Semiconductor Industry Trends and What They Mean to CMP

Robert L. Rhoades, Ph.D. (Entrepix, Inc.)
Karey Holland, Ph.D. (Techcet Group, LLC)
Semiconductor Industry Trends and What They Mean to CMP

Market Drivers and Transitions

Trend #1 – Continuing “Speedsters”

Trend #2 – The New Mainstream

Trend #3 – Emerging Devices

What Does All This Mean for CMP?
Market Driver – The Consumer


- Transition: 51% of semiconductor devices produced in 2005 were for consumer products.
- Effects of a consumer driven market – “Consumers Demand More for Less” and ‘More in Less’.
- Historically enabled by innovations following Moore’s Law.

### Consumers Demanding More for Less

<table>
<thead>
<tr>
<th>Year</th>
<th>Transition</th>
<th>Effects</th>
<th>Historically enabled</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>51%</td>
<td>Consumers Demand More for Less</td>
<td>Innovations following Moore’s Law</td>
</tr>
<tr>
<td>1990</td>
<td>51%</td>
<td>Consumers Demand More for Less</td>
<td>Innovations following Moore’s Law</td>
</tr>
<tr>
<td>2000</td>
<td>51%</td>
<td>Consumers Demand More for Less</td>
<td>Innovations following Moore’s Law</td>
</tr>
<tr>
<td>2006</td>
<td>51%</td>
<td>Consumers Demand More for Less</td>
<td>Innovations following Moore’s Law</td>
</tr>
</tbody>
</table>

- Transition: 51% of semiconductor devices produced in 2005 were for consumer products.
- Effects of a consumer driven market – “Consumers Demand More for Less” and ‘More in Less’.
- Historically enabled by innovations following Moore’s Law.
A Consumer-Driven Transition

Source: 2007 Industry Strategy Symposium –
Steve Newberry, CEO, Lam Research Corporation

Consumers are paying less AND getting more, even though ASPs have flattened.

Companies that have adapted still continue posting better financial returns.

Conclusion:

- Appropriate mfg - 300mm (digital), 200/150mm (analog) & extending the useful life of fabs and process platforms.

Source: 2007 Industry Strategy Symposium – Bill McClean, President, IC Insights
• Historical progression for >20 years
  0.5 um → 0.35 → 0.25 → 0.18 → 0.15 → 90 nm → 65 nm → etc.

• Devices, equipment platforms, even entire fabs were identified by their “target node”

• Industry language referenced the expectations
  Leading edge – mainstream – trailing edge
  Early adopters – fast followers – late stage
  Etc.

Changes now well underway may provide alternative ways of looking at the industry.
Industry Groupings

Particularly from a CMP perspective

- **Group I** – The most advanced, leading edge devices
  - Wafer sizes: 300mm & possibly 450mm (future)
  - Technology nodes: 65nm, 45nm and below
  - Materials: high k, metal gates, ULK, Cu barriers, etc.

- **Group II** – Improvements to mainstream ICs
  - Wafer sizes: 200mm & 150mm
  - Technology nodes: 90nm to 350nm and above
  - Materials: oxides, tungsten, etc.

- **Group III** – Emerging technologies & new applications
  - Wafer sizes: 200mm, 150mm, 100mm and smaller
  - Technology nodes: various
  - Materials: wide range of metals, oxides, polymers, and more
  - MEMS, nanotechnology, SiC, GaN, optics, etc.
Semiconductor Industry Trends and What They Mean to CMP

Market Drivers and Transitions

Trend #1 – Continuing “Speedsters”

Trend #2 – The New Mainstream

Trend #3 – Emerging Devices

What Does All This Mean for CMP?
## Segment Characteristics

### Financial Factors and Trends Across 3 Industry Segments

<table>
<thead>
<tr>
<th>Financial Factor</th>
<th>Speedster</th>
<th></th>
<th>New Mainstream</th>
<th></th>
<th>Emerging</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level</td>
<td>Direction</td>
<td>Level</td>
<td>Direction</td>
<td>Level</td>
<td>Direction</td>
</tr>
<tr>
<td>Average Annual Capital</td>
<td>High</td>
<td>↑</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology R&amp;D</td>
<td>High</td>
<td>↑</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing Cost/chip</td>
<td>High</td>
<td>↓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>High</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Selling Price (ASP)</td>
<td>High</td>
<td>↓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Microprocessor transistors per chip have increased by over 5 orders of magnitude in 35 years.

Current generation chips have more than 1.7 billion transistors.

