

TRENDS IN CMP AND THE IMPACT ON CMP SLURRIES AND PADS

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LINX BACKGROUND

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Linx Consulting

1. *We help our clients to succeed by creating knowledge and developing unique insights at the intersection of electronic thin film processes and the chemicals industry*
2. *The knowledge is based on a core understanding of the semiconductor device technology; manufacturing processes and roadmaps; and the structural industry dynamics*
3. *This knowledge is leveraged to create advanced models, simulations and real-world forecasts*
4. *Our perspectives are by direct research and leveraging our extensive experience throughout the global industry value chain, including:*
 - Experience in global electronics and advanced materials and thin film processing industries
 - Experience in the global chemicals industry
 - Experience at Device Producers
 - Experience at OEMs



Linx Consulting Service Portfolio

- **Multi-Client Reports**

- IC Materials
 - CMP
 - Deposition
 - Patterning
 - Cleaning
 - Gases
- III-Vs, TSV, WLP, Solar

- **Proprietary Projects**

- Market Planning
- M & A
- Growth and Diversification
- Supply Chain Optimization
- Technology Commercialization
- Strategic Planning
- Voice of the Customer

- **Econometric Semiconductor Forecast**

- Financial planning
- Sales and Operational planning
- Forecasting

Hilltop Economics LLC

- **Cost Modeling**

- Client demand modeling
- Product development
- Bill of Materials quantification

IC Knowledge, LLC

- | | | |
|--------|-------------|----------------------|
| – Semi | – Packaging | – Nano Technology |
| – LCD | – PV | – LED/ Compound Semi |



Industry Analysis Reports Offered

CMP Focused:

- 1. *CMP Technologies and Markets to the Sub-10nm Node (6th edition)***
- 2. *Specialty Abrasives in CMP (4th edition)***
- 3. *CMP in TSV (2nd edition)***
- 4. *Wafer Polishing Technologies and Markets***

5. *Advanced Thin Films for FEOL and BEOL Applications (5th Edition)*
6. *Advanced Cleaning and Surface Preparation: Technologies and Markets (5th Edition)*
7. *Advanced Patterning Forecasting (Semi-Annual)*
8. *Chemicals and Materials for TSV Applications*
9. *Electronic Specialty Gases*
10. *Global Market for MO Precursors*

- 11. *The Econometric Semiconductor Forecasting Service***

- 12. *Strategic Cost Model***



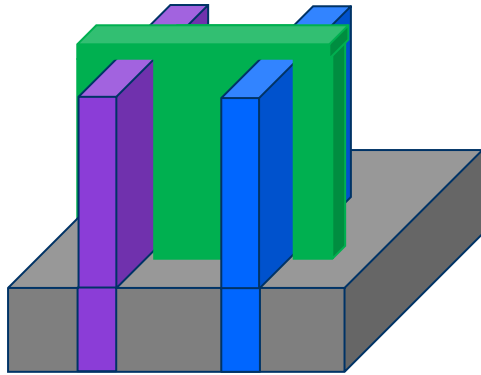
SEMI INDUSTRY TRENDS

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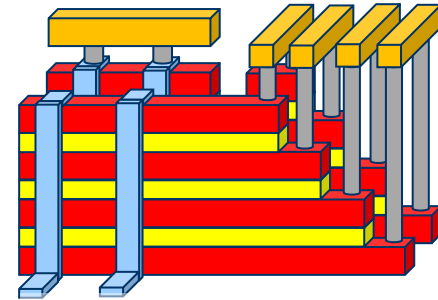
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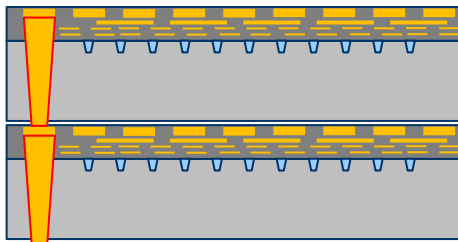
3D Processing and New Materials Drive Scaling



