Memory Technology and Overall Trends in the Semiconductor Industry

Dr. Handel H. Jones
Founder and CEO, International Business Strategies, Inc.
International Business Strategies Background

- Has been in business for over 28 years
- Previous experience in managing 1.5K+ engineers at Rockwell International, which included avionics, communications, and semiconductors. Strong emphasis on communications
- Interface with most global leaders in electronics industry, with customers in U.S., Europe, South Korea, Japan, Taiwan, China, India, etc
- Interface and support for major global corporations such as Intel, Qualcomm, Broadcom, Microsoft, Nokia, Samsung, SK Hynix, Sony, Toshiba, Apple, Cisco, Huawei, IBM, Fujitsu, Canon, NEC, Hitachi, Renesas, TSMC, STMicroelectronics, TI, ARM, Cadence, Synopsys, Mentor Graphics, Seagate, Globalfoundries, SMIC, NXP, and others
- Participated with French Government on their advanced technology initiatives
- Interface and support for financial institutions such as Goldman Sachs, Carlyle, Blackstone, CitiGroup, Warburg Pincus, Walden, KKR, Morgan Stanley, Credit Suisse, BNP Paribas, Bain Capital, Bank of America, TPG, and others
- Involved with advanced technology concepts, price-sensitive platforms for smartphone and other high-volume platforms, and high-performance infrastructure companies on global basis
- Strong expertise in China. Published two books on China: China’s Globalization (How China Becomes No. 1) and Chinamerica (McGraw Hill). Forbes blog contributor, China Daily articles, Global Times editorials, EE Times, etc
- Involved in number of due diligence projects on number of IPOs
- Support for strategic initiatives for number of global technology leaders

**IBS has high market share on technology and strategy business**
Key Issues in Memory Technology

- Memories are becoming key part of system architectures
- Heterogeneous processing is driving concept of shared memory, with need for higher throughput and lower power consumption
- 3D XPoint can change memory architectures
  - ZNAND from Samsung is potential competitor
  - Vertical STT structures are being developed, but manufacturing is very difficult
- DRAM gigabyte prices have declined 50% in past 12 months, and key reason is predatory strategies of leader
- NAND gigabyte prices have declined 40% in past 12 months, with strong market share pressures
  - Samsung’s 3D NAND has cost crossover with 2D NAND in 48 layers
  - Shortages are emerging for NAND, and gigabyte prices are increasing
- eNVM structures are being enhanced, but with 28nm being most advanced technology node
- New eNVM technology is also being developed

**CAPEX for 3D NAND memory is strong in 2016, but DRAM is flat**
Semiconductor market is declining in 2016
## Memory Market by Product

