AR-VR : Computing Gets Interactive

Harsha Nagaraju
Sr. Segment Manager
Micron Technology
Agenda

- Micron – Company update
- AR-VR
  - What is it? Where is fits?
  - How is the market looking
  - Evolution and Landscape
- General Architecture
  - Memory Recommendations
- Road to advanced AR VR Devices
Micron by the Numbers

37 Years strong in

20 Countries with 13 Manufacturing and R&D sites,

30,000+ Team Members and

Net Sales in 2015 of

$16,100,000,000
Global Manufacturing Scale

1. Boise, Idaho USA
2. Lehi, Utah USA
3. Manassas, VA USA
4. A grate, Italy
5. Muar, Malaysia
6. Singapore
7. Taiwan (Inotera)
8. Taiwan
9. Xian, China
10. Hiroshima, Japan
11. Akita, Japan
And an expansive product offering

**DRAM Families**
- SDRAM
- DDR
- DDR2
- DDR3
- DDR4
- RLDRAM®
- Mobile LPDRAM

**DRAM Modules**
- FBDIMM
- RDIMM
- VLP RDIMM
- VLP UDIMM
- UDIMM
- SODIMM
- SORDIMM
- Mini-DIMM
- VLP Mini-DIMM
- LRDIMM
- NVDIMM

**Bare Die**
- Multiple Technologies

**NAND Flash**
- TLC, MLC, SLC
- Serial NAND
- Enterprise NAND
- NAND MCP
- 3D NAND

**Solid State Drives**
- Client SSD
- Enterprise SATA
- Enterprise SAS
- Enterprise PCIe

**Managed NAND**
- MCP
eMMC™
- Embedded USB

**NOR Flash**
- Parallel NOR
- Serial NOR
- NOR MCP
Serving a broad set of customer applications

You may not know it, but MICRON MEMORY is in the things you use every day.
Memory Industry: FY 2008 vs Today

**FY2008 Memory Revenue (% of Group Total)**¹

<table>
<thead>
<tr>
<th>Company</th>
<th>FY2008 Revenue</th>
<th>Group Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung</td>
<td>31%</td>
<td>100%</td>
</tr>
<tr>
<td>Hynix</td>
<td>17%</td>
<td>100%</td>
</tr>
<tr>
<td>Micron²</td>
<td>12%</td>
<td>100%</td>
</tr>
<tr>
<td>SanDisk</td>
<td>8%</td>
<td>100%</td>
</tr>
<tr>
<td>Elpida</td>
<td>8%</td>
<td>100%</td>
</tr>
<tr>
<td>Toshiba³</td>
<td>7%</td>
<td>100%</td>
</tr>
<tr>
<td>Qimonda</td>
<td>6%</td>
<td>100%</td>
</tr>
<tr>
<td>Spansion</td>
<td>6%</td>
<td>100%</td>
</tr>
<tr>
<td>Nanya</td>
<td>3%</td>
<td>100%</td>
</tr>
<tr>
<td>Macronix</td>
<td>2%</td>
<td>100%</td>
</tr>
<tr>
<td>Winbond</td>
<td>2%</td>
<td>100%</td>
</tr>
</tbody>
</table>

**LTM Memory Revenue (% of Group Total)**¹

<table>
<thead>
<tr>
<th>Company</th>
<th>LTM Revenue</th>
<th>Group Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung</td>
<td>38%</td>
<td>100%</td>
</tr>
<tr>
<td>SK Hynix</td>
<td>22%</td>
<td>100%</td>
</tr>
<tr>
<td>Micron²</td>
<td>20%</td>
<td>100%</td>
</tr>
<tr>
<td>Toshiba³</td>
<td>10%</td>
<td>100%</td>
</tr>
<tr>
<td>SanDisk</td>
<td>7%</td>
<td>100%</td>
</tr>
<tr>
<td>Nanya</td>
<td>2%</td>
<td>100%</td>
</tr>
<tr>
<td>Winbond</td>
<td>1%</td>
<td>100%</td>
</tr>
<tr>
<td>Macronix</td>
<td>1%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Micron

1. Group total defined as only those companies listed on this page, although others may also exist.
2. Micron includes NAND sold to Intel from IM Flash.
3. Samsung and Toshiba include total memory revenue as reported.