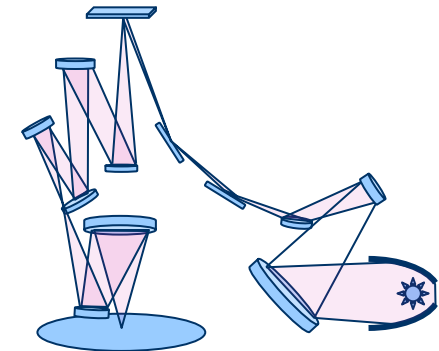
Gate Architecture



New Memory



3D Packaging



EUV



Better Inspection Tools are Impacting CMP

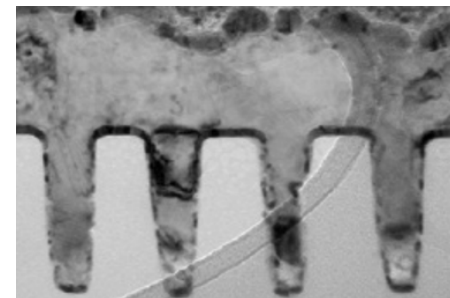
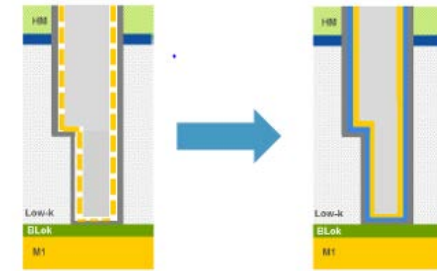
- Optical (particle detection) systems such as SP3 and SP5 are identifying new defects
- Optical (particle detection) performance improvements have enabled the CMP community, and more generally wafer fabs, to “see” and identify more a greater number of process defects
- It is expected the most advanced detection capability will reach 10-15nm particle detection as well as enhanced capabilities to pick up micro-scratches
- In general, many new defects are driven by the introduction of new materials and processes
- A lot of the particle related challenges in the future will be driven by introduction of new devices (not yet in production) with many different new materials. Examples of new devices include the following:
 - Advanced DRAM structures with new transistors, capacitor dielectrics and capacitor electrodes
 - STTMRAM, a possible replacement for DRAM
 - VNAND (3D NAND), which will have a lot of challenges due to the high aspect ratios and deep structures will be a challenge
- Based on the above, the industry will need to use very pure chemicals, with greater dilution to lower metallic and particulate contamination
- P3 buffing will also be more widely used to control defectivity



Logic Growth Drivers



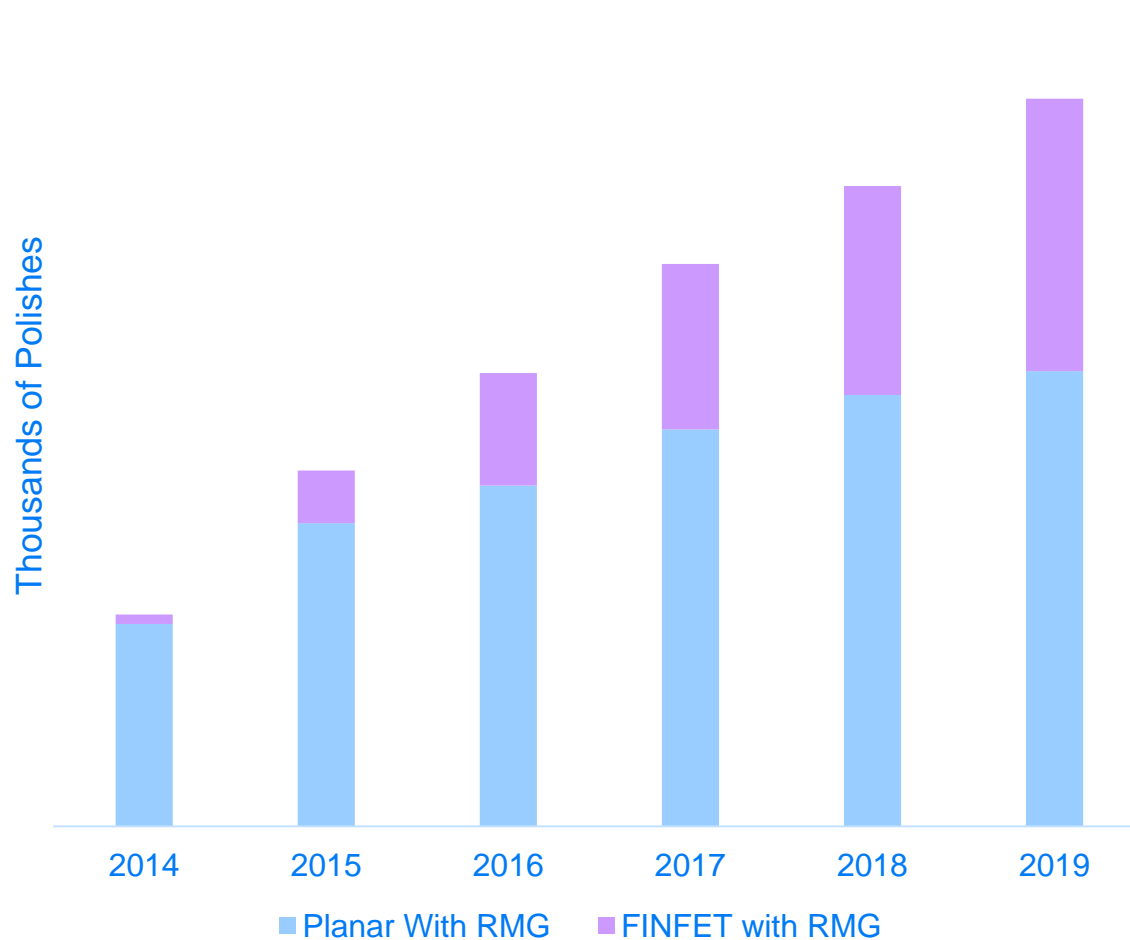
- RMG and FEOL finFET processing has added up to 7 CMP steps for advanced devices
- Buffs becoming critical to reduce defectivity
- IMEC has demonstrated the integration of high-mobility channel InGaAs n-channel and Ge p-channel metal-oxide-semiconductor field-effect transistors. Also possible - all Ge High Mobility Structures
- CVD Co improves Cu wetting and extends Cu gap fill. CVD Co is thin, continuous, conformal layer that repairs any discontinuities for barrier/seed
- A cross-section TEM of a 50-nm trench structure coated with a ~5nm Ru:TaN liner followed by ECD copper. The filling characteristics are equivalent to seeded copper, and direct plated films possess generally larger grain size characteristics



