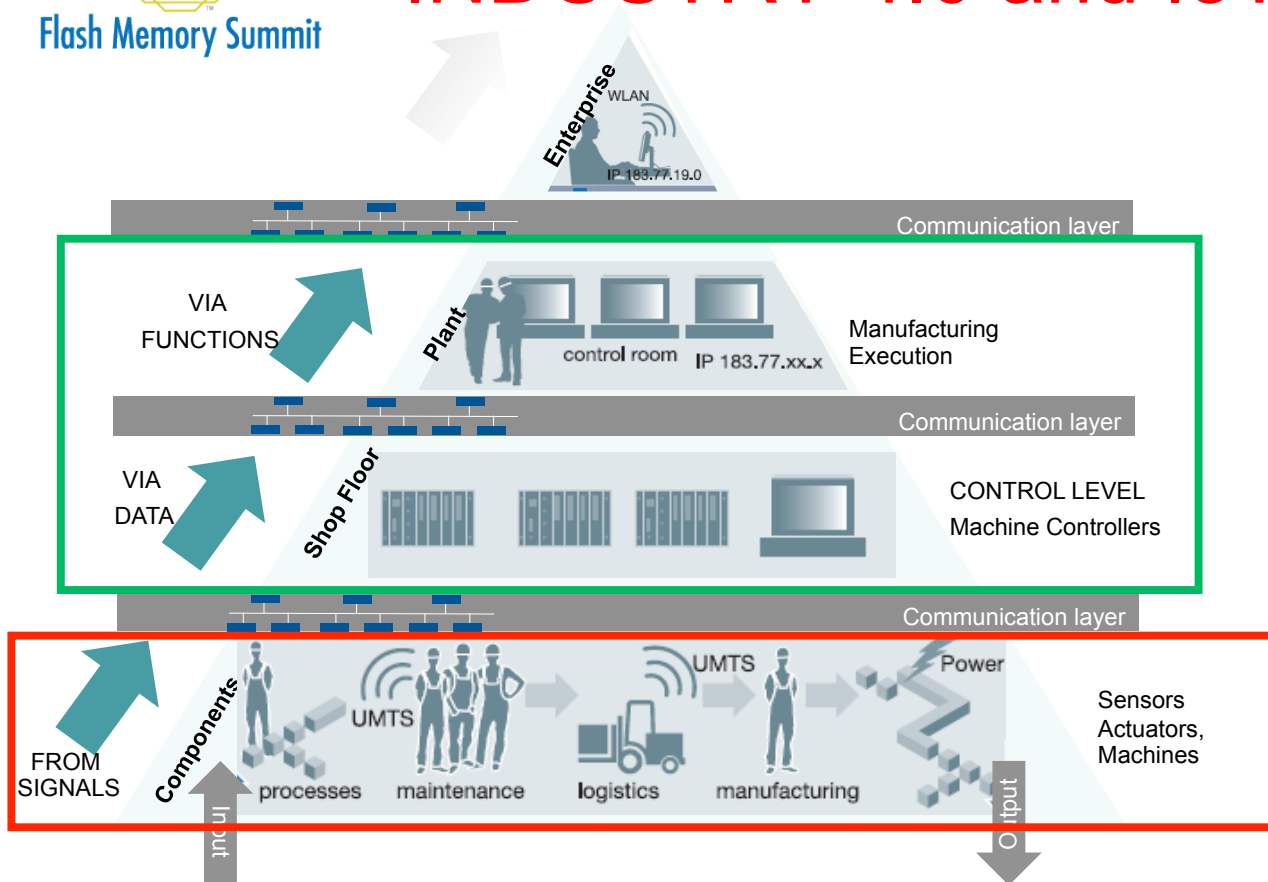
Industry 4.0

- The “smart factory,”
 - Cyber-physical systems monitor factory processes and make decentralized decisions.
 - Internet of Things communicate and cooperate both with each other and with humans
- Includes
 - Interoperability — machines, devices, sensors and people
 - Information transparency — create a virtual copy of the physical world through sensor data in order to contextualize information.
 - Technical assistance —support humans in making decisions and solving problems *and* accomplish tasks that are too difficult or unsafe for humans.
 - Decentralized decision-making — the ability of cyber-physical systems to make simple decisions on their own and become as autonomous as possible



