Non-Volatile RAM for the Internet of Things (IOT)

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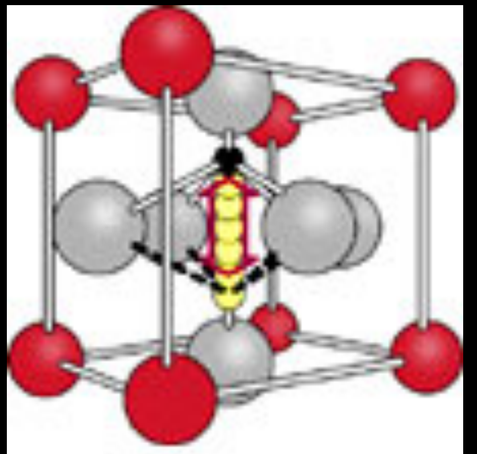
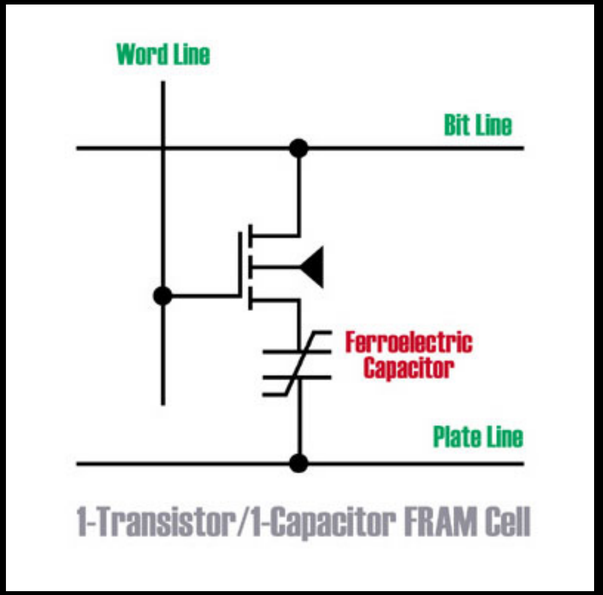
Ferroelectric RAM (FRAM)

- **Certain Ceramic Materials Are Polarized By An Electric Field (Ferroelectrics)**
  - KNO_3 - Potassium Nitrate
  - PZT - Lead Zirconate Titanate
  - SBT (Y1) - Strontium Barium Titanate
- **A Ferroelectric capacitor is Two Metal Plates with Ferro Dielectric**
- **Ferroelectric RAM (FRAM) is a DRAM With a Ferrocapacitor**
  - Simple 1T-1C Cell Structure like DRAM
  - Low Standby and Active Power
  - DRAM Read/Write Speed (55 ns access, 110 ns Cycle Time)
  - Virtually Unlimited Endurance ($10^{10\text{-}15}$ Cycles)
  - Non-volatile - 10 Year Data Retention without Power
  - Wide Temperature Range (Commercial, Industrial, Automotive)
  - Resistant to Radiation, Electric & Magnetic Fields



Ferroelectric Crystal:
The center atom moves to store ones and zeros.

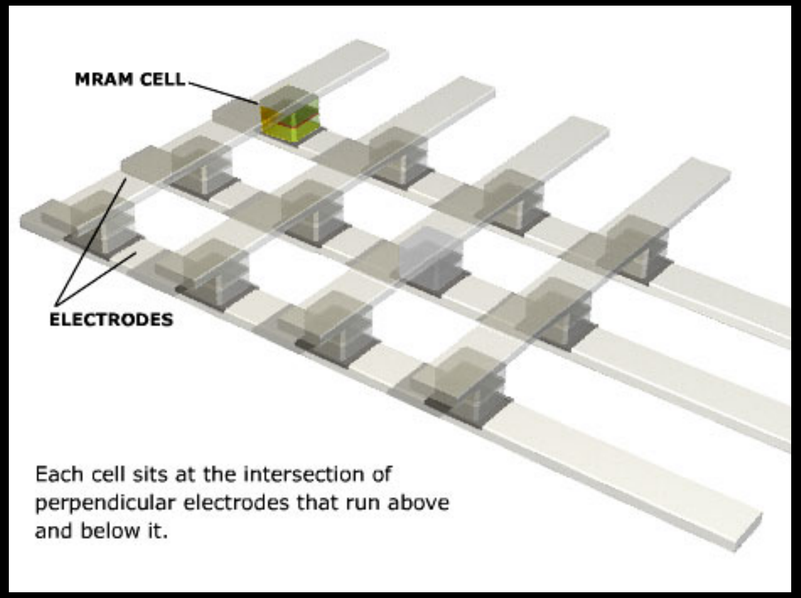


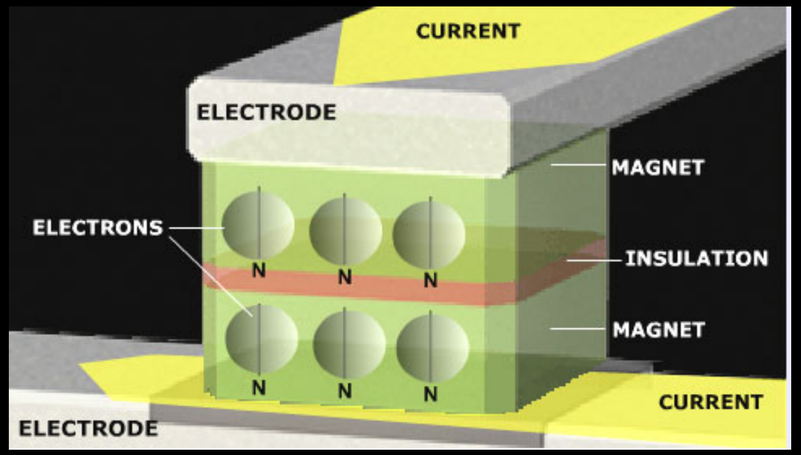
1-Transistor/1-Capacitor FRAM Cell

Magnetoresistive RAM (MRAM)

- **Ferromagnetic Memory On Silicon**
  - Concurrent Current From X and Y Lines Polarize Magnetic Tunnel Junction (MTJ)
  - Non-Destructive Readout By Sensing Variation In Resistance Due To Polarization

- **Nonvolatile RAM**
  - Fast 35 ns Read/Write Speed
  - Unlimited Endurance
  - Long Data Retention
  - Low Soft Error Rates (Lower Than SRAM)
  - Wide Temperature Range (Comm, Ind, Auto)
  - Radiation Hard

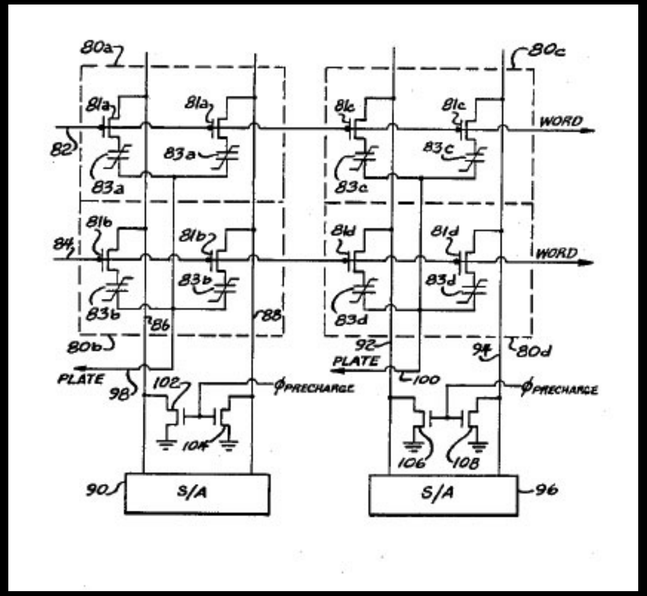




Ramtron International (Now Infineon Technologies)

