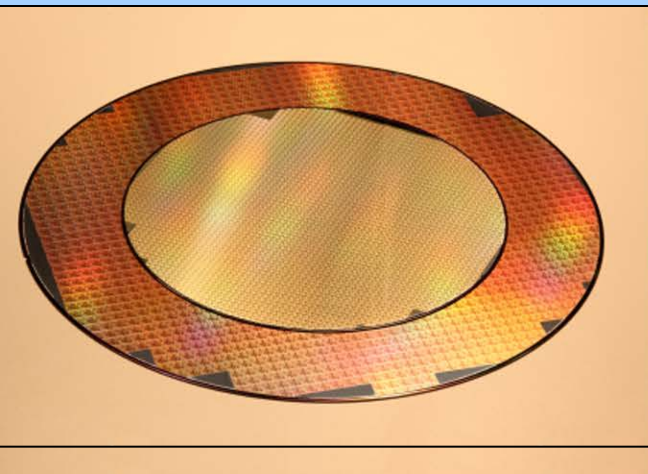
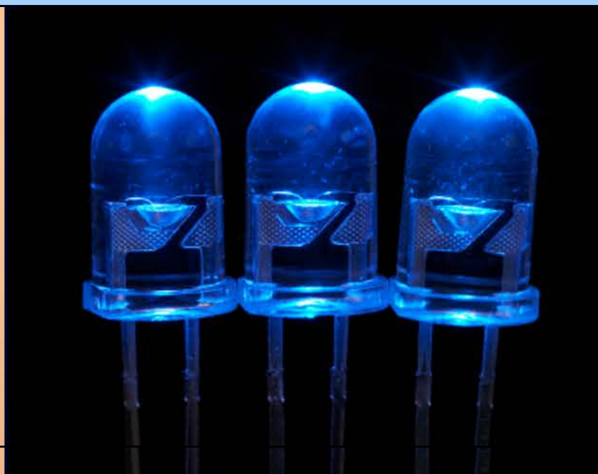
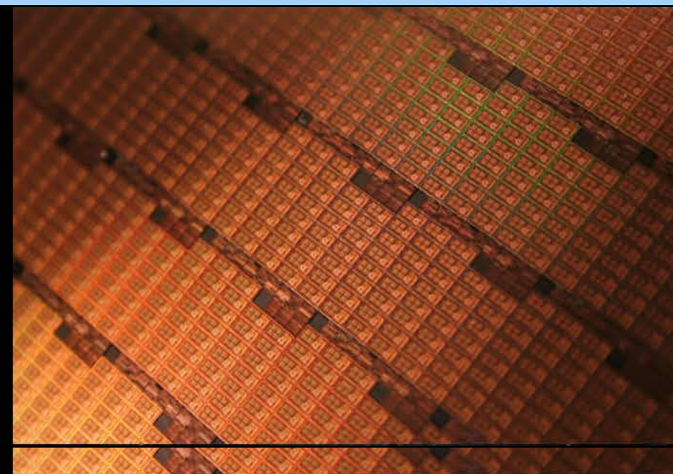

CMP Defects and Evolution of PCMP Cleans

March 27, 2017

Iqbal Ali
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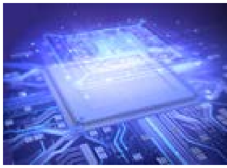
(408)839-9924

SPCC & PCMP Conference, Austin, TX

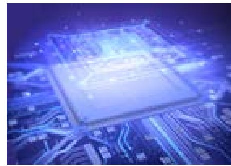
LINX-Consulting
see beyond the horizon

Agenda

1. Introduction to Linx Consulting
2. Where Have We Been and Where are We Going?
3. Defects in CMP
4. Post-CMP Clean
5. Conclusions



Introduction to Linx Consulting



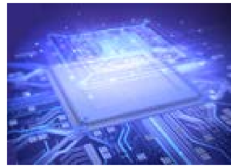
Linx Consulting

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
    - Bulk Chemicals
  - 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

