eMRAM: Winning the IoT and AI Applications

MRAM Developer’s Day
August 6th – Santa Clara, CA

Michael Mendicino| VP – Product Management; Leading Edge CMOS
Knowing what will drive growth...

- One technology doesn’t fit all
- Intelligence is inherent
- Understand and anticipate the needs of the market segments

and how we meet it
# IoT Semiconductor Value

$17B in 2017 \rightarrow $34B in 2020 \rightarrow $63B 2025 (Est.)

## Semiconductor Clients IoT TAM (B$)

### Challenges:
- Standardization
- Fragmentation
- End-to-end solutions
- Business models
- Security
- Low power

**Sources:**
- "For 2025: Inquiry to Gartner's analysts Dean Freeman and Peter Middleton, December 19,2016"
# IoT spanning many technologies and applications
MCUs/SoCs use CMOS platforms from 130nm to FDSOI to FinFETs

## Key Applications

<table>
<thead>
<tr>
<th>Applications</th>
<th>Edge Gateways</th>
<th>IoT Factory Controllers</th>
<th>Wearables</th>
<th>Health and Fitness Monitors</th>
<th>Smart Vending</th>
<th>Automotive Infotainment, ADAS</th>
<th>AR / VR</th>
<th>ISPI / Vision Processing</th>
<th>AI</th>
</tr>
</thead>
</table>

## Tiers >>

<table>
<thead>
<tr>
<th>Class</th>
<th>Low</th>
<th>Mid</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>ARM Cortex M0 to M3/M4</td>
<td>ARM Cortex M3/M4 to Cortex-A9</td>
<td>ARM Cortex-A9+, Intel Xeon</td>
</tr>
<tr>
<td>Processor</td>
<td>8-16bit</td>
<td>16-32bit</td>
<td>32-64bit</td>
</tr>
<tr>
<td>Speed</td>
<td>Upto 250MHz</td>
<td>Upto 1 GHz</td>
<td>Above 1 GHz</td>
</tr>
<tr>
<td>Memory</td>
<td>OTP / MTP: upto 256KB</td>
<td>Embedded NVM Flash/MTP: upto 2MB</td>
<td>External Flash &gt; 4GB</td>
</tr>
<tr>
<td>OS</td>
<td>None / Simple RTOS / Proprietary</td>
<td>Proprietary/ RTOS / Android Wear</td>
<td>Mobile OS: Android / Wear / iOS HLOS: / Windows 10 IoT Enterprise</td>
</tr>
<tr>
<td>Connectivity (RF)</td>
<td>Bluetooth® Smart (BLE) / 15.4, Zigbee – typically off-chip</td>
<td>BLE /15.4, Zigbee, Wi-Fi – Integrated Cellular LTE Cat 1 / M – External (optional)</td>
<td>BLE / 15.4, Wi-Fi, USB; LTE Cat 1/ M /NB-IoT → 5G – External</td>
</tr>
<tr>
<td>Metal Layers</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Complexity

| Complexity | 5-10 | 8-13 |

Sources: Gartner, McKinsey, Industry and Customer data points, and GF internal assessments.

© 2018 GLOBALFOUNDRIES
The SoC Differentiator
Value for IoT: versatile, integration, low-power, low cost

- **COMPUTE (MCU, MPU, WPU)**
  - <100MHz to ~1GHz

- **CONNECTIVITY (RF Tx and Rx)**
  - Local area, cellular, wired

- **MEMORY (Embedded, External)**
  - eNVM, SRAM

- **SENSORY, LOCATION**
  - Low power sensors, integrated security and application context

- **POWER MANAGEMENT / BATTERY LIFE**
  - Energy harvesting, short burst battery usage, solar

- **SECURITY (Embedded)**
  - Certified foundry, crypto engines, key vaults, Physical Uncloneable Function (PUF)

- **PACKAGING**
  - Smaller, thinner, and simpler form factors

- **IP**
  - Foundational, complex, specialized

- **INTEGRATION**
  - NVM, RF, Analog/Mixed-Signal, Sensors

Source: Industry, Customer/Prospects/Partners, and GF Internal assessments
IoT (MCU based SoC)

- **Compute:**
  - MRAM Replaces FLASH & SRAM
  - Low power modes
  - 10’s of uA/MHz Active
  - 10nA Standby
  - Fast wake up
  - Security engines

- **Power Management**

- **MCU**
  - Ultra Low Power
  - (MRAM, Security)

- **Connectivity**
  - Low Data Rate
  - RF (802.15.4, .15.1)
  - Wired (PLC, CAN)

