



Electronics Materials Information

Critical Materials Report Advisory:

QUARTERLY UPDATE

for

The Critical Materials Council
for Semiconductor Fabricators
(CMCFabs)

By TECHCET Group
A TECHCET CA LLC Company

March 2016

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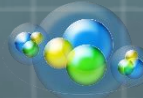
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Electronics Materials Information



Section 1

QUARTERLY UPDATE

ALD/CVD High K and Metal Precursors

Sematech Critical Materials Council

Jonas Sundqvist, Ph.D.

September 2016

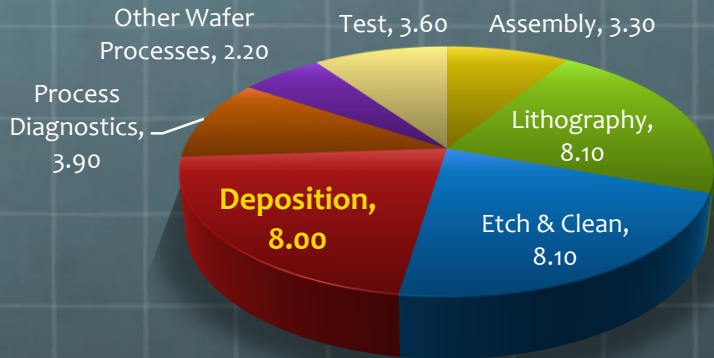
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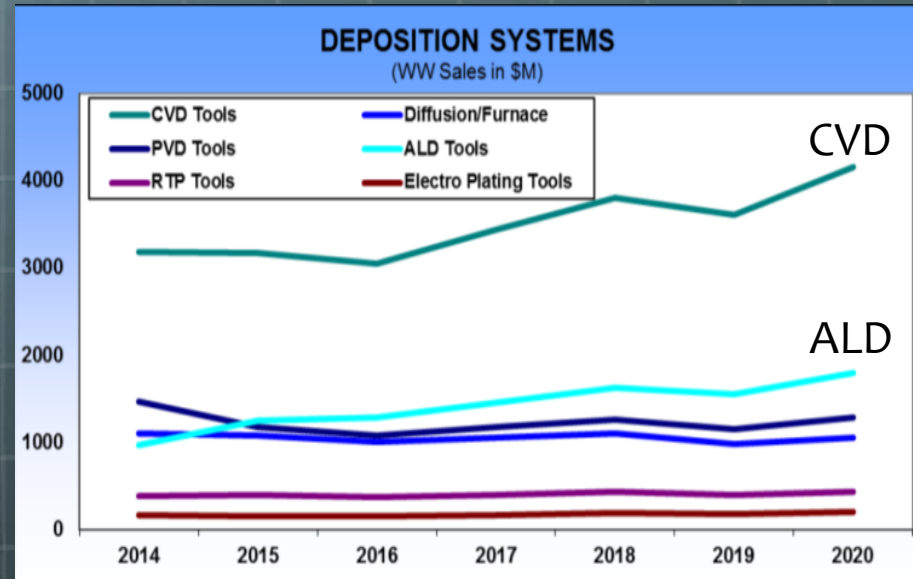
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ALD/CVD Industry Outlook