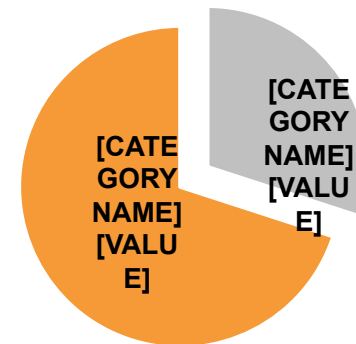
Flash Memory Summit

INDUSTRY 4.0 and IoT



BY 2020

16B Industrial IOT devices will be connected
2X the earth's population





Non-volatile Memory Challenges

- **High-reliability NVMs to accurately/completely log data**
- **Energy-efficient NVMs to extend battery life**
- **High-performance NVMs to quickly access programs & log data**



Flash Memory Summit

Why This Matters

- **Industry 4.0 relies on processing and storage at the Edge of the Network**
- High-speed Robots, CNCs, Motors, Actuators, Valves, etc. operate with precision at high speed
 - Require high resolution of “State” in case of power or communication interruption
 - High-reliability, instant data capture ensures maximum uptime and accurate recovery



PLC



CNC



Circuit Breaker



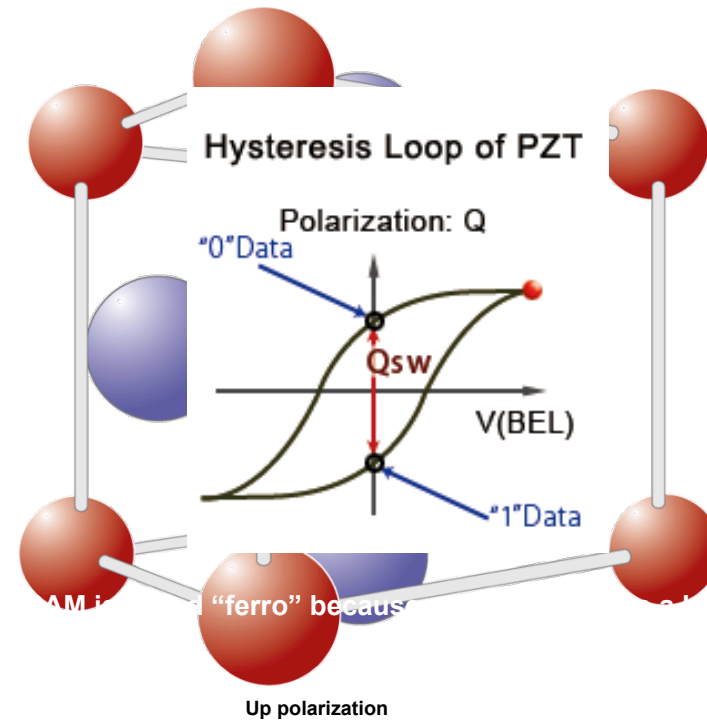
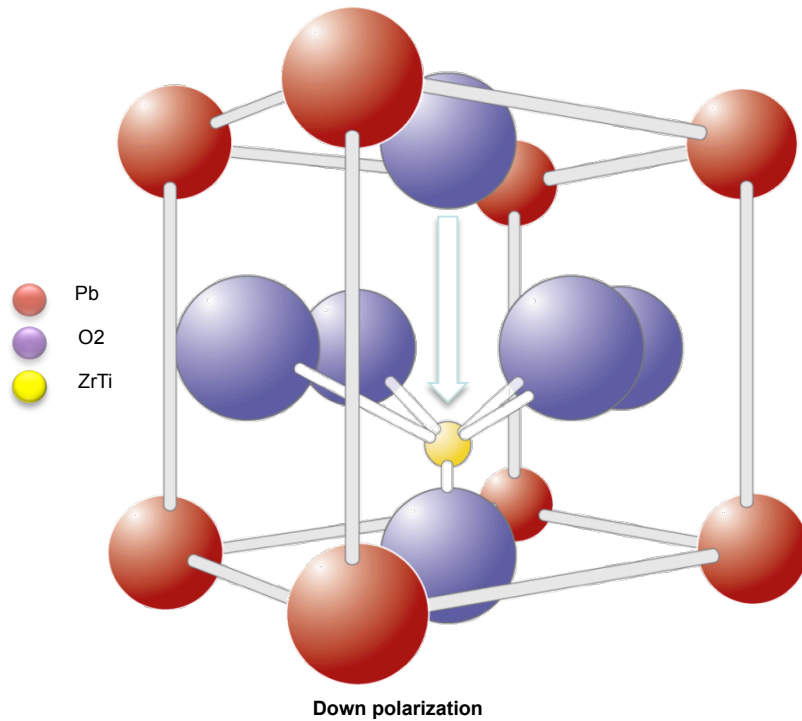
Flash Memory Summit