- **Sensing/Acting**
  - Integrate in package
  - Provide standard interfaces
  - Provide intelligent peripherals in MCU to offload MCU and reduce power

- **Integration**

- **Power:**
  - MRAM Enabled ‘Instant-on’ from shut-down
  - Switch mode DC-DC for efficiency
  - Controllable Vdds for RF, MCU, Peripherals
  - Brown-out and Low voltage detect for last gasp

- **Connectivity:**
  - Standards based
  - Low power (<10mA RX BTLE)
  - Separate Vdd

- **Sensing/Acting:**
  - Integrate in package
  - Provide standard interfaces
  - Provide intelligent peripherals in MCU to offload MCU and reduce power

- **Integration**

- **Uniquely MRAM offers power and area savings**
- **Differentiator when paired with RF on low-power process**
- **Flash compatibility and scaling?**
AI/ML is up to a **$12B opportunity by 2025**

- **High-end Inferencing & Training**
  - Data Center, Cloud, Automotive
  - Mostly ASIC engagement
  - *High-performance, high-density CMOS platform*
  - Die size >200mm²

- **Low to Mid-range Inferencing**
  - Client: Edge, IoT, Smartphones, Cameras, Drones, Auto ADAS
  - Classic foundry and ASIC
  - *Low-power, low-cost CMOS platform*
  - Die size <200mm²

Source: Tractica Artificial Intelligence Market Outlook
Artificial Intelligence: GF Experience

High-End: FinFET / Low-End: LP or FDSOI

**High performance compute:**
- High-frequency CPUs / metal stack
- 2.5D integration with multiple HBM
- High-density embedded memory
- 32b MACs / embedded memory

**Balance of compute, power & cost:**
- FDX SoC Platform
- RISC-V, ARM and DSP IP Cores
- 16b MACs / embedded memory
- SoC Design services
- Safety requirements (ISO26262 - Auto)
**AI / ML: Requirements**

**Key Features**

- **Operations per Watt** (Logic, Memory access, bus interconnect)
- **Total high access speed memory content** (Mb, embedded, high bandwidth)

**Power, Performance, Area**

- **Power**: TOPS/W, Power @ Constant Freq
- **Perf**: ~500MHz-1.5GHz logic & memory, high activity factor (AF)
- **Die Size**: ~50-200mm²; 200+

**Memory**

- **Die Content**: 45%-Logic, **45%-Memory**, 10%-Analog I/O
  - High-speed, high-density, low power local system memory
  - High-density, on/off-chip memory

**Architecture/IP**

- GPU, APU, 3D SRAM, Scalable Embedded Memory
- 3rd Party IP Cores
How to win: IoT and AI/ML
Create Maximum Value for IoT and AI/ML

**IoT**
- Low Power CMOS
- Integrated RF and mmWave
- Low Power (MRAM) Memory
- Low cost
- Extensive IP Portfolio
- Extensive Design Ecosystem
- Ultra-low power
- Low-leakage
- Low-Voltage
- Analog/power mgmt: LDMOS, Mismatch, Noise, SCE

**AI/ML**
- High-performance
- High-density CMOS
- High Bandwidth (MRAM) Memory
- 3D stacking
- BEOL + MIMcap
- High speed interface IP
- High Density (MRAM) Memory
- Low leakage
- Low-Voltage
- Analog/power mgmt: LDMOS, Mismatch, Noise, SCE
FDX™ - The Ideal Platform for IoT and edge AI/ML

Application Tiers

- 22FDX® can cover 300 MHz to 2 GHz and above for ARM cores
- RISC-V, ARM and DSP cores for AI/ML

Technology Capabilities

- Lower dynamic and leakage power
  - Logic: 80% lower total power vs 40nm; operation down to 0.4V
  - Memory: 1pA/cell standby & 0.28V retention voltage
- High performance RF/LDMOS, mmWave, Analog capability
- Connectivity: BLE / 15.4, Wi-Fi, Cellular LTE Cat M/NB-IoT
- Body-bias driven power management
- eMRAM for non-volatile memory

Value

22FDX is a great fit for IoT and edge AI/ML clients that require ULP / ULL and performance-on-demand processing with integrated RF and versatile embedded memory