Sources: Applied Materials, IMEC and Albany NanoTech



Emerging Logic CMP Operations (1000s)



FinFET contains the following steps:

1. STI (included in other section)
2. Poly
3. ILD 0
4. POP
5. MG
6. SAC
7. W (included in W)

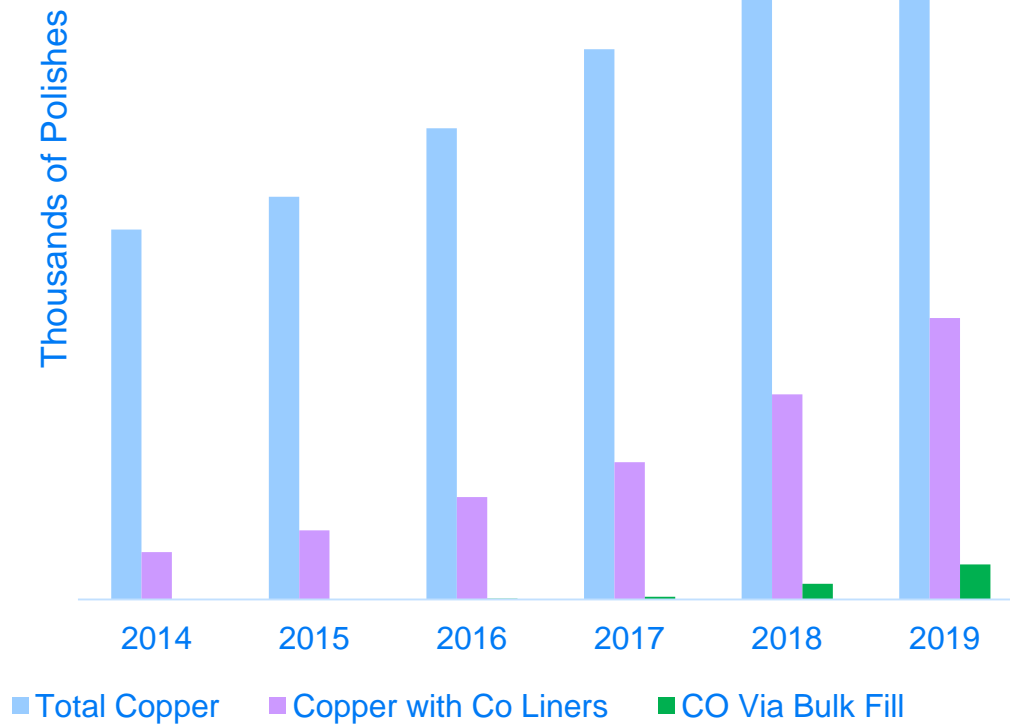
Can also include:

- High mobility channel
- Novel contacts and gates with high mobility channel



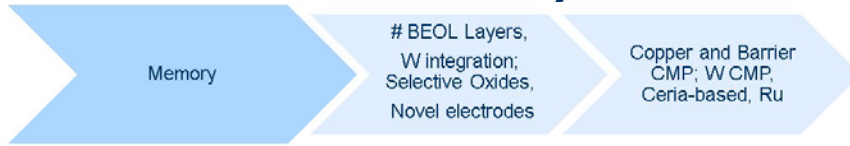
Total Cu, Co via and Co Containing CMP Operations (1000s) ASIC