Photo and CMP are 2 critical processes required to stay on trend line:

- **Photo → SHRINKS**
- **CMP → STACKS**

Moore’s Law has not been derailed by industry cycles, technology hurdles, or the economy ... but it does not really apply to every semiconductor company ... only the “Speedsters”!
Speedster Summary

• Typical companies: microprocessor and memory makers, large-scale foundries
• Willing to spend capital on new fab construction (mostly 300 mm)
• Willing to adapt new materials or processes as needed to achieve performance
• Designs AND process technology both change at a rapid pace
• Design focus = performance
• Process focus = speed or acceptable yield
Semiconductor Industry Trends and What They Mean to CMP

Market Drivers and Transitions

Trend #1 – Continuing “Speedsters”

Trend #2 – The New Mainstream

Trend #3 – Emerging Devices

What Does All This Mean for CMP?
### Financial Factors and Trends Across 3 Industry Segments

<table>
<thead>
<tr>
<th>Financial Factor</th>
<th>Speedster</th>
<th>New Mainstream</th>
<th>Emerging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Annual Capital</td>
<td>High 🕐</td>
<td>Moderate 🖤</td>
<td></td>
</tr>
<tr>
<td>Technology R&amp;D</td>
<td>High 🕐</td>
<td>Moderate ✏</td>
<td></td>
</tr>
<tr>
<td>Manufacturing Cost/chip</td>
<td>High 🖤</td>
<td>Moderate 🖤</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>High -</td>
<td>High 🕐</td>
<td></td>
</tr>
<tr>
<td>Average Selling Price (ASP)</td>
<td>High 🖤</td>
<td>Low -</td>
<td></td>
</tr>
</tbody>
</table>
Manufacturing Complexity

VOLUME

Device Shrinks
Increasing Functionality and Computing Power

TECHNOLOGY

CMP Jigsaw Puzzle

COST

COST PER SQUARE INCH vs. WAFER SIZE

1995

Glass (oxide)
Tungsten

2001

Glass (oxide)
Tungsten
Copper
Shallow Trench
Polysilicon

2007

Glass (oxide)
Tungsten
Copper
Shallow Trench
Polysilicon
Low-k
Cap Ultra Low-k
Metal Gates
Gate Insulators
High-k Dielectrics
Ir & Pt Electrodes
Magnetics

Sources: Cabot Microelectronics Corp. & Entripy, Inc.

13

Industry Trends and CMP - July 2007
• Wide range of products including digital, analog, mixed signal, power, etc.
• Adapting to a world of flat or falling ASP’s
• Cost factors and yield becoming MUCH more important than technology factors
• Some devices enjoy long lifecycles (but not all)
• Designs may change rapidly, but process technology intentionally being held much more stable
• Design focus = features and simplicity
• Process focus = cost and maximizing yield
Semiconductor Industry Trends and What They Mean to CMP

Market Drivers and Transitions

Trend #1 – Continuing “Speedsters”

Trend #2 – The New Mainstream

Trend #3 – Emerging Devices

What Does All This Mean for CMP?
### Segment Characteristics

#### Financial Factors and Trends Across 3 Industry Segments

<table>
<thead>
<tr>
<th>Financial Factor</th>
<th>Speedster</th>
<th>New Mainstream</th>
<th>Emerging</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level</td>
<td>Direction</td>
<td>Level</td>
</tr>
<tr>
<td>Average Annual Capital</td>
<td>High</td>
<td>↑</td>
<td>Moderate</td>
</tr>
<tr>
<td>Technology R&amp;D</td>
<td>High</td>
<td>↑</td>
<td>Moderate</td>
</tr>
<tr>
<td>Manufacturing Cost/chip</td>
<td>High</td>
<td>↓</td>
<td>Moderate</td>
</tr>
<tr>
<td>Volume</td>
<td>High</td>
<td>-</td>
<td>High</td>
</tr>
<tr>
<td>Average Selling Price (ASP)</td>
<td>High</td>
<td>↓</td>
<td>Low</td>
</tr>
</tbody>
</table>
CMP is still evolving for CMOS applications ... And many newer applications are now also being developed beyond “traditional” CMP.

