A Perspective on Semiconductor Equipment

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Outline

• Semiconductor Industry
  – Overview of circuit fabrication
• Semiconductor Equipment Industry
• Some equipment business strategies
• Product development and life cycles
Semiconductor Industry

• 1948 – Bell Labs invention of transistors
  – Era of discrete transistor products
• 1963 – Intel & TI develop integrated circuits
  – Provided on-chip connection of transistors
  – Building blocks for complex board products for large electronic systems
• 1970&80’s – Challenges from Japan, Korea
• 1990’s
  – Rise of “Fabless” Design Companies
  – Rise of “Foundry Companies”
    • Taiwan, Singapore, Malaysia, China
IC Technology Trend

Transistor Physical Gate Length

Technology Node

Log Scale

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Integrated Circuit Fabrication - simplified

Cleaning

Metrology

Etching

Oxidation or Film Deposition

Metrology

Lithography

Cleaning
New Gate Processes for sub-100nm nodes

Gate Dielectrics

180 - 130nm
- Polysilicon
- Oxide
- Si substrate
- Thermal SiO₂
- Furnace

130 - 100nm
- Polysilicon
- Oxide
- Si substrate
- Thermally Nitrided SiO₂
- Furnace

100 - 70 nm
- Ge doped Polysilicon
- Oxynitride
- Oxide
- Si substrate
- Oxide/Nitride Stack
- Mini-Batch

70 - 50 nm
- Ge doped
- High-k Oxide/Nitride Stack
- Si substrate
- ALD/Mini-Batch

50 - 35nm
- Metal gate
- High-k
- Si substrate
- High-K Gates
- ALD
Semiconductor Equipment

- 1950’s – Adapted the equipment from other industries
- 1960’s – Internal eqpt. Development by major users
  - Motorola, T.I., AT&T, IBM, Fairchild, Others
- 1970’s – Rise of a dedicated equipment industry
- 1980’s – Growth of number and size of companies
  - Formation and growth of eqpt. companies in Japan
- 1990’s – Consolidation by mergers
- 2000’s – Continued consolidation
  - Offshore subsidiaries of U.S., European based companies
  - Formation of new companies in China, Korea, S.E. Asia
Equipment Types

- Deposition – formation of surface films
- Lithography – pattern transfer
- Etching – cuts the pattern into a layer
- Cleaning – removal of residue or contamination
- Metrology – measurement of results
- Storage/Transport – management of lot tracking and robotic movements
- Host level fab management system
A Typical Vertical Furnace

Small Batch Tool

3 feet wide
8 feet deep
10 feet high

Load size: 25
Wafer size: 300-mm wafers
Basic Reaction Cycle of ALD

I. Introduction of A(g) onto the substrate surface

II. Formation of an A(s) monolayer surface

III. Introduction of B(g) onto A(s) surface

IV. Formation of B(s) monolayer surface
Side view of the ALD System
Multi-chamber single wafer process
TOP View of the ALD Reactor Chamber
Business Strategies

• Applied Materials -
  – Founded to be a chemical supplier to semiconductor fibs
  – Entered equipment building as a way to generate cash flow
  – Recognized the potential of being an equipment supplier
  – Strategy changed in mid-70’s to become a company offering products in several areas
  – Growth until today dominates tool selections except in photolithography tools
Business Strategies

- TEL (Tokyo Electron Limited)
  - Initially a trading company in Japan
    - Sales of US, European built equipment into Japan
    - Joint Ventures for sales + customization of eqpt.
  - Japanese designed products by mid-1980’s
  - Dissolution of Joint Ventures
  - Now global competitor with broad product line
Business Strategies

• Nikon, Cannon
  – Focused on a single area – patterning eqpt.
  – Leverage experience in other optical products
Business Strategies

• ASML
  – Grew out of development of an stepper type exposure tool at Philips Semiconductor
  – Joint Venture of Philips with ASMI
  – Focused on a single area – patterning eqpt.
  – Merger with Silicon Valley Group in 2000
    • Short term expansion into other equipment areas
    • Return to single product focus
Product Development Cycle