© 2018 GLOBALFOUNDRIES
<table>
<thead>
<tr>
<th>Design/Technology Enablement</th>
<th>Ecosystem Providers</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASIC <strong>Design Services</strong></td>
<td>Ecosystem Providers</td>
</tr>
<tr>
<td>(Spec-to-Packaged/Tested Parts)</td>
<td>Ecosystem Providers</td>
</tr>
<tr>
<td><strong>Design Services</strong></td>
<td>GlobalFoundries</td>
</tr>
<tr>
<td>(Outsource Analog/Mixed Signal, SoC Design,)</td>
<td>Invecas</td>
</tr>
<tr>
<td><strong>Design Augmentation</strong></td>
<td>Unifyq</td>
</tr>
<tr>
<td>(layout, digital, analog engineering capacity)</td>
<td>Open-Silicon</td>
</tr>
<tr>
<td><strong>Methodology Support</strong></td>
<td>VeriSilicon</td>
</tr>
<tr>
<td>(Body Bias, DVFS, Porting flow, …)</td>
<td>Sasken</td>
</tr>
<tr>
<td><strong>Interface IP</strong></td>
<td>IceCap</td>
</tr>
<tr>
<td>(SerDes, PCIe, USB, LPDDR, MIPI, HDMI, …)</td>
<td>Infysys</td>
</tr>
<tr>
<td><strong>Analog IP</strong></td>
<td>Synopsys</td>
</tr>
<tr>
<td>(Data Converters, I/Os, PLLs, eFuse, eNVM…)</td>
<td>Innovision</td>
</tr>
<tr>
<td><strong>Foundation IP</strong></td>
<td>Arteris</td>
</tr>
<tr>
<td>(Std. Cells, Compilers, GPIO, PLLs, eFuse…)</td>
<td>Dolphin</td>
</tr>
<tr>
<td><strong>Reference Designs</strong></td>
<td>Kilopass</td>
</tr>
<tr>
<td>(Logic, Bitcells, Analog, RF)</td>
<td>Rambus</td>
</tr>
<tr>
<td><strong>Reference Flows</strong></td>
<td>Synopsys</td>
</tr>
<tr>
<td>(SoC-Digital, Custom-Analog/Mixed Signal)</td>
<td>Mentor</td>
</tr>
<tr>
<td><strong>PDK Support</strong></td>
<td>Cadence</td>
</tr>
<tr>
<td>(TCAD, Models, OPC, DRC, DFM, LVS)</td>
<td>Silvaco</td>
</tr>
</tbody>
</table>
## Key Benefits

<table>
<thead>
<tr>
<th></th>
<th>Incumbent</th>
<th>eMRAM-F</th>
<th>SRAM</th>
<th>eMRAM-S</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IoT &amp; AI/ML (edge)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Key Benefits</td>
<td>Incumbent</td>
<td>&lt;28nm scaling Low Pwr/Fast Write</td>
<td>Fast Read/Wrt</td>
<td>2X SRAM density &lt;10nS Read# Low Pwr, NVM</td>
</tr>
<tr>
<td>Speed (Rd/Wr)</td>
<td>10ns / 20us</td>
<td>25ns / &lt;200ns</td>
<td>&lt;1ns</td>
<td>≈ 5ns# / 10ns</td>
</tr>
<tr>
<td>Endurance</td>
<td>10⁵</td>
<td>≈10⁸</td>
<td>N/A</td>
<td>≈10¹⁴</td>
</tr>
<tr>
<td>Data Retention</td>
<td>&gt;20 years</td>
<td>15 years</td>
<td>-</td>
<td>&lt;1 month</td>
</tr>
<tr>
<td>Reflow retention (260°C/5min)</td>
<td>Yes</td>
<td>Yes</td>
<td>N/A</td>
<td>No</td>
</tr>
<tr>
<td>Power off retention</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Op Temp (Tj)</td>
<td>150°C Auto grade 1</td>
<td>125°C Con/Ind./Auto*</td>
<td>up to 150°C Auto Grade 1</td>
<td>105°C Enterprise *</td>
</tr>
</tbody>
</table>

### Notes
- #Auto grade 1 Tj=150°C (future)
- #Architecture techniques and high speed MTJ stack to get to <<10ns Read
22FDX eMRAM for Low-Power IoT MCU

Advantage of 22FDX eMRAM

<table>
<thead>
<tr>
<th></th>
<th>eFlash</th>
<th>eMRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tech. Node</td>
<td>40nm</td>
<td>22nm</td>
</tr>
<tr>
<td>Macro Area</td>
<td>1X</td>
<td>0.7X</td>
</tr>
<tr>
<td>RD/WT Performance</td>
<td>10ns/10000ns</td>
<td>25ns/200ns*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15ns/40ns**</td>
</tr>
<tr>
<td>Active Energy</td>
<td>10~1000pJ</td>
<td>1~100pJ</td>
</tr>
<tr>
<td>Standby power</td>
<td>100~500uW</td>
<td>&lt;50uW</td>
</tr>
<tr>
<td>Mask adder</td>
<td>12+</td>
<td>3-4</td>
</tr>
<tr>
<td>MPW readiness</td>
<td>Now</td>
<td>Now</td>
</tr>
<tr>
<td>Production</td>
<td>Now</td>
<td>1H'19</td>
</tr>
</tbody>
</table>