- Pioneer In Ferroelectric RAM From 1984
- First FRAM Announced At 1988 ISSCC
- First FRAM 4K Product Announced In 1991
- Owns Key FRAM Patents
- More than 100 million units shipped
- Major FRAM Licensees include TI, Samsung, NEC, Fujitsu, Infineon, Toshiba, Hitachi, Rohm, Asahi
- Acquired By Cypress Semiconductor in 2012
- Cypress Acquired By Infineon in 2020

Ramtron HQ in Colorado Springs



Ramtron Patented 1T-1C FRAM Cell

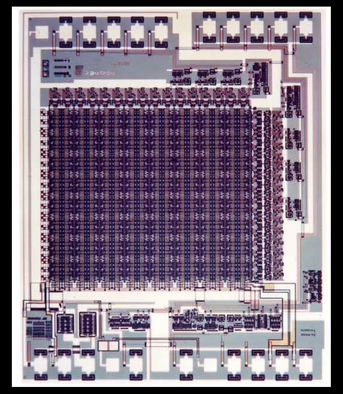
Ramtron Founders

- Founded by George Rohrer, Larry McMillan, Dr. Carlos Araujo in 1984
- Financed By Stock Sale On Australian Exchange
- First CEO Was Ross Lyndon-James, Ramtron Australia Ltd.
- Rohrer Held The First Ferroelectric Device Patent (1972)

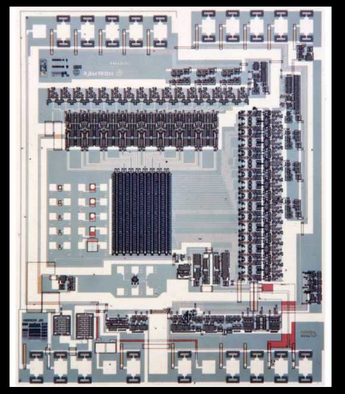
George Rohrer, Larry McMillan, Ross Lyndon-James on University of Colorado-Colorado Springs Campus

First Ramtron FRAM Devices

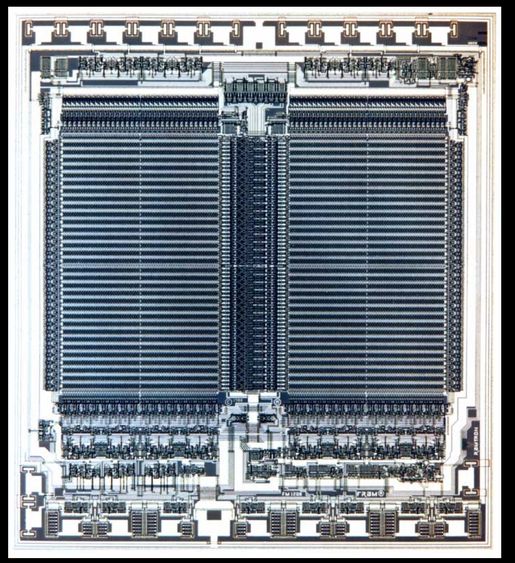
- Early Device Development using KNO_3 done at UCCS Microelectronic Laboratory starting in 1984
- Key Staff Members Join from Colorado Springs DRAM Company Inmos Corporation
  - Dr. Fred Gnadinger, VP of R&D
  - Sheffield Eaton, Lead FRAM Designer
- Device Focus Shifts to PZT - Lead Zirconate Titanate
- Ramtron Partners with ITT Semiconductor (Freiburg, Germany)
- First 256b FRAM Shown at ISSCC 1988
  - 10T Shadow RAM (FMx801)
- First 256b 2T2C FRAM Shown at ISIF 1989
  - 2T2C (FMx8101)
- First 4Kb FRAM Shipped To Customers In 1991 (FM1208)



FMx801 10T FRAM



FMx8101 2T2C FRAM



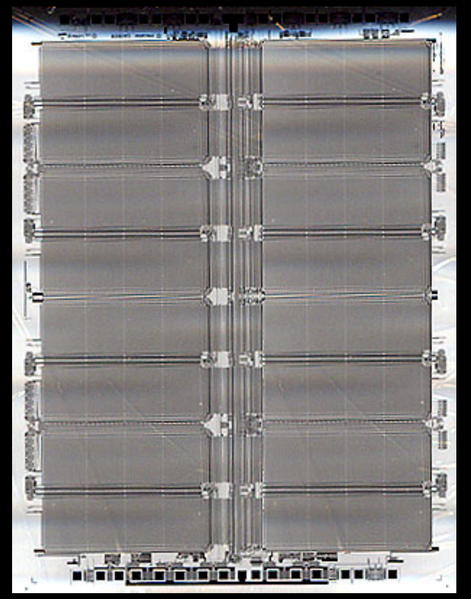
FM1208 4K 2T2C FRAM

First FRAM Production - 1993

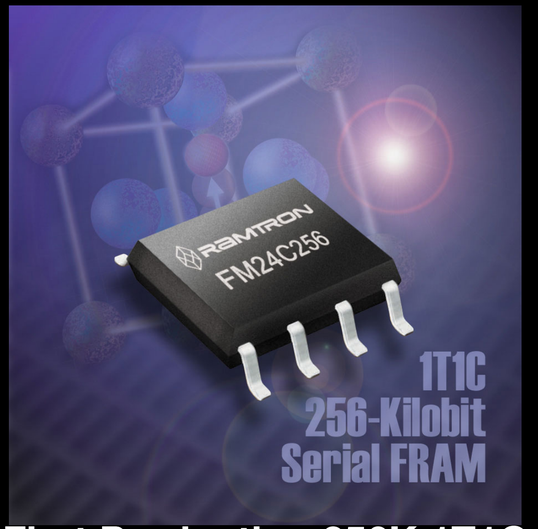
- Sega Genesis “Sonic the Hedgehog” Game Cartridge
- FRAM Used As A Save Game Feature In Place of a Battery Backed SRAM

Ramtron 1T1C FRAM Development

- Ramtron Partnered with Seiko Epson (Japan)
- Seiko Epson Program Yielded First 256Kb 1T1C In 1992
- Ramtron Partnered with Rohm Corporation (Japan)
- Rohm (now Lapis Semiconductor) Becomes First FRAM Production Fab
- Ramtron Announces First Serial FRAM & eFRAM Products in 1998
  - 4K & 16K I^2C & SPI FRAM
  - 16Kb RF ID Chip
- Ramtron Partners with Fujitsu Semiconductor
- Ramtron & Fujitsu Described 1Mb 1T1C FRAM In June 1998
- First Production 1T1C FRAM Announced In 2002
  - Main Application is Automatic Electric Meters at ENEL (Italy)
  - 30 million units shipped, 80% of households in Italy



Ramtron/Seiko 256K 1T1C FRAM (1992)



First Production 256K 1T1C Serial FRAM (2002)

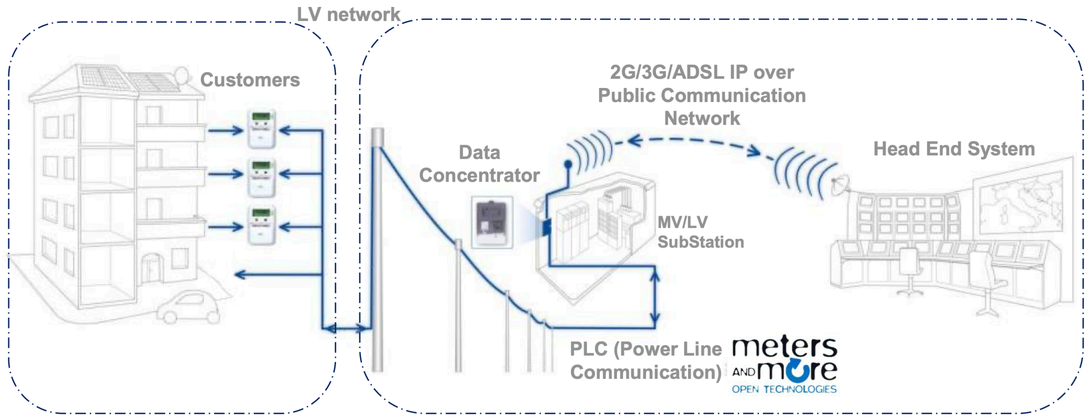
Smart Meters

- Ampy Automation (UK) Selected Ramtron 256K FRAM for their Smart Power Meter
- ENEL (Italian National Power Company) selected Ampy as Standard Power Meter in Italy
- 33 Million Installed in Italy from 2001-2006
- Over 80 Million Installed Worldwide Today
- FRAM Provides Data Logging of Power Usage
- Power Line Communications to Control Center Via Network of Data Concentrator Nodes