• MRS – Market Requirements Statement
• Design objectives and process objectives
• Build of one or more prototypes
• Design verification and improvement
• Product introduction
• Transfer to pilot / full production
• Support and Sustaining Activities
• End of Product Life Cycle Strategies
Product Development Cycle

- **MRS – Market Requirements Statement**
  - Marketing Dept. is the responsible group
  - Defines goals of a new model/type eqpt.
  - Defines performance and cost goals
  - Needs to be tested with key customers
  - Input for engineering designs
Product Development Cycle

• **Functional Specifications**
  – Design Engineering Dept. is responsible
  – Defines the design goals of a new model/type
  – Defines the expected performance objectives
  – Uses a lot of computer assisted design
    • Stress analysis
    • Computational flow dynamics and thermal modeling
    • System throughput analysis
  – Defines a budget for sub-system cost objectives
  – Defines a reliability budget for sub-systems
  – Needs to be aligned with the MRS
  – Provides the input for engineering designs
Key Group Interactions During Product Development

- General Management and Finance
- Marketing and Sales
- Materials and Manufacturing
Product Design Cycle

- Design is broken into major blocks
  - Decisions made about use of existing blocks
    - Process modules
    - Controls
    - Robotic handling
    - Software
  - Major new blocks broken into smaller areas
  - Design broken into single designer team tasks
  - Tasks get scheduled in order needed
Control of the Design

• Program manager
  – Coordinates schedules

• Management program reviews
  – Focus on schedules, costs, performance

• Engineering Design reviews
  – Concept
  – Detailed design
  – Final design review
Control of the Design

• Engineering reviews should focus on
  – Performance
  – Reliability
  – Cost
Building Prototypes

• Decisions about
  – Design / Fabrication of design blocks
    • Design & build internally
    • Design internally / outsource fabrication
    • Outsource design and fabrication

• Identify and qualify outside suppliers
  – Jointly with manufacturing engineering and purchasing
Build of one or more prototypes

- Integration of new with existing blocks
  - Process modules
  - Controls
  - Robotic handling
  - Environmental controls (low O₂, low H₂O)
  - Software
- Integration to fab wide transport
- Testing of tool-host communications
- SEMI-S2 and other code compliance reviews
Design Verification with prototypes

- System level testing
  - Performance of new with existing blocks
- Process development / recipe development
  - Demonstrations meeting MRS objectives
  - Customer demonstrations
- Mini-marathons
  - Test for weak components
  - Test sub-system reliability
- Implement reliability or performance fixes
Tools for Design Verification

• DOE (Design of Experiments) testing
  – Highly efficient use of test time and resources
• SPC (Statistical Process Control)
  – Testing for system performance repeatability

• Assessment of system reliability
Product introduction

Needs

• Defined target market
• Defined performance guarantees
• Operation and maintenance manuals
• SEMI S-2 and other code reviews
Transfer to pilot production
Release to full production

Needs

• Completion of design documentation
  – Commercial component specifications
  – Component designs / drawing trees
  – Assembly drawings / assembly plan
  – Work instructions

• Supplier identification / qualification

• Personnel training
  – At suppliers
  – For final assembly and test
Support and Sustaining Activities

• Training of field installation staff
• Training in-factory support staff
• Training customer site maintenance staff
• Planning for spare parts logistics
• CIP (Continuous Improvement Programs)
  – Fix identified problems
  – Add performance enhancement
  – Develop and release new options
End of Product Life Cycle Strategies

Plan for -

• Replacement of aging models
• Phase out of existing models
  – Last date for acceptance of new orders
• Support plan for existing customers
  – Spare and consumable parts strategy
  – Parts and support by a third party company?
Summary

- Equipment for the semiconductor industry
  - Technically challenging
  - A strong base of U.S. based companies
  - Presents a lot of job opportunities in
    - Various fields of engineering
    - Management of Technology
    - Technical marketing and sales