ENABLING ADVANCED CHIP MANUFACTURING WITH NEW MATERIALS

ASM International
Analyst and Investor Technology Seminar
Semicon West July 9, 2014
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OUTLINE

› New Materials: Moore’s law enablers
› ALD as enabler of new materials
  • What is Atomic Layer Deposition (ALD)?
  • Key strengths of ALD
› ASM and ALD
› ASM Products and selected applications
› Summary and Conclusions
OUTLINE

› **New Materials: Moore’s law enablers**
› **ALD as enabler of new materials**
  • What is Atomic Layer Deposition (ALD)?
  • Key strengths of ALD
› **ASM and ALD**
› **ASM Products and selected applications**
› **Summary and Conclusions**
SCALING IS INCREASINGLY ENABLED BY NEW MATERIALS AND 3D TECHNOLOGIES


Scaling enabled by Litho

Scaling enabled by Materials

- Low-k
- High-k
- Strained Si

Scaling enabled by 3D

- Double / Quad Patterning
- High-mobility channel materials
- FinFET
- 3D SIC
- 3D Memory
- GAA

Confidential and Proprietary Information
INCREASING INTRODUCTION RATE OF NEW MATERIALS
NEW MATERIALS AND PROCESSES: MOORE’S LAW ENABLERS

**Higher Capacitance, Lower Leakage**
- High-k and Metal Gates
- DRAM, RF, decoupling capacitors

**Less Cross Talk, Faster Interconnect**
- (Porous) Low-k Materials
- Improved Metals

**Higher Mobility, Lower Resistance**
- Strain and new Channel Materials
- New metal contacts

**Smaller Feature Sizes**
- Sub-Rayleigh limit patterning using SDDP
- Conformal SiO₂
- Anisotropic Etch

**Higher Capacitance, Lower Leakage**
- High-k and Metal Gates
- DRAM, RF, decoupling capacitors

**Less Cross Talk, Faster Interconnect**
- (Porous) Low-k Materials
- Improved Metals
Semiconductor growth drivers are mobile devices. Performance per Watt becoming key metric factor in chip design. Driving further innovation in materials.

Source: Gartner, April 2014
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New materials and 3D applications require more precise and controlled thin film deposition.

Compared to conventional deposition techniques ALD offers superior:
- Uniformity
- Conformality
- Interface control
WHAT IS ATOMIC LAYER DEPOSITION (ALD)?

Step 1: (Metal) Precursor Chemisorption

Step 2: Purge

Step 3: Reaction to Oxide/Nitride with O₂, H₂O, NH₃ co-reactant

Step 4: Purge

and repeat…
KEY STRENGTHS OF ALD RELATIVE TO CONVENTIONAL DEPOSITION

**Uniformity**
- **Mean:** 291.0133
- **Maximum:** 292.6831
- **Minimum:** 288.7532
- **Std. Dev.:** 0.9947308
- **Range:** 3.9299
- **HiLo Var.:** 0.68 %

**Step Coverage**
SEM’s Courtesy of Philips Research Labs

**TiN**

**Interface Control**
- Atomically engineered interfaces to optimize leakage current, reliability and work-functions

**Composition Control**
- Excellent composition control for ternary alloys; all ALD solution demonstrated for GST

29 nm SiO₂
<1% 3σ
<0.7% M-m
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ASM AND ALD

› **ASM is a leading player in the ALD market**
  - ASM introduced ALD into the semiconductor market in 1999
  - Developing ALD technology since then
  - Strong IP position
  - Number 1 in high-k gate and strong position in spacer defined double patterning (SDDP)

› **The ALD market offers strong growth opportunities**
  - High-k metal gate
  - Spacer defined double patterning
  - Other emerging applications
ASM NEW MATERIALS DEVELOPMENT STRATEGY

- **N+≥3**
  - **New Materials Screening**
  - **ASM MicroChemistry, Finland**
    - Basic materials R&D
    - Chemical synthesis
    - Pre-cursor screening

- **N+2,3**
  - **Process Integration**
  - **ASMB @IMEC, Belgium**
    - Process development
    - Integration
    - Device characterization

- **N+1,2**
  - **Product Development**
  - **Product Line Site**
    - Engineering
    - Product development
    - Product marketing
CRITICAL ALD SUPPLY CHAIN COMPONENTS

Fundamental Capability | Process Performance | Productivity | Integrated Process | Final Product Capability

Pre-curators

Reactors

Fab facilities, pumps & abatement

Pre-cursor Delivery, Valves and Vessels

High productivity tools
EXTENDIBILITY OF HAFNIUM BASED OXIDES

45nm HK first RPMG Planar FET

32 nm HK last RPMG Planar FET

28nm HK first RPMG Planar FET

22nm HK last RPMG FinFET

High Performance

Low Standby Power

Fraction of HK Adopters


HfSiO

HfO2

HfXXO

Other

Top: TEM’s reproduced with permission of Chipworks
Bottom: ASM estimates 2012
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FINFET CHALLENGES: ALD ENABLES FURTHER SCALING IN 3D