- Integrated PLC communication
- Remote reading and control
- Integrated Circuit Breaker
- Flexible multi tariff system
- Antitampering functionalities
- Bidirectional measurement

System Architecture

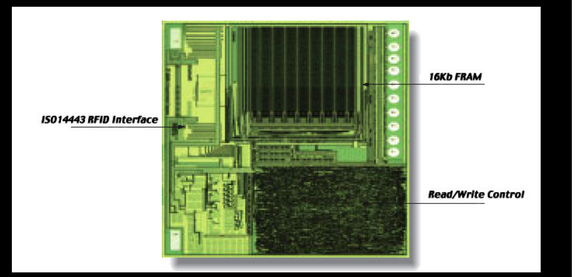
PLC based



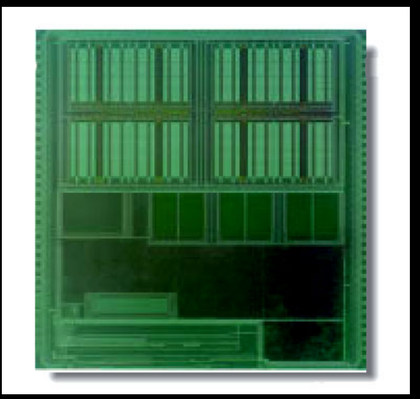
Fujitsu FRAM Program

- Ramtron Second Production FRAM Fab
  - 0.5 micron 3LM FRAM Process
  - +5 and +3 volt Operation
  - 2T2C and 1T1C FRAM Cells Supported
  - Densities Up to 1Mb
  - >1 Million/Month 256Kb FRAMs Produced For Ramtron
  - 3 Million/Month eFRAM Smartcards For Fujitsu
- Next Generation 350 nm Process
  - 1Mb 1T1C eFRAM at 3 volts
- Next Generation 180 nm Process
  - 4Mb & 8Mb 1T1C FRAM & eFRAM at 1.8 Volts

Fujitsu Iwate, Japan FRAM Factory

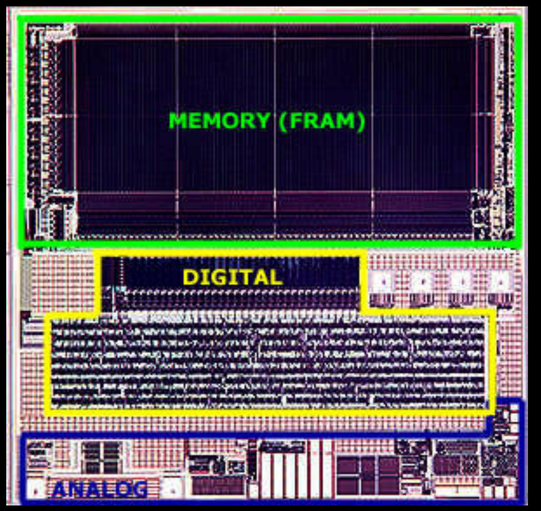


Custom 16Kb RF ID
MB89R111
For Cubic Corp

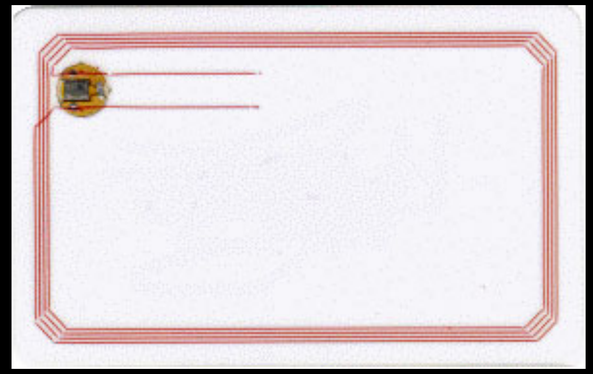


Contacted/Contactless
Smartcard
MB89R202
1Mb FRAM/ARM MCU

Cubic Go Card Program



- Cubic Go Card RF ID
  - First eFRAM Product
  - 16Kb FRAM+Logic+RF Interface
  - Automatic Fare Collection Card
  - First Built At Rohm, Later At Fujitsu
- Cubic Uses Go Card In Major Cities
  - Washington Subway
  - Chicago Transit Authority
  - London Underground
  - Hong Kong Underground



Fujitsu RF ID Products

- Fujitsu offers off-the-Shelf Contactless RF ID Solutions
- Fujitsu has shipped more than 4 billion FRAM RF ID chips
- Fujitsu offers COT and Custom Development eFRAM options

RFID LSI

Part Number	Datasheet	Operating Freq.	Memory Density	Commands	Serial Interface	Read/Write Cycle
MB97R8110	PDF	UHF 860-960MHz	8KByte	ISO/IEC18000-63 EPC C1G2 Ver.1.2.0	SPI (*) (Master/Slave)	10^{13} times
MB97R8120	PDF	UHF 860-960MHz	8KByte	ISO/IEC18000-63 EPC C1G2 Ver.1.2.0	-	10^{13} times
MB97R8050	PDF	UHF 860-960MHz	36Byte (EPC128bit)	ISO/IEC18000-63 EPC C1G2 Ver.1.2.0	-	10^{10} times
MB89R118C	PDF	HF 13.56MHz	2KByte	ISO/IEC15693	-	10^{12} times
MB89R119B	PDF	HF 13.56MHz	256Byte	ISO/IEC15693	-	10^{12} times
MB89R112	PDF	HF 13.56MHz	8KByte	ISO/IEC15693	-	10^{12} times

(*) For Batteryless Wireless Applications

› Learn more

Authentication LSI

Part Number	Datasheet	Power Supply Voltage	Interface	Communication Freq.	Operating Temp.	Read/Write Cycle	Package
MB94R330	PDF	3.0 to 3.6V	I^2C	400KHz	-20 to +85℃	10^{12} times	SON-8

› Learn more

Fujitsu Memory Products

Serial Memory Lineup

● SPI Interface (for High Reliability Use, AEC-Q100 Compliant) *1, *2

Part number	Memory density	Power supply voltage	Operating frequency	Operating temperature	Read/Write cycles	Data retention *3	Package
MB85RS4MTY	4Mbit	1.8 to 3.6V	50MHz	-40 to +125°C	10 trillion	10 years (+85°C)	DFN-8 (SOP-8 *4)
MB85RS4MLY	4Mbit	1.7 to 1.95V	50MHz	-40 to +125°C	10 trillion	10 years (+85°C)	DFN-8 (SOP-8 *4)
MB85RS2MTY	2Mbit	1.8 to 3.6V	50MHz	-40 to +125°C	10 trillion	10 years (+85°C)	DFN-8, SOP-8
MB85RS2MLY	2Mbit	1.7 to 1.95V	50MHz	-40 to +125°C	10 trillion	10 years (+85°C)	DFN-8, SOP-8
MB85RS256TY	256Kbit	1.8 to 3.6V	40MHz	-40 to +125°C	10 trillion	10 years (+85°C)	SOP-8
MB85RS128TY	128Kbit	1.8 to 3.6V	40MHz	-40 to +125°C	10 trillion	10 years (+85°C)	SOP-8
MB85RS64VY	64Kbit	2.7 to 5.5V	33MHz	-40 to +125°C	10 trillion	10 years (+85°C)	SOP-8