Wafer Equipment Market (Billion US\$)
VLSI Research April 2016



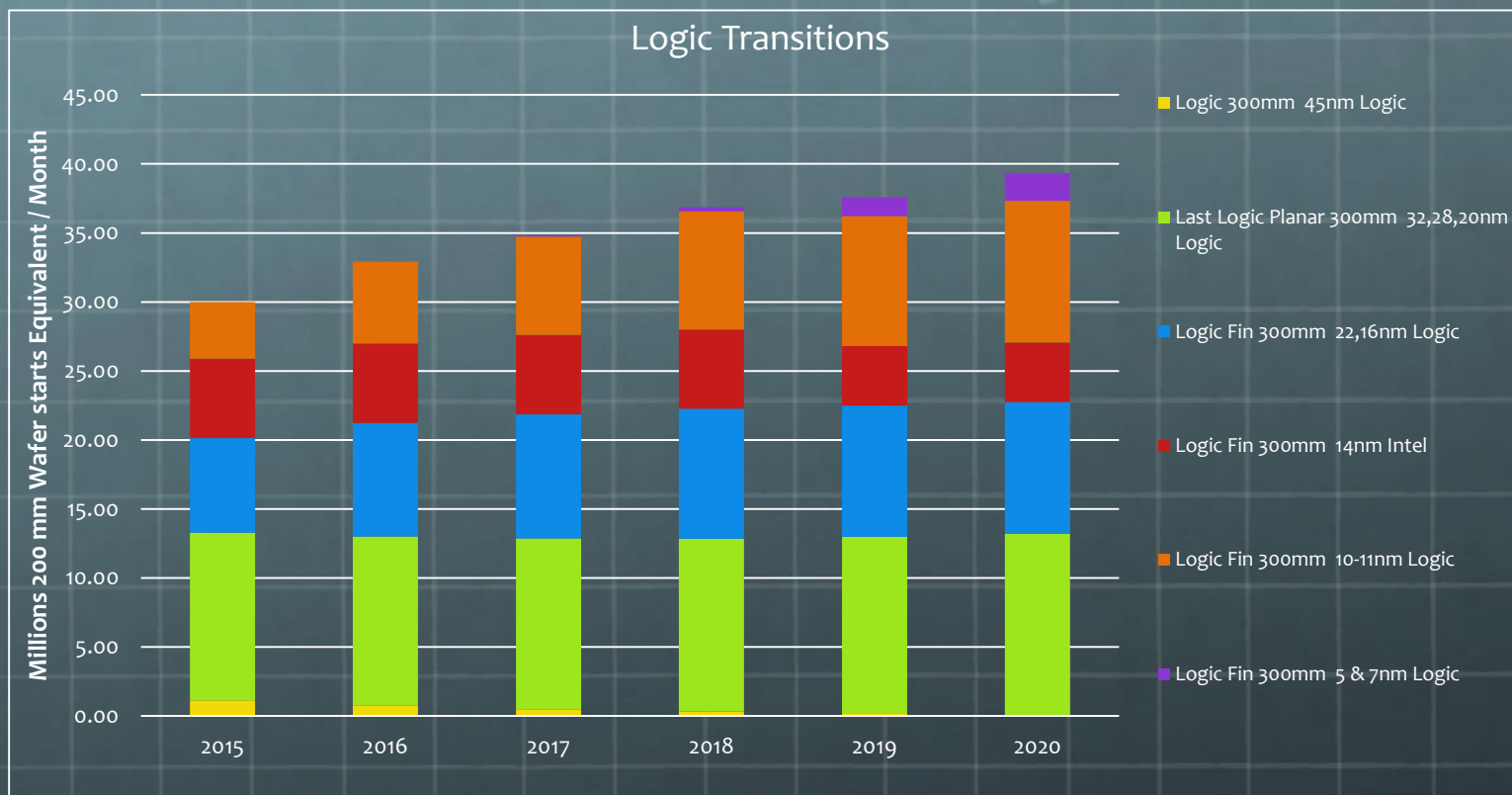
Adopted from ASMI INVESTOR PRESENTATION
July 28, 2016, Q2 2016 RESULTS



Risto Puhakka VLSI Research May 2016, CMC Conference Hillsboro

- 🌐 CVD & ALD show continued high growth Potential
- 🌐 Growth driven by scaled 3D devices (FinFET & 3DNAND) and Wafer starts
- 🌐 ALD passed PVD in 2015(!)

