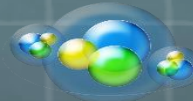




Electronics Materials Information



ALD/CVD Material & Equipment Market Trends

Jonas Sundqvist, Ph.D, Techcet & Fraunhofer IKTS



by Techcet Group

a Techcet CA LLC Company

CMC 2016

www.Techcet.com

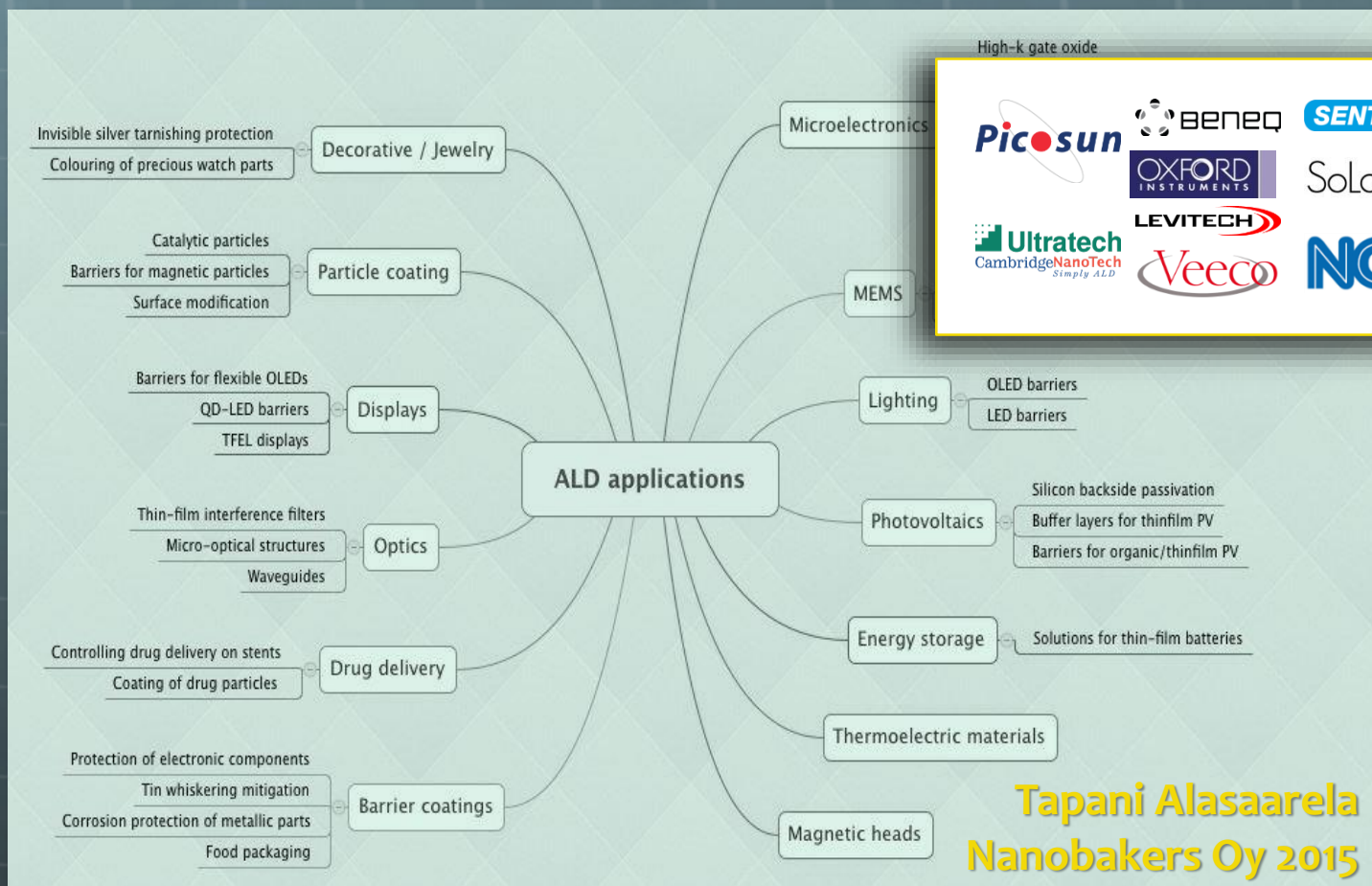
info@Techcet.com

Outline

- 🌐 **ALD Semiconductor Applications**
- 🌐 **ALD Equipment Market**
- 🌐 **ALD/CVD Precursor Market & Growth Trends**
- 🌐 **Novel ALD processes and technologies**
- 🌐 **Summary**