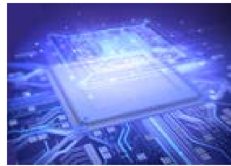
Hilltop Economics LLC

- **Cost Modeling**
  - Client demand modeling
  - Product development
  - Bill of Materials quantification

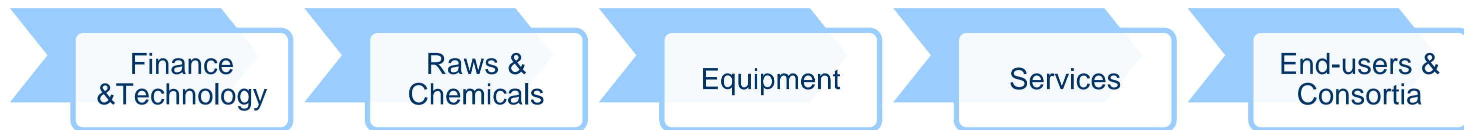
IC Knowledge, LLC

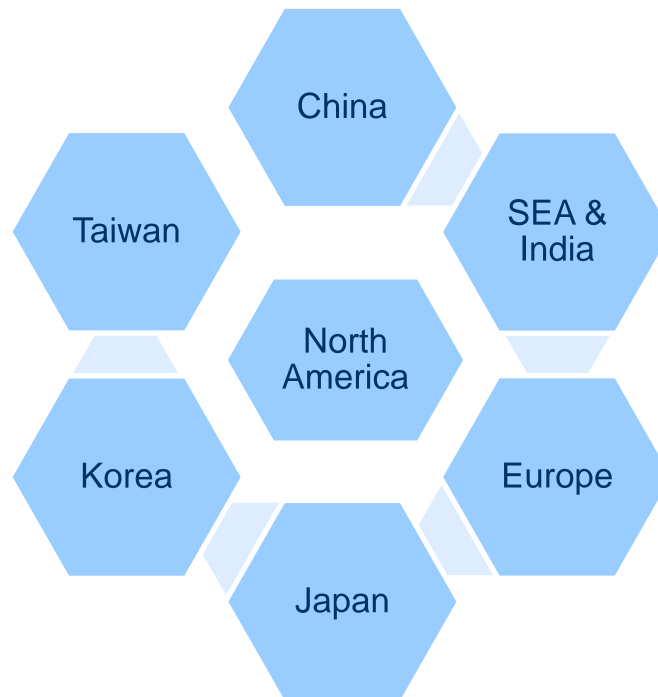
- Semi
- LCD
- Packaging
- PV
- Nano Technology
- LED/ Compound Semi

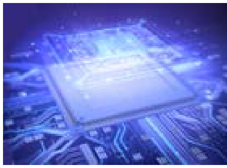
Conference Production - Surface Prep & Cleaning Conference & PCMP Cleans
www.spcc2017.com



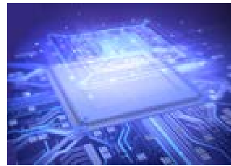
Customer Base in Semiconductors







Where Have We Been and Where are We Going?

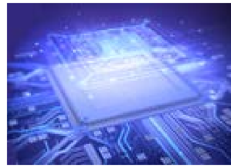


Total Cleans Chemicals Market

millions

	2014	2015	2016	2017	2018	2019	2020
PCMP	$122	$132	$147	$163	$175	$186	$192
Solvent Strip	$132	$132	$126	$146	$171	$197	$225
Bulk Wets	$1,324	$1,316	$1,383	$1,371	$1,401	$1,372	$1,342
PERR	$416	$399	$396	$402	$408	$423	$436

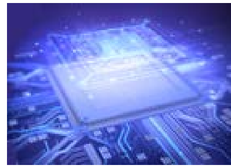
Post CMP Clean Market



millions

	2014	2015	2016	2017	2018	2019	2020
W PCMP	$24	$27	$30	$32	$34	$35	$34
Oxide PCMP	$18	$20	$21	$22	$23	$23	$23
STI PCMP	$8	$9	$10	$11	$12	$12	$12
Cu PCMP	$71	$76	$86	$97	$106	$116	$123