ALD/CVD Industry Outlook



Intel 45 nm and all sub 45 nm nodes except for 32/28 Low power use ALD



Growth in Wafer Starts & Transition to 10 & 7 nm will drive growth in ALD & CVD Metal precursors further especially Hf High-k & Cobalt (see slide 11)

Scaling trend → ALD Migration

I - Migration to ALD due to shrink

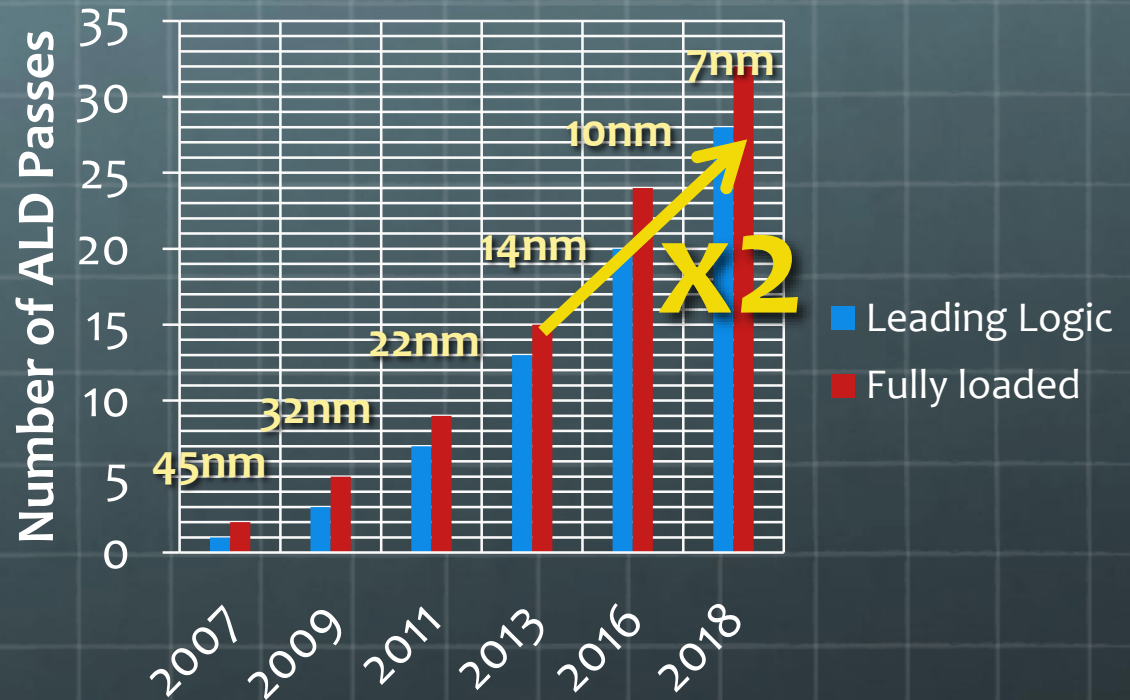
- LPCVD SiN and SiO₂
 - PECVD SiN and SiO₂
 - CVD Metals
 - CVD Metal nitrides
 - PVD Metals
- ALD

II - New Materials & Unit Processes:

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

III - 3D Devices:

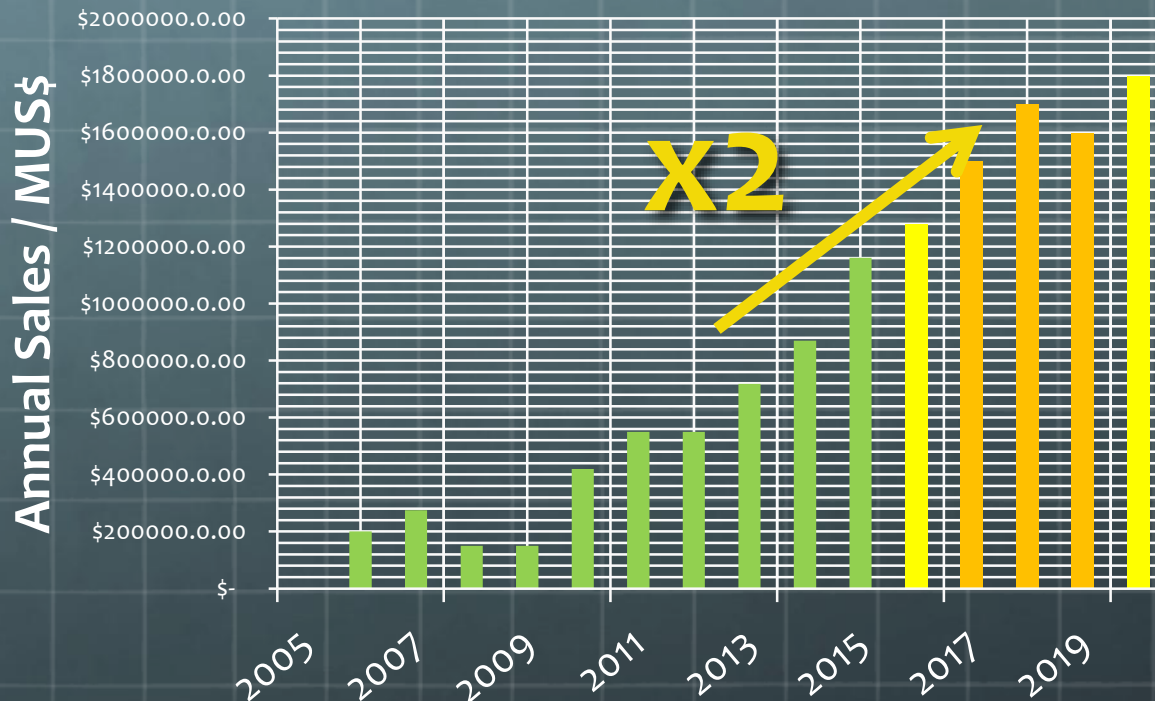
- ✓ DRAM, FinFET, 3DNAND → More ALD



🌐 15 ALD passes at 14nm and more than 30 at 7 nm according to estimations

ALD Equipment Market

ALD Wafer Systems Sales (Gartner, VLSI, ASMI)



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

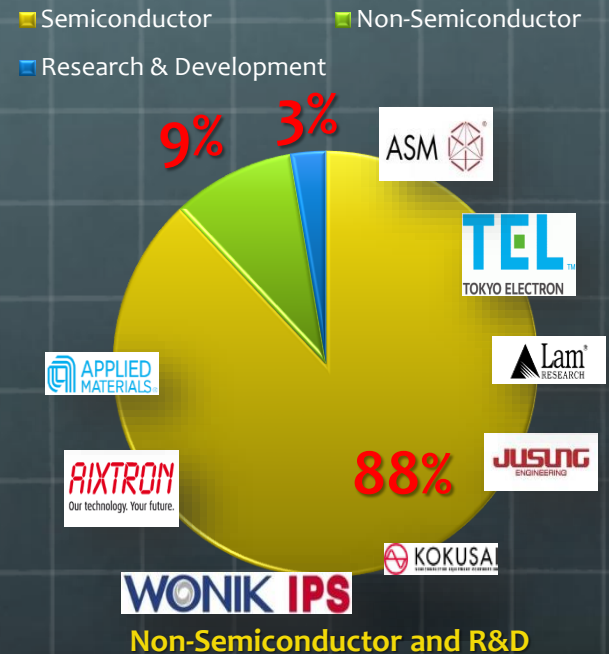
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ALD Equipment 2015 US\$ 1.1 to 1.3 B

