CMP: Where have we been and where are we headed next?

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Outline

Where have we been?

- Semiconductor Industry
- Birth of a Sub-Industry (Early Years)
- CMP Evolution and Revolution
- Maturing

Where are we headed next?

- Splintering into 3 sub-segments
- Direction depends on end user market
- Expect slippery curves on the road ahead

Author’s Note

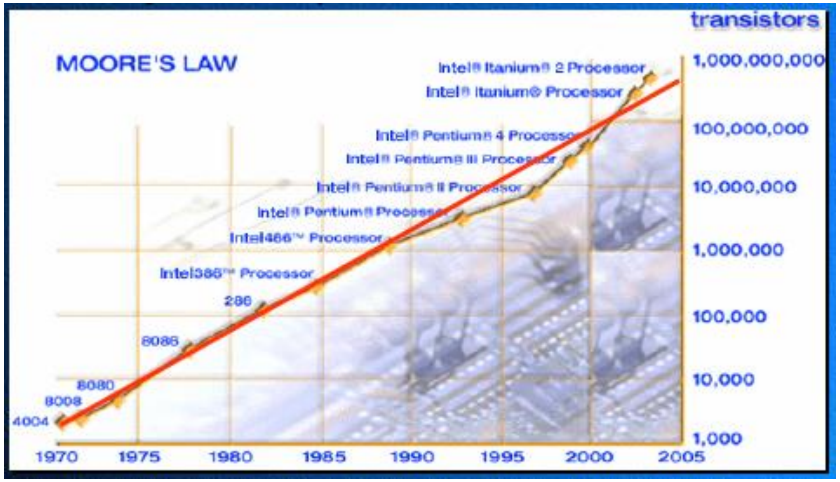
Opinions given in this talk do not necessarily represent the official position of any of the companies, organizations or individuals involved.

Opinions also do not necessarily represent this conference, its’ sponsors, or virtually anyone else.

Your mileage may vary.