ALD Semiconductor Applications

ALD Applications & Markets

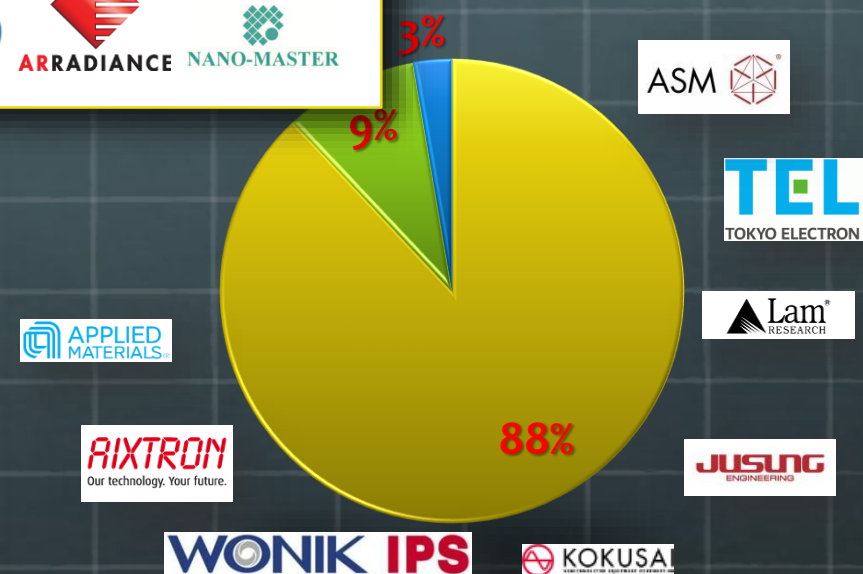


Tapani Alasaarela
Nanobakers Oy 2015



ALD Equipment 2015
1.0 to 1.2 M

semiconductor Research & Development

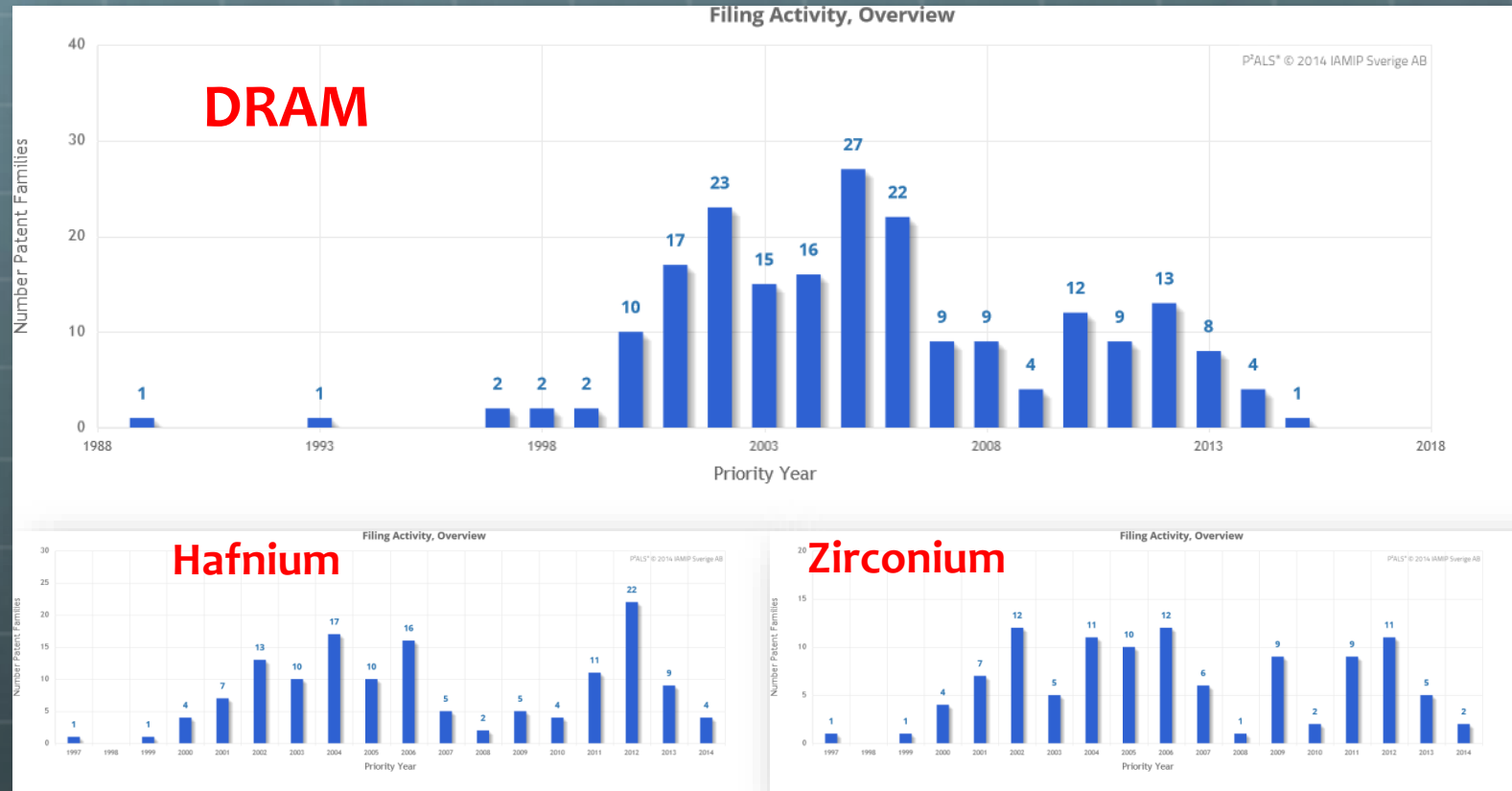


Estimates 2016, BALD Engineering
(Market reports, Financial Analysts, OEMs)

ALD Applications for Memory & Logic

2003

2004

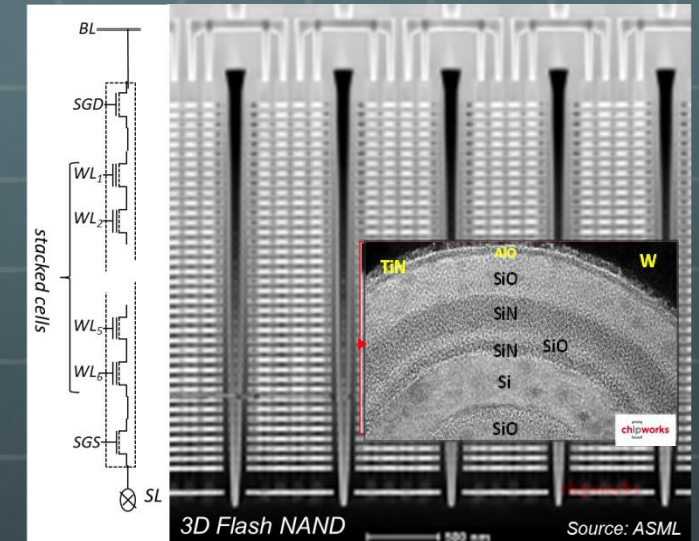
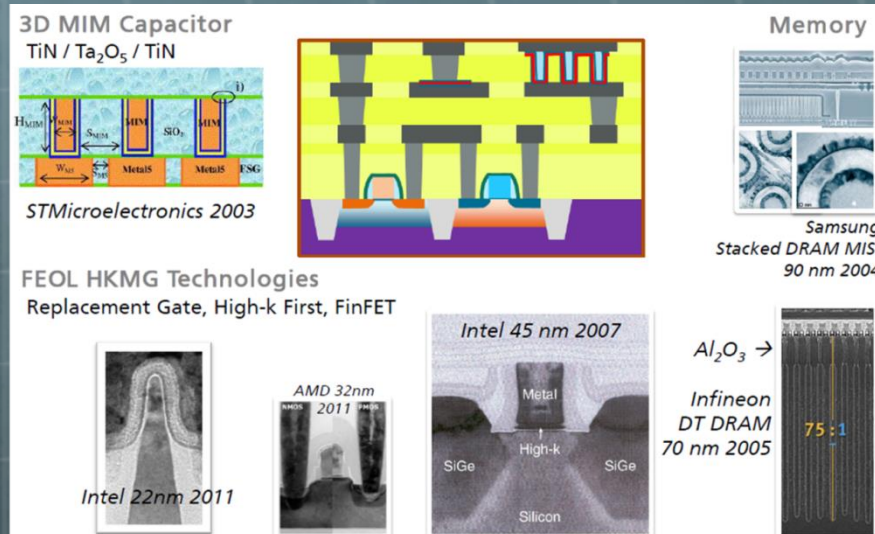
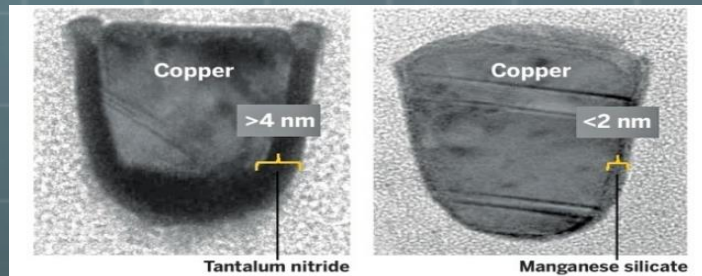
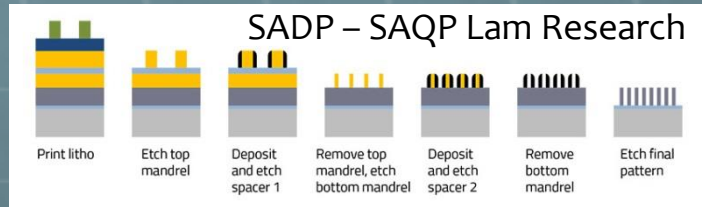