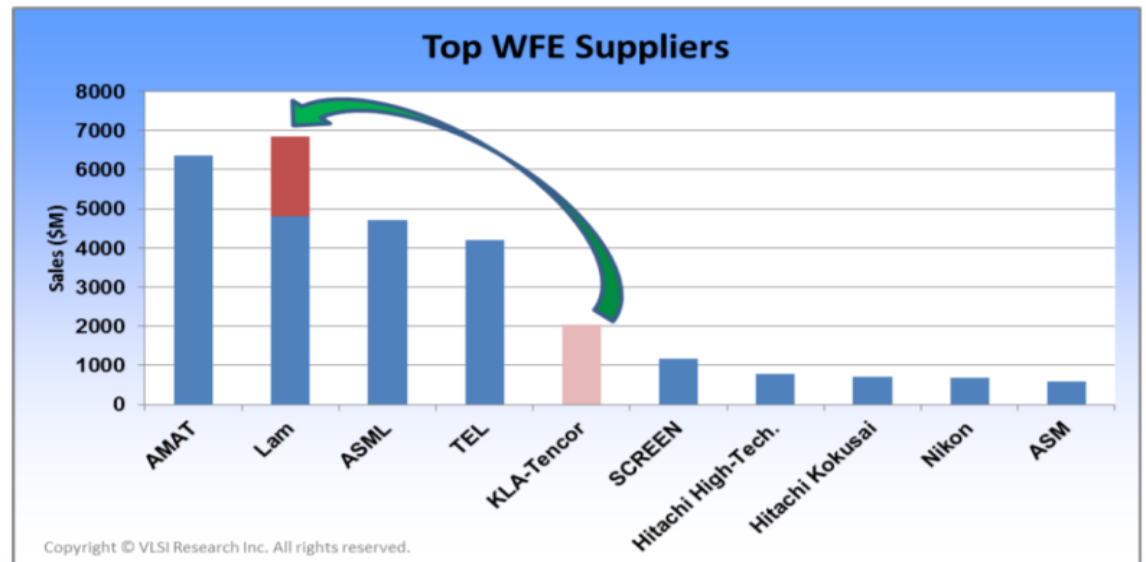


OEM Mergers

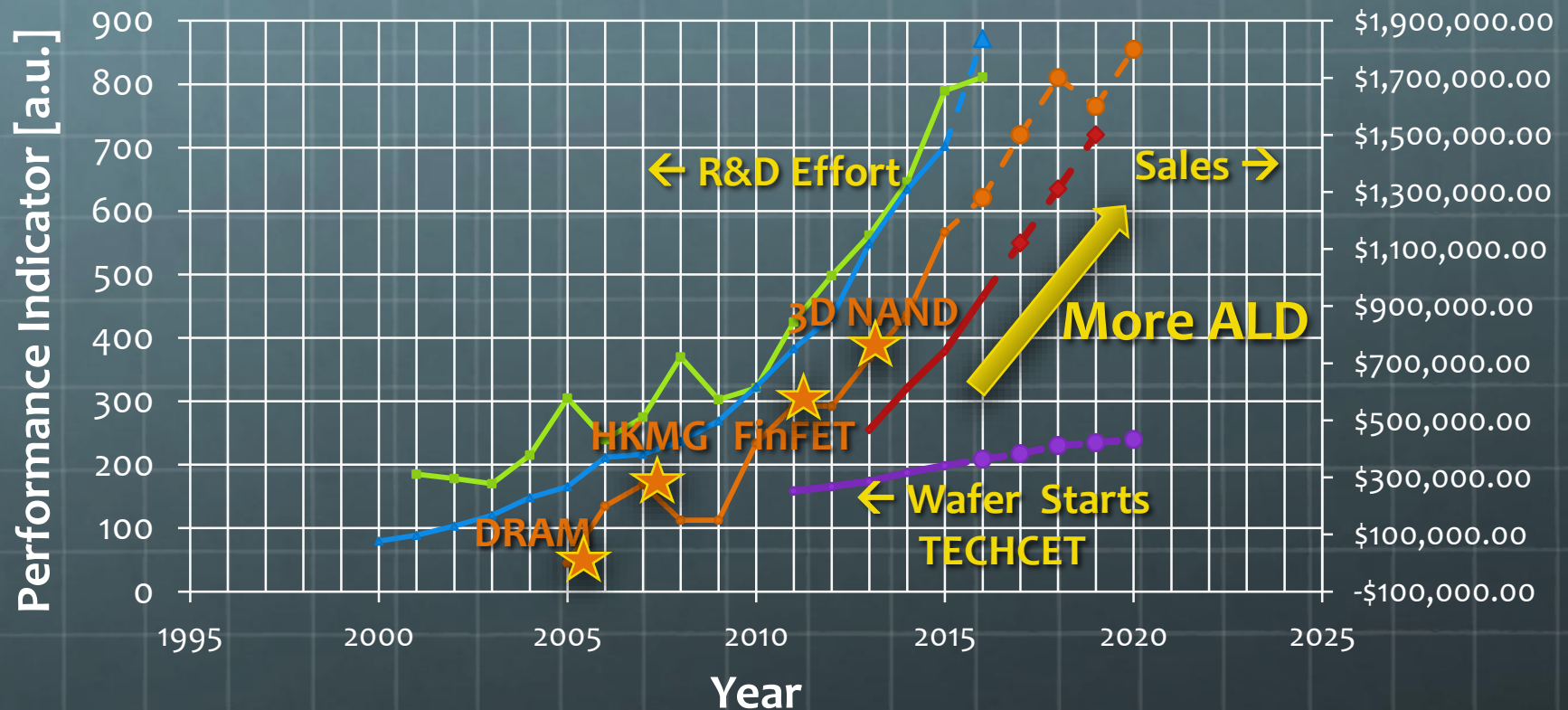
- The Lam Research & KLA Merger increases concentration
- However ALD Innovation drive by smaller Companies (ASM, Jusung, Ultratech, Veeco, Picosun, Beneq)