Many New Materials Enable Moore's Law



Source: ASM

(IL: Interface Layer)

(PM: Patterning Materials)

- Patterning Related
- BEOL
- FEOL
- Starting Materials

(*): Projection

1960
- Al
- SiO, SiN
- Si

1970
- BPSG
- Al
- SiO, SiN
- Si

1980
- TiW
- WSi, MoSi
- BPSG
- Al
- SiO, SiN
- Si

1990
- TiSi
- PtSi
- TiW
- WSi, W
- BPSG
- Al
- SiO, SiN
- Si

2000
- TaO
- SOG
- SiOC
- Ta/TaN
- Cu
- SiOF
- TiSi
- PtSi
- TiW/TiN
- WSi, W
- BPSG
- Al
- SiO, SiN
- Si

2010
- SiCN
- TiAlC MG
- ZrO
- Hf(Si)O
- AlO
- pSiOC
- SOI
- SiGe(B)
- TaO
- SOG
- SiOC
- Ta/TaN
- Cu
- SiOF
- TiSi
- PtSi
- TiN
- W
- BPSG
- Al
- SiO, SiN
- Si

2015
- Other PM's
- EUV
- Co
- Si(C)P
- FDSOI
- SiC
- Air
- SiCO
- LaO
- LT SiO
- SiCN
- TiAlC MG
- ZrO
- Hf(Si)O
- AlO
- pSiOC
- SOI
- SiGe(B)
- TaO
- SOG
- SiOC
- Ta/TaN
- Cu
- SiOF
- TiSi
- PtSi
- TiN
- W
- BPSG
- Al
- SiO, SiN
- Si

2020(*)
- sSOI/GeOI
- Ge IL
- III-V IL
- GaN
- InSb
- InGaAs
- Ge
- STO
- Ru
- Other PM's
- EUV
- Co
- Si(C)P
- FDSOI
- SiC
- Air
- SiCO
- LaO
- LT SiO
- SiCN
- TiAlC MG
- ZrO
- Hf(Si)O
- AlO
- pSiOC
- SOI
- SiGe(B)
- TaO
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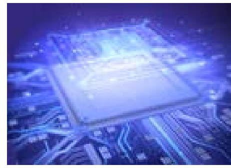
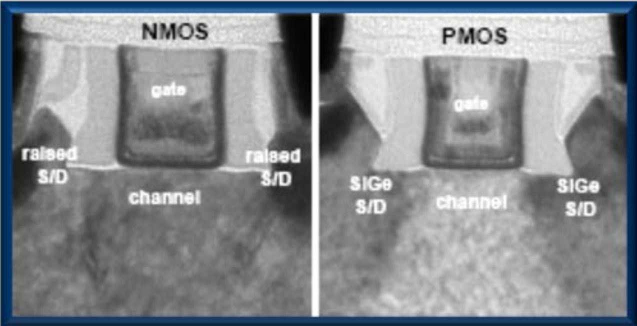
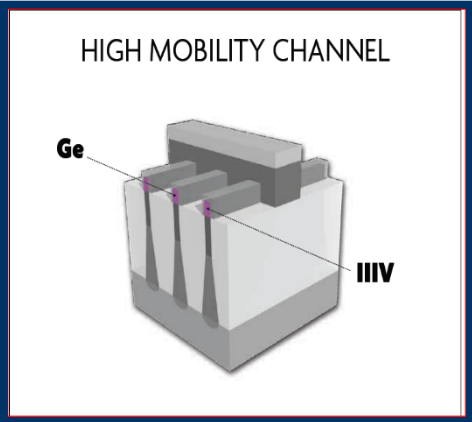
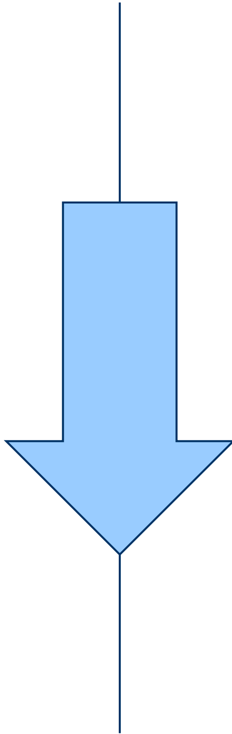


