Material process control challenges

leading edge technologies

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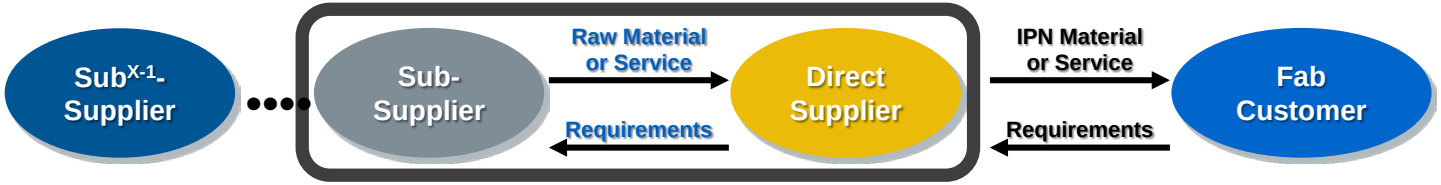
Todays Advanced Materials Challenges

- An Increasing number of materials are enablers to new process innovations as technologies become more complex
- Enabling raw materials supply chains that are new to the electronic materials industry
- Materials process control requirements are on the rise as 10nm and below are introduced into Manufacturing
- New metrology, material characterization techniques and advanced process control methods are required to maintain consistent yields and parametric control

Critical Elements of Supply Chain Quality



Customer Requirements

- Business relationship / contracts
- Documented requirements (e.g. drawings, procurement specs)
- Single or sole sourced
- Special lot selection? (“cherry-picking”)
- CofA / CofC Alignment

Change Control

- Customer notification requirements
- Change horizon forecast

Process Monitor & Control

- Key and control parameters
- Ship to control
- Capable, stable, and correlated metrology
- Regular process control system (PCS) reviews
- FMEA procedures

Material Disposition Management

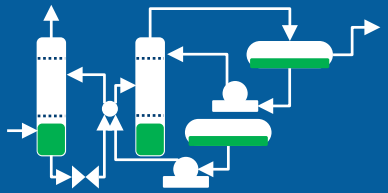
- Quality excursion management
- Customer notification requirements before sending questionable or discrepant material

Business Processes

- Supplier quality systems health assessments
- Report cards & Business reviews
- AAR of Supply Chain Disruptions
- Business Continuity Planning
- Continuous Improvement Plans

Delivering Consistent Material

Supply Chain Understanding



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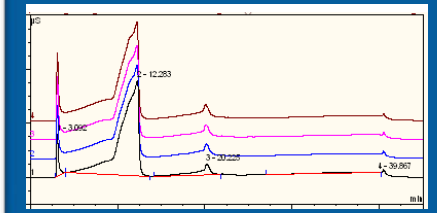
Depth of Material Characterization



Key Parameters

Advanced Metrology

"Fingerprinting" Capabilities