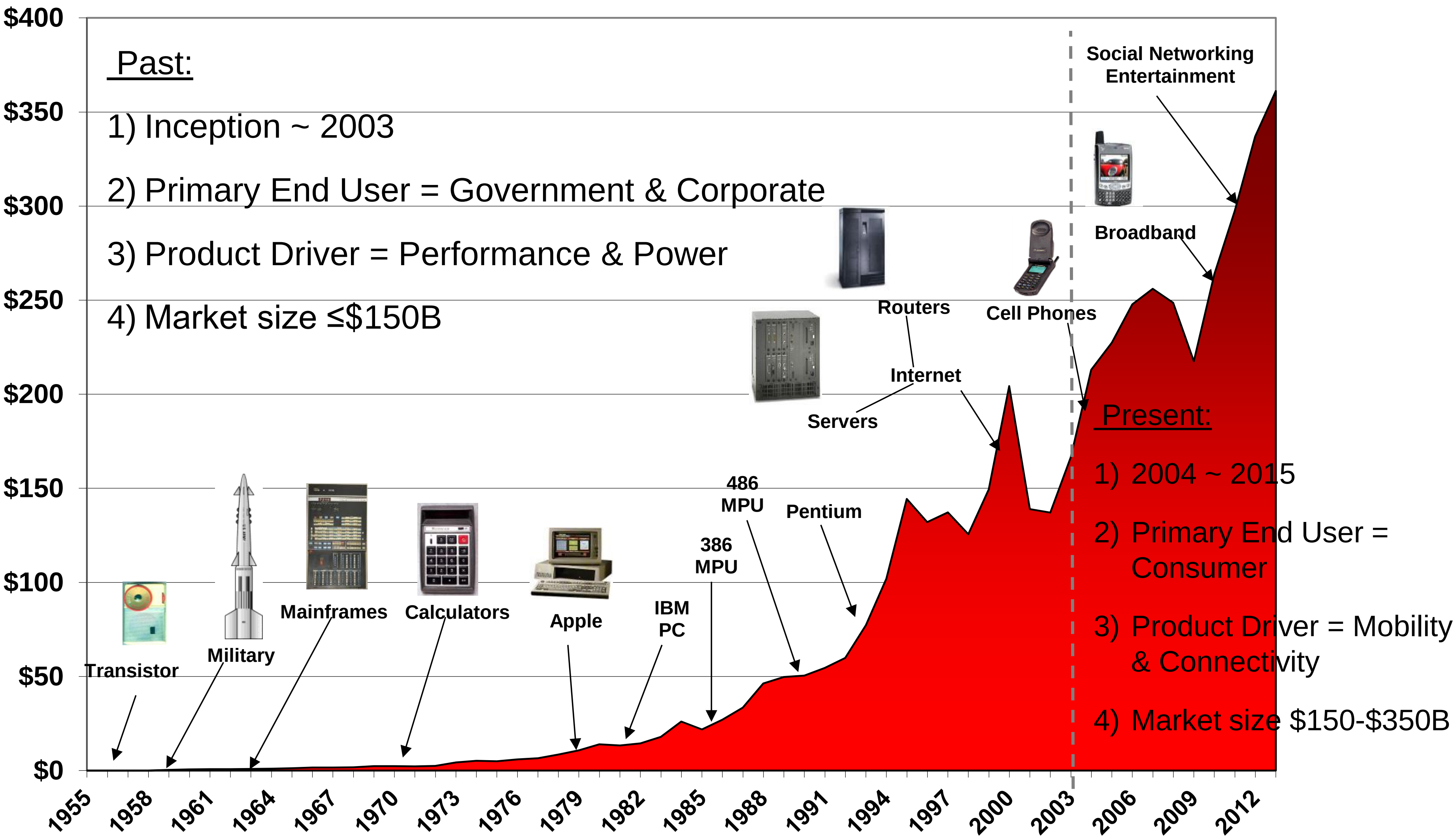
Industry Trends

- Moore's Law dominated the CMOS industry for >40 years
  - Not affected by cycles, markets, analysts, or the economy
- Photolithography and CMP are two critical process technologies to continue both cost and performance improvements
  - Photolithography enables SHRINKS
  - CMP enables more complex STACKS
- Trend still holds for certain industry segments, but many companies are choosing to pursue other paths
- CMP is also being used in numerous other technologies beyond CMOS



Source: Intel Corporation

Semiconductor Market



Source: SIA/WSTS and Semico Research Corp.

History

- **CMP = Chemical Mechanical Planarization (or Polishing)**
- **Adapted from optical lens polishing methods, i.e. telescope mirrors**
- **Timeline:**

  1983 – Process invented at IBM Base Technology Lab in East Fishkill, NY

  1986 – Oxide CMP development and pilot line

  1988 – Tungsten CMP development (East Fishkill and Yorktown Heights)

  1988 – Sematech CMP project launched

  1992 – CMP first included in SIA roadmap

  1995 – Industry embraces CMP. Ramping in numerous fabs.

- **Traditional silicon polishing is actually CMP as well (and much older)**
- **CMP is now accepted as a “mainstream” process in fabs worldwide**

Early Adopters

- Early Device Manufacturers (after IBM)
  - Intel, Micron, Motorola, Texas Instruments, National, Rockwell
- Equipment OEM’s
  - Westech (later IPEC then Speedfam-IPEC then Novellus now Lam)
  - Strasbaugh
  - 2nd wave included Ebara, Speedfam, Cybeq, Applied Materials, etc.
- Consumable Suppliers (Market share leaders)
  - Slurries: Cabot, Rodel, and several homebrews (IBM, Intel, etc.)
  - Pads: Rodel (Dow), Thomas West, Universal Photonics

Early Years

- Birth of a sub-industry: Mid-1980’s to mid-1990’s

- Trends
  - Immature consumables supply chain
  - Strong growth for the few established suppliers
  - High gross margins for best performers
  - Lots of market entrants attracted by high CAGR
  - Numerous “homebrew” slurries at early adopter fabs
  - At least 5 polisher OEM’s in contention (plus several startups)
  - Paranoia surrounded even the simplest process “secrets”

Early Stage

- General factors
  - Poor understanding of pad-slurry-film interactions
  - Poor understanding of defect mechanisms
  - Tolerance for variability was high
  - Removal rate was often the primary focus for process engineers
  - Uniformity was tough to control and often drifted >10% 1-sigma
  - Defectivity was important but not dominant in most fabs
  - Decisions: Performance then Consistency then Cost (a distant 3rd)

Evolving Years

- Growth and Evolution: Mid-1990’s to early 2000’s

- Market Trends
  - Maturing consumables supply chain
  - Continued strong growth for established suppliers
  - Splintering market among fab users… inconsistent expectations
  - Declining gross margins for many consumables products
  - Most “homebrew” slurries starting to wane
  - Copper CMP became process of choice for advanced nodes, but ILD with tungsten plugs remains strong for most other devices
  - Emergence of 2 dominant polisher OEM’s (AMAT and Ebara)