New Structures Require CMP

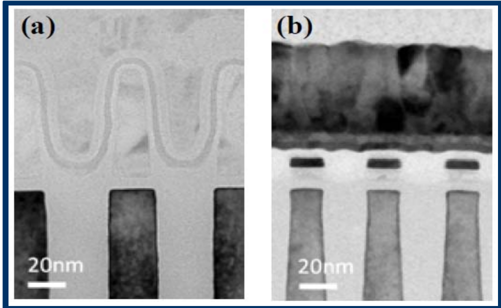
Logic



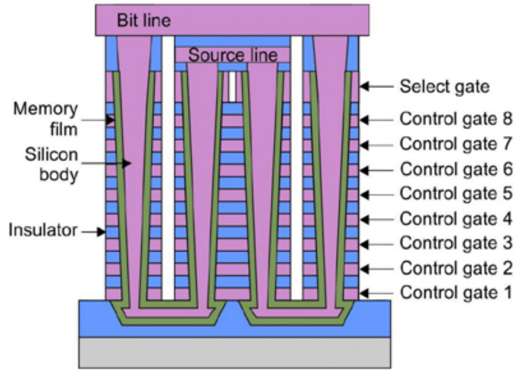




NAND



EDN Network



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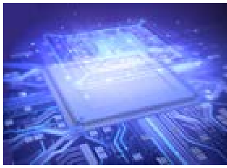
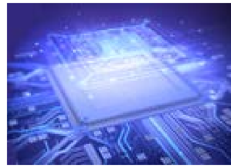


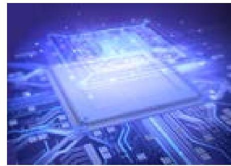
Defects in CMP



Defectivity Paradigm Shift at 20nm and Beyond

1. Pursuit of Moore's Law is driving ever increasing design innovation, process sensitivity & complexity
2. Paradigm shift in thoughts about what we did not care about earlier in >20nm era & what we care to control now!
    - Complex Chemistry: Compatibility Issues
    - New Defect Sources, increase Defect Sensitivity
3. Metrology techniques of all types are challenged to provide sufficient sensitivity for early detection & prevention
    - Supplier Infrastructure Development needed for better defect detection & characterization
    - Metrology and Quality Control
4. Proactive engagement and collaboration across the supply chain are essential to HVM readiness

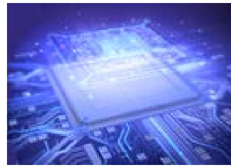
Source: A. Sengupta, Intel. Semicon West 2015



Defects from CMP Process

- Major defects induced by CMP are caused by:
  1. Organic Residue
  2. Surface Particle
  3. Scratching
  4. Surface Flaking
  5. Grain Roughness
  6. Pattern Damage

- Due to limited redundancy, each defect directly has an impact on the device performance or yield leads to all kinds are potential killer defect
- Organic residues and surface particles are the most frequently observed
- Consumables designed to minimize defects are required including:
  - Ultra-fine/colloidal abrasive
  - Soft pads without sacrificing planarity
  - Mild conditioning with proper pad surface roughness
- In-situ clean from CMP tool is the most effective for clean wafer since it cleans wafer with wet state



Metrology Issues

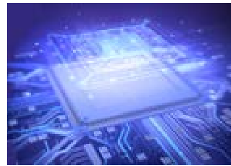
- Real-time metrology is practically impossible.
- In-line metrology is challenged to measure critical particle sizes below 20nm
  - High cost of systems
  - Off-line analysis to augment particle characterization

- Optical (particle detection) systems such as SP3 and SP5 are identifying new defects
  - On-wafer metrology has become the only approach able to show defects.
  - In many cases it is possible to identify the source from on-wafer analysis.
  - The expectation for particle shedding, and contamination continues to reduce.
  - In general, many new defects are driven by the introduction of new materials and processes

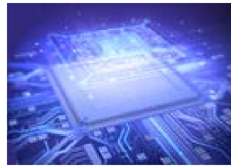
- Killer defects, or critical particles are now in the order of 10 or 20 nm.
  - On-wafer analysis is struggling to define particles sizes or discriminate defects as residues or discrete solids.
  - Defect sources vary from chemicals, water, seals, filters, piping etc.