2011

2005

2007

ALD Applications for Memory & Logic



Application	Logic	Memory / Capacitor	R&D
High-k	HfO ₂	Al ₂ O ₃ , ZrO ₂ , HfO ₂ , Nb ₂ O ₅ , Ta ₂ O ₅	ATO, SrOx, SrTiO ₃ , BST
Metal Gates/Electrodes	TiN, TaN, TiAl, TiAlN TiC, TaC	TiN	Ru
Contacts	TiSi, NiSi, CoSi, W		Pt
Spacer/Liners/Multi patterning	SiO ₂ , SiN _x	SiO ₂ , SiN _x , Al ₂ O ₃	Inorganic/organic hybride
BEOL	TiN, TaN, Co		Mn, MnSi ₂ , Ru, CNT, Graphene, SAMs

Scaling trend → ALD Migration

I - Migration to ALD due to shrink

- LPCVD SiN and SiO₂
- PECVD SiN and SiO₂
- CVD Metals
- CVD Metal nitrides
- PVD Metals

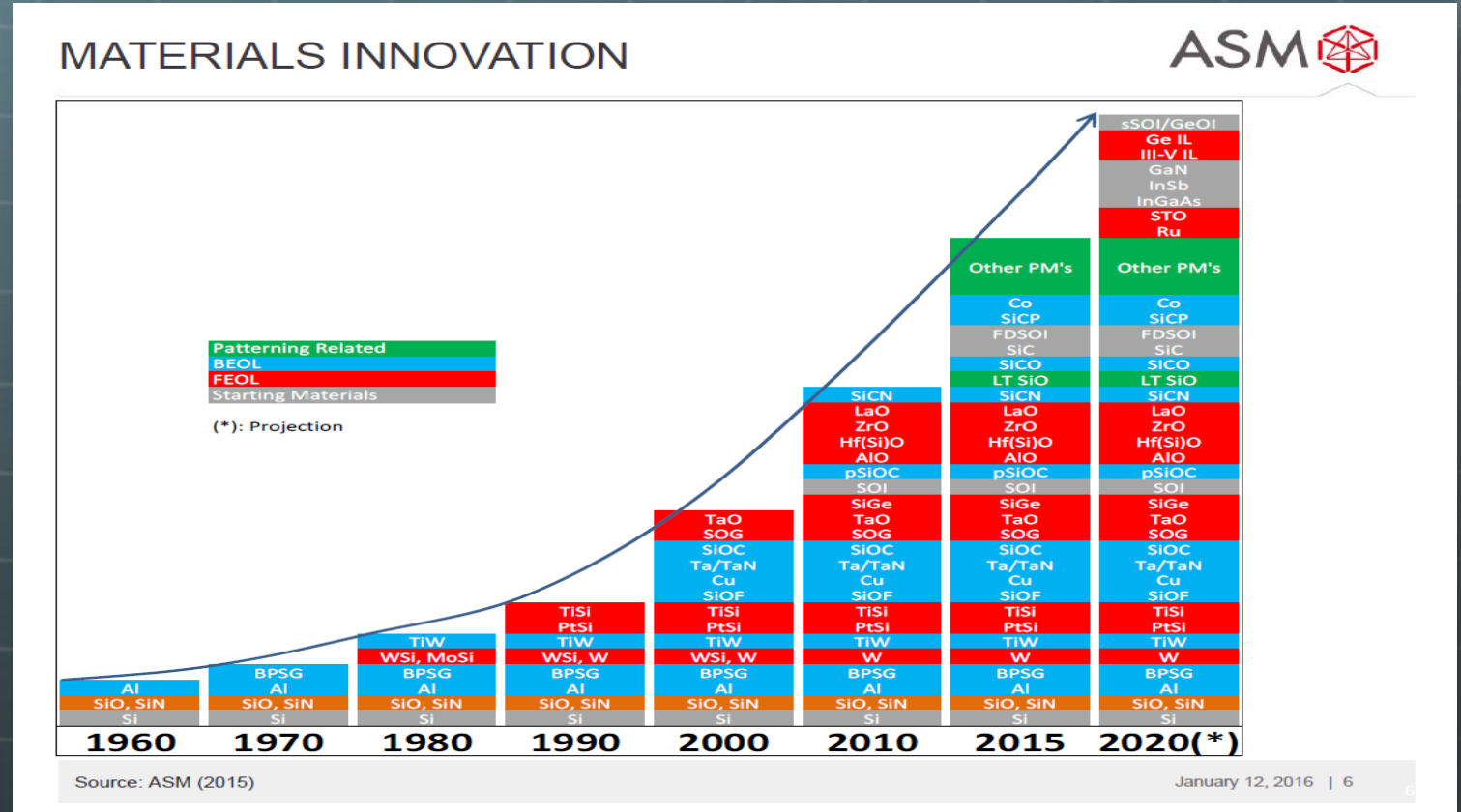
→ ALD

II - New Materials & Unit Processes:

- MIM Caps & High-k / Metal Gate
- Cu barriers
- Multipatterning

III - 3D Devices:

- ✓ DRAM, FinFET, 3DNAND → More ALD



Scaling trend → ALD Migration

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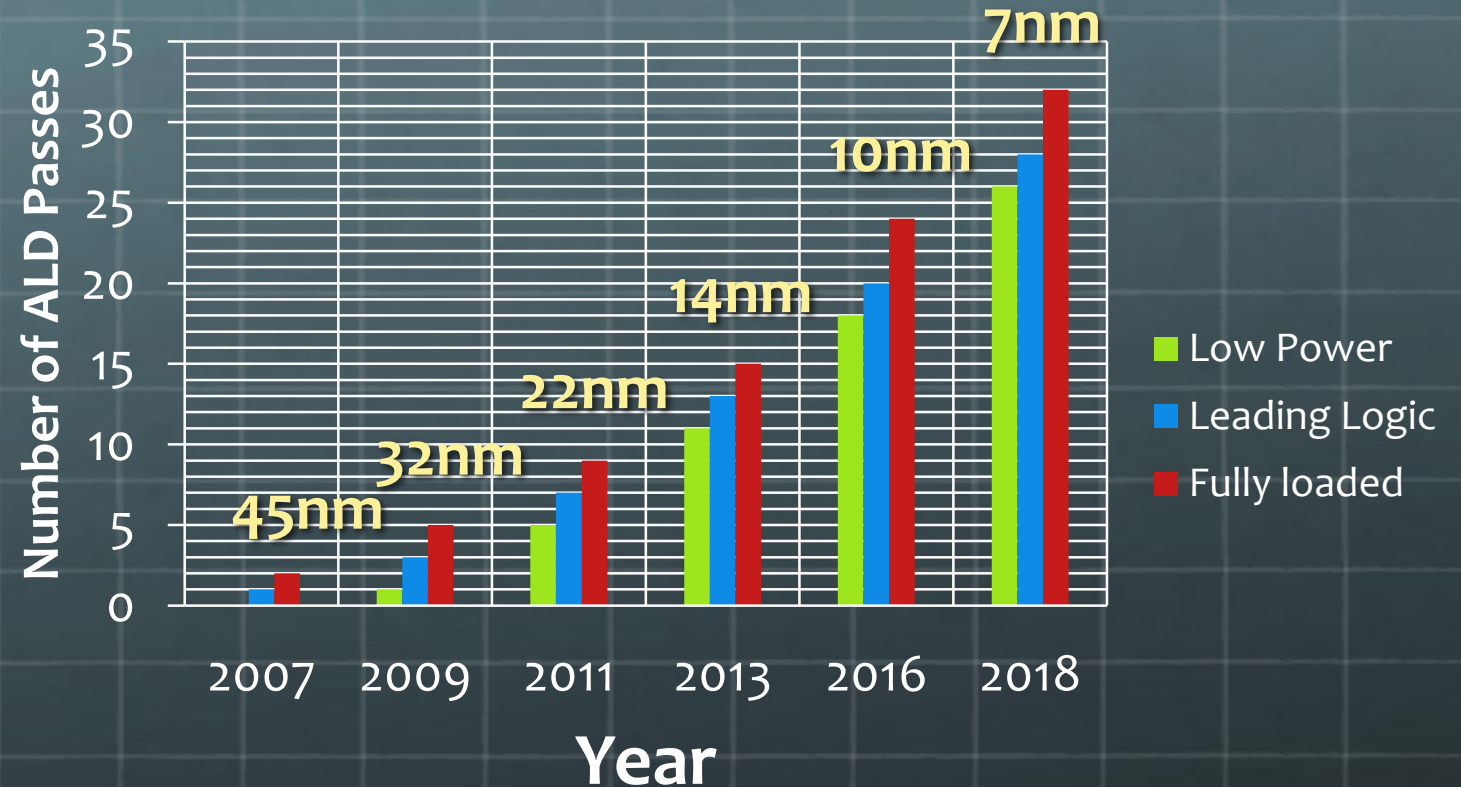
→ ALD

II - New Materials & Unit Processes:

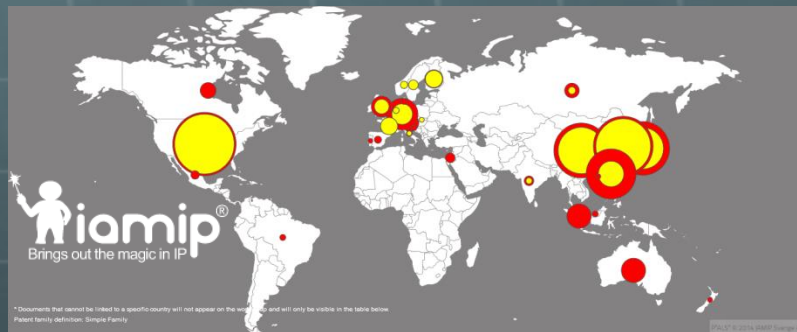
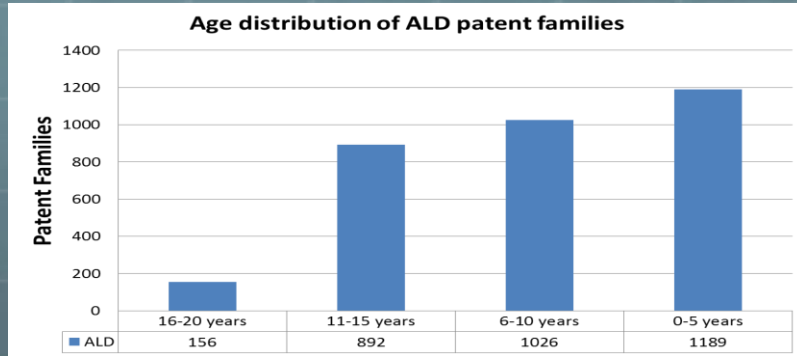
- MIM Caps & High-k / Metal Gate
- Cu barriers
- Multipatterning

III - 3D Devices:

- ✓ DRAM, FinFET, 3DNAND → More ALD



ALD Global Supply Chain



Chemicals & Gases

Air Liquide, Adeka, Air Products, SAFC, DSC, UPChem, Soulbrain, ..

Components

Swagelock, MKS, In USA, Rasirc, Edwards, Fujikin, Bronkhorst, ...

ALD OEMs



Fabs

Intel, Samsung, TSMC, Globalfoundries, SMIC, UMC, SK Hynix, Micron, ST Microelectronics, Infineon, NXP, Bosch Sensor Tech, TDK, TI, ...

“ALD is now firmly established as a **key enabling technology**. Today, ALD has become a critical technology for the manufacture of virtually all leading-edge semiconductor devices. The leading customers in our industry have already ramped several device generations based on our ALD equipment – for high-k metal gate applications in Logic and Foundry and for multiple patterning applications in the Memory sector” (Chuck Del Prado, CEO , ASM)

