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

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Ferroelectric RAM (FRAM)

• Certain Ceramic Material Are Polarized By An Electric Field (Ferroelectrics)
  • KNO₃ - Potassium Nitrate
  • PZT - Lead Zirconate Titanate
  • SBT (Y1) - Strontium Barium Titanate

• A Ferrocapacitor is Two Metal Plates with Ferro Dielectric

• Ferroelectric RAM (FRAM) is DRAM With 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 ($10^{10-15}$ Cycles)
  • Non-volatile - 10 Year Data Retention without Power
  • Wide Temperature Range (Commercial, Industrial, Automotive)
  • Resistant to Radiation, Electric & Magnetic Fields
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 Cypress Semiconductor)

- 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
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 $\text{KNO}_3$ 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)
- Volume Production of 4Kb FRAM In 1993
  - Sega Genesis Game Cartridges Were the Largest Application
Ramtron 1T1C FRAM Development

- Ramtron Partners with Seiko Epson (Japan)
- Seiko Epson Program Yielded First 256Kb 1T1C In 1992
- Ramtron Partners with Rohm Corporation (Japan)
- Rohm (now Lapis Semiconductor) Becomes First FRAM Production Fab
- Ramtron Announces First Serial FRAM & eFRAM Products in 1998
  - 4K & 16K I²C & 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
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
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 um² Cell Size (32F²)
  - 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
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

LaunchPad Demo System
Fujitsu RF ID Products

- Fujitsu offers off-the-Shelf Contactless RF ID Solutions
- Fujitsu offers COT and Custom Development eFRAM options

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Operating Frequency</th>
<th>Memory Density</th>
<th>Commands</th>
<th>Serial Interface</th>
<th>Data Retention Guaranteed</th>
<th>Read/Write Cycles</th>
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<tbody>
<tr>
<td>MB97R803A/B</td>
<td>UHF 860-960MHz</td>
<td>4KBytes</td>
<td>ISO/IEC18000-6C EPC C1G2 Ver.1.2.0</td>
<td>–</td>
<td>10 years (+55°C)</td>
<td>$10^{10}$ (10 billion) times</td>
</tr>
<tr>
<td>MB97R804A/B</td>
<td>UHF 860-960MHz</td>
<td>4KBytes</td>
<td>ISO/IEC18000-6C EPC C1G2 Ver.1.2.0</td>
<td>SPI</td>
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<tr>
<td>MB97R8050</td>
<td>UHF 860-960MHz</td>
<td>128bits</td>
<td>ISO/IEC18000-6C EPC C1G2 Ver.1.2.0</td>
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<td>$10^{10}$ (10 billion) times</td>
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<tr>
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<td>HF 13.56MHz</td>
<td>2KBytes</td>
<td>ISO/IEC15693</td>
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<tr>
<td>MB89R119B</td>
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<td>256Bytes</td>
<td>ISO/IEC15693</td>
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<td>MB89R112</td>
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<td>9KBytes</td>
<td>ISO/IEC15693</td>
<td>SPI</td>
<td>10 years (+85°C)</td>
<td>$10^{12}$ (1 trillion) times</td>
</tr>
</tbody>
</table>
Plated Magnetic Memories Date from 1960 Core Memory
- Plated Wire (1970s)
- Permalloy On Glass (1970s)
- Permalloy On Silicon (1980s)


Darpa Funds 3 MRAM Programs in 1995
- NVE/Cypress
- Motorola (Freescale)
- IBM
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
- Everspin offers 8 & 16 bit Parallel MRAM, SPI & QSPI MRAM Products today
ST-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 ST-MRAM Products
  • 64Mb DDR3 (2012)
  • 256Mb DDR3 (2016)
  • 1Gb DDR4 (2018)

• Avalanche Technology became second commercial ST-MRAM supplier in 2019
  • 1Mb-16Mb SPI PSRAM (Persistent SRAM)
  • 1Mb-16Mb QSPI PSRAM
Emerging ST MRAM Foundry Offerings

- Everspin Technologies announced development of 40, 28, and 22 nm ST 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

- ST MRAM expected to become mainstream embedded memory alternative to NOR Flash, EEPROM & SRAM
Standalone Non-Volatile RAM Products

- Standalone Non-Volatile RAM Products Available from Cypress (Ramtron), Fujitsu, Lapis (Rohm), Everspin (Freescale), and Avalanche
- Parallel RAM (64Kb to 1Gb)
- Serial I2C FRAM (4Kb to 1 Mb)
- Serial SPI, QSPI FRAM & MRAM (4Kb to 16Mb)
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 Smartcards,

• 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