- Equipment suppliers are driving to deliver ultraclean products which are certified with the latest analytical techniques, and targeted at delivering best possible performance.

Defectivity Requirements Impact Consumables



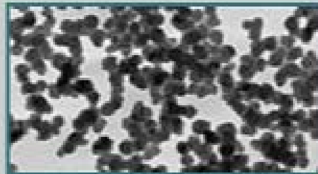
- For advanced nodes, the industry needs to have extremely tight control on the slurries and pad quality
- Greater use of high purity particles and chemicals to minimize contamination and increase reproducibility
- In advanced slurries, quality and morphology of the slurry particles will be critical
  - No agglomerations and angular particles
  - Need mostly spherical particles and to minimize the number of edges
- Trend to low abrasives or abrasive free – 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 tuned as a key point of the overall process control
- Galvanic corrosion needs to be controlled in-situ – this is controlled by using the correct ingredients/formulations
- Advanced slurry formulations may utilize 10 to 15 distinct ingredients
- Buff slurries include products from Cabot Micro and Dow/Klebosol
  - In general high purity colloidal silicas are preferred for buffing and there appears to be a trend towards ultra high purity colloidal silica buffs



Ultra High Purity Colloidal Silica (UHPCS)

- Fuso manufactures high purity colloidal silica by particle growth method using hydrolysis and condensation with high purity alkoxysilane as a starting material
- Compared with colloidal silica starting from sodium silicate, this product is more pure, spherical shaped and stable at neutrality
- The purity of the product excluding nonionic and ionic dispersing agent is 99.9999% or more
- It is believed that, based on customer's requirement, it's possible to control particle size, degrees of the particle shape and select the dispersing agent, water, alcohol, glycol, etc.

SEM Pictures



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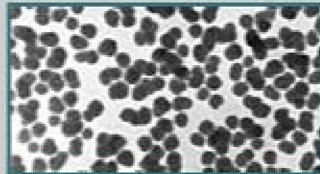

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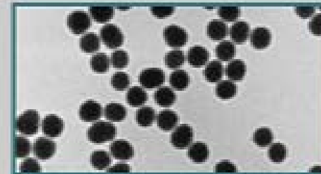

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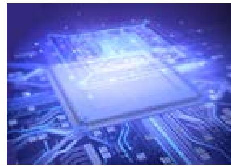


Abrasives Selected to Enhance Yield

$ Million

$160
$140
$120
$100
$80
$60
$40
$20
$-

20.0%
15.0%
10.0%
5.0%
0.0%
-5.0%
-10.0%
-15.0%
-20.0%

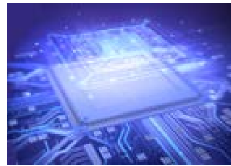
-14.9%
-4.9%
11.7%
5.7%
17.8%

Alumina
Fumed Silica
UHPCS
Colloidal Silica
Ceria

2006
2016
CAGR

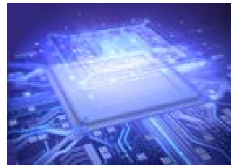
Abrasives that do not drive optimized cost and yield solutions are transitioned away and replaced

