MRAM, XPoint, ReRAM
PM Fuel to Propel
Tomorrow's Computing Advances

Jim Handy
Objective Analysis

Tom Coughlin
Coughlin Associates
The Market is at a Nexus

Everything Is Changing!
Emerging Memory Technologies

- MRAM: Magnetic RAM
- ReRAM: Resistive RAM
- PCM: Phase-Change Memory (i.e. 3D XPoint)
- FRAM: Ferroelectric RAM
- Etc.

All are nonvolatile memories: “NVM”
What We learned at IEDM

- The field has not narrowed:
  - MRAM, PCM, ReRAM, & FRAM all well represented

- First big application is still unclear
  - Embedded NVM? Stand-alone? Embedded RAM? Neural nets?
  - Everybody points to ballooning “Big Data”

- Everybody’s participating
  - Samsung, SK hynix, Micron, Toshiba, Intel, TSMC, Macronix, etc.

- Flash might not be dead after all
Papers By Type

<table>
<thead>
<tr>
<th>Technology</th>
<th>Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash</td>
<td>9</td>
</tr>
<tr>
<td>RAM</td>
<td>3</td>
</tr>
<tr>
<td>MRAM</td>
<td>13</td>
</tr>
<tr>
<td>ReRAM</td>
<td>17</td>
</tr>
<tr>
<td>FRAM</td>
<td>30</td>
</tr>
<tr>
<td>PCM</td>
<td>9</td>
</tr>
<tr>
<td>Neural Nets</td>
<td>25</td>
</tr>
</tbody>
</table>

- Neural Nets and FRAM take the prize
  - FRAM’s suddenly “New” again!
- MRAMs had a conference of their own after IEDM
  - 10 more presentations
- ReRAM well represented
- Flash coverage surprising
  - It’s not dead yet!
What We learned at IRDS Rebooting Computing and elsewhere

- IEEE events in November 2018 near Washington, D.C.
- End of Moore’s Law scaling leading to new Computing Models
  - Approximate Computing
  - Adiabatic Computing
  - Neuromorphic Computing (often using emerging memory technologies)
  - Quantum Computing
- Rise of new architectures like RISC-V
- Development of special purpose application accelerators
Emerging Memory Report

- Why Emerging Memories are Necessary
- Understanding Bit Selectors
- The Technologies
- Process Equipment Requirements
- Emerging Memory Companies
- Forecasting Emerging Memories

Now available for online purchase
Why Emerging Memories are Necessary

- Flash can’t scale with process advances
  - NAND flash went 3D at 15nm
    - 3D is not cost-effective in a CMOS logic process
  - NOR scaling stops with FinFET
    - 28nm & smaller processes need something new

- Low DRAM densities load down the memory bus

- AI is expensive on a von Neumann machine, hence new computer architectures
How Scaling Limits Help New Memories

<table>
<thead>
<tr>
<th>Process Geometry</th>
<th>Relative Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>500nm</td>
<td>$1,000.00</td>
</tr>
<tr>
<td>250nm</td>
<td>$100.00</td>
</tr>
<tr>
<td>130nm</td>
<td>$10.00</td>
</tr>
<tr>
<td>65nm</td>
<td>$1.00</td>
</tr>
<tr>
<td>32nm</td>
<td>$0.10</td>
</tr>
<tr>
<td>16nm</td>
<td>$0.01</td>
</tr>
<tr>
<td>8nm</td>
<td>$0.01</td>
</tr>
<tr>
<td>4nm</td>
<td>$0.01</td>
</tr>
<tr>
<td>2nm</td>
<td>$0.01</td>
</tr>
</tbody>
</table>

- Flash
- New Tech
Biggifying Memory with DRAM

SNIA has made important contributions!
SNIA has made important contributions!
Simplifying AI

\[ V1 \cdot R1 + V2 \cdot R2 + V3 \cdot R3 + V4 \cdot R4 \]

\[ = V1 \times (1/R1) + V2 \times (1/R2) + V3 \times (1/R3) + V4 \times (1/R4) \]
64Kb Array = 256 sums of 256 Multiplies EACH!
All in a single cycle.

Should SNIA participate in this?
Big Data Analytics

- A big topic at **Rebooting Computing**
- Graph problems: High Communication/Computation ratio
- Feature recognition: Works OK with low precision (i.e. Analog)
Lightspeeur® 2802M, Production AI Accelerator Chip with MRAM (from 2019 CES)

- Includes: The GME (Gyrfalcon MRAM Engine)
- 9.9 TOPS/W in a 22nm ASIC
- Produced via TSMC Collaboration
- Industry leading features, like Non-Volatile Memory

<table>
<thead>
<tr>
<th>~ 40 MB of Memory</th>
<th>Large embedded models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multiple AI models :</td>
</tr>
<tr>
<td></td>
<td>Image Classification</td>
</tr>
<tr>
<td></td>
<td>Voice identification</td>
</tr>
<tr>
<td></td>
<td>Text to speech</td>
</tr>
</tbody>
</table>

- Power Savings: 20-50% when compared to SRAM or “other MRAM”
- Custom Designs: One Time Programmable Memory
- Up to 10 ns Read Speed (~30 TOPS/W)
- Non-Power Leakage
Emerging Memory Report

- Why Emerging Memories are Necessary
- **Understanding Bit Selectors**
- The Technologies
- Process Equipment Requirements
- Emerging Memory Companies
- Forecasting Emerging Memories
“The select device is a big issue: How to combine it with the memory element? You can make a ReRAM out of an eggshell, but you can’t scale that!”