ALD Equipment

ALD Equipment Evolution

Single Wafer

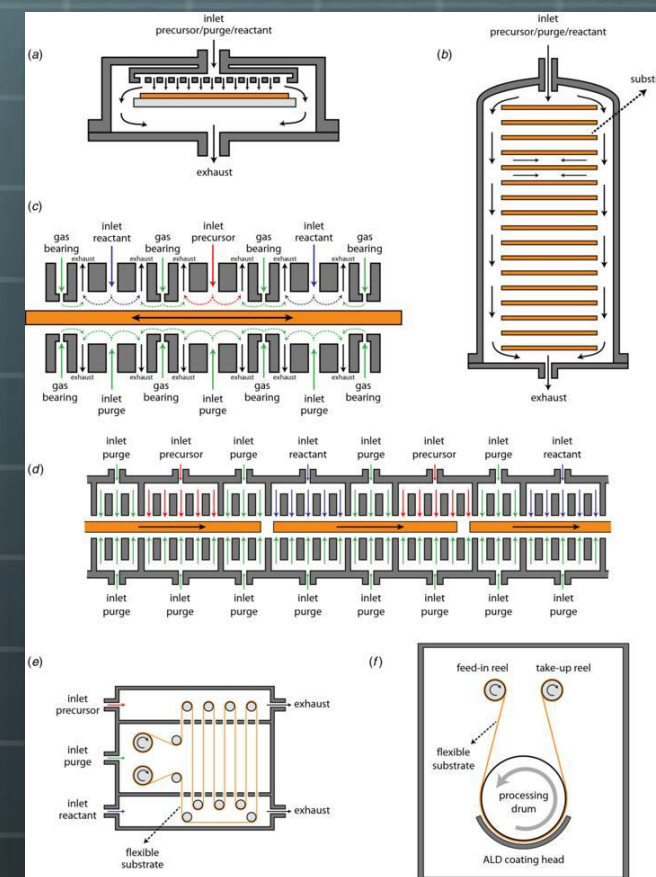
Multi Wafer

Reactor Types



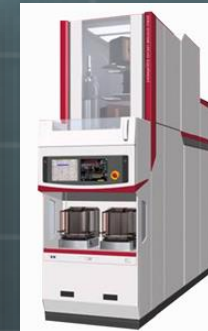
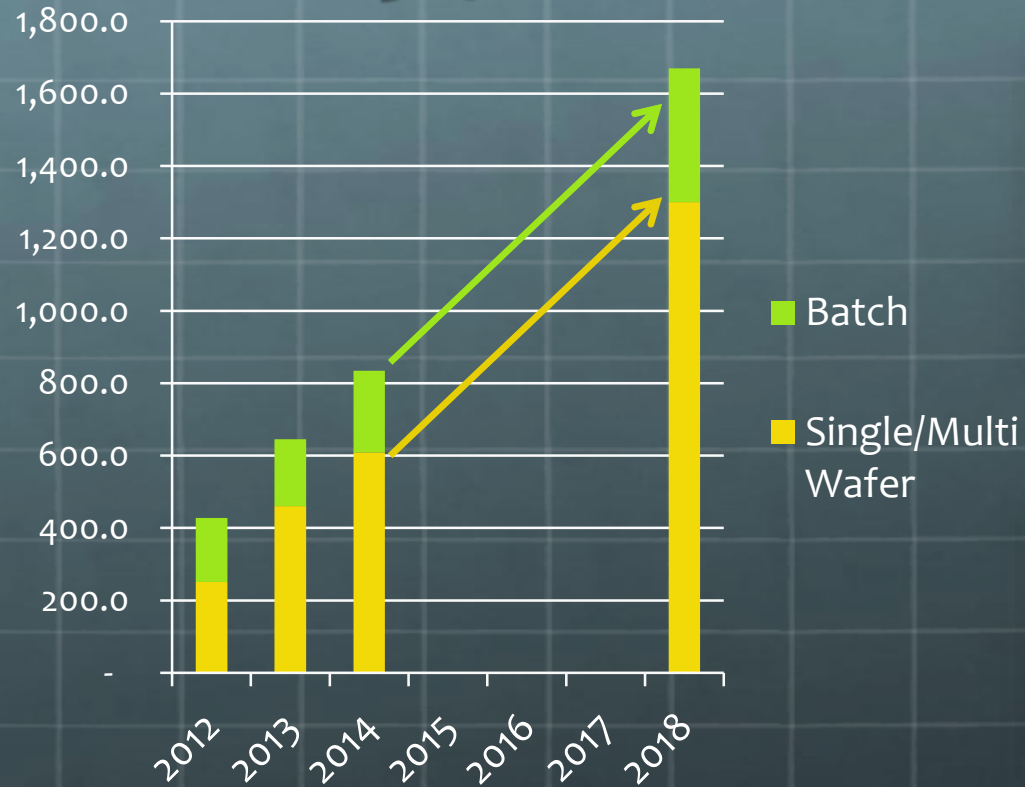
Large Batch