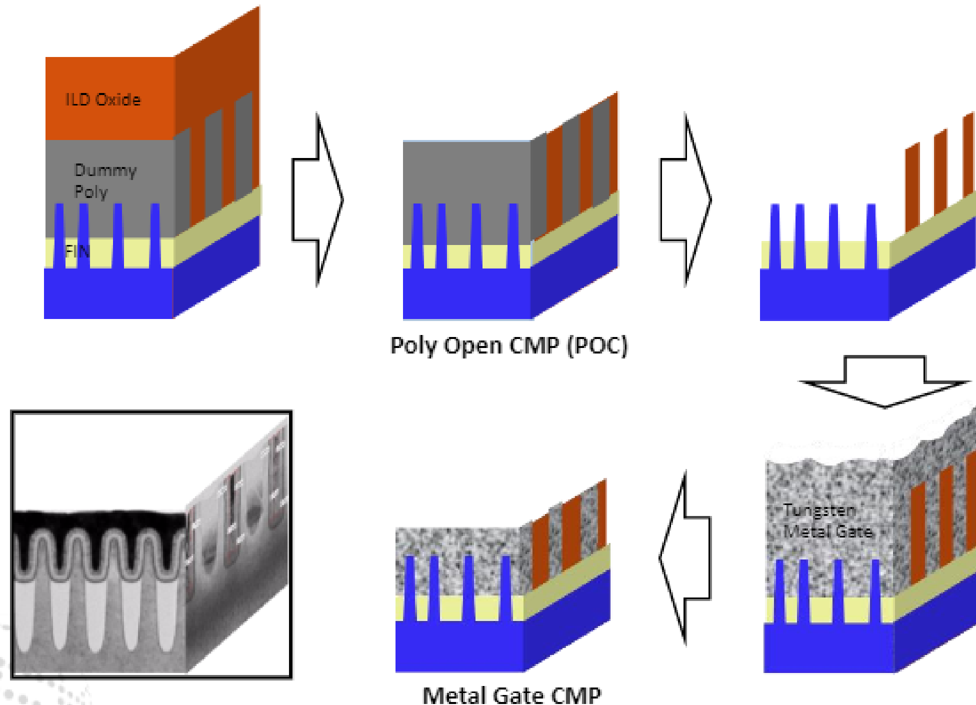
Buffing Can Reduce CMP Defects



- The industry trend is to use softer pads for barrier polishing to combat scratches on the wafer surface during buffing
- Typically, higher purity slurry/or wafer clean solutions are used in buffing to reduce micro-scratches, metallic and ionic contaminants
- Until recently, the Polytex Supreme was the pad of choice for barrier polishing. However, these pads cause scratches and higher defectivity due to the nature of the pad surface
- These pads were replaced by Fujibo pads for lower scratches and defectivity
- The trend now is to use VP3500/3100 pads for better defectivity, lower scratches and better planarity
- The use of high purity slurry and wafer clean solution have some impact on the output and COO. However, it is well understood that removal of yield limiter defectivity outweighs the slight increase in cost due to buffing
- Once the polishing process is complete, a post-CMP cleaning process must not only remove residual slurry particles but also trace levels of metal ions, which otherwise could significantly decrease yield

Replacement Metal Gate (RMG) Process Flow in FinFET Structure





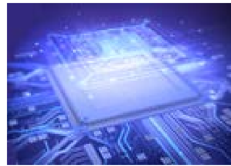
Reduction in defectivity

- Morphology and purity of slurry abrasives
- Reduction in slurry abrasive content in slurry formulation
- Advanced polishing pads to reduce micro-scratches and other defects
- Reduction in down force for polishing to have minimum abrasion
- Polisher with advanced features for process control
- Reduction in post-CMP cleaning contacts
- Use of ultra-high purity chemicals for slurry formulation

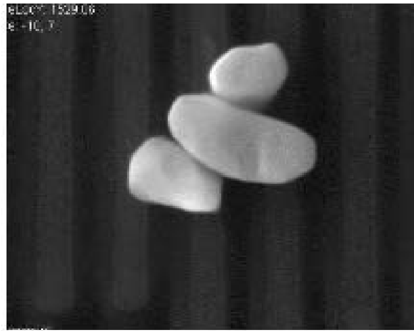
Typical Source of Surface Particle Defects

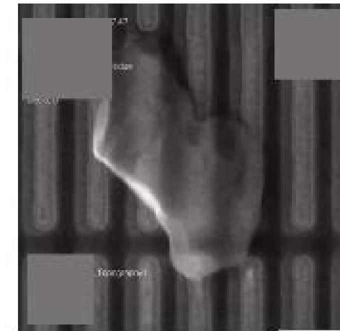
- Thorough understanding of replacement metal gate (RMG) process flow
- Look into the integrational aspect of defect source
- Understanding mechanism of formation of surface particles
- Role of CMP cleaner module in reducing defects