● SPI Interface (for General Use) *1

Part number	Memory density	Power supply voltage	Operating frequency	Operating temperature	Read/Write cycles	Data retention	Package
8Mbit Quad *5 (Under development)	8Mbit	2.7 to 3.6V, 1.7 to 1.95V	108MHz	-40 to +105°C	10 trillion	10 years (+85°C)	SOP-16
MB85RS4MT	4Mbit	1.8 to 3.6V	40MHz	-40 to +85°C	10 trillion	10 years (+85°C)	SOP-8
MB85RQ4ML *5	4Mbit	1.7 to 1.95V	108MHz	-40 to +85°C	10 trillion	10 years (+85°C)	SOP-16
MB85RS2MTA	2Mbit	1.7 to 3.6V	40MHz	-40 to +85°C	10 trillion	10 years (+85°C)	SOP-8
MB85RS1MT	1Mbit	1.8 to 3.6V	30MHz	-40 to +85°C	10 trillion	10 years (+85°C)	SOP-8 / DFN-8
MB85RS1MT (1.7V-operating)	1Mbit	1.7 to 3.6V	30MHz	-40 to +85°C	10 trillion	10 years (+85°C)	WL-CSP-8
MB85RS512T	512Kbit	1.8 to 3.6V	30MHz	-40 to +85°C	10 trillion	10 years (+85°C)	SOP-8
MB85RS256B	256Kbit	2.7 to 3.6V	33MHz	-40 to +85°C	1 trillion	10 years (+85°C)	SOP-8
MB85RS128B	128Kbit	2.7 to 3.6V	33MHz	-40 to +85°C	1 trillion	10 years (+85°C)	SOP-8
MB85RS64V	64Kbit	3.0 to 5.5V	20MHz	-40 to +85°C	1 trillion	10 years (+85°C)	SOP-8
MB85RS64	64Kbit	2.7 to 3.6V	20MHz	-40 to +85°C	1 trillion	10 years (+85°C)	SOP-8
MB85RS64T	64Kbit	1.8 to 3.6V	10MHz	-40 to +85°C	10 trillion	10 years (+85°C)	SOP-8 / SON-8
MB85RS64T (1.7V-operating)	64Kbit	1.7 to 3.6V	10MHz	-40 to +85°C	10 trillion	10 years (+85°C)	SOP-8
MB85RS64TU	64Kbit	1.8 to 3.6V	10MHz	-55 to +85°C	10 trillion	10 years (+85°C)	SOP-8 / SON-8
MB85RS16N	16Kbit	2.7 to 3.6V	20MHz	-40 to +95°C	1 trillion	10 years (+95°C)	SOP-8 / SON-8
MB85RDP16LX	16Kbit	1.65 to 1.95V	15MHz	-40 to +105°C	10 trillion	10 years (+105°C)	SON-8

FRAM

Serial Memory Lineup

● I2C Interface *1

Part number	Memory density	Power supply voltage	Operating frequency	Operating temperature	Read/Write cycles	Data retention	Package
MB85RC1MT	1Mbit	1.8 to 3.6V	3.4MHz	-40 to +85°C	10 trillion	10 years (+85°C)	SOP-8
MB85RC512T	512Kbit	1.7 to 3.6V	3.4MHz	-40 to +85°C	10 trillion	10 years (+85°C)	SOP-8
MB85RC256V	256Kbit	2.7 to 5.5V	1MHz	-40 to +85°C	1 trillion	10 years (+85°C)	SOP-8
MB85RC128A	128Kbit	2.7 to 3.6V	1MHz	-40 to +85°C	1 trillion	10 years (+85°C)	SOP-8
MB85RC64TA	64Kbit	1.8 to 3.6V	3.4MHz	-40 to +105°C	10 trillion	10 years (+85°C)	SOP-8 / SON-8
MB85RC64V	64Kbit	3.0 to 5.5V	1MHz	-40 to +85°C	1 trillion	10 years (+85°C)	SOP-8
MB85RC16	16Kbit	2.7 to 3.6V	1MHz	-40 to +85°C	1 trillion	10 years (+85°C)	SOP-8 / SON-8
MB85RC16V	16Kbit	3.0 to 5.5V	1MHz	-40 to +85°C	1 trillion	10 years (+85°C)	SOP-8
MB85RC04V	4Kbit	3.0 to 5.5V	1MHz	-40 to +85°C	1 trillion	10 years (+85°C)	SOP-8

*1: Please refer to datasheet of each product in details.

Parallel Memory Lineup *1

● Parallel Interface *1

Part number	Memory density (configuration)	Power supply voltage	Cycle time	Operating temperature	Read/Write cycles	Data retention	Package
8Mbit parallel (Under development)	8Mbit	1.8 to 3.6V	110ns *2	-40 to +85°C	100 trillion	10 years (+85°C)	TSOP-44 , FBGA-48
MB85R8M2T	8Mbit (512K×16)	1.8 to 3.6V	150ns	-40 to +85°C	10 trillion	10 years (+85°C)	FBGA-48
MB85R4M2T	4Mbit (256K×16)	1.8 to 3.6V	150ns	-40 to +85°C	10 trillion	10 years (+85°C)	TSOP-44
MB85R256F	256Kbit (32K×8)	2.7 to 3.6V	150ns	-40 to +85°C	1 trillion	10 years (+85°C)	TSOP-28 / SOP-28

*1: Please refer to datasheet of each product in details.

*2: Using page mode, fast write operation with minimum 25ns is available.

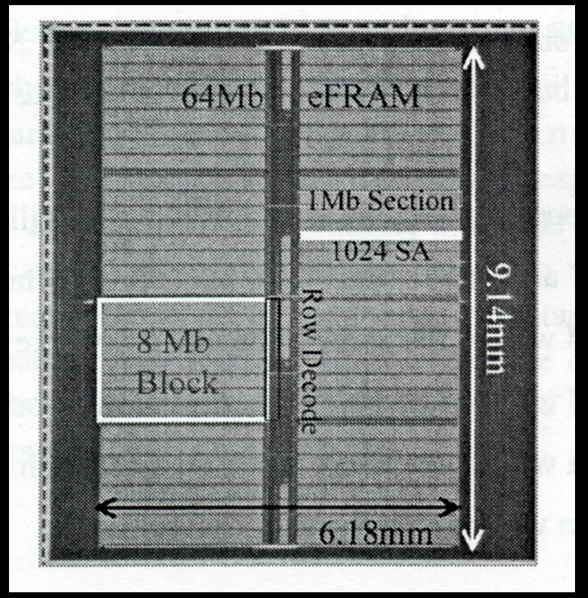
Screenshot

Cypress/Infineon FRAM Products

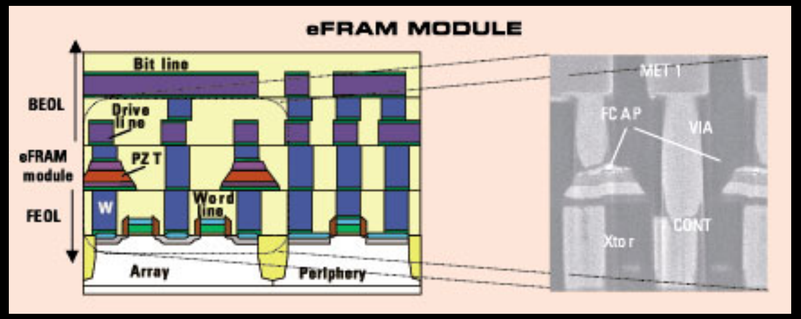
- By 2012, Ramtron had secured a FRAM manufacturing facility at IBM (Burlington, VT) - now Global Foundries
- Cypress Semiconductor purchased Ramtron in Sept 2012
- I believe that Cypress must have developed their own in-house manufacturing of FRAM products as they continued to expand the product line
- Infineon Technologies acquired Cypress in 2020 along with the FRAM product line
- Today Infineon offers broadest product line of FRAM Memory Products
  - 4Kb to 16Mb density
  - I2C, SPI, QSPI, and Parallel Interfaces
  - Commercial, Industrial, Military, and Space grade products