- Co Liners is a subset of Copper
- Co Via is stand alone

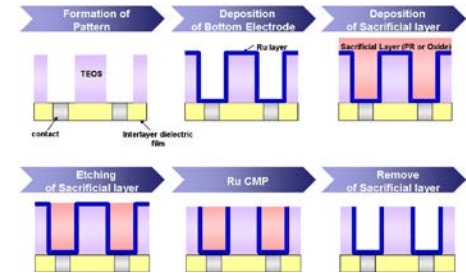




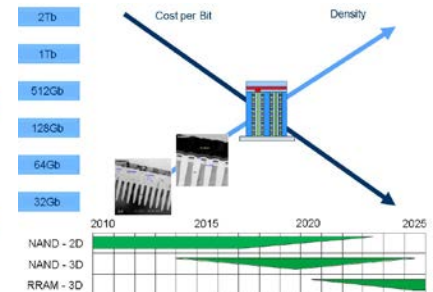
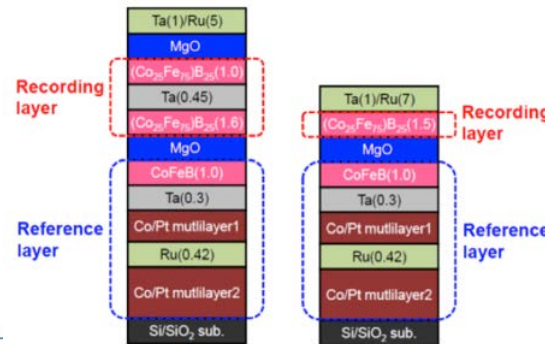
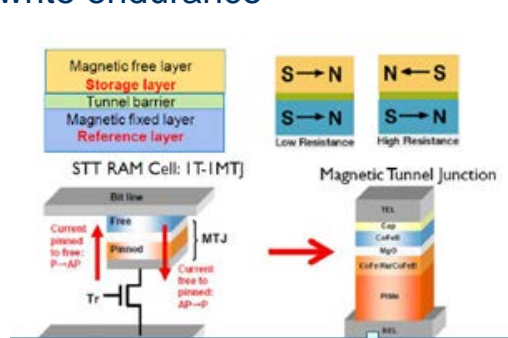
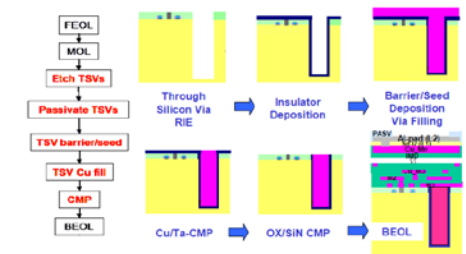
Memory Growth Drivers



- Ru electrodes may be used with novel dielectrics for DRAM
- DRAM scaling comes to an end within ~ 5 years. TSV technology can be used to continue to scale density. HMC, etc.
- 2D and 3D NAND will be integrated simultaneously. 2D structures will require higher planarity and 3D will open up new W polishes as well as oxide steps
- MRAM provides non-volatile storage, high read write speeds, lower energy dissipation and high write endurance



Via-Middle TSV Process Flow



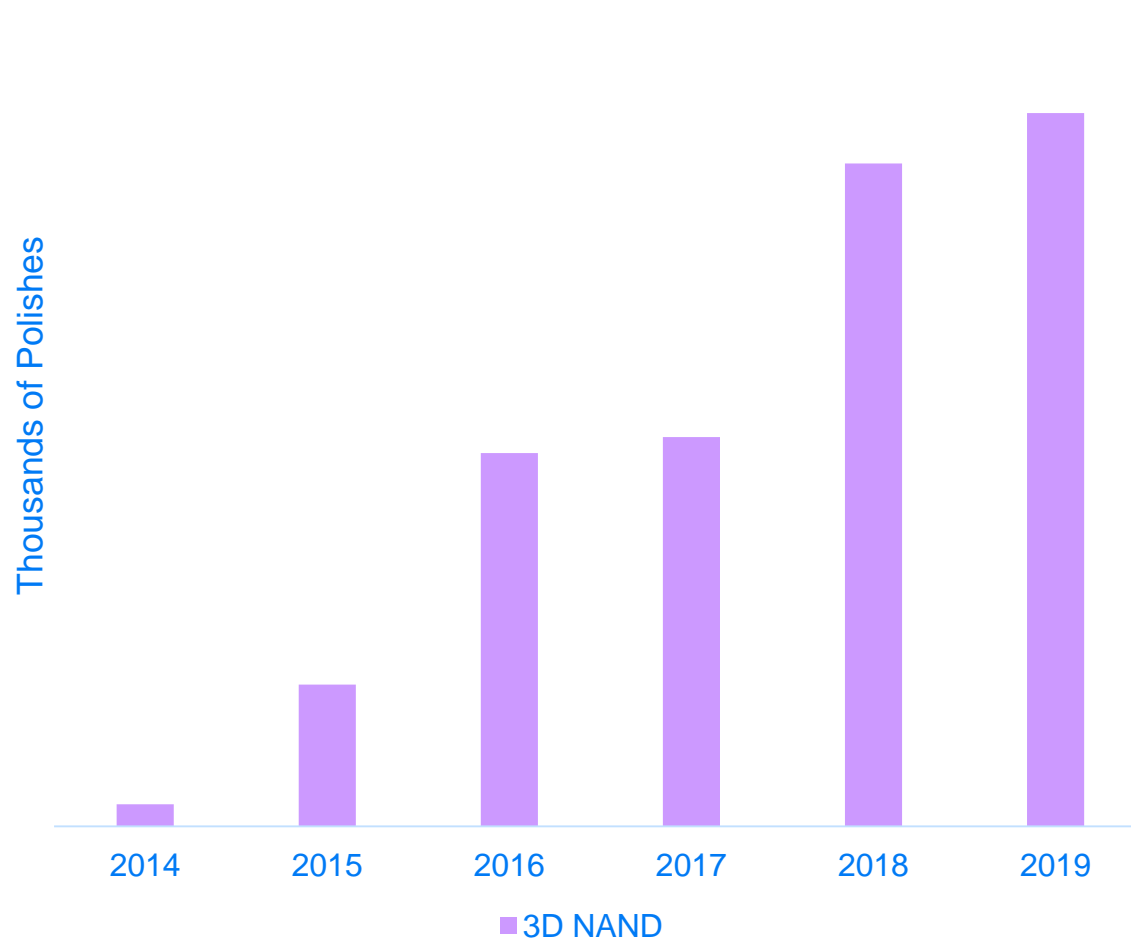
Sources: Matheson, JG Park, UMC/Sematech