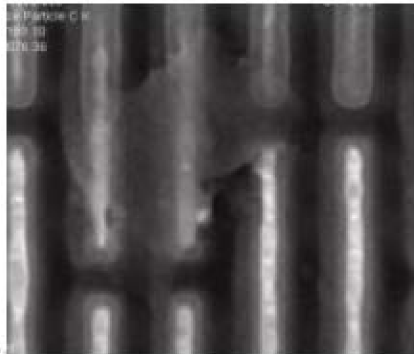
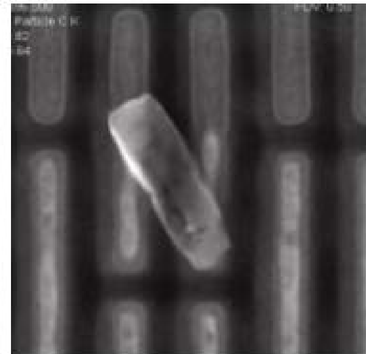
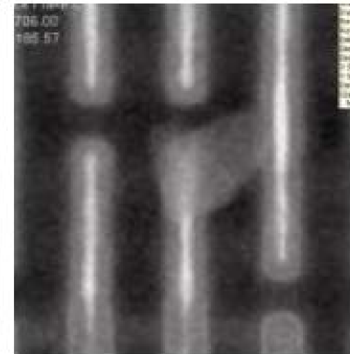
Source: Hong Jin Kim, GF,CAMP 2016



Particle Defects at Post Metal Gate CMP

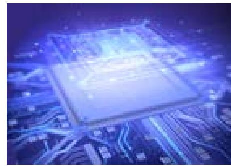




Source: Hong Jin Kim, GF, CAMP2016

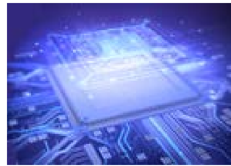
Post CMP Cleans



Evolution of PCMP Cleans

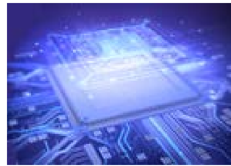
- Due to stringent requirements of defectivity reduction/elimination, steps to remove defectivity from all possible sources are done with extreme care
- Post-CMP cleaning solutions can have a large effect on wafer defectivity levels which are very active in preventing corrosion, surface contamination and cost of operation performance
- Optimized cleaning solutions are especially critical for post-copper CMP cleaning process as they enable decreased organic contaminant counts
- Typically, proprietary formulations are used to increase performance, reliability and yield with reduced contamination and increase in queue time
- In addition, the desired level of surface roughness can be tuned by selecting different cleaning chemistries by choosing right concentration and dispensed volume for post-CMP cleaning
- Industry moving away from TMAH on PCMP cleans. All new PCMP formulations are TMAH free, with specialty amines being evaluated as replacement components, over the last 2 to 3 years

Post-CMP Cleaning Chemistries Evolution



- The aqueous based chemistry consists of cleaning agents, chelating agents and corrosion preventing compound and other proprietary chemicals during and after the cleaning process
- The primary function of these chemicals is to protect the planarized metals and dielectrics, preventing corrosion while providing a smooth defect free wafer surface
- PCMP cleaning chemistry effectively removes organic residues, provide corrosion protection (static etch rate), galvanic corrosion protection, dendrite protection, and minimize oxide formation by protecting the surface layer from oxidation
- PCMP Cleaning should remove trace metal ions from the wafer surface, provide excellent cleaning on dielectrics and excellent film wetting properties for water mark free cleaning, with no biological growth by providing a passivation layer to prevent from atmospheric corrosion
- PCMP use significant levels of dilution – 50 to 150X, reducing post-CMP COO
- This is primarily to use optimum dilution of the chemistry for effective removal of particles and other defects without any significant impact on remaining chemicals on the post-CMP surface