- Top 5 has 73% share of total WFE

VLSI Research
CMC Conf. May 2016



ALD Forecast



- ALD Conference delegates
- ALD Google Scholar x100
- ALD Systems Sales (Gartner, VLSI, ASMI)

- Total ALD Annual Wafer Starts (200mm Equivalent, TECHCET)
- ALD Single Wafer System Sales (Gartner, VLSI, ASMI)

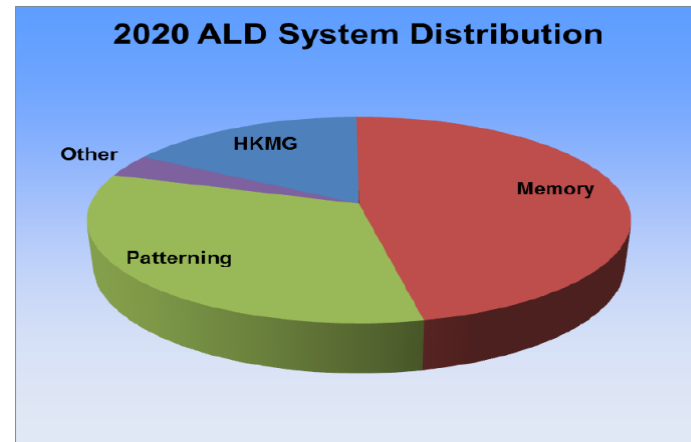
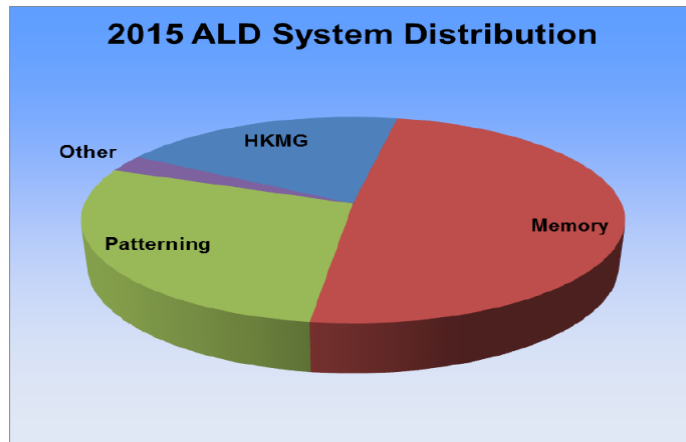
ALD / CVD Precursor Forecast

Forecasts Adjustment made with respect to:

- High-k consumption rate for DRAM 1,5X
- Wafer starts

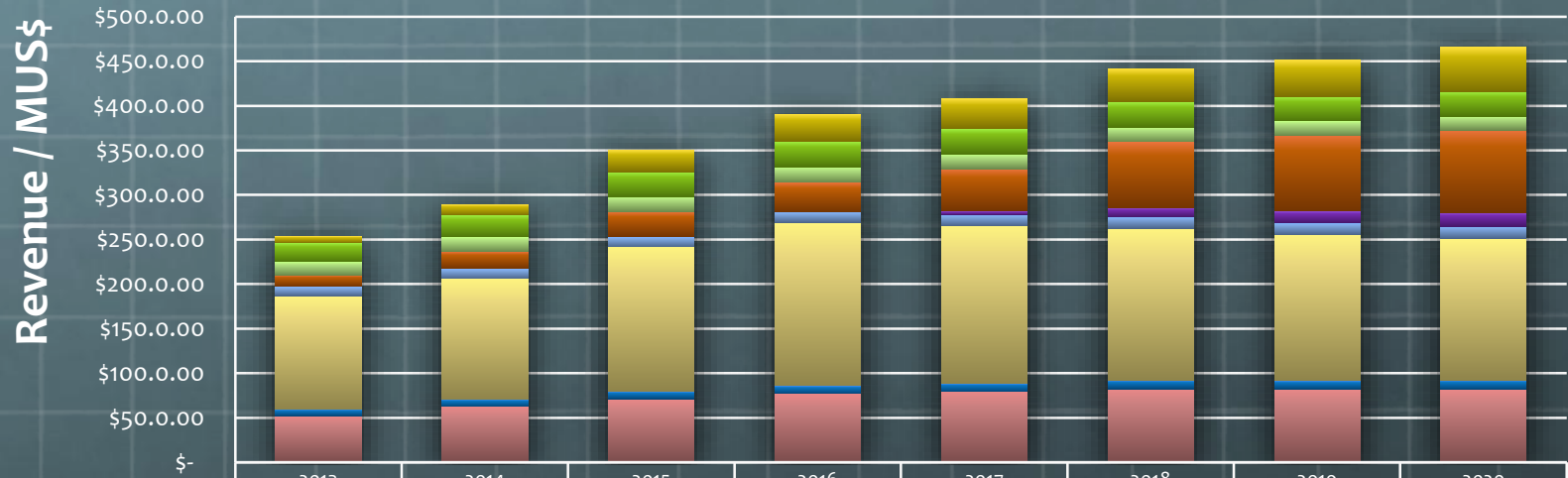
ALD Distribution

Memory and patterning films drive demand



ALD / CVD Precursor Forecast

Total ALD&Metal Precursor Market



	2013	2014	2015	2016	2017	2018	2019	2020
■ Total Co (CoCOP)	\$7.424.30	\$12.198.75	\$24.761.50	\$30.710.48	\$33.639.00	\$36.626.88	\$40.286.11	\$49.504.55
■ Total Ta (PDMAT)	\$21.357.07	\$24.527.87	\$27.433.77	\$28.421.69	\$28.160.26	\$28.387.77	\$27.671.87	\$27.350.01
■ Total Ti (TDMAT)	\$14.689.46	\$16.097.26	\$17.010.20	\$17.062.11	\$16.693.87	\$16.524.25	\$16.040.44	\$15.664.01
■ Total Hf HKMG (HfCl ₄)	\$12.833.71	\$19.013.84	\$27.709.20	\$32.808.70	\$47.154.44	\$73.713.14	\$84.969.13	\$92.591.75
■ Total (Hf,Ta, Sr etc.)	\$213.43	\$204.27	\$185.51	\$558.75	\$3.920.17	\$10.234.64	\$13.115.37	\$15.416.58
■ Total Al (TMA)	\$10.450.75	\$11.400.98	\$11.694.49	\$11.957.20	\$12.398.51	\$12.830.79	\$13.096.79	\$13.617.42
■ Total Zr Capacitor (ZrCp, TEMAZr)	\$127.174.94	\$135.077.72	\$161.860.51	\$182.923.78	\$176.992.10	\$170.572.05	\$163.798.04	\$159.044.79
■ Total Ti (TiCl ₄)	\$7.455.01	\$8.185.54	\$8.690.89	\$8.997.96	\$9.358.50	\$9.698.35	\$9.857.72	\$10.224.30
■ Total W (WF ₆)	\$52.223.39	\$62.793.82	\$71.072.71	\$77.229.32	\$79.349.68	\$82.374.13	\$82.092.59	\$81.950.51