Texas Instruments eFRAM Program

- TI/Agilent/Ramtron Program Started In August 2001
- 64Mb eFRAM Vehicle on 130 nm Process at Kilby Fab in Dallas
- 60 Person Development Team
- 4Mb eFRAM Test Vehicle Described At IEDM 2002
  - +1.5 volt Power Supply
  - 2 Mask eFRAM Process Adder
  - 0.54 um^2 Cell Size ($32F^2$)
  - MOCVD IR/PZT/IR Thin Film FerroCap
  - 40 ns Access
  - >1E12 Endurance Measured
- TI Became Ramtron's 3rd Foundry Partner
- TI Today offers many low-power eFRAM MCU Products based upon this process



64Mb FRAM Test Vehicle



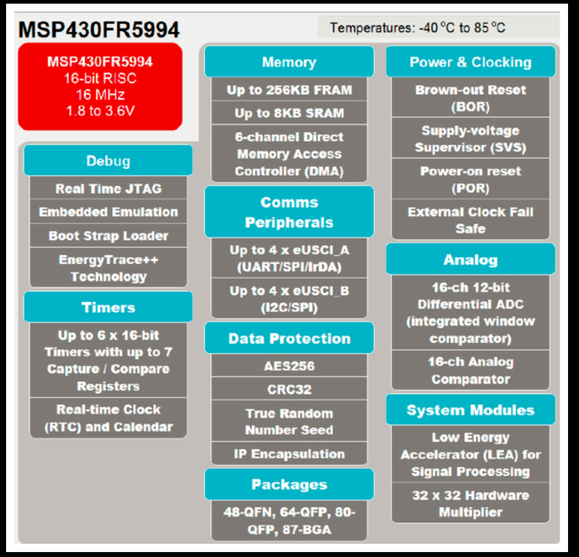
eFRAM Process Cross Section

TI 430 MCU Family

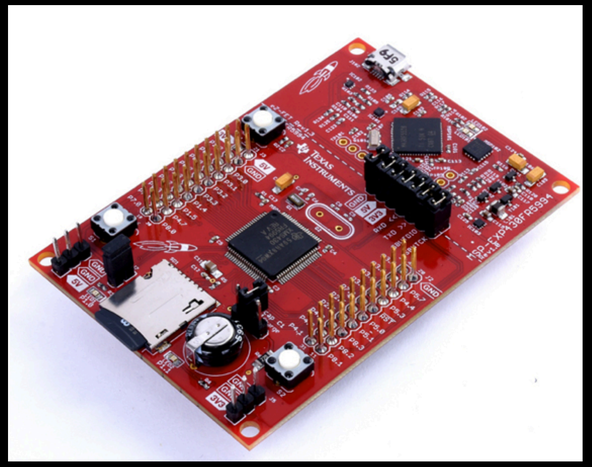
- Texas Instruments has become the leading Off-the-Shelf MCU Supplier offering eFRAM

- FRAM Series MCUs
  - 4 to 256KBytes of eFRAM (10^{15} endurance)
  - 0.5 to 8KBytes of eSRAM
  - 1.8 to 3.6 volt power supply
  - 118 uA/MHz active power
  - 350 na standby with RTC operating
  - 35 na shutdown mode
  - Many I/O Options
  - Many Package Options
  - Commercial & Industrial Temperature

- Why Pick FRAM MCU For IOT Applications
  - Low power for Battery or Energy Harvesting Applications
  - Flexibility of Partitioning Programs & Data in FRAM
  - Easy In Product Software Updates
  - Wide Temperature Range Operation
  - Single Chip Solution in Many Cases
  - Radiation Tolerance for Medical & Food Products Sterilized Using Radiation



TI 430FR5994 Features 256KBytes of eFRAM



LaunchPad Demo System

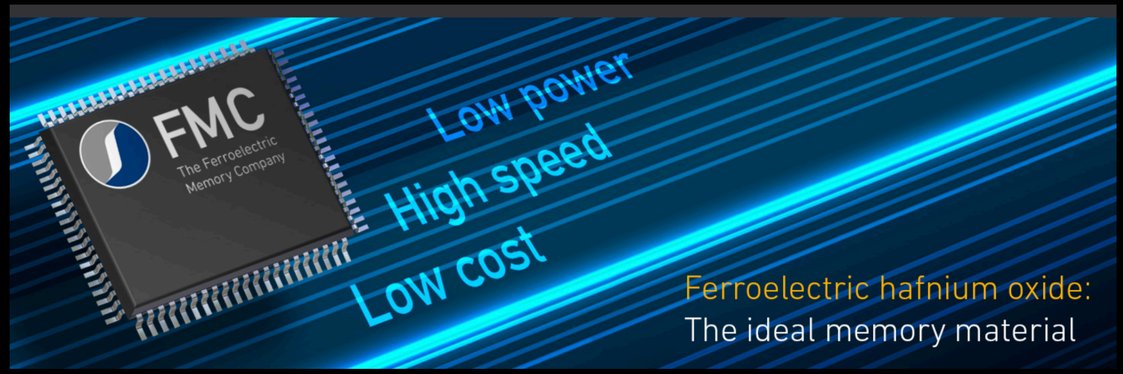
Symetrix

- Dr. Carlos Paz de Araujo and Dr. Larry McMillian were founders of Ramtron in 1984
- First Ramtron FRAM prototypes were built at University of Colorado-Colorado Springs Microelectronics lab
- In 1986, they left Ramtron to found Symetrix
- The focus of Symetrix was Ferroelectrics using Y1 (Strontium Barium Titanate, SBT)
- First success was Y1 use as high dielectric constant capacitor in a GaAs RF chip for Panasonic cellphones
- Partnered with Panasonic to develop FRAM using Y1.
- Panasonic began shipping RF ID for Japan Railroad Card in 2008. 100M Cards Shipped.

Dr. Gota Kona, Dr. Carlos Paz de Araujo, Dr. Larry McMillian
Began Cooperative Research in 1984
Araujo & McMillian Founded Symetrix in 1986

FRAM Update

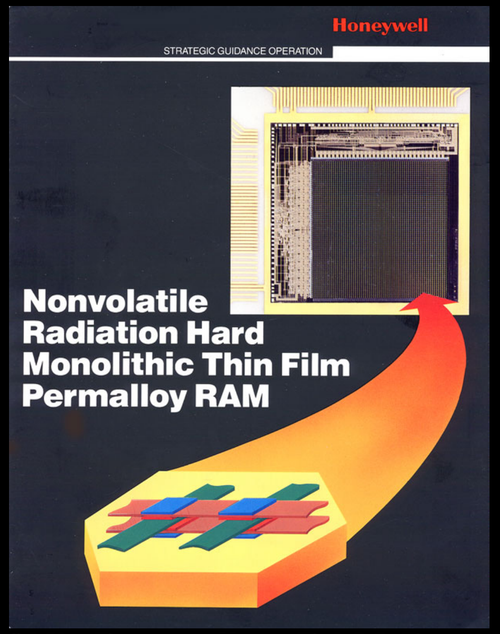
- Oct 2018 - Ferroelectric Memory Company formed in Dresden, Germany to develop high density ferroelectric memory based upon HFO_2, Hafnium Oxide
- HFO_2 is the common high dielectric constant material used in today's DRAMs
- Oct 2020 - ARM Spinout Cerfe Labs formed to develop CeRAM based upon Symetrix technology
- Both Efforts Target 1T FRAM Based Upon FerroFET Device