- Materials properties and channel length must be uniform over fin height
- Conformal coverage required
- ALD technology has become critical for HK and MG layers
ASM PRODUCTS
ALD

› Pulsar® XP
  • ALD for high-k
  • Cross-flow reactor
  • Solid source delivery system

› EmerALD® XP
  • ALD for metal gates
  • Showerhead reactor
WHAT IS PLASMA ENHANCED ATOMIC LAYER DEPOSITION (PEALD)?

Step 1: (Metal) Precursor Chemi-sorption

Step 2: Purge

Step 3: Reaction to Oxide/Nitride or metal with O,N,H Radicals

Step 4: Purge

and repeat…
ALD IS ENABLING SUB-RAYLEIGH LIMIT LITHOGRAPHY WITH SPACER DEFINED DOUBLE PATTERNING

Pitch: P

Pitch: ½ P

90nm

ALD SiO2 Spacer

45nm

Anisotropic Etch

PEALD SiO2 on resist

Spacer Defined Double Patterning with PEALD in production since 3x nm DRAM and Flash

Key enablers brought by PEALD
- Uniformity: CD control
- Low temperatures (50°C!!)
- Good step coverage
- Dense films
- Extendible to other materials
LINERS AND SPACERS FOR 15 AND 10 nm FinFET’S

**PEALD SiO$_2$ and Si$_3$N$_4$ permanent spacers**

- Low temperature (300 – 500 °C)
- High conformality
- High quality (low WER, low leakage current)
ASM PRODUCTS
PEALD AND PECVD

› XP8

- High productivity single wafer tool for both PEALD and PECVD applications
- Accommodates up to 8 chambers for PEALD or PECVD
- PEALD and PECVD can be integrated on the same platform
## Market Requirements: 22nm → 14nm → 10nm and beyond

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<td>• Thick Epi layers for power devices</td>
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Advanced transistors enabled with Intrepid® XP
- Strained epitaxial films for planar logic devices
- Relaxed & strained epitaxy for Si, SiGe & Ge based FinFETs through 7nm
  - Channel (SRBs), S/D stressor, contact & passivation cap layer

Integrated, low thermal budget pre-clean module
- High quality surface with low interface contamination

High productivity & lowest CoO
- Platform capability with 4 process modules
  - Flexible configuration with pre-clean (3+1 & 2+2)
- Differentiated film growth processes enabling devices with high drive currents & best-in-class productivity
- High throughput with pulsed Epi processes & high doping levels
Power devices require multiple & thick Epitaxial films to withstand high breakdown voltages (600V ~ 800V)

Breakdown voltage of the device dictates number of Epi layers needed

In HVM by several power device manufacturers enabled by:

ASM Product: Epsilon® 3200
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**Strong IP protected portfolio**
EXTENDIBILITY OF ASM’S LOW-K SOLUTION

- Aurora® low-k (k=2.8~3.1)
- Aurora® low-k (k=2.6)
- Aurora® ELK (2.3-2.5)
- Aurora® ELK (2.0)
- UV-assisted process
- Pore Seal / Restoration

ILD k-value

90~45nm 32nm 22nm 15nm 11nm 8nm
## ASM PRODUCTS

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**PRODUCTIVITY AND INNOVATION**

**Productivity**
- One A412 PLUS = > 80 kwpm (example: 2.5 hr process, 95% available, 150 product wafer load)
- Dual boat/dual reactor system
- Clustering between reactors possible – only vertical furnace in the market with this capability

**Innovation: novel processes**
- Example 1: Novel hard mask materials – e.g. for fabrication of high aspect ratio structures in silicon (with IMEC)
- Example 2: Low temp reactive curing of dielectric film (WER 5A/s)

- No defects
- No pattern collapse
- No line wiggling

Flat and low WER of dielectric film after 1 hr of curing at 300°C
Gartner April, 2014

Key customer ALD and PEALD penetrations in 22nm and 14nm: market segments with high expected growth

Share of 22nm and 14nm of total Equipment spending increasing in 2014-2015
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SUMMARY AND CONCLUSIONS

› Scaling is increasingly enabled by new materials and 3D technologies

› ALD and PEALD enable new materials and 3D

› The ALD market offers strong growth opportunities

› Intrepid® XP, system with 4 Epi reactors, targeting strained Epi layers for CMOS, and Epsilon® 3200 for analog/power

› ASM’s low-k technology continues to be extendible

› ASM’s Vertical Furnace is providing high productivity, in combination with continued process innovation