Spatial ALD

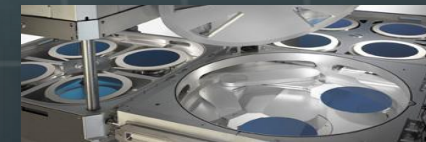


ALD Equipment Market

x2 in 3-4 Years



Main Growth in Single Wafer & Multi Wafer



ALD Precursor Market & Growth Trends

ALD / CVD Metal & High-k Forecast

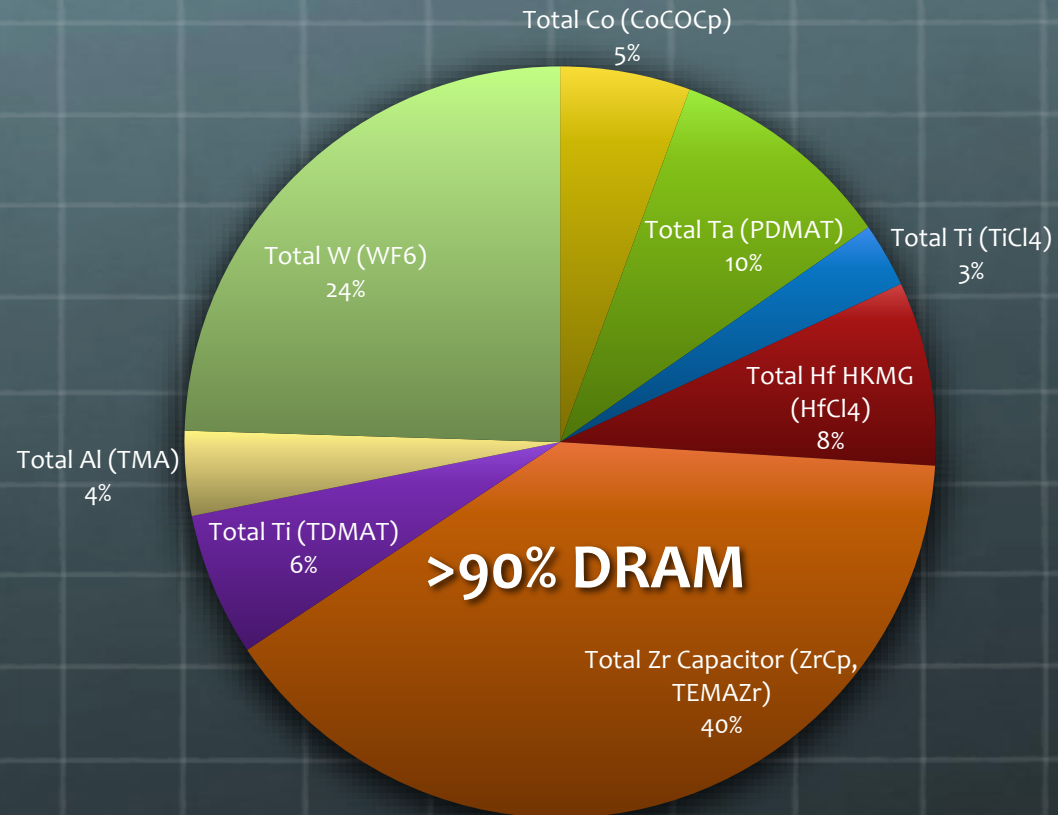
- 🌐 \$255M 2015 Market 9.4% 5 yr. CAGR

- 🌐 High Growth forecasted in BEOL Cu Metallization Barrier/seed

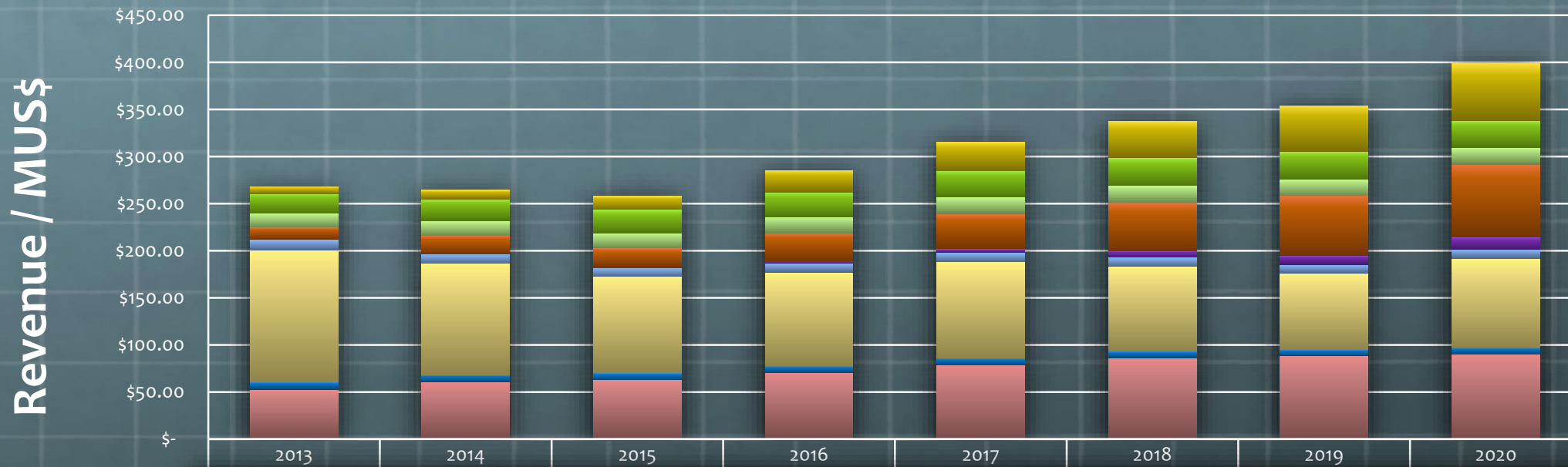
- 🌐 High-k is being introduced on 200mm technologies >65nm

- 🌐 MEMS utilization of ALD metal and barrier layers are increasing

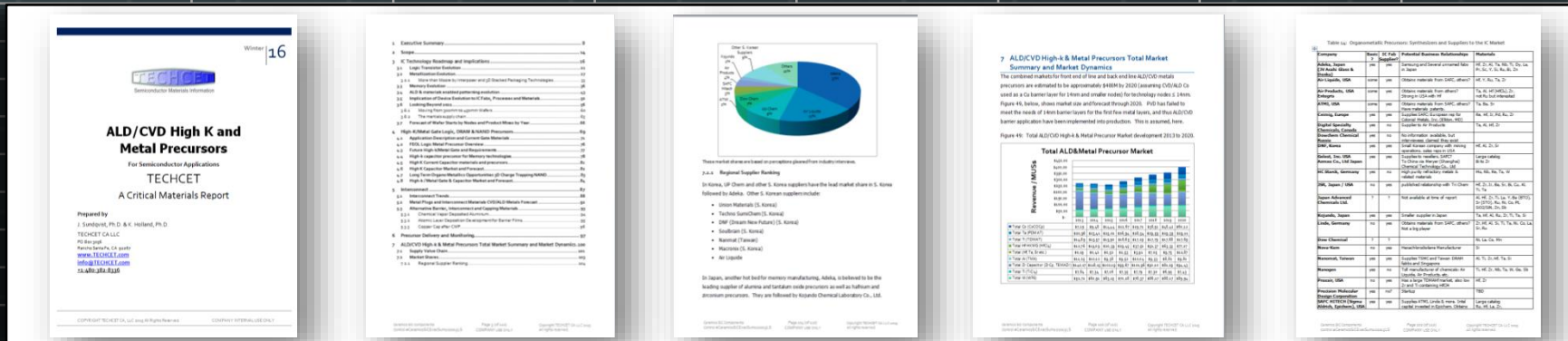
ALD/CVD High-k & Metal Precursors 2015



ALD/CVD Metal Precursor Market 2015 to 2020



- | | | |
|--------------------------------------|--|--|
| ■ Total Co (CoCOCp) | | |
| ■ Total Ta (PDMAT) | | |
| ■ Total Ti (TDMAT) | | |
| ■ Total Hf HKMG (HfCl ₄) | | |
| ■ Total (Hf, Ta, Sr etc.) | | |
| ■ Total Al (TMA) | | |
| ■ Total Zr Capacitor (ZrCp, TEMAZr) | | |
| ■ Total Ti (TiCl ₄) | | |
| ■ Total W (WF ₆) | | |

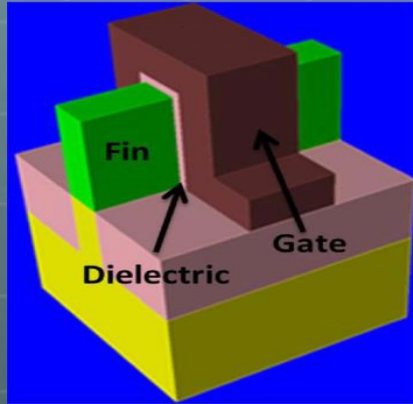


The combined revenues for all high-k and metal precursors (inorganic and organic) used for front end of line (pre-interconnect) and back end of line (interconnects) device fabrication of logic and memory is estimated to have totaled over \$258M in 2015 and could approach \$400M by 2020