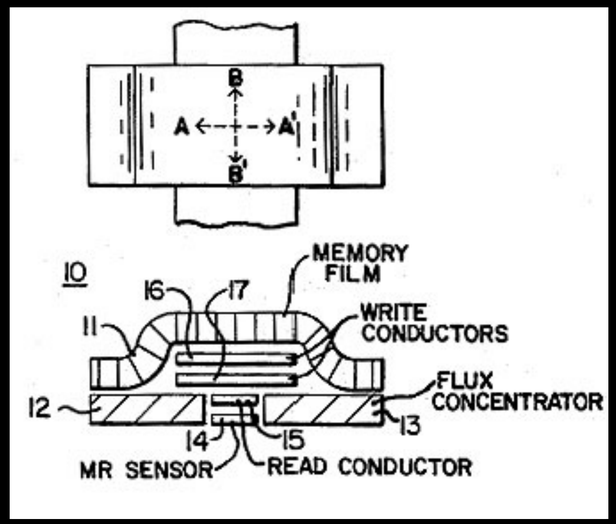
Cerfe Labs

MRAM - Historical View

- Plated Magnetic Memories Date from 1960
  Core Memory
  - Plated Wire (1970s)
  - Permalloy On Glass (1970s)
  - Permalloy On Silicon (1980s)
- Dr. James Daughton from Honeywell Solid State Electronics Founds NVE Corporation in 1989. Now the Leading Magnetic Sensor Company
- DARPA Funds 3 MRAM Programs in 1995
  - NVE/Cypress
  - Motorola (Freescale)
  - IBM



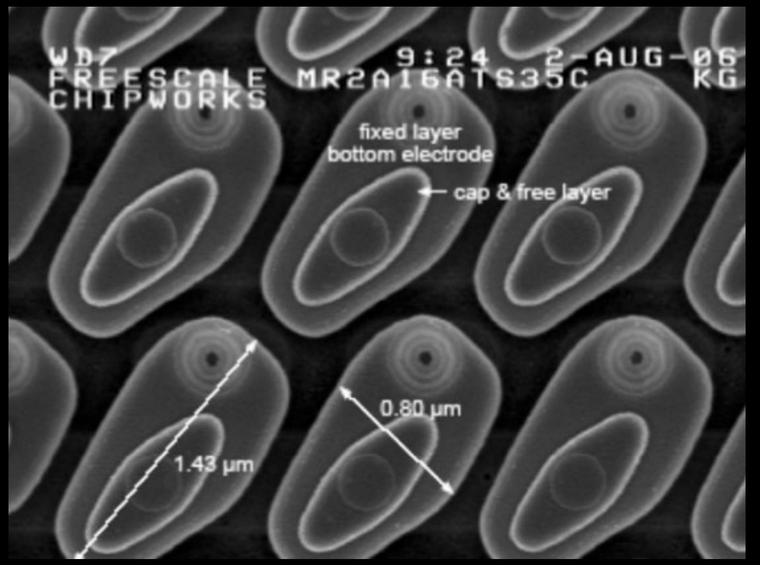
Honeywell 2Kb Permalloy RAM Brochure - 1986



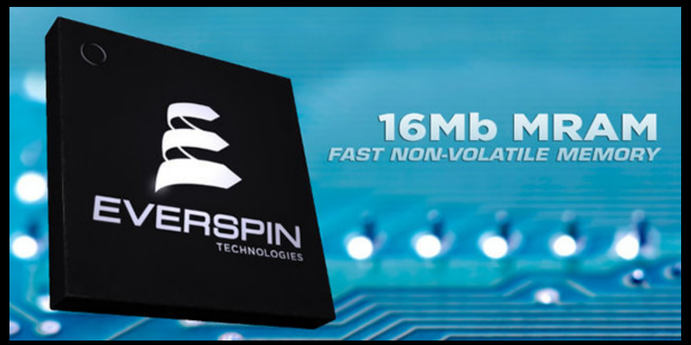
US Patent #4455636
Olin Lutes, Honeywell, Inc. 1983

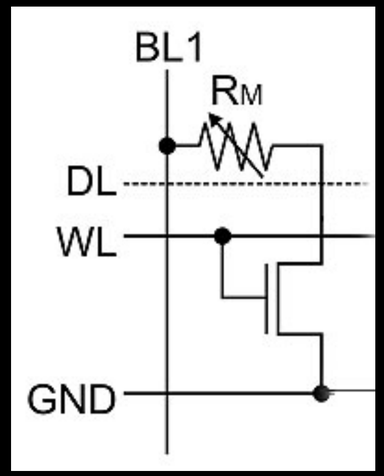
MRAM Development

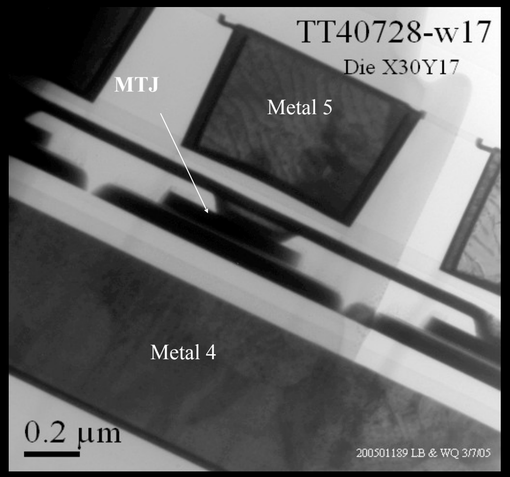
- Freescale Semiconductor (Motorola) Pioneered the Toggle MRAM
  - 256Kb MRAM (2001)
  - 1Mb MRAM (2002)
  - 4Mb MRAM (2004)
  - First 4Mb Production MRAM (2006)
  - First 16Mb MRAM, First 32Mb MRAM
- Freescale MRAM Business Becomes Everspin Technologies (Nasdaq: MRAM) in 2008
- Everspin offers 8 & 16 bit Parallel MRAM, SPI & QSPI MRAM Products today



Magnetic Tunnel Junction Top View







1T-1MTJ Cell Design, Cross Section

Toggle MRAM Products

- Everspin Technologies has offered Toggle MRAM Products Commercially Since 2006

Serial SPI Interface

Size	Speed / Frequency	V_{DD}	
256Kb	40MHz	3.3v	MR25H256›
1Mb	40MHz	3.3v	MR25H10›
4Mb	40MHz	3.3v	MR25H40›
4Mb	50MHz	3.3v	MR20H40›
128Kb	40MHz	3.3v	MR25H128A›

Quad Serial SPI Interface

Size	Speed / Frequency	V_{DD}	V_{DDQ}	
1Mb	40MHz/104MHz	3.3v	1.8	MR10Q010›

8-bit Parallel Interface MRAM

Size	Speed / Frequency	V_{DD}	V_{DDQ}	
256Kb	35ns	3.3v		MR256A08B›
256Kb	45ns	3.3v	1.8	MR256D08B›
256Kb	45ns	2.7-3.6v	1.8	MR256DL08B›
1Mb	35ns	3.3v		MR0A08B›
1Mb	45ns	3.3v	1.8	MR0D08B›
1Mb	45ns	2.7-3.6v	1.8	MR0DL08B›
4Mb	35ns	3.3v		MR2A08A›
16Mb	35ns/45ns	3.3v		MR4A08B›