* MRAM-F Flash interface performance 25 / 200ns; ** MRAM-F SRAM interface performance 15ns / 40ns

22FDX + eMRAM + RF

Low Vdd and power

Fast ON/OFF

High Speed

Connectivity

eMRAM at 22nm FD-SOI is ideal for low power IoT MCU
We've Been Busy!

- Risk production by the end of 2018
- Released with eMRAM model supported
- Quarterly, starting in Q1'18
- PDK
- MPW
- eFlash and SRAM interfaces available
- eMRAM
- Production

Adapting to the ever-evolving needs of the semiconductor industry, we’ve been busy working on advancements in MRAM technology. Our latest developments include the release of our eMRAM model, supported starting in Q1'18. This is in line with our commitment to providing PDKs and MPW services.

We’ve been particularly focused on enhancing our eFlash and SRAM interfaces, ensuring they are ready for production by the end of 2018. Our eMRAM technology, with its risk production by the end of 2018, is a testament to our dedication to innovation and excellence.

Our team of experts has been diligently working to refine our processes, ensuring the highest quality and efficiency in our products. This includes the development and implementation of new features, such as enhanced performance and improved reliability.

We're excited to share more about our 22FDX® eMRAM solution. Contact us for more information or to discuss how our technology can benefit your next project. We look forward to hearing from you!

© 2018 GLOBALFOUNDRIES
Deep partnership proves mutually beneficial

22FDX® eMRAM

- Released with eMRAM model supported
- Quarterly, starting in Q1’18
- eFlash and SRAM interfaces available
- Risk production by the end of 2018

GLOBALFOUNDRIES Surpasses $2 Billion in Design Win Revenue on 22FDX® Technology

With 50 client designs and growing, 22FDX proves its value as a cost-effective solution for power-sensitive applications.

Santa Clara, Calif., July 9, 2018 — GLOBALFOUNDRIES today announced that the company’s 22nm FD-SOI (22FDX®) technology has delivered more than two billion dollars of client design win revenue. With more than 50 total client designs, 22FDX is proving to be the industry’s leading platform for power-optimized chips across a range of high-growth applications such as automotive, 5G connectivity and the Internet-of-Things (IoT).

For clients who need significant reductions in power and die size relative to a bulk CMOS process, 22FDX offers the industry’s lowest operating voltage, delivering up to 500MHz frequencies at only 0.4 volts. The technology also delivers efficient single-chip integration of RF, transceiver, baseband, processor, and power management components, providing an unparalleled combination of both high performance RF and mmWave with low-power, high density logic for devices that require long-lasting battery life, increased processing capability, and connectivity.

See also: 22nm FD-SOI Embedded MRAM with Full Solder Reflow Compatibility and Enhanced Magnetic Immunity; K. Lee et al, 2018 VLSI Symposium
GF FD-SOI Roadmap: 12FDX™

• Integration for connected and interactive systems

• Unparalleled energy efficiency
  – 7nm FinFET power efficiency with Body-Bias
  – Enhanced body-biasing and Vt mixing

• Connectivity across wireless protocols
  – Superior RF/Analog: high $f_t/f_{\text{MAX}}$
  – Planar devices with lower parasitics
  – Optimized for 1/f Noise and RTS

• Smart scaling: avoid triple- and quad-patterning
  – Full node shrink vs. 22FDX®
  – 40% fewer masks than 7nm FinFET (optical)
  – Flexible layouts for analog designs
Key Challenges
Memory challenges coming from all directions!

- eFlash scaling < 2x nm
- Compatibility w/ advanced SOI / FinFET processes
- DRAM Leakage <2x nm
- RowHammer, Power, Latency

Memory Innovation Requirements

- Memory bandwidth ‘Gap’
- x2 CPU Speed → 2 Yrs
- x2 Memory BW → 6 Yrs

MRAM Solutions
- Technology
- Architecture
- Application

Accessible TAM
- Customer and market acceptance

IOT and AI/ML demand
- lowest possible power memory solutions
- FDX™ versatile platform with leadership eMRAM Here and Now!
- Unmatched value proposition for IoT and AI/ML leads to new and disruptive applications
- Right technology for growth segments