**Top Five Market Share: 75%**

**Top Five Market Share: 96%**

Source: Micron

1. Micron data is from FY 2008; Competitor data is from CQ4-07 – CQ3-08.
2. Micron includes NAND sold to Intel from IM Flash.
3. Samsung and Toshiba include total memory revenue as reported.
AR VR – What is it?
THE NEXT WAVE OF TECH

AR Applications:  
Commercial & Industrial
Medical
Education & Training
eCommerce, Advertising
Gaming & Entertainment

VR Applications:  
Gaming & Entertainment
Concerts & Theme parks

AR and VR headsets both provide stereo 3D high definition video and audio, but....

• AR is open and partly immersive – you can see through and around it.
  • AR puts virtual things into users’ real worlds, augmenting them

• VR is closed and fully immersive
  • VR puts users inside virtual worlds, immersing them

• Images are created using applications that mix virtual content and real life contents together

• Creation of an actual world, not just some contents of it

• Primary addressable markets: eCommerce, Voice calls, Web Browsing, Education/Training, Medical, Advertising

• Primary addressable markets: 3D films, Games, Theme parks, Live Sports and Concerts

*Other names and brands may be claimed as the property of others
AR VR – Where does it fit
Wearable Vision

- Multiple wearables per person
- Connected with each other
AR VR – What’s the fuss?
Past the Hype Cycle peak?

[Diagram showing the Hype Cycle with various technologies and innovation phases, including peak, trough, slope of enlightenment, and plateau of productivity.]

Source: Gartner (July 2016)
- Hardware: 18-20$B opportunity in 2020
- AR to outsell VR devices in the long term
Investments in AR VR

- $5B capital invested since 2010 with more than 60% in the 2014-2016
- $1.1B already invested in Q1 2016
- Diverse range of investor types – VCs have led the way, strategic capital and private equity have followed

VR/AR DEAL FLOW AND CAPITAL INVESTED

<table>
<thead>
<tr>
<th>Year</th>
<th>Capital Invested (SM)</th>
<th>Deal Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>$13</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>$23</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>$39</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>$54</td>
<td></td>
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<tr>
<td>2014</td>
<td>$223</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>$1,104</td>
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</tbody>
</table>

MOST ACTIVE VR INVESTORS

<table>
<thead>
<tr>
<th>Rank</th>
<th>Investor</th>
<th>Number of investments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rothenberg Ventures</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>River*</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>Intel Capital</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Google Ventures</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Partech Ventures</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Qualcomm Ventures</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>Dolby Family Ventures</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Formation 8</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>JAFCO</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>Andreessen Horowitz</td>
<td>3</td>
</tr>
</tbody>
</table>

MOST CAPITALIZED VR COMPANIES

<table>
<thead>
<tr>
<th>Rank</th>
<th>Company</th>
<th>Total amount raised</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oculus VR</td>
<td>$2.1B*</td>
</tr>
<tr>
<td>2</td>
<td>Magic Leap</td>
<td>$593.7M</td>
</tr>
<tr>
<td>3</td>
<td>LENSAR**</td>
<td>$191.1M</td>
</tr>
<tr>
<td>4</td>
<td>Jaunt</td>
<td>$101.3M</td>
</tr>
<tr>
<td>5</td>
<td>Blippar</td>
<td>$70.1M</td>
</tr>
<tr>
<td>6</td>
<td>Vuforia</td>
<td>$65M</td>
</tr>
<tr>
<td>7</td>
<td>Matterport</td>
<td>$57.7M</td>
</tr>
<tr>
<td>8</td>
<td>Avegant</td>
<td>$37M</td>
</tr>
<tr>
<td>9</td>
<td>NextVR</td>
<td>$36M</td>
</tr>
<tr>
<td>10</td>
<td>Playful</td>
<td>$33M</td>
</tr>
</tbody>
</table>

Source: Pitchbook 2015

*Note: Metaio acquired by Apple for $32M in May 2015
*Includes FB acquisition
**Agreed to $59M acquisition on 11/16/2015
AR VR – Evolution and Landscape
**Tethered/Untethered...Immersive/Non-Immersive**

- Places the user in a virtual world, immersing them
- Limited mobility
- 3D Films, Gaming, Theme parks, Live sports, Concerts and Training