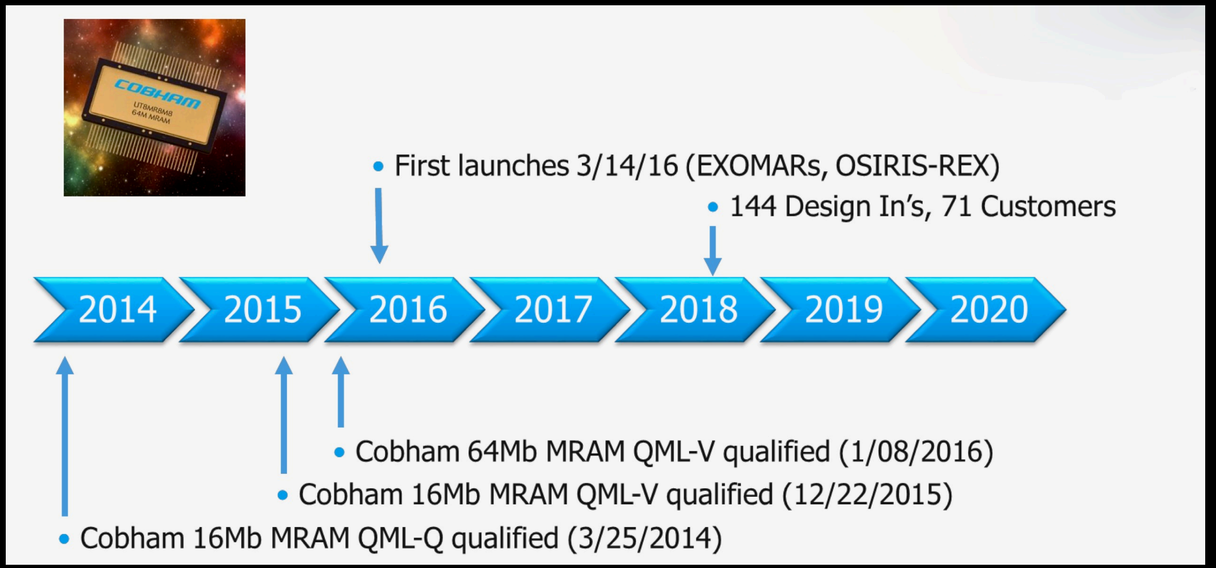
16-bit Parallel Interface MRAM

Size	Speed / Frequency	V_{DD}	
1Mb	35ns	3.3v	MR0A16A›
4Mb	35ns	3.3v	MR2A16A›
16Mb	35ns/45ns	3.3v	MR4A16B›
2Mb	35ns	3.3v	MR1A16A›
8Mb	35ns	3.3v	MR3A16A›
32Mb	35ns	3.3v	MR5A16A›

Rad Hard MRAM

- MRAM operates over wide temperature range, exhibits low soft error rate, and is radiation tolerant
- Honeywell Aerospace partnered with Freescale and Everspin to develop 1Mb and 16Mb Rad Hard MRAM which was QML Qualified in 2013. It is build on 150 nm SOI CMOS with MRAM processing by Everspin
- Cobham (Aeroflex) partnered with Everspin to develop a 16Mb Rad Hard MRAM that was first QML Qualified in 2014. It is built using 180 nm TSMC CMOS with Everspin MRAM processing.
- Both companies offer 64Mb MRAM in multi chip package
- Cobham MRAM first launched in space in 2014.
- MRAM is currently on the OSIRIS-REX mission on the Asteroid Bennu

OSIRIS-REX Asteroid Return Mission



STT-MRAM Development

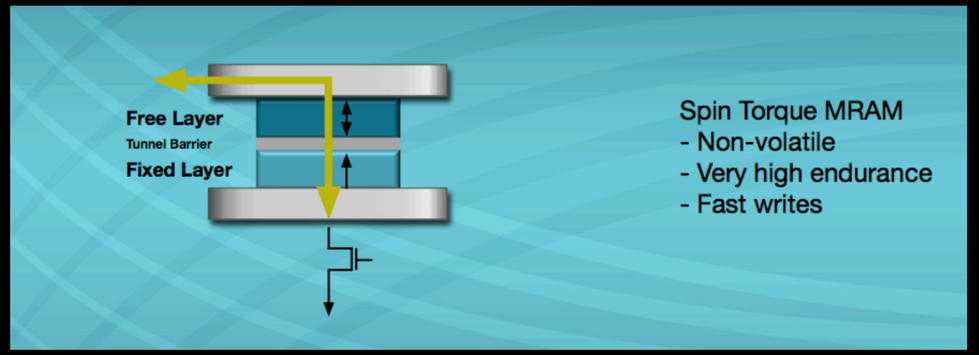
- Spin Torque MRAM writes the MTJ using current through the device barrier. This is done at lower current allowing MRAM scaling to below 22 nm

- In 2008, Grandis was awarded a contract by DARPA to develop STT-MRAM

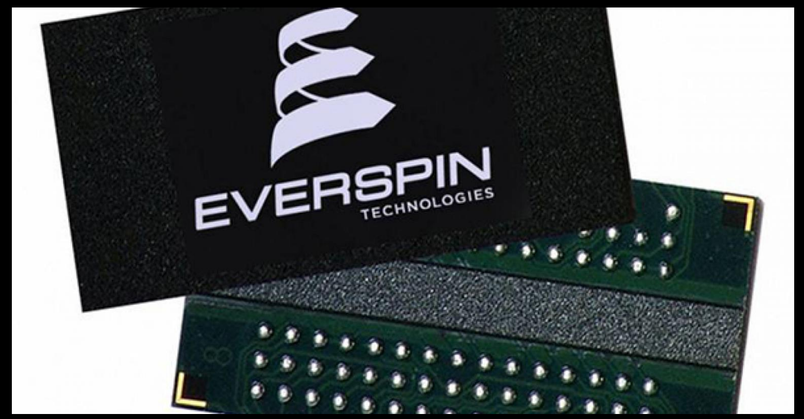
- In 2011, Grandis was acquired by Samsung

- Everspin developed STT-MRAM Products
  - 64Mb DDR3 (2012)
  - 256Mb DDR3 (2016)
  - 1Gb DDR4 (2018)

- Avalanche Technology became the second commercial STT-MRAM supplier in 2019
  - 1Mb-16Mb SPI PSRAM (Persistent SRAM)
  - 1Mb-16Mb QSPI PSRAM
  - 1Mb-64Mb Parallel PSRAM



Spin Torque MRAM (STT-MRAM)



First 1Gb DDR4 ST-MRAM (2019)

STT-MRAM Products

- Everspin Technologies currently offers 256Mb and 1Gb Parallel STT-MRAM products for Enterprise Storage Applications
- Everspin Technologies has introduced a high speed serial xSPI STT-MRAM products in Quad and Octal interface formats which target FPGA Configuration Memory

256Mb STT-MRAM (ST-DDR3)

Size	Speed / Frequency	Configuration	
256Mb	667MHz	32Mb x8, 16Mb x16	EMD3D256M›

1Gb STT-MRAM (ST-DDR4)

Size	Speed / Frequency	Configuration	
1Gb	667MHz	128Mb x8, 64Mb x16	EMD4E001G›

xSPI Octal Interface MRAM

Size	Speed / Frequency	V_{DD}	
16Mb	200MHz	1.8v	EM016LXO›
64Mb	200MHz	1.8v	EM064LXO›
8Mb	200MHz	1.8v	EM008LXO›
32Mb	200MHz	1.8v	EM032LXO›

xSPI Quad Interface MRAM

Size	Speed / Frequency	V_{DD}	
16Mb	133MHz	1.8v	EM016LXQ›
64Mb	133MHz	1.8v	EM064LXQ›
8Mb	133MHz	1.8v	EM008LXQ›
32Mb	133MHz	1.8v	EM032LXQ›

STT-MRAM Products

- Avalanche Technologies has been offering ST-MRAM products since 2019 from IDT (a division of Renesas Electronics)

Serial High Performance	
Densities	1Mb, 4Mb, 8Mb, 16Mb
Voltages	1.8V (1.71V to 2.00V) 3.0V (2.70V to 3.60V)
Packages	8-pad WSON, 8-pin SOIC, 24-ball FBGA
Temperature Ranges	Industrial (-40°C to 85°C), Industrial Plus (-40°C to 105°C)