NVM Choices

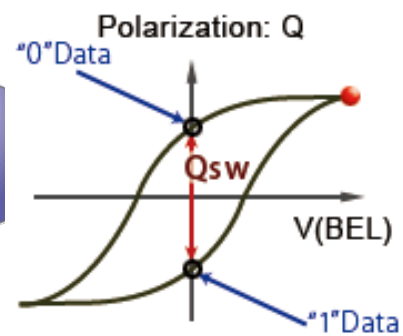
- Flash (NAND, NOR)
 - Good for code storage, but long latency and early wear-out for datalogging
- EEPROM
 - High power consumption, wear-out for datalogging
- MRAM
 - Very high power consumption, limited product offerings
- F-RAM
 - Low power consumption, instant write, high endurance

What is Ferroelectric RAM (F-RAM)

F-RAM is a NVM which stores data as a polarization of a ferroelectric material (Lead-Zirconate-Titanate)



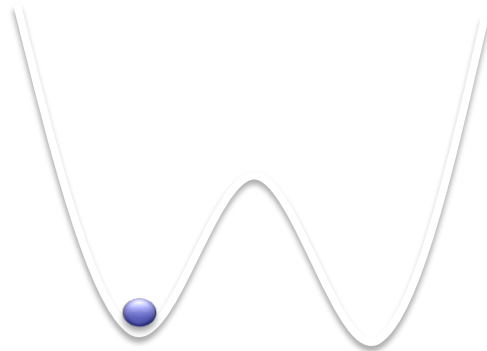
Hysteresis Loop of PZT



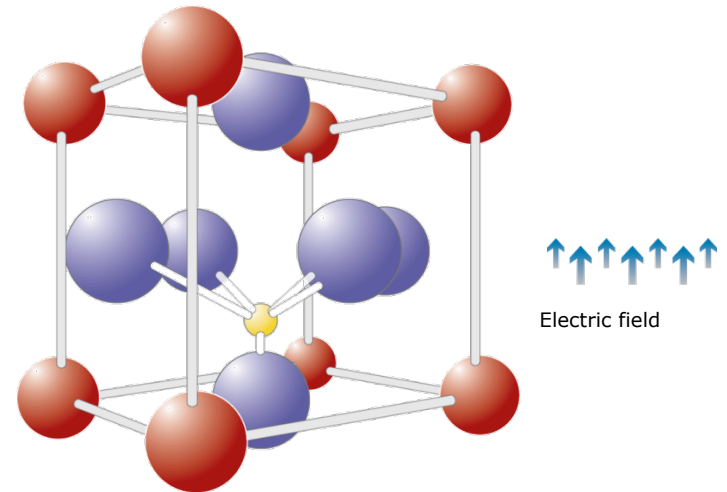
"ferro" because

What is F-RAM

Energy (E)



Position (central atom)





Flash Memory Summit

What is F-RAM

As an electric field is applied, dipoles shift in a crystalline structure to store information

This structure results in a number of advantages

Symmetrical atomic position → **Non volatility**

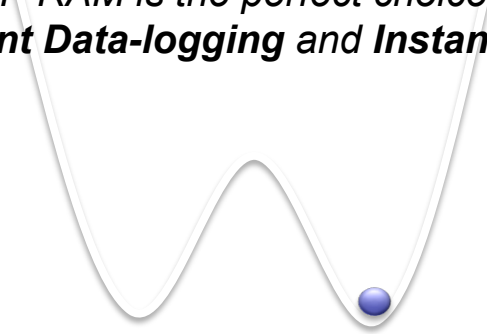
Switch in states is instantaneous → **Fast writes** and **Low energy**

Based on “atomic position” vs. “trapped charge” → **SER immunity** and **Radiation tolerant**

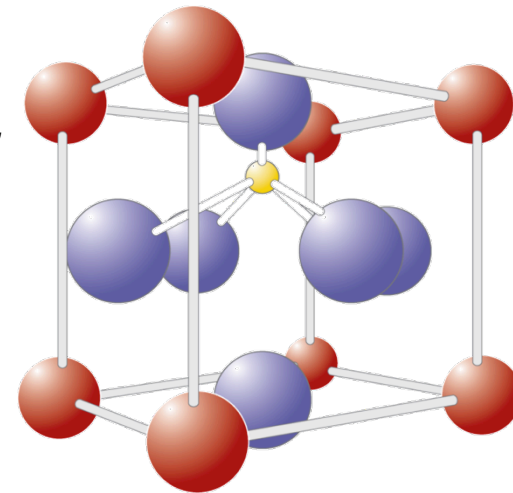
Two symmetrical states and has no reason to degrade → **Data retention 100 yrs**