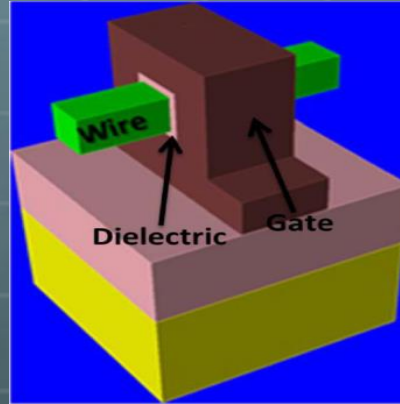
Novel ALD processes and technologies

Drivers for Atomic Layer Processing: Feature size shrink, 3DIC Scaling & EUV alternative

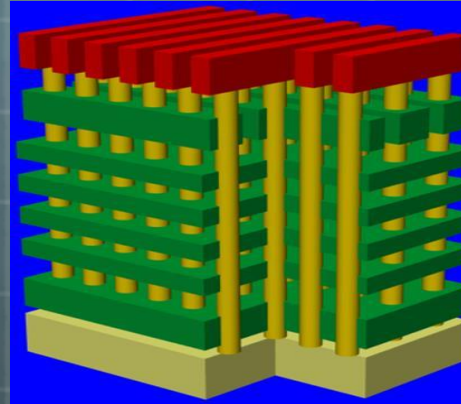
22 nm



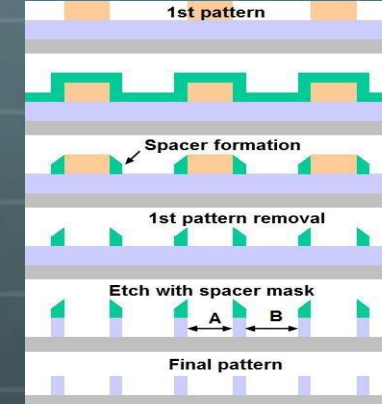
<10 nm



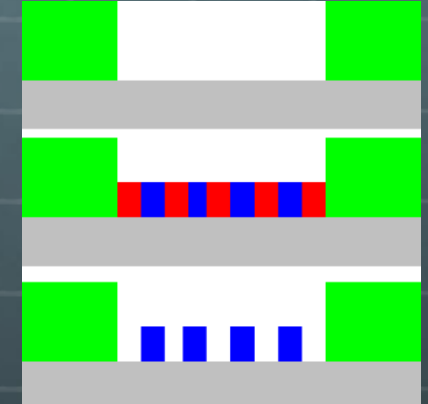
3DIC's



22 nm



<10 nm



FinFET > Gate-all-around Transistor > 3DNAND

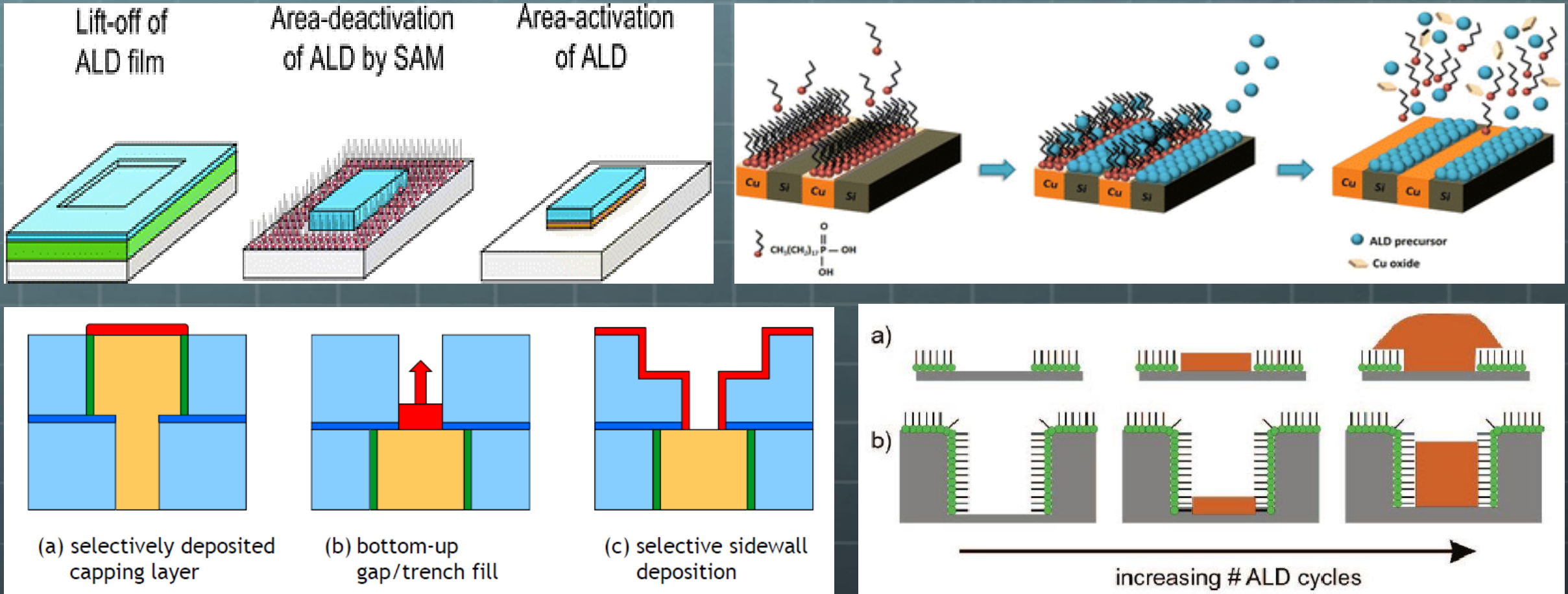
3D Device scaling

Multiple Patterning > BCP Patterning

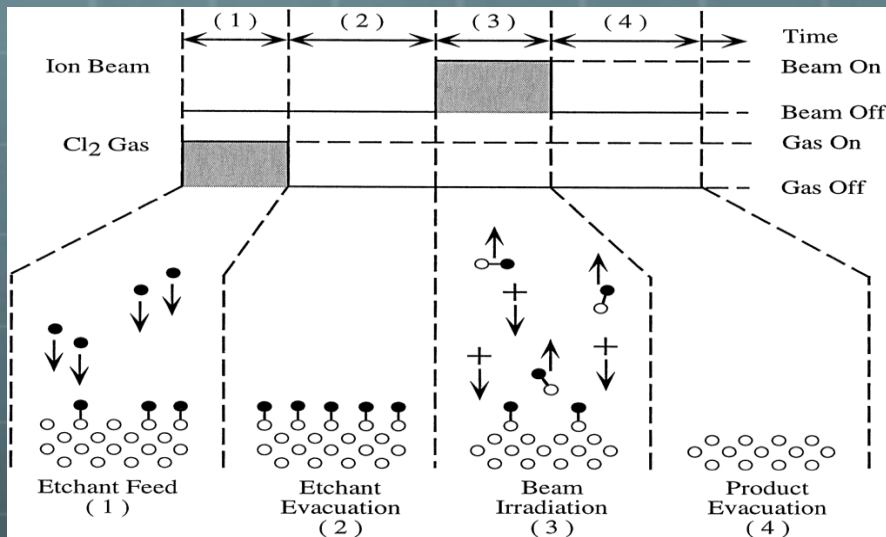
Nano Patterning

- controlling process drift becomes much more challenging
- next-generation tolerances are in atomic scale
- device aspect ratios continue to increase