• **MEMS**
  - Oxides (doped or undoped)
  - Polysilicon (usually structural)
  - Nitrides and oxynitrides
  - Separation layer (MEMS-first or MEMS-last)
  - Metals (esp. for reflective surfaces)

• **Integrated Optics**
  - Grating structures
  - Embedded waveguides
  - Integrated optical elements

• **Advanced Substrates**
  - Strained layer epi substrates
  - Custom III-IV and II-IV epi layers
  - SOI
  - GaN, GaP, SiC, etc.
  - Various surfaces for direct wafer bonding

• **Other**
  - Phase change memory materials
  - Photoresist and other polymers
  - Magnetic materials (active or shielding)
  - Advanced packaging
  - 3D IC’s and similar device technologies
Example: MEMS

Typical Devices:
- Accelerometers
- Torque sensors
- Optical devices
- Microfluidic processors

Typical Materials
- Undoped oxides (TEOS, silane, etc.)
- Doped oxides (PSG, BPSG, etc.)
- Polysilicon
- Some metals (specialized apps)

Key Aspects of the Application
- Materials and core processes generally adapted from CMOS fabrication
- CMP is an enabling technology for many designs
- Thicknesses and step heights substantially larger than typical of CMOS
- Lengthy polish times challenge process stability & consumables lifetime

Photos downloaded from web sites, including Sandia National Lab
Emerging Segment Summary

- Many products not even based on traditional CMOS
- Often adapting silicon CMOS process techniques
- Startup or new entry mentality
- Frequently start on smaller wafer sizes and transition up as volume production increases
- Process technology is generally not mature due to some fraction of “creative” steps
- Design focus = new devices
- Process focus = achieving acceptable yield and ramp
Semiconductor Industry Trends and What They Mean to CMP

Market Drivers and Transitions

Trend #1 – Continuing “Speedsters”

Trend #2 – The New Mainstream

Trend #3 – Emerging Devices

What Does All This Mean for CMP?
The Challenge for CMP

This Is No Longer Your Father’s Oldsmobile

Source: 2007 Industry Strategy Symposium – Steve Newberry, CEO, Lam Research Corporation

Challenging Realities:
- Continued consolidation and collaboration
- Reduce cost and mitigate risk
- Accelerate time to revenue
- Maximize responsiveness & ultimately financial return

CMP LIFECYCLE

High Volume Manufacturing
Consumables Benchmarking
Further Cost Reductions
Process Enhancements
Next Generation Technology
Design Considerations
Integration
Optimization
Qualification
Pilot Production
Not surprisingly, materials targeted for CMP and photolithography (masks + PR) have highest growth rates.
2007 CMP Pad Market Share

Pad Market Share Est. 2006

- JSR
- PPG
- Thomas West Inc.
- Others
- Rohm and Haas Electronic Materials

Pad Revenues ($M)

- 2004
- 2005
- 2006
- 2007
Oxide CMP Abrasives

Revenues ($M)

Volumes Shipped (%)

2002 2003 2004 2005 2006 2007

Colloidal Revenues
Fumed Revenues
Volume % Colloidal
Post CMP Clean Chemicals

KLiters

Percent Change Yr/Yr

0%
10%
20%
30%
40%
50%
60%
70%
80%
90%

2002 2003 2004 2005 2006 2007

Industry Trends and CMP - July 2007
How is any of this information useful?

Management decisions are influenced by certain perspectives and trends depending on business model and market segment.

<table>
<thead>
<tr>
<th>Speedsters</th>
<th></th>
</tr>
</thead>
</table>
| EQUIPMENT           | Willing to buy for new fabs or to retool existing fabs  
                     | Drive improvements in both capability and productivity |
| CONSUMABLES         | Push performance in nearly every aspect of CMP       
                     | Defectivity is becoming an increasing focus          |
| MATERIALS           | Adapt existing materials whenever feasible, but …   
                     | Will not hesitate to integrate new materials when necessary |
**Decision Drivers**

### New Mainstream

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preserve capital and extend depreciated tools whenever possible</td>
</tr>
<tr>
<td>Buy tools only for &quot;must have&quot; capacity expansions</td>
</tr>
<tr>
<td>Generally staying focused on 200mm and below</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONSUMABLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme focus on reducing cost per wafer</td>
</tr>
<tr>
<td>Defectivity and other factors to improve yield are also key</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adapt proven materials and process methods … period.</td>
</tr>
<tr>
<td>Optimize process flows for simplicity and yield</td>
</tr>
</tbody>
</table>

### Emerging Technology

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preserve capital and minimize overhead</td>
</tr>
<tr>
<td>Outsourcing is a strong trend (fabless)</td>
</tr>
<tr>
<td>Generally start at small wafer sizes and work up to 200mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONSUMABLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not locked in to &quot;traditional&quot; CMP pad/slurry offerings</td>
</tr>
<tr>
<td>Lots of small-volume niche opportunities</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willing to explore a wide range of materials for unique properties</td>
</tr>
<tr>
<td>Process requirements vary by several orders of magnitude</td>
</tr>
</tbody>
</table>
Thank you…