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>DRAM ($M)</strong></td>
<td>45,682</td>
<td>39,803</td>
<td>42,641</td>
<td>46,060</td>
<td>49,335</td>
<td>52,419</td>
<td>55,585</td>
<td>59,315</td>
<td>63,419</td>
<td>67,954</td>
<td>72,901</td>
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<tr>
<td>Growth rate (%)</td>
<td>NA</td>
<td>(12.87)</td>
<td>7.13</td>
<td>8.02</td>
<td>7.11</td>
<td>6.25</td>
<td>6.04</td>
<td>6.71</td>
<td>6.92</td>
<td>7.15</td>
<td>7.28</td>
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<tr>
<td>Percent total (%)</td>
<td>58.42</td>
<td>54.35</td>
<td>53.75</td>
<td>54.60</td>
<td>55.66</td>
<td>55.35</td>
<td>54.28</td>
<td>53.03</td>
<td>52.23</td>
<td>51.19</td>
<td>50.20</td>
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<tr>
<td><strong>NAND Flash ($M)</strong></td>
<td>28,978</td>
<td>30,039</td>
<td>33,419</td>
<td>35,112</td>
<td>36,154</td>
<td>39,065</td>
<td>43,468</td>
<td>49,034</td>
<td>54,278</td>
<td>60,828</td>
<td>68,026</td>
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<tr>
<td>Growth rate (%)</td>
<td>NA</td>
<td>3.66</td>
<td>11.25</td>
<td>5.07</td>
<td>2.97</td>
<td>8.05</td>
<td>11.27</td>
<td>12.80</td>
<td>10.69</td>
<td>12.07</td>
<td>11.83</td>
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<tr>
<td>Percent total (%)</td>
<td>37.06</td>
<td>41.01</td>
<td>42.12</td>
<td>41.62</td>
<td>40.79</td>
<td>41.25</td>
<td>42.45</td>
<td>43.83</td>
<td>44.71</td>
<td>45.82</td>
<td>46.85</td>
</tr>
<tr>
<td><strong>Other memory ($M)</strong></td>
<td>3,538</td>
<td>3,399</td>
<td>3,276</td>
<td>3,186</td>
<td>3,143</td>
<td>3,227</td>
<td>3,350</td>
<td>3,512</td>
<td>3,714</td>
<td>3,971</td>
<td>4,288</td>
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<tr>
<td>Growth rate (%)</td>
<td>NA</td>
<td>(3.94)</td>
<td>(3.61)</td>
<td>(2.75)</td>
<td>(1.34)</td>
<td>2.68</td>
<td>3.79</td>
<td>4.84</td>
<td>5.76</td>
<td>6.92</td>
<td>7.97</td>
</tr>
<tr>
<td>Percent total (%)</td>
<td>4.52</td>
<td>4.64</td>
<td>4.13</td>
<td>3.78</td>
<td>3.55</td>
<td>3.41</td>
<td>3.27</td>
<td>3.14</td>
<td>3.06</td>
<td>2.99</td>
<td>2.95</td>
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<tr>
<td><strong>TOTAL Memory ($M)</strong></td>
<td>78,198</td>
<td>73,241</td>
<td>79,336</td>
<td>84,358</td>
<td>88,632</td>
<td>94,711</td>
<td>102,403</td>
<td>111,861</td>
<td>121,411</td>
<td>132,753</td>
<td>145,215</td>
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<tr>
<td>Growth rate (%)</td>
<td>NA</td>
<td>(6.34)</td>
<td>8.32</td>
<td>6.33</td>
<td>5.07</td>
<td>6.86</td>
<td>8.12</td>
<td>9.24</td>
<td>8.54</td>
<td>9.34</td>
<td>9.39</td>
</tr>
</tbody>
</table>

Source: International Business Strategies, Inc.

CAGR of memory is higher than total semiconductor market
# NAND Flash Cost Summary

<table>
<thead>
<tr>
<th></th>
<th>Cost per GB ($)</th>
<th>MLC</th>
<th>TLC</th>
</tr>
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<tbody>
<tr>
<td><strong>2D</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With depreciation</td>
<td>0.318</td>
<td>0.230</td>
<td></td>
</tr>
<tr>
<td>Without depreciation</td>
<td>0.197</td>
<td>0.137</td>
<td></td>
</tr>
<tr>
<td><strong>3D</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32 layers with depreciation</td>
<td>0.281</td>
<td>0.190</td>
<td></td>
</tr>
<tr>
<td>32 layers without depreciation</td>
<td>0.219</td>
<td>0.148</td>
<td></td>
</tr>
<tr>
<td>48 layers with depreciation</td>
<td>0.173</td>
<td>0.116</td>
<td></td>
</tr>
<tr>
<td>48 layers without depreciation</td>
<td>0.137</td>
<td>0.091</td>
<td></td>
</tr>
<tr>
<td>64 layers with depreciation</td>
<td>0.157</td>
<td>0.105</td>
<td></td>
</tr>
<tr>
<td>64 layers without depreciation</td>
<td>0.131</td>
<td>0.076</td>
<td></td>
</tr>
</tbody>
</table>

Source: International Business Strategies, Inc.

Cost crossover between 3D NAND and 2D NAND
Revenues of 3D NAND will be higher than 2D NAND in 2018.

Source: International Business Strategies, Inc.
Key Issues in NAND Flash

• 3D NAND is positioned to dominate NAND Flash market
  – 10X or higher endurance than 2D NAND
  – Lower latency
  – Higher system performance support

• 64 layers could be in volume production in 2017
  – After 64 layers, cost saving will decline on relative basis

• Samsung is 12 to 18 months ahead of competitors in 3D NAND
  – Samsung has 512GB SSD in BGA format with PCIe interface
  – ZNAND is SLC but fill part of performance gap between DRAM and NAND Flash

• $24B is being invested to build facility in Wuhan (China), with Tsinghua Unigroup as lead investor

• Intel is manufacturing 3D NAND in Dalian (China) along with 3D XPoint, which can change architecture of system memory