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3D NAND W CMP Operations (1000s)



3D NAND W Polishes

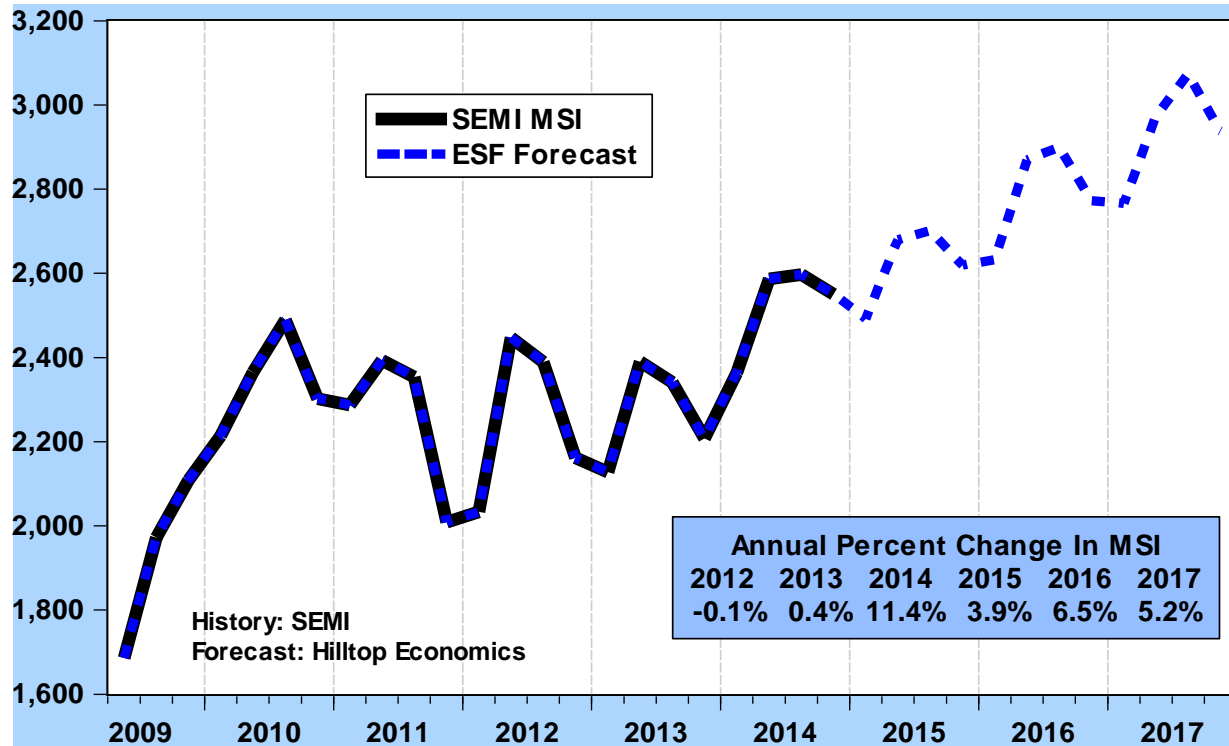
- We break this out due to the belief that 2 polishes are for very thick layers of W



CMP MARKET SITUATION



Econometric Semiconductor Forecast – Materials Demand Track Silicon



The mean absolute error is an exceptionally low 3.5%, an indication that the model and forecasting process has effectively captured semiconductor MSI's relationship to the macro economy.

