Flash Market
Current & Future

Jim Handy

OBJECTIVE
ANALYSIS
<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>TBD</td>
</tr>
</tbody>
</table>
Outline

• Today’s Shortages
  – 3D NAND
• How Long Will 3D NAND Last?
• What About China?
• Mergers Etc.
• 3D XPoint
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NAND Prices Are Up Today

Average $/GB

Spot
Contract


$0.00 $0.05 $0.10 $0.15 $0.20 $0.25 $0.30 $0.35

OBJECTIVE ANALYSIS – www.OBJECTIVE-ANALYSIS.com
Driving a NAND Revenue Jump

Annual Revenues ($Billions)

- 2006
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017

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What Drives the NAND Market?

• Gigabyte consumption
  – Usually grows pretty steadily
• Price/GB
  – A function of Moore’s Law and Supply/Demand balance
• Revenues = GB x $/GB
Market Cycles & Shortages
DRAM Examples

- 1993-1995: x4 to x16 Transition
- 2005: 90nm Difficulties

Price per GB


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The Next Downturn: Why? How? When?

- Stable prices to mid-2018
  - Stable prices drive profits
  - Largest-ever price-cost gap
- 2018 price collapse
  - 3D suddenly becomes cost-competitive
  - Instant overcapacity
    - Caused by 3D fabs becoming efficient
    - China investments will create trouble much later
The Longer Shortage, The Bigger The Collapse!

- Flat Pricing
- Collapse
- Cost

Price per Gigabyte vs. Time
When Will Shortage End? That’s Hard to Predict

• When will 3D NAND be mastered?
  – All vendors are now shipping
    • This does not imply that 3D costs less than planar

• 2017 is the year of the big ramp
  – Manufacturers hope that volume will improve costs

• Our guess: Mid-2018 cost parity for all
  – Capacity will be used efficiently
  – This drives an oversupply
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## Planar vs. 3D NAND Mfg. Cost

<table>
<thead>
<tr>
<th></th>
<th>Planar</th>
<th>3D</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>
What’s So Hard About 3D NAND?

- High aspect ratio trenches
- No doping on source or drain
- Perfectly parallel walls
- Tens of stairsteps
- Uniform layer across wafer
- Single-litho stairstep
- Hard mask etching
- Processing inside of hole
- Etch through varying materials
- Charge trap storage
- Polysilicon channels
- Deposition on hole sides

Source: Applied Materials

O B J E C T I V E  A N A L Y S I S  –  w w w . O B J E C T I V E - A N A L Y S I S . c o m
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String Stacking
Micron’s 64-Layer 3D NAND

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String Stacking Has Changed
The 3D NAND Roadmap

Old Roadmaps:

<table>
<thead>
<tr>
<th>Year</th>
<th>Layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>24 Layers</td>
</tr>
<tr>
<td>2014</td>
<td>32 Layers</td>
</tr>
<tr>
<td>2015</td>
<td>48 Layers</td>
</tr>
<tr>
<td>2016</td>
<td>64 Layers</td>
</tr>
<tr>
<td>2017</td>
<td>96 Layers</td>
</tr>
<tr>
<td>2018</td>
<td>ReRAM</td>
</tr>
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</table>

Current Roadmaps:

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<tr>
<td>2017</td>
<td>96 Layers</td>
</tr>
<tr>
<td>2018</td>
<td>128 Layers</td>
</tr>
<tr>
<td>2019</td>
<td>192 Layers</td>
</tr>
<tr>
<td>2020</td>
<td>256 Layers</td>
</tr>
<tr>
<td>2021</td>
<td>384 Layers</td>
</tr>
<tr>
<td>2022</td>
<td>512 Layers</td>
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China Spending is Just Starting
Impact of China Spend

- Production boost for its technology partner
- China will acquire a share of the market
- Timing not likely to create a collapse
  - This should already have occurred
- Will lengthen ongoing oversupply
  - Watch for a market exit
Speaking of Market Exits...

“What the heck is going on at Toshiba?”
Toshiba: How Did This Happen?

• Nuclear cost overruns
  – Westinghouse bankrupt
• Toshiba can’t escape liabilities
• Semiconductor division’s value matches liabilities
Everybody Wants Their Way!

- Toshiba
- Western Digital (SanDisk)
- Japan’s government
- SK hynix
- Foxconn/Hon Hai
- US government
- Private investors
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3D XPoint Is Moving Ahead

• NVMe “Optane” SSDs are shipping
  – Aimed at PC applications
  – Sever DIMMs are the natural application

• Good fit for the memory/storage hierarchy:
  – Faster than NAND, slower than DRAM
  – Costlier than NAND, cheaper than DRAM

• Opens door to in-memory storage – “SCM”

• Applications are being developed for it
This Will Require a Huge Effort!

- DDR can support variable access times
  - Fancy arrangement of flags and software
- O/S, BIOS, & CPU support in development
  - Cache & memory management
  - Special CPU instructions for persistence
- Persistence will require application support
  - SNIA developed a PM Programming Standard
    - https://www.SNIA.org/PM
  - Linux “pmem” initiative: www.pmem.io
A Chicken & Egg Problem

- 3D XPoint will sell in volume once it’s priced lower than DRAM
- 3D XPoint mfg. costs will fall below DRAM once the volume is high enough
Summary

• We’re in a shortage
  – Prices high until 3D NAND is cost-effective
• A collapse will follow
• 3D NAND may last a very long time
• China will be important after the collapse
• Consolidation will continue
• 3D XPoint is real
Thank You!

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