- Puts virtual things into users’ real worlds, augmenting them
  - Use can see through and around glass
- Mobile experiences possible
- eCommerce, Voice Calls, Web Browsing, Medical, Advertising, Automobile
### Competitive Landscape

<table>
<thead>
<tr>
<th>Immersive</th>
<th>Mixed Reality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Virtual</strong></td>
<td><strong>Augmented Reality</strong></td>
</tr>
<tr>
<td>HTC VIVE</td>
<td>magic Leap</td>
</tr>
<tr>
<td>oculus</td>
<td>Microsoft HoloLens</td>
</tr>
<tr>
<td>SONY</td>
<td>ODG</td>
</tr>
<tr>
<td><strong>Virtual Reality</strong></td>
<td><strong>Augmented Reality</strong></td>
</tr>
<tr>
<td>Samsung Gear VR</td>
<td>META</td>
</tr>
<tr>
<td></td>
<td>EPSON</td>
</tr>
<tr>
<td></td>
<td>DAQRI</td>
</tr>
<tr>
<td></td>
<td>IMAX</td>
</tr>
<tr>
<td></td>
<td>SULON</td>
</tr>
<tr>
<td></td>
<td>SKULLY</td>
</tr>
<tr>
<td></td>
<td>Vuzix</td>
</tr>
<tr>
<td></td>
<td>Recon</td>
</tr>
</tbody>
</table>

**Virtual**: real world is blocked out (i.e. user can only see the virtual world and virtual objects)

**Augmented**: real world is not blocked out (i.e. user can see the real world and virtual objects)

**Immersive**: trick the user’s brain into reacting as though it was a real experience

**Ambient**: one or more of the characteristics (position tracking, FOV etc.) doesn’t provide the same level of experience as Immersive

*Other names and brands may be claimed as the property of others*
AR VR – Architecture & Recommendations
VR experiences are complex with many moving pieces involved.

They must all come together near perfectly for a realistic experience.
Keys Specifications

- **Key to good VR Experience**
  - Refresh rates (min: 60fps)
  - Field of View (min: 100 deg)
  - Display quality (OLED or LCDs)

- **Memory utilization**
  - Not all designs will have significant memory in them
  - Due to its mobile nature, requirement for continuous image processing, AR and untethered VR devices likely to be memory rich
Teardown of HTC Vive* (Tethered VR)

- Tethered devices likely to outsource computing to standalone computing devices like PC/Gaming Consoles
- Flash Memory (Serial NOR) in densities ranging from 4Mb - 256Mb most popular
- Likely to migrate to Serial NAND as sophisticated features push for higher densities

*Other names and brands may be claimed as the property of others
Microsoft Hololens* (Untethered)

- Untethered devices likely pack powerful processors and high density memory for local compute capabilities
- Cutting Edge Mobile Memory – 16-64Gb LPDDR4/LPDDR5 most popular
- Higher Storage Density requirements – 32-128GB eMMC. UFS likely as well
<table>
<thead>
<tr>
<th>Application</th>
<th>Package</th>
<th>Memory</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tethered VR</strong></td>
<td>Discrete</td>
<td>-</td>
<td>SPI NOR (4Mb – 256Mb)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LPDRAM</td>
<td>SPI NAND (1Gb – 8Gb)</td>
</tr>
<tr>
<td></td>
<td>MCP (MCP)</td>
<td>LPDRAM + Flash</td>
<td></td>
</tr>
<tr>
<td><strong>Untethered AR VR</strong></td>
<td>Discrete</td>
<td>LPDDR 4 (8Gb – 32Gb)</td>
<td>eMMC (NAND + uC) (8GB – 128GB)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LPDDR 5*</td>
<td>UFS (NAND + uC) (64GB-256GB)</td>
</tr>
<tr>
<td></td>
<td>MCP (MCP)</td>
<td>eMCP (e.MMC + LPDDR)</td>
<td>SD Cards*** (32GB – 512GB)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>uMCP (UFS + LPDDR)</td>
<td>BGA SSDs*** (128GB – 512GB)</td>
</tr>
</tbody>
</table>

* Likely follow mobile adoption
** All densities are package only. Different pkgs. Possible.
*** Potential data storage for future designs
**Package Options**