Evolving Stage

- Other factors impacting CMP
  - Improving understanding of pad-slurry-film interactions
  - More customers starting to design for CMP
  - Emergence of strong programs in academic R&D
  - Tolerance for variability in CMP was dropping fast
  - Tolerance for “rookie mistakes” from new suppliers also dropping
  - Shrinking feature sizes drove rapid change in defect requirements
  - Plenty of evolution and a few pockets of revolution
    - Oxide slurries evolved to tighter PSD’s and better batch to batch consistency
    - Tungsten slurry saw revolution from Al2O3 with ferric nitrate to SSW-2000
    - STI slurries first split into 2 camps: Direct STI and STI with REB then revolution to ceria slurries
    - Cu slurries came on strong as the new drivers for both technology and commercial impact, but quickly started seeing price erosion in the market
  - Decisions: Consistency then Performance then Cost (a close 3rd)

Maturing Years

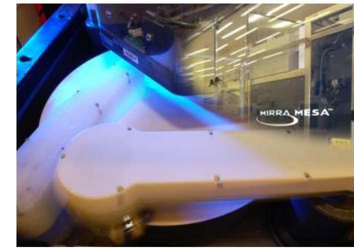
- Maturing: Early 2000’s to present day

- Market Trends
  - Mature slurry supply chain
  - Growth now only slightly higher than semiconductor CAGR
  - Some products nearly commoditized
    - A few slurries are roughly same cost per POU gallon as gasoline
  - No recent slurry market entrants, but still not much consolidation
    - Each application acts almost like an independent slurry market
  - Tougher to capture … Splintered market among fab users
    - Leading Edge – Still focused on maximum performance (Semi Roadmap)
    - More than Moore – Extreme cost focus, stay with proven process technology
    - Emerging Technology – New materials, new devices, uncertain volumes

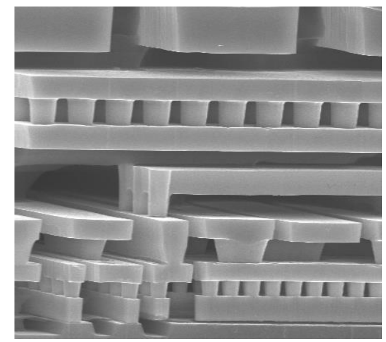
Industry Segments

Particularly from a CMP perspective

- Leading Edge Devices
  - Wafer sizes: 300mm & likely 450mm
  - Technology nodes: 32nm, 25nm and below
  - Materials: high k, metal gates, ULK, advanced barriers, etc.



- Mainstream or “More than Moore”
  - Wafer sizes: 300mm (some), 200mm & 150mm
  - Technology nodes: 90nm to 0.5μm and above
  - Materials for CMP: oxides, tungsten, Cu, etc.
  - Developing advanced 3D packaging with TSV’s



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- Emerging Technology
  - 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.

Maturing Stage

- Factors impacting CMP now
  - Extreme price increases for CeO_2 (moderating in past year)
  - Improved understanding of pad surface texture (& pad conditioning)
  - Tolerance for variability nearing zero in advanced architectures
  - Many fab engineering teams are now very short staffed
    - Fabs expect suppliers to provide stronger applications support
  - Evolution of endpoint and APC for advanced nodes
  - Splintered market drives splintered CMP requirements
    - Leading Edge – Defectivity is king, need lower rates for ultrathin films
    - More than Moore – Willing to trade some performance for lower cost
    - Emerging Technology – New materials and wildly different performance demands
  - Decisions: Depends somewhat on target market, but generally now Cost focused assuming Performance and Consistency are a given

CMP Direction

- **Simple Question: “Where is CMP headed next?”**
- Does not have a simple answer … more like 3 answers
- Leading Edge Fabs
  - Performance is still primary focus, but cost is also important
  - Finely tuned slurries and optimized processes
  - Will try new pads, conditioning, etc. to solve problems
  - 450mm is likely for the top tier … but timing is still unclear
  - Defectivity is mission critical and often difficult to even define in traditional language for devices at 22nm and below
  - CMP is aiming for Maximum Performance

CMP Direction

- More than Moore Fabs
  - Cost focus is extreme, but still requires acceptable performance
  - Trying to drive all consumables toward commodity pricing
  - Consistency and yield are mission critical
  - CMP is aiming for Minimum Cost
- Emerging Technology Projects
  - Often involve new materials and new integrations
  - Focus is on achieving acceptable yield and ramping into HVM
  - Willing to try new formulations, new methods… whatever works!
  - CMP is aiming for Innovative Solutions

What's Next?

- CMP will continue to evolve, but in different ways depending on the end user's target market
  - Leading Edge – Performance is still primary but cost is also key
  - More than Moore – Cost focus will drive toward commodity consumables (slurries, pads, conditioning, cleaners, etc.)
  - Emerging Technology– New devices drive strong innovation

- In established CMP processes, two factors dominate:

DEFECTIVITY
Is <u>King</u>

and

COST
Is <u>Queen</u>

It's a bit of an uncomfortable marriage !

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