Post-CMP Copper Cleaning



Copper

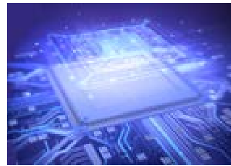
Acidic cleans:

- Typically comprise of organic acids, employ an under etching mechanism, where a layer of CuO and Cu_2O is dissolved from the wafer surface, thereby liberating the lodged particle
- Ideally this would be capable of under etching foreign particles embedded in Cu, and smooth over mild physical CMP induced damage, with the potential downfalls of organic residue and Cu corrosion
- This is especially true, if cobalt is used in the integration. The acidic chemistry might have galvanic corrosion in copper/Cobalt integration

Alkaline cleans:

- Typically use a dissolution mechanism with water soluble organic solvents, which penetrates, swells, and dissolves the BTA film while lifting off surface particles
- In alkaline pH cleans, the negative zeta potential (NZP) aids in keeping the removed particles in the solution and does not allow them to re-attach to the wafer surface or PVA brush
- Due to the complexity of the various hydrophobic low-k dielectrics, integrated with copper, it is very difficult to use a commodity type of post-CMP cleaning chemicals
- The industry is using formulated PCMP chemicals to work with various Cu/low-k integration

Post-CMP Oxide and Tungsten Cleaning



Oxide

- Usually for oxide cleaning, basic solutions like Ammonia or TMAH are used in conjunction with brush cleaning and/or megasonic cleaning. Most of the time, the chemistry is flowed through the brush
- Cleaning phosphosilicate glass (PSG) is generally more difficult than un-doped oxides. Because PSG is softer than an un-doped oxide, it usually has more microscratches

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- HF immersion can greatly reduce the metallic contamination, but it enlarges the microscratches, leading to a large number of detectable defects
- Alkaline formulated cleaning solution (PlanarClean®) is widely used for oxide cleaning

Tungsten

- The requirements for extreme control on scratch requirements, organic contaminants and other surface defects, leads to the use of post-CMP Tungsten buffing

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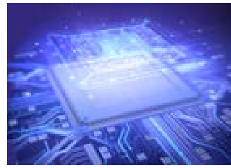
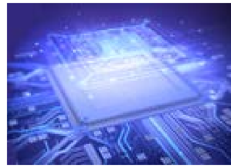
- This was more predominant for front-end applications, which require extremely low scratch surfaces with minimum contamination and higher planarity
- Typically, formulated cleans like PlanarClean® AG are used over commodity cleans for W buffing process through enhanced reliability and yield with reduced micro-scratches, lower corrosion and defects
- The industry trend is to provide improved cost-of-ownership by reducing the amount of chemistry



Post-CMP STI Cleaning

STI

- One of the major issues with ceria is higher defectivity, primarily due to scratching and particle defects due to strong bonding between ceria and oxide
- STI buff reduces CMP defectivity by chemical buff on P2 using appropriate type of chemistry, compatible with the slurry used for STI polishing
- Typical approach for post-STI process defect reduction is oxide buff on P3 to remove residues and scratches, followed by brush-box cleaning
- Versum Materials have developed a buffing chemistry (DP1036) on P3 to reduce ceria particles and other residues in the buff step with minimum loss in oxide/nitride film thickness
- It appears that post-STI chemical buff on P3 reduces the micro-scratches and other defects dramatically with insignificant loss of oxide/nitride thickness
- The buffing reduces the particle defectivity on wafers coming into cleaning module
- This significantly reduces the possibility of brush loading, extending the brush life and reducing maintenance requirements



Conclusions

- The use of SP3/SP5 for defect detection provides tremendous pressure on the CMP Process
- Buffing on the final platen has significant impact on removing particles, defects and micro-scratches
- New abrasives are also used to control the CMP process and reduce defects as the trend is to use lower abrasive and chemistry content to reduce defectivity
- Consumable manufacturers need to develop defect-free pads, slurry and clean chemistry
- Development of PCMP clean solution is a challenge due to the introduction of new materials with increases in the demand for lower defectivity, particles and micro-scratches
- The PCMP clean chemicals market will continue to grow at a rapid rate