Scott deBoer, Micron Fellow, 7/28/15
Bit Selectors & Sneak Paths

- Wordlines
- Bitlines

- Red circle = High Resistance
- Green circle = Low Resistance

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Bit Selectors & Sneak Paths

Wordlines

Select

Valid

Bitlines
Bit Selectors & Sneak Paths

Wordlines

Select

Valid

Bitlines
Bit Selectors & Sneak Paths
Bit Selectors & Sneak Paths

Wordlines

Select

Valid

Sneak

Bitlines

Sneak
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Emerging Memory Technologies

- MRAM
- ReRAM
- PCM/Xpoint
- FRAM
- Other technologies
Magnetic RAM (MRAM)

Bit is set/reset through magnetization
Resistive RAM (ReRAM)

Two main types:
- Conductive Bridge
- Oxygen Vacancy
Phase Change Memory (PCM)

- Bit set via heat/cool cycle
  - Crystalline conducts
  - Amorphous insulates

Source: Objective Analysis
Ferroelectric RAM (FRAM)

- Central atom is up or down

Source: Objective Analysis
Other Technologies

- Carbon Nanotubes
- Graphene Memories
- Conductive Electron RAM (CeRAM)
- Polymeric ferroelectrics
- Ferroelectric tunnel junctions (FTJ)
- Ferroelectric FETs (FeFETs)
- Interfacial PCM/TRAM
- Magnetoelectric RAM (MeRAM)
- Racetrack Memory
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Process Equipment Requirements

- All new memories are built between metal layers
  - Tool sets are similar for MRAM, PCM, ReRAM, etc.

Source: Coughlin Associates, 2018
Emerging Memory Report

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Emerging Memory Companies

- New Technology Developers
- Chip Makers
- Equipment Makers

<table>
<thead>
<tr>
<th>Emerging Memory Companies</th>
<th>New Technology Developers</th>
<th>Chip Makers</th>
<th>Equipment Makers</th>
</tr>
</thead>
<tbody>
<tr>
<td>4DS Memory</td>
<td>Cypress Semiconductor</td>
<td>imec</td>
<td>MicroSense</td>
</tr>
<tr>
<td>Adesto Technologies</td>
<td>EverSpin</td>
<td>Integral Solutions (ISI)</td>
<td>Nantero</td>
</tr>
<tr>
<td>Ferroelectric Memory Co.</td>
<td>Intel</td>
<td>NEC</td>
<td>Seagate Technology</td>
</tr>
<tr>
<td>Fujitsu Semiconductor</td>
<td>Jusung Engineering</td>
<td>Neoark</td>
<td>SK hynix</td>
</tr>
<tr>
<td>Global Foundries</td>
<td>Keysight Technologies</td>
<td>NVE</td>
<td>SMIC</td>
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<tr>
<td>BAE Systems</td>
<td>KLA Tencor</td>
<td>Ovonyx</td>
<td>Sony Corporation</td>
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<tr>
<td>BeSang</td>
<td>Hitachi High Technology</td>
<td>Knowm</td>
<td>Spin Memory</td>
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<td>Knowm</td>
<td>Knowm</td>
<td>Spin Memory</td>
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<tr>
<td>Honeywell</td>
<td>Lam Research</td>
<td>Qualcomm</td>
<td>Symetrix</td>
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<td>Magnetic Solutions</td>
<td>Rambus</td>
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<td>TDK</td>
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<td>Hprobes</td>
<td>MagOasis</td>
<td>Ramtron</td>
<td>TDK</td>
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<tr>
<td>Crossbar</td>
<td>IBM</td>
<td>Micron Technology</td>
<td>Renesas Electronics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Texas Instruments (TI)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Western Digital/SanDisk</td>
</tr>
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Timeline for Change

Logic

NAND

DRAM

Source: Objective Analysis, 2018
Emerging Memory PB Shipments

Emerging NVM market could exceed $6B by 2028!

2018 Coughlin Associates
The Report

Emerging Memories Poised to Explode

- In-depth coverage of everything in this presentation
- 160 pages, 111 figures, 31 tables
- Can be purchased on-line for immediate download

Two ways to order:

- https://Objective-Analysis.com/reports/#Emerging
Questions?
Technical and Market Analysis
Consulting
Reports and Newsletter
- Emerging Memories Poised to Explode: Emerging Memory Report
- Digital Storage in Media and Entertainment
- Digital Storage Technology Newsletter
OBJECTIVE ANALYSIS

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## Objective Analysis

### Semiconductor Forecast Accuracy

<table>
<thead>
<tr>
<th>Year</th>
<th>Forecast</th>
<th>Actual</th>
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</thead>
<tbody>
<tr>
<td>2008</td>
<td>Zero growth at best.</td>
<td>-3%</td>
</tr>
<tr>
<td>2009</td>
<td>Growth in the mid teens</td>
<td>-9%</td>
</tr>
<tr>
<td>2010</td>
<td>Should approach 30%</td>
<td>32%</td>
</tr>
<tr>
<td>2011</td>
<td>Muted revenue growth: 5%</td>
<td>0%</td>
</tr>
<tr>
<td>2012</td>
<td>Revenues drop as much as -5%</td>
<td>-2.7%</td>
</tr>
<tr>
<td>2013</td>
<td>Revenues increase nearly 10%</td>
<td>4.9%</td>
</tr>
<tr>
<td>2014</td>
<td>Revenues up 20%+</td>
<td>9.9%</td>
</tr>
<tr>
<td>2015</td>
<td>Revenues up ~10%</td>
<td>-0.2%</td>
</tr>
<tr>
<td>2016</td>
<td>Revenues up ~10%</td>
<td>1.1%</td>
</tr>
<tr>
<td>2017</td>
<td>Revenues up ~20%</td>
<td>22%</td>
</tr>
<tr>
<td>2018</td>
<td>Strong start supports 10+% growth</td>
<td>TBD</td>
</tr>
</tbody>
</table>