Tungsten / WF6 Update

- Lam Research Enables Next-Generation Memory with Industry's First ALD Process for Low-Fluorine Tungsten Fill
- Uses Hydrogen down stream treatment
- Targeting 3D NAND Tungsten metallization
 - lowers fluorine content by up to 100x
 - lowers stress by up to 10x
 - reduces resistivity by over 30%



Tungsten / WF6 Update

- WF6 is used in Tungsten metallization in CMOS, DRAM and 3DNAND – Fluorine is diffusing into the device causing derterminal reliability issues. Alternatives are:
 - WF6 process w/ H₂ treatment (see Lam Research)
 - MO-precursor → High resistivity
 - Entegris 6 kg WCl₆ ProEvap™ Vessel launched






Harvard University initiates ALD patent infringement suits towards US chip makers

- Harvard University initiates patent infringement suits to protect inventors' rights in atomic layer deposition **alkyl amide precursor used for High-k applications like DRAM and other high aspect ratio capacitor based technologies.**
- US chip makers Micron & Globalfoundries are named
- Hf & Zr metal alkyl amides are used for HfO₂ and ZrO₂ based high-k dielectrics in DRAM and embedded DRAM
- Logic Gate Stack does not use alkyl amides

Air Products Spin Off Update



 **September 01, 2016 Lehigh Valley, Pa. Versum Materials, Inc., the planned Electronic Materials Division spin-off company from Air Products today announced the proposed members of its Board of Directors.**

About Versum Materials

With \$1 billion in sales in fiscal 2015, Versum Materials has approximately 1,900 employees, 14 manufacturing and six research and development facilities in the Americas and Asia. Versum Materials is comprised of two primary business segments, Materials (74% of fiscal 2015 revenues) and Delivery Systems and Services (26% of fiscal 2015 revenues). It participates in six of seven key semiconductor process steps, supplying high purity specialty process gas, cleaners and etchants, slurries, organosilanes and organometallics deposition films, and equipment.

Mergers: Linde & Praxair






Praxair, Linde said to be discussing \$60 billion merger (8/19/2016) Praxair Inc. is in discussions to combine with Germany's Linde AG.

- 1) **There is a lot of overlap** between the two companies
- 2) Both Linde and Praxair have **discontinued ALD / CVD Precursor businesses** from the past → No short term impact for ALD/CVD

Mergers: Dow/DuPont

Mergers: Commission opens in-depth investigation into proposed merger between Dow and DuPont

(8/15/2016) by CMCFabsftp - Brussels, 11 August 2016 The European Union's antitrust authority opened a full-blown investigation into the proposed merger of Dow Chemical Co. and DuPont Co., which could require the companies to make bigger concessions to clear their blockbuster deal. **The European Commission has opened an in-depth probe to assess whether the proposed merger of Dow and [...]**

-  The Merger would create the world's largest integrated crop protection and seeds company.
-  Dow has exited all ALD Precursor business except for TMA
-  Metal alkyl amide license deal with Harvard university handed over to STREM Chemicals (see Harvard lawsuit next)

“The livelihood of farmers depends on access to seeds and crop protection at competitive prices. We need to make sure that the proposed merger does not lead to higher prices or less innovation for these products.”

Dow TMA Incident

OSHA Cites Dow Subsidiary Following January Explosion

(8/12/2016) by CMCFabstfp - Federal labor officials last week cited a Dow Chemical subsidiary over violations found in the wake of an explosion early this year. The Occupational Safety and Health Administration conducted an inspection of Rohm-Haas Electronics Material's North Andover, Mass., facility following the Jan. 7 explosion that injured four workers. The workers were purging cylinders of residual [...]

OSHA Cites Massachusetts Firm for Chemical Explosion

A Massachusetts chemicals manufacturer has been cited by federal labor officials following a **January explosion that injured four workers**. The U.S. Department of Labor says an investigation by the Occupational Safety and Health Administration determined that **Rohm-Haas Electronics Material failed to adequately design, inspect, maintain and operate the chemical process that led to the fire [...]**

"In total, the agency levied 11 workplace safety violations against the company and proposed \$129,200 in penalties. OSHA will also place Rohm-Haas in its Severe Violators Enforcement Program."

Thank You!
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