3D NAND is disruptive new technology
Key Issues in DRAM

• Samsung is in initial production of 8Gb in 18nm
  – New design structure can shrink to 15nm
  – Samsung is developing vertical STT, but device structure is complex, with access time of 10ns and 7.5μA for writing one bit

• SK Hynix is at 20nm for DRAM
  – In relatively strong market position
  – Has been follower of Samsung

• Micron Technology has wafer fabs in multiple locations
  – May need external funding to track CAPEX of Samsung
  – Expect Micron to participate in China’s memory ecosystem

• Wide bandwidth architectures as supported by HBM2 will have high growth

• STT and RRAM structures are being developed but are not close to high-volume production, which means saturation of DRAM functionality

• Changes in system architecture can reduce amount of DRAM needed and give high throughput, but power consumption is still problem

DRAM is at plateau of innovation
Samsung’s 4GB HBM2

Initial target is high-performance data centers

Source: Samsung Electronics Co. Ltd.
Key Issues in eNVM

- New eNVM device structures at 28nm are being developed by several companies that are interfacing with TSMC and other foundry vendors
- Companies are developing RRAM and MRAM, with indications that MRAM will be key technology in intermediate time frame
- Many IoT applications need eNVM along with ultra-low power technology
- Best eNVM process options for IoT applications include following:
  - TSMC’s ultra-low power technology, where 28nm will have long lifetime
  - 22nm FD SOI will be widely used in future
- Key problem with eNVM is high cost
  - Need to keep number of masks to 10% of total masks, eg, four to five masks for 28nm bulk CMOS
  - For MRAM, need embedded transistor as well as BEOL processing
- Chip-scale packaging is option but has cost and size penalties

High-cost of eNVM is significant challenge for semiconductor industry
<table>
<thead>
<tr>
<th>Expenditures ($B)</th>
<th>Location</th>
<th>Product</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td><strong>2016</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yangtze River Storage Technology</td>
<td>Wuhan</td>
<td>3D NAND</td>
<td>30nm</td>
</tr>
<tr>
<td>SMIC</td>
<td>Beijing, Shanghai</td>
<td>Logic</td>
<td>40nm, 28nm</td>
</tr>
<tr>
<td>UMC and partners</td>
<td>Xiamen</td>
<td>Logic</td>
<td>55nm, 40nm, 28nm</td>
</tr>
<tr>
<td></td>
<td>Fujian</td>
<td>DRAM</td>
<td>32nm</td>
</tr>
<tr>
<td>Samsung</td>
<td>Xi'an</td>
<td>3D NAND</td>
<td>30nm</td>
</tr>
<tr>
<td>Intel</td>
<td>Dalian</td>
<td>3D NAND</td>
<td>30nm</td>
</tr>
<tr>
<td>SK Hynix</td>
<td>Wuxi</td>
<td>DRAM</td>
<td>20nm</td>
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<td>TSMC</td>
<td>Nanjing</td>
<td>Logic</td>
<td>16nm</td>
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<td>Globalfoundries and partners</td>
<td>Chongqing</td>
<td>Logic</td>
<td>130/180nm to 40nm</td>
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<tr>
<td>Powerchip and partners</td>
<td>Hefei</td>
<td>LCD driver IC</td>
<td>90nm, 110nm, 150nm</td>
</tr>
</tbody>
</table>

*Source: International Business Strategies, Inc.*

**Strong emphasis on memory**
Foundry Market by Technology Node

Growth of foundry market is higher than semiconductor market

Source: International Business Strategies, Inc.
Conclusion

• 3D NAND growth is high, with mobile platforms as largest consumption segment
  – 2D capacity is migrating to 3D capacity
  – Shortages are emerging in NAND market, and prices will increase

• Need breakthrough in DRAM technology
  – Expect large investments in China
  – However, Chinese DRAM vendors will not have major impact on supply chain before 2020

• Specialty memory has good growth potential, but it is difficult to change from being
  niche vendor to mainstream vendor

• Intel is trying to change architecture of memory for data centers, with 3D XPoint and
  3D NAND as key building blocks
  – Competitive offering will be ZNAND with HBM2 and 1024-bit wide access in future
  – Heterogeneous processing requires adoption of shared memory architectures

• Limits of eNVM technology are slowing migration to smaller feature dimensions
  – 28nm roadmap is being developed, but with price premiums
  – Growth of foundry market segments, eg, automotive and IoT, depends on enhancing eNVM
    structures

Need to accelerate technology enhancements for memory