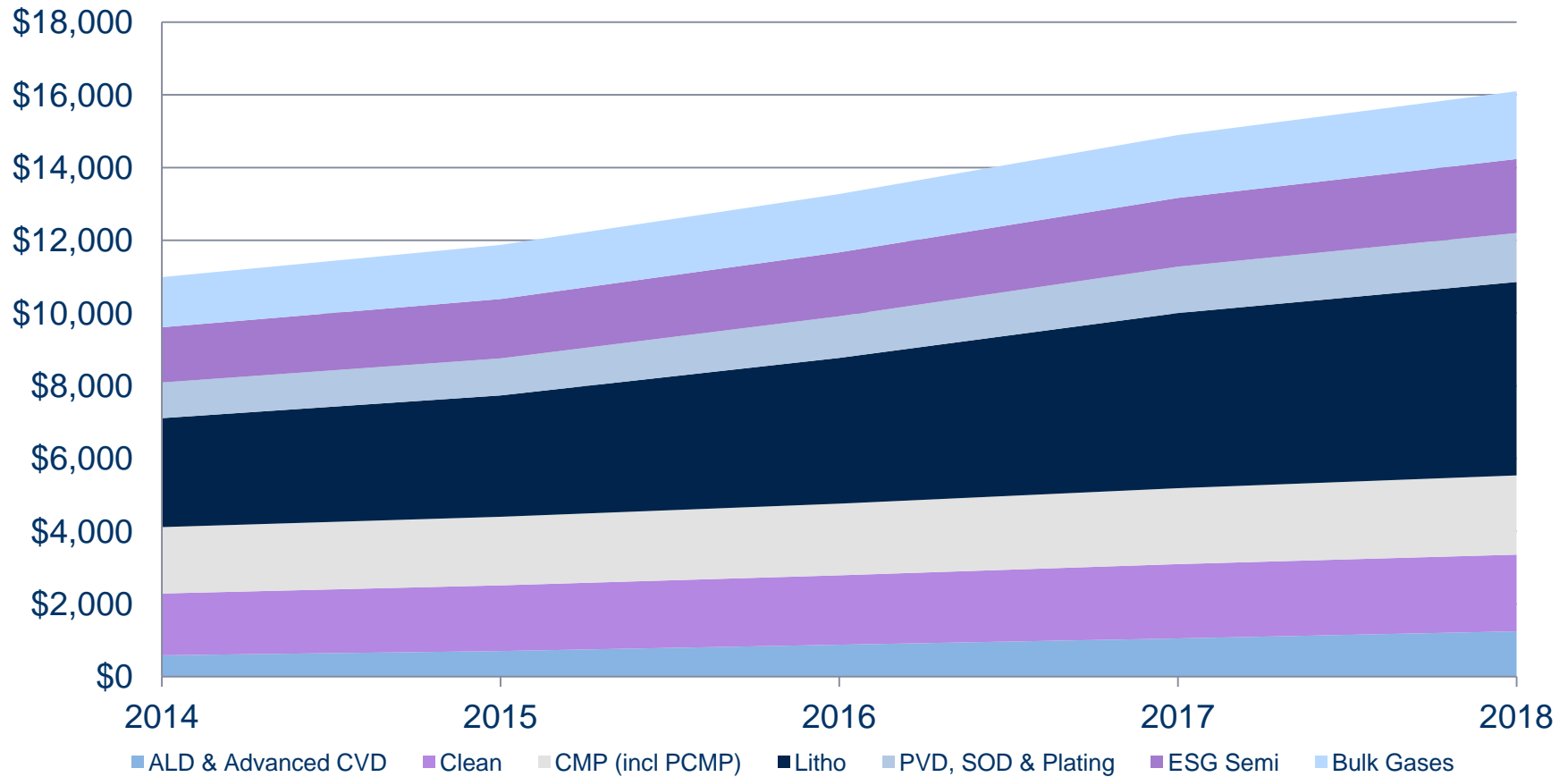
Source: Hilltop Economics LLC

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