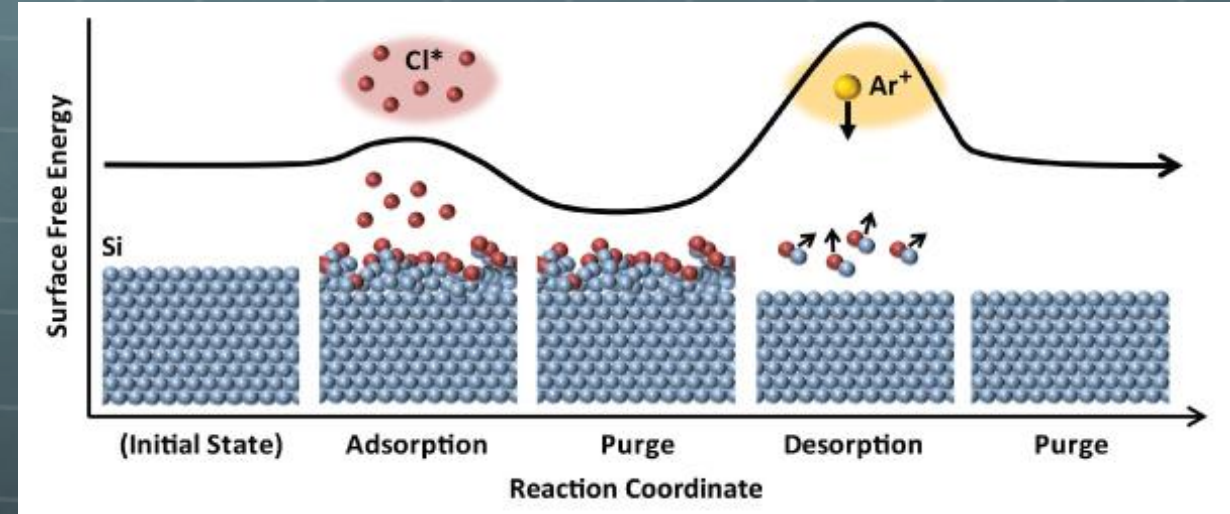
Selective ALD will enable patterning <7nm



Atomic Layer Etching - ALE



S. D. Athavale and D. J. Economou, J. Vac. Sci. Technol. A 13, 966 (1995).



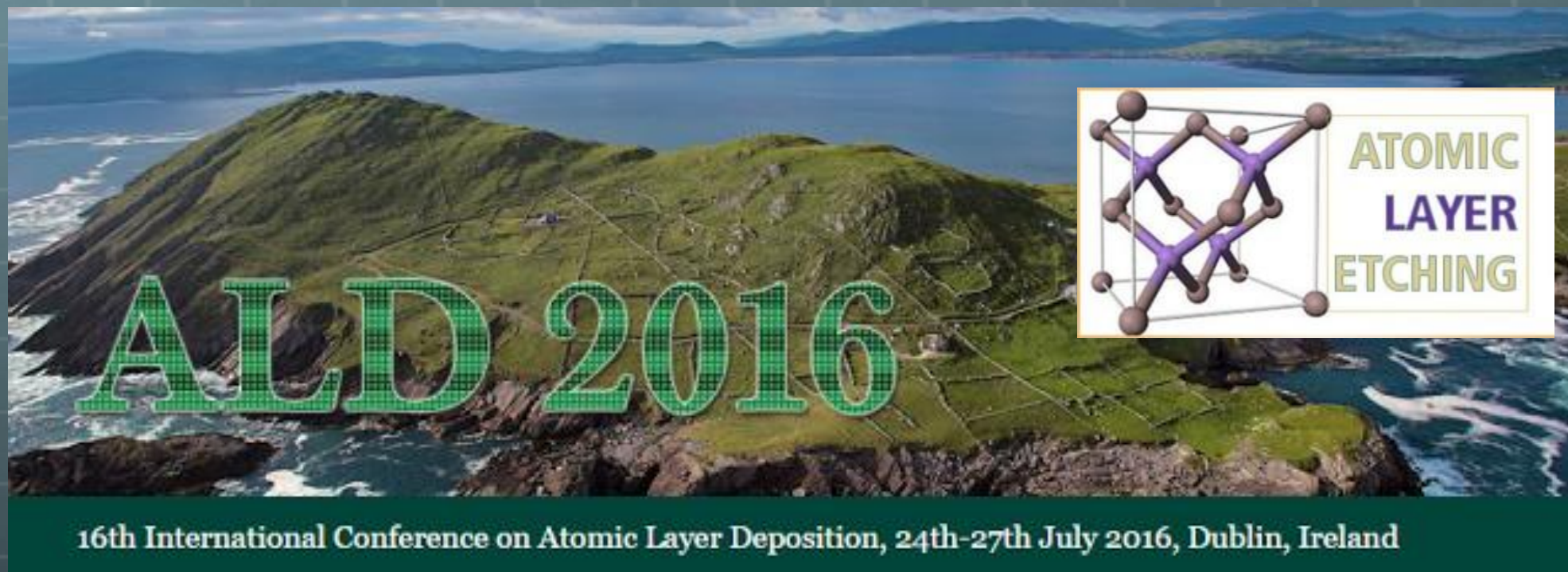
T. Faraz et al.
ECS J. Solid State Sci. Technol. 2015;4:N5023-N5032

ALE cyclic process, consisting of four steps: (1) Chemisorption of a gas (chlorine in this case) on the surface (chemisorption step). (2) Chamber evacuation to remove all but the chemisorbed gas. (3) Ion irradiation to chemically sputter the top layer of substrate atoms (etching step). (4) Product evacuation to remove the etch products from the chamber

Summary

- **ALD/CVD Metal & High-k** precursor market has totaled over \$258M in 2015 and could approach \$400M by 2020
- **ALD/CVD Dielectric precursor** market will grow from \$250M to \$300M by 2020 driven by multipatterning and migration from LPCVD & PECVD to ALD
- **ALD Equipment** market to Double from \$650 M to \$ 1,300 M in the next 3-4 years
- **Nano Patterning & 3D Devices** drive the market for Atomic layer Processing for:
 - Deposition
 - Etching
 - Selective bottom up growth

ALD2016 Dublin Ireland



ALD 2016 Co-Chairs:

Simon Elliott
Tyndall National Institute,
Ireland



Jonas Sundqvist
Division of Solid State Physics,
Lund University, Sweden



www.ald2016.com

Thank you!

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<http://techcet.com/product/high-kald-precursors/>