Flash Market Update, 2018

Jim Handy
<table>
<thead>
<tr>
<th>Year</th>
<th>Forecast</th>
<th>Actual</th>
</tr>
</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>
Agenda

• NAND Flash Outlook
• Emerging Memories
• 3D XPoint
• China’s Memory Plans
• Summary
NAND Flash
Vicious Cycle of a Price Collapse

- Manufacturers Over Invest
- Prices Collapse
- Manufacturers Under Invest
- Prices Stabilize
- Shortage

OBJECTIVE ANALYSIS – www.OBJECTIVE-ANALYSIS.com
NAND Flash Prices Falling

<table>
<thead>
<tr>
<th>Price per GB</th>
<th>Samsung</th>
<th>SK hynix</th>
<th>Micron</th>
<th>Spot</th>
</tr>
</thead>
<tbody>
<tr>
<td>3Q17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4Q17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1Q18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2Q18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Memory Price Cycles

Price per GB

$100,000.00
$10,000.00
$1,000.00
$100.00
$10.00
$1.00

1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015

Price
Cost
Collapse to Cost

What IS Cost?
NAND Flash Maker Profits

Net Profit

1Q16  2Q16  3Q16  4Q16  1Q17  2Q17  3Q17  4Q17  1Q18

Intel  Samsung  Micron  SK hynix  Toshiba

OJECTIVE ANALYSIS – www.OJECTIVE-ANALYSIS.com
Planar vs. 3D NAND Mfg. Cost

<table>
<thead>
<tr>
<th></th>
<th>16nm Planar</th>
<th>3D-32</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terabytes/Wafer</td>
<td>5.6</td>
<td>17.2</td>
</tr>
<tr>
<td>Wafer Cost</td>
<td>$1,200</td>
<td>$2,000</td>
</tr>
<tr>
<td>Cost/GB</td>
<td>$0.21</td>
<td>$0.12</td>
</tr>
</tbody>
</table>
The Longer Shortage, The Bigger The Collapse!

- Flat Pricing
- Collapse
- Price per Gigabyte
- Time

OBJECTIVE ANALYSIS – www.OBJECTIVE-ANALYSIS.com
3D NAND Roadmap

Objective Analysis – www.Objective-Analysis.com
### Key DRAM & NAND Makers

<table>
<thead>
<tr>
<th>Company</th>
<th>DRAM</th>
<th>NAND</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung</td>
<td>46%</td>
<td>33%</td>
<td>Focus: large customers &amp; internal SSDs</td>
</tr>
<tr>
<td>SK hynix</td>
<td>26%</td>
<td>11%</td>
<td>Finally shipping 3D NAND in volume</td>
</tr>
<tr>
<td>Toshiba</td>
<td>--</td>
<td>19%</td>
<td>Spun off and ready to grow</td>
</tr>
<tr>
<td>WDC/SanDisk</td>
<td>--</td>
<td>18%</td>
<td>Rarely supplies chips</td>
</tr>
<tr>
<td>Micron</td>
<td>21%</td>
<td>12%</td>
<td>Breaking ties with Intel</td>
</tr>
<tr>
<td>Intel</td>
<td>--</td>
<td>7%</td>
<td>Only producing for Intel SSDs</td>
</tr>
</tbody>
</table>
How Collapse Will Evolve

• NAND oversupply
  – Prices plunge to 3D-64 cost: <$0.08/GB
  – Planar capacity no longer viable
    • Closed or converted to DRAM
• Subsequent DRAM oversupply
  – Some facilities no longer viable
    • Closed or converted to SRAM/NOR/Foundry
• Subsequent other oversupplies
2018 Revenue Growth Slows

• Great first half but mid-year collapse
  – Memory cycle is still alive!
• Strong start supports revenue growth
  – DRAM +12%, down from ~80%
  – NAND +9%, down from ~50%
• Downturn commences in 2H18
  – 2019 will be a down year
Emerging Memories
# Today’s Memories Are Limited