**NAND MCP**
- SLC NAND
- LPDRAM
- Substrate
- Ultra low cost smart Phones
  - AIMM, DSC, CH

**e.MMC**
- MLC NAND
- LPDRAM
- Controller
- Application Processor
- Driver
- Substrate
- Premium smart phones & Tablets, Auto, Wearables, AR/VR

**eMCP**
- e.MMC
- LPDRAM
- Application Processor
- Driver
- Substrate
- Mid-to-Low cost smart phones, Wearables, IoT, M2M, IMM, Telemetrics, AR/VR

**ePOP**
- Application Processor
- Driver
- Substrate
- High end smart watches, High-to-Mid cost wearables, Industrial, IoT

**Likely Packages for AR/VR Devices**
AR VR – Road to Advanced Devices
AR/VR (Current Gen)

2016

Machine Vision/Depth Sensing
Virtual Reality Content

2018

Light Field Tech
Accurate Eye tracking

Efficient semiconductors

2020

Battery Tech improvements
Headphone Technology

High performing GPU

Advanced AR/VR Devices

WINDOW OF INNOVATION
Leading with new innovations: HMC

Breaking through “memory wall”
- Evolutionary DRAM roadmaps hit limitations of bandwidth and power efficiency
- Micron introduces a new class of memory: Hybrid Memory Cube
- Unique combination of DRAMs on Logic smashes through the memory wall

Unparalleled performance
- Provides 15X the bandwidth of a DDR3 module
- Uses 70% less energy per bit than existing memory technologies
- Reduces the memory footprint by nearly 90% compared to today’s RDIMMs

Key applications
- Data packet processing, data packet buffering, and storage applications
- Enterprise and computing applications

How did we do it?
- Micron-designed logic controller
- High speed link to CPU
- Massively parallel “Through Silicon Via” connection to DRAM
Leading with new innovations: 3D NAND

HOW 3D NAND ENABLES INNOVATION

Our 3D NAND solutions bring significant performance, power, and capacity advantages to storage applications.

Pack in More Capacity
Get 3 times the capacity of existing NAND products—enough to enable 3.5TB gum stick-sized SSDs or more than 10TB in standard 2.5-inch SSDs.

Boost Performance
Achieve significantly higher read/write bandwidth and I/O speeds, as well as improved random read performance, thanks to our 3D NAND’s fast 4K read mode.

Save Power
Reduce power consumption significantly in standby mode thanks to 3D NAND’s new sleep mode features that cut power to inactive NAND die (even when other die in the same package are active).

How did we do it?
We’re the first to employ floating gate cell technology in 3D NAND—a proven cell technology that enables better performance, quality, and reliability. We stack 32 storage tiers to achieve the highest-capacity NAND die available today: 256Gb multilevel cell (MLC) and 384Gb triple-level cell (TLC) 3D NAND.
Leading with new innovations: 3D XPoint™ Memory

FIRST NEW MEMORY CATEGORY IN DECADES

- Combining the very best capabilities of existing technologies, 3D XPoint has the potential to dramatically transform computing architectures

1000X FASTER THAN NAND

1000X ENDURANCE OF NAND

10X DENSER THAN CONVENTIONAL MEMORY
eMMC, UFS, and PCIe Comparison (32-256GB)

**Sequential Read MB/s**

- eMMC5.x BGA: 500
- UFS2.1 x2 BGA: 800
- SATA: 600
- PCIe 3 x4 M.2: 1,000

**Sequential Write MB/s**

- eMMC5.x BGA: 2400
- UFS2.1 x2 BGA: 2200
- SATA: 1200
- PCIe 3 x4 M.2: 1000
What can hardware look like?

**OVERVIEW**

R-7 is a totally new device incorporating ODG's next generation optics, electronics and industrial design.

Targeted to Enterprise customers, the R-7 delivers a powerful and robust solution in a new lighter and tighter profile.

**DETAILS**

**HARDWARE:**
- Qualcomm Snapdragon™ 805 2.7GHz quad-core Processor
- 3GB Pop LP-DDR3 RAM
- 64GB Storage
- 1300mAh Lithium-Ion Battery Capacity
- 3 Replaceable Magnetic Nose Bridges