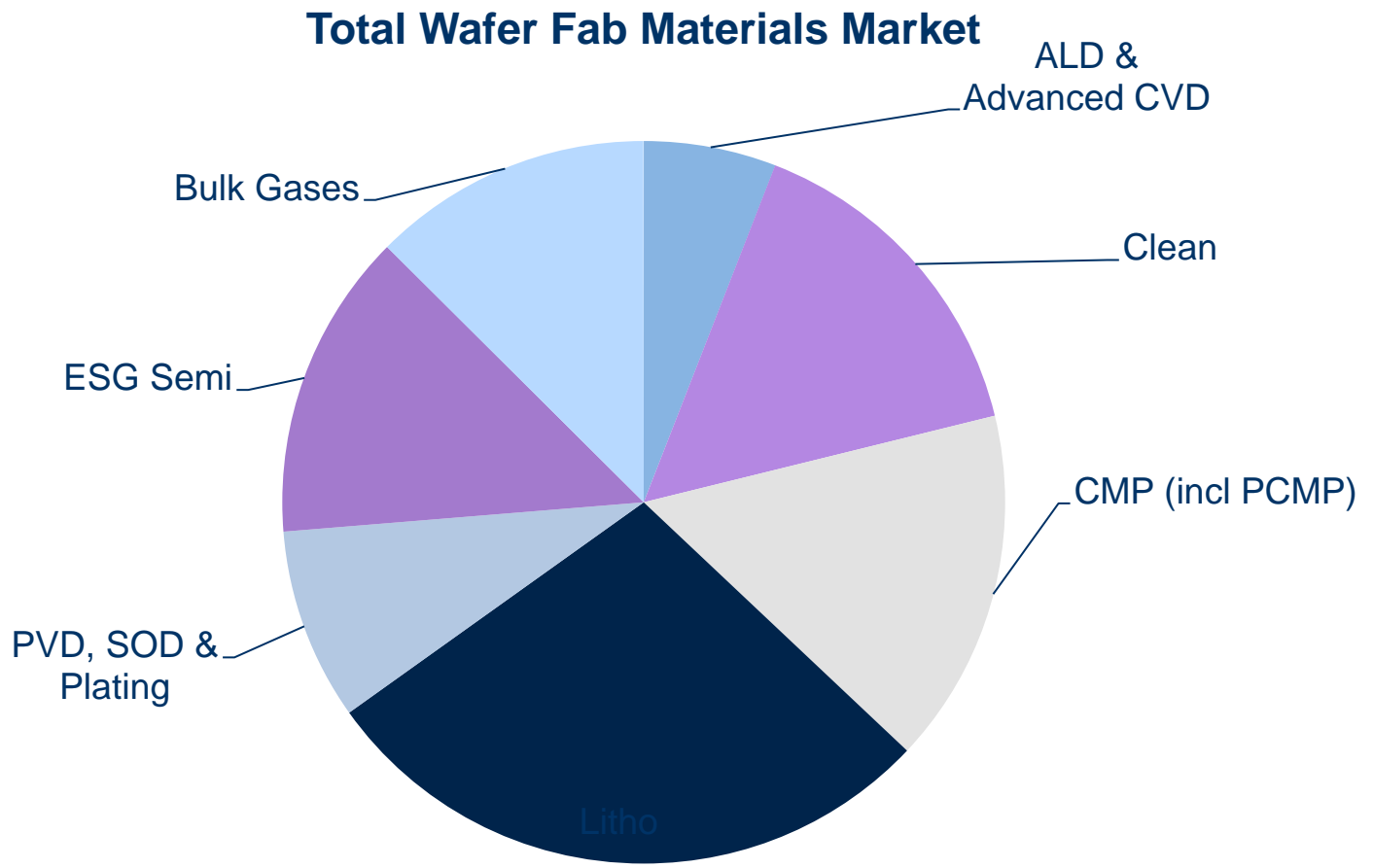


FEOL Wafer Fab Materials (\$M)