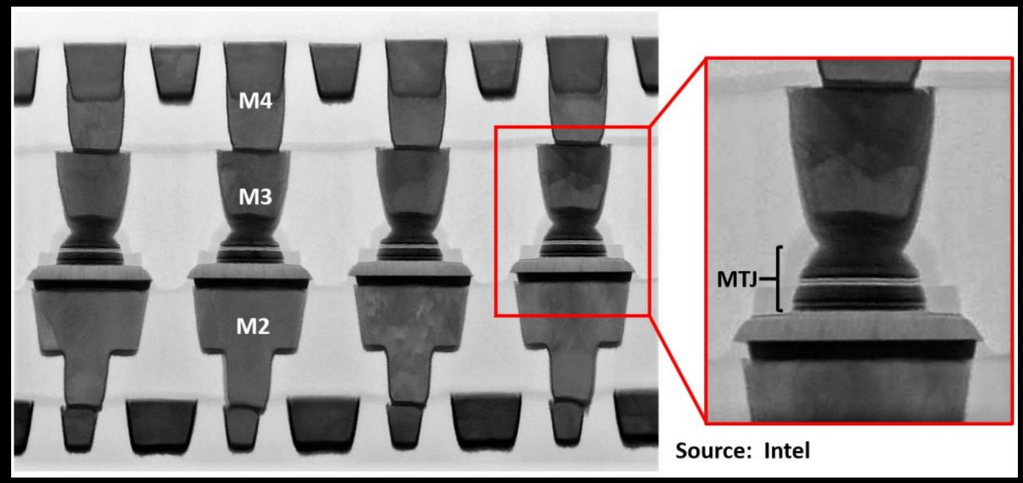
Serial SPI	
Densities	1Mb, 4Mb, 8Mb, 16Mb
Voltages	3.0V (2.70V to 3.60V)
Packages	8-pad WSON, 8-pin SOIC
Temperature Ranges	Industrial (-40°C to 85°C), Industrial Plus (-40°C to 105°C)

Parallel x8	
Densities	1Mb, 4Mb, 8Mb, 16Mb, 32Mb
Voltages	3.0V (2.70V to 3.60V)
Packages	44-pin TSOP, 48-ball FBGA
Temperature Ranges	Industrial (-40°C to 85°C), Industrial Plus (-40°C to 105°C)

Parallel x16	
Densities	1Mb, 4Mb, 8Mb, 16Mb, 32Mb, 64Mb
Voltages	3.0V (2.70V to 3.60V)
Packages	44-pin TSOP, 54-pin TSOP, 48-ball FBGA
Temperature Ranges	Industrial (-40°C to 85°C), Industrial Plus (-40°C to 105°C)

Emerging ST MRAM Foundry Offerings

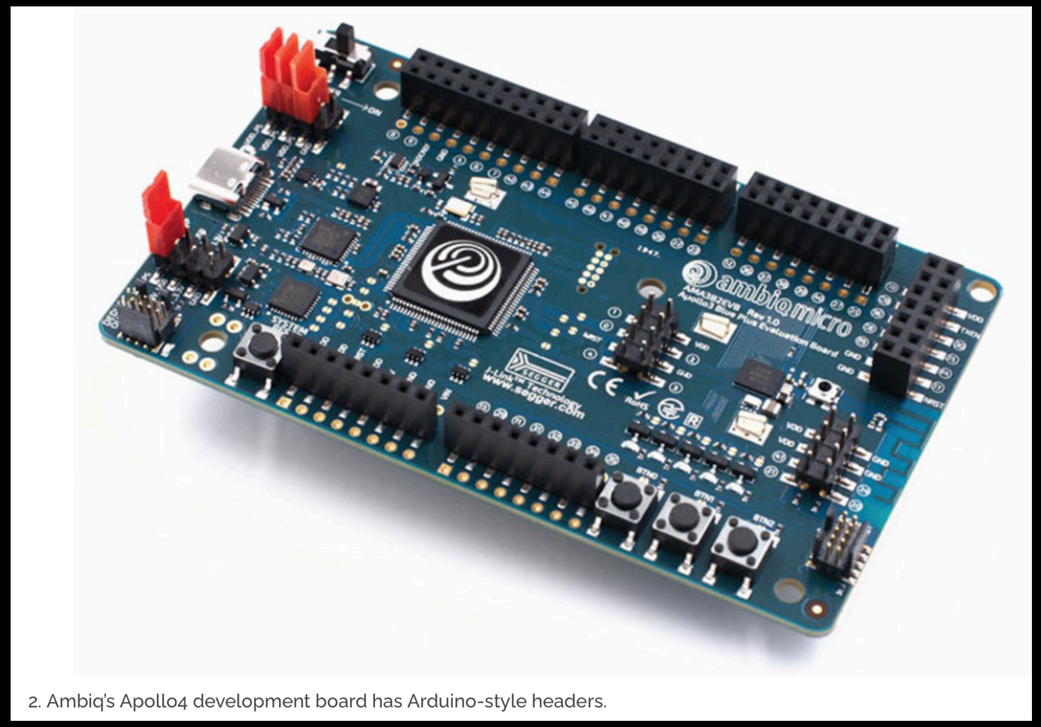
- Everspin Technologies announced development of 40, 28, and 22 nm STT eMRAM foundry offerings with Global Foundries (Singapore) in 2017
- Avalanche Technology announced 28 nm eMRAM foundry with UMC (Taiwan) in 2018
- Samsung announced 28 nm eMRAM foundry (Korea) in 2018
- Intel announced 22 nm eMRAM process for their products in 2019
- Gyrfalcon announced Edge AI Processor Chip using 22 nm eMRAM process from TSMC (Taiwan) in 2019
- STT MRAM is expected to become mainstream embedded memory alternative to NOR Flash, EEPROM & SRAM



Intel Corporation 22 nm ST eMRAM (2019)

MRAM Update

- Mar 2020 - Everspin & Global Foundries to develop 12 nm eMRAM
- Apr 2020 - Samsung 28 nm eMRAM found in Sony GNSS chip in Huawei Smartwatch
- April 2020 - TSMC developing 16 nm eMRAM for 4Q22 Risk Production
- Sept 2020 - Ambiq Micro announced ARM Cortex M4 microcomputer with 3MB eMRAM built on 22 nm TSMC process
- Numen developing rad hard ST-MRAM for NASA AI Core Project



2. Ambiq's Apollo4 development board has Arduino-style headers.

Ambiq Apollo4 Microprocessor has 3MB eMRAM

Software Consideration with Non-Volatile RAM

- NAND Flash Memory Has Significant Software Overhead
  - Limited Endurance Requires Wear Leveling and Block Management
  - Poor Reliability Require Extensive ECC Software
  - Slow Write Speed Essentially Requires Copy in SRAM or DRAM with Write in Background or At Power Down
  - May Lose Critical Data During Power Loss without Backup Supply or Battery
  - Probably not suitable for industrial or automotive temperatures

- NOR Flash Has Similar Difficulty Managing Write Data as NAND Flash
  - Good for data reads, poor for data writes

- EEPROM Provides Random Access Read and Write But
  - Limited Endurance Means Can’t Perform Real Time Writes, Only Periodic Saves
  - 10 mS write speed too slow for real time writing, typically keep copy in SRAM or DRAM
  - May Lose Critical Data During Power Loss without Backup Supply (SuperCAP) or Battery

- FRAM & MRAM provides random access read & writes like SRAM or DRAM
  - High Endurance eliminates concern about write data loss
  - Always non-volatile without backup when power is lost
  - Can map both programs and data into common data space and change dynamically in the field
  - Instant-On, No Boot From Flash to DRAM or SRAM
  - Can have very low power operation for battery powered or energy harvested application
  - Operates over wide temperature & is radiation tolerant

FRAM Application

- Data Logging - Crash Recorders, Video Recorders, Medical Devices
- Metering - Power Meters, Water Meters, Gas Meters
- Battery Powered or Energy Harvesting Applications - RF ID, NFC Chips, Contactless Smart cards,
- Medical Applications Requiring Radiation Sterilization
- Small Single Chip Systems Where FRAM Becomes Consolidated Program & Data Storage - Smoke Detector, Thermostats, Smart Locks, Motion Detectors

MRAM Applications

- Enterprise Data Storage - Write Buffers, Meta Data Storage, Index Memory
- Industrial, Automotive, Avionics & Space Applications - Wide Temperature Range, Lower Soft Error Rate, More Reliable Than Flash
- Instant-On Systems - No Need to Boot Data from Flash to DRAM or SRAM
- Medical Systems - Fast Data Logging, Data Never Lost During Power Fail
- Replace SRAM, NOR Flash, EEPROM in future single chip MCU Systems
- Replace Large Cache in High Performance Multiprocessor Systems
- Distributed Persistent Memory for AI Systems