<table>
<thead>
<tr>
<th></th>
<th>SRAM</th>
<th>DRAM</th>
<th>ROM</th>
<th>EEPROM</th>
<th>NOR</th>
<th>NAND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonvolatile</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Erasable</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Programmable</td>
<td>Yes</td>
<td>Yes</td>
<td>Factory</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Smallest Write</td>
<td>Byte</td>
<td>Byte</td>
<td>N/A</td>
<td>Byte</td>
<td>Byte</td>
<td>Page</td>
</tr>
<tr>
<td>Smallest Read</td>
<td>Byte</td>
<td>Page</td>
<td>Byte</td>
<td>Byte</td>
<td>Byte</td>
<td>Page</td>
</tr>
<tr>
<td>Read Speed</td>
<td>V Fast</td>
<td>Fast</td>
<td>Fast</td>
<td>Fast</td>
<td>Fast</td>
<td>Slow</td>
</tr>
<tr>
<td>Write Speed</td>
<td>V Fast</td>
<td>Fast</td>
<td>N/A</td>
<td>Slow</td>
<td>Slow</td>
<td>Slow</td>
</tr>
<tr>
<td>Sleep Power</td>
<td>V Low</td>
<td>High</td>
<td>Zero</td>
<td>Zero</td>
<td>Zero</td>
<td>Zero</td>
</tr>
<tr>
<td>Price/GB</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Med</td>
<td>V Low</td>
</tr>
<tr>
<td>Applications</td>
<td>Small Fast</td>
<td>Main Memory</td>
<td>Stable Code Volume</td>
<td>Serial #, Trim</td>
<td>Code</td>
<td>Data</td>
</tr>
</tbody>
</table>

**OBJECTIVE ANALYSIS – www.OBJECTIVE-ANALYSIS.com**
## Emerging Memories Perform Better

<table>
<thead>
<tr>
<th></th>
<th>MRAM</th>
<th>ReRAM</th>
<th>FRAM</th>
<th>PCM</th>
<th>XPoint</th>
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</thead>
<tbody>
<tr>
<td>Nonvolatile</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Erasable</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Programmable</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Smallest Write</td>
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<td>Byte</td>
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<td>Read Speed</td>
<td>Fast</td>
<td>Fast</td>
<td>Fast</td>
<td>Fast</td>
<td>Fast</td>
</tr>
<tr>
<td>Write Speed</td>
<td>Fast</td>
<td>Fast</td>
<td>Fast</td>
<td>Fast</td>
<td>Fast</td>
</tr>
<tr>
<td>Active Power</td>
<td>Low</td>
<td>Med</td>
<td>Low</td>
<td>High</td>
<td>High?</td>
</tr>
<tr>
<td>Sleep Power</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
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<tr>
<td>Price/GB</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High?</td>
</tr>
<tr>
<td>Applications</td>
<td>Niche</td>
<td>TBD</td>
<td>Low Power</td>
<td>Obsolete</td>
<td>Main Memory</td>
</tr>
</tbody>
</table>

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PM Market Drivers

• Early adopters need unique features
  – Less sensitive to cost
• Foundry will drive process refinement
  – Ports to stand-alone memories later
• Volume depends on economies of scale
  – Economies of scale depend on volume
• Persistence requires software support
  – SNIA & others are making this happen
Emerging Memory Revenues

Source: Coughlin Associates & Objective Analysis, 2018
Emerging Memory Report

• Covers all major emerging memory technologies and companies
• Describes major driving applications
• Persistent memory forecasts (both embedded and stand-alone)
• Projections for capital investments
• Now Available!
• https://tomcoughlin.com/tech-papers/
3D XPoint
3D XPoint Helps Reduce DRAM Needs

Source: *A Close Look at the Intel/Micron 3D XPoint Memory*, Objective Analysis 2015

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3D XPoint Status

• Continued delays
  – DIMMs now slated for 2019 production

• Issue is scale
  – Cost must be below DRAM
    • Volume must reach 10% of DRAM
    • Production currently stopped
  – Intel selling below cost to develop market
China
$100 Billion+ of Chip Imports/Year!

Source: Objective Analysis, 2018

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China’s Memory Aspirations

• 91% of China’s chips sourced externally
  – China consumes 32% of world’s ICs
• The country is wealthy today
  – Plenty of cash to fix this problem
• There is prestige in semiconductors
• Memory is a commodity
  – Easy market to penetrate if you have cash
China Spending is Just Starting
YMTC’s Plans

- Open 2H18
- 100K starts
- 32-Layer 3D
- YMTC’s own technology
Xtacking CMOS Memory Array
Impact of China Spend

• China will acquire a share of the market
• Timing unlikely to cause a collapse
  – This should already have occurred
• Will lengthen ongoing oversupply
  – Watch for a market exit
• Will probably use a technology partner
  – Partner will receive a production boost
China Report

- Details of China’s approach & methods
- Compares China’s effort to other countries’ DRAM market entry (Japan, Korea, …)
- Compared to China’s penetration of other markets: PV, LCD panels, LEDs, Steel …
- Explains likely outcome
  - Impact on others: Competitors, OEMs, investors

- Coming this month (August 2018)
Summary

- NAND flash collapse just starting
  - Other markets will follow
- Emerging memories show great promise
- 3D XPoint is still a challenge
- China will be important soon
Thank You!

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