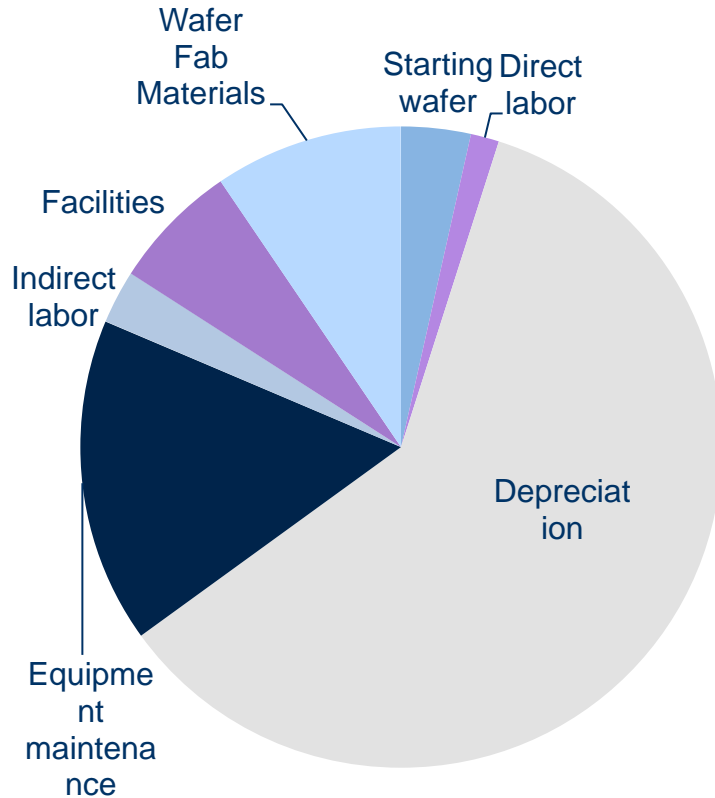
CMP Consumables is a Large Segment



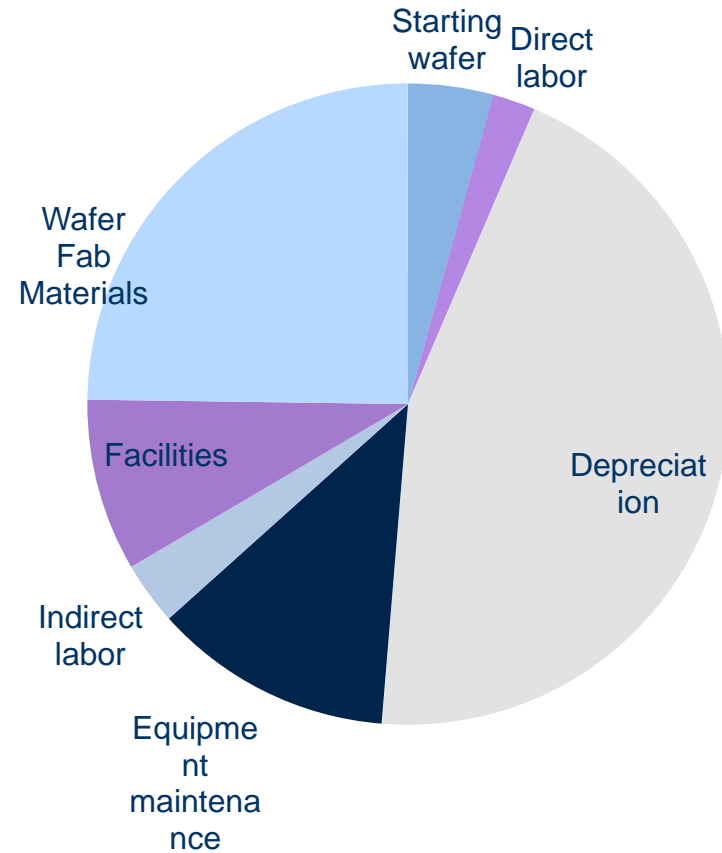


Leading Fab Cost Structures

28nm ASIC



20nm DRAM



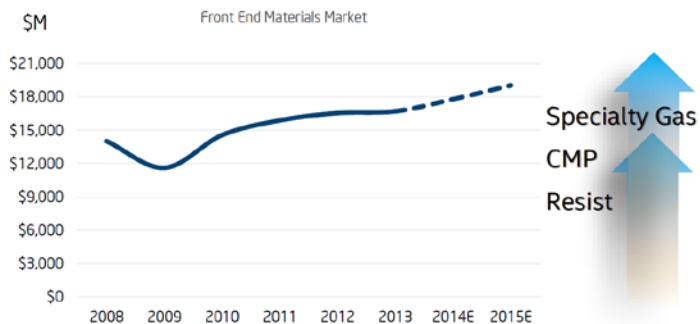


Growing Importance of Process Materials

Wafer fab materials supply in the semiconductor industry has segmented into discrete segments

- Special Commodities, which will cycle
- Specialty Materials, which solve problems, but are limited by small scale production
- Wafer fab materials represent about 20% of the cost for a 200mm logic wafer and about 10% of the costs for a 300mm logic wafer

Materials Segment	Special Commodities	Specialty Chemicals
Driver	<ul style="list-style-type: none"> • Large volume • Consistency • Cost 	<ul style="list-style-type: none"> • Low volume • High service requirements • Proprietary products <ul style="list-style-type: none"> • not easily substituted • Purchased for performance • Profit margins are higher
Key technologies	<ul style="list-style-type: none"> • High volume manufacturing 	<ul style="list-style-type: none"> • Proprietary formulations • Synthesis • Applications expertise



Source: Hendry Intel SMC 2014

CMP slurries and pads that can differentiate are still considered to be specialty chemical products as they are enabling integrations and device structures



Conclusions

- Strong industry growth outlook over the next several years
- CMP Consumables are becoming a major fab cost driver
- For 22nm and 14nm, the industry needs to have extremely tight control on the slurries and pad quality to control defects
- In advanced slurries, morphology of the slurry particles will be critical - No agglomerations and angular particles
- Trend to low abrasives – 0.5% or lower solids content as the slurry formulation trend is to greater chemo effect than mechanical effect
- Selectivity requirements will prove challenging to slurries as selectivity is increased and pads are tuned as a key point of the overall process control
- Defectivity control will be key for pads in terms of reducing scratching, dishing and erosion. Lower downforce and pad life extensions
- New applications in both memory and logic will continue to drive the opportunities for CMP going forward