Energy (E)

*F-RAM is the perfect choice for
“Power Efficient Data-logging and Instantaneous Back-up”*



Position (central atom)





F-RAM Data Retention

Primary F-RAM reliability measure is the retention lifetime of a capacitor cell that has been previously stored in a polarization state for an extended time and then written to the opposite polarization state (OS)¹

Retention Specs for Cypress F-RAMs²:

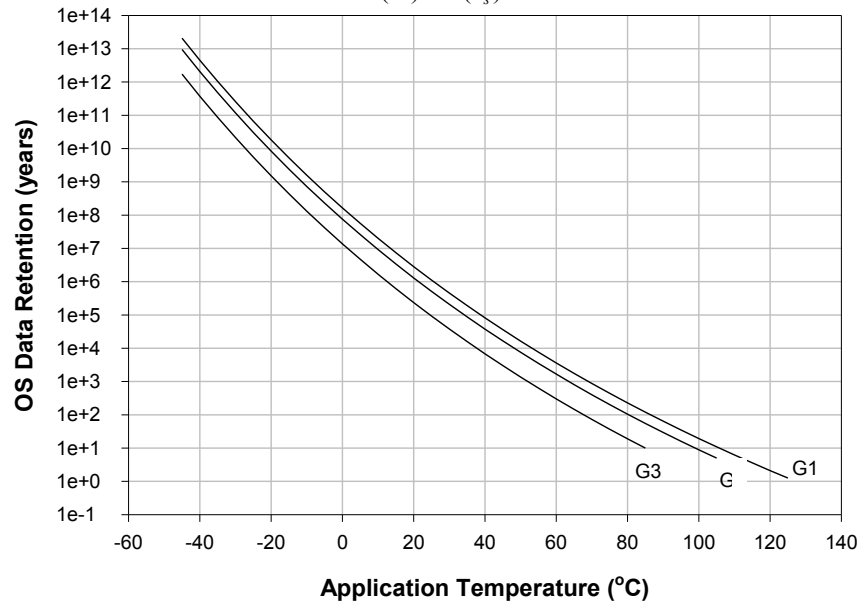
Cypress F-RAM	Data Retention
AEC-Q100 Grade 3 (G3)	>10 yrs @ 85°C
AEC-Q100 Grade 2 (G2)	>5 yrs @ 105°C
AEC-Q100 Grade 1 (G1)	>11k hrs @ 125°C

The specifications can be converted to multi-temperature profiles

Example for G1 F-RAM³:

Temperature	Time Factor	Profile Life time
(T)	(t)	L(P)
T1=125°C	10%	> 10.46 years
T2=105°C	15%	
T3=85°C	25%	
T3=55°C	50%	

$$L(T) = L(T_s) e^{\frac{E_a}{k} \left(\frac{1}{T} - \frac{1}{T_s} \right)}$$



¹ This type of retention is called as Opposite State (OS) retention. F-RAM has unlimited Same State (SS) retention life within the specified temperature range

² Conditions: 130nm 2T2C F-RAMs (all AEC-Q-100 Qualified F-RAMs are currently 2T2C)

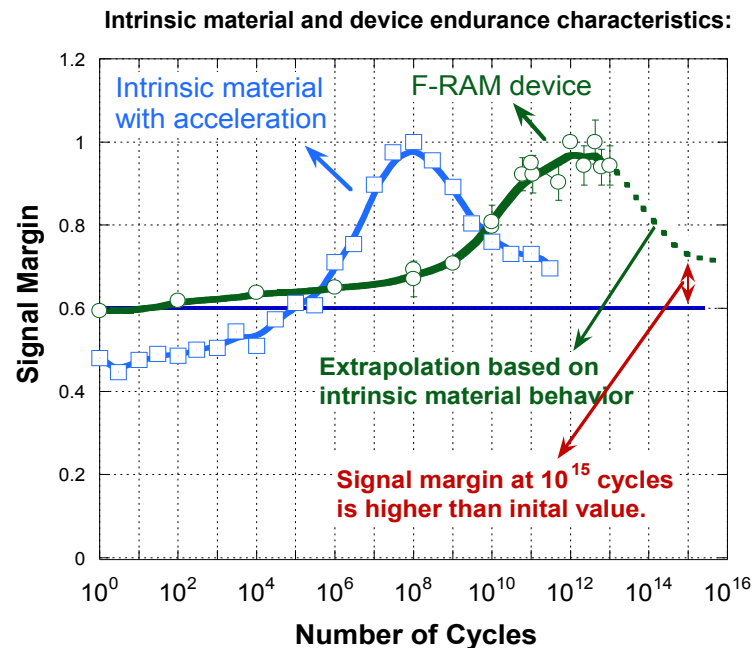
³ G3 Stress temperature T_s = 125°C, G2 and G1 Stress temperature T_s = 150°C



F-RAM Endurance

Memory endurance is specified as number of times that a memory cell can be written-to or erased

- F-RAM endurance tests are difficult to practically perform due to very high endurance performance of F-RAM.
- Innovative test methodologies are needed to determine the endurance limit of 0.13µm F-RAM product
- Endurance behavior of scribe line test structures i.e., intrinsic material can be measured with acceleration
- F-RAM device endurance can be measured up to 10^{13} cycles through lab tests¹ and extrapolated to 10^{15} based on slope of the curve for intrinsic material
- Signal margin vs. cycles for both F-RAM device and intrinsic material shows higher signal margin of the F-RAM device at 10^{15} cycles compared with the initial value²



¹ Continuous 1 byte writes on FM22L16 at speed of 110ns cycle time (i.e., 220ns for writing both state): 0.025 days for 10^{10} cycles, 2.55 days for 10^{12} cycles, 255 days for 10^{14} cycles
Ref. <http://www.cypress.com/?docID=44702>

² Cypress takes a guard band and specs up to 10^{14} (instead of 10^{15}) on datasheets for endurance



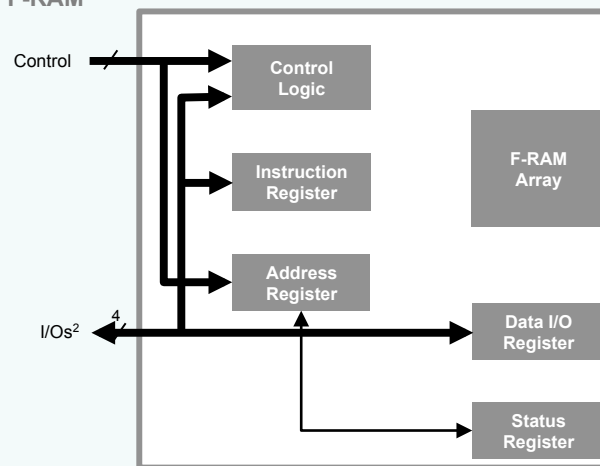
Flash Memory Summit

2Mb-to-16Mb Excelon™ F-RAM

Features

- **Excelon-Ultra**
 - 4Mb
 - 108-MHz Single Data Rate (SDR)/54-MHz Double Data Rate (DDR) Quad SPI
 - Industrial temperature range: -40°C to +85°C
- **Excelon-Auto**
 - 2Mb Auto E, 4Mb Auto A
 - 50-MHz SPI
 - Automotive (AEC-Q100) temperature range grade A: -40°C to +85°C
 - Automotive (AEC-Q100) temperature range grade E: -40°C to +125°C
- **Excelon-LP**
 - 4Mb, 8Mb
 - 20-MHz SPI (Commercial), 50-MHz SPI (Industrial)
 - Ultra-low (0.10-µA) hibernate current
 - Ultra-low (0.75-µA) deep power-down current
 - Ultra-low (1.00-µA) standby current
 - Commercial temperature range: 0°C to +70°C
 - Industrial temperature range: -40°C to +85°C
- **Common Features for Excelon-Ultra/Auto/LP**
 - Operating voltage range: 1.71–1.89 V, 1.80–3.60 V
 - 100-trillion read/write cycle endurance
 - 100-year data retention

Excelon F-RAM



Family Table

Density	Standby Current (Typ.)	Active Current (Typ.)	Packages
2Mb	1 µA	3 mA	SOIC (8)
4Mb	1 µA	3 mA	SOIC (8), GQFN (8)
8Mb	1 µA	3 mA	GQFN (8)
16Mb	1 µA	3 mA	SOIC (8), GQNF (8)





IoT Dataloggers

- Fast Writes
- Low Power
- Infinite endurance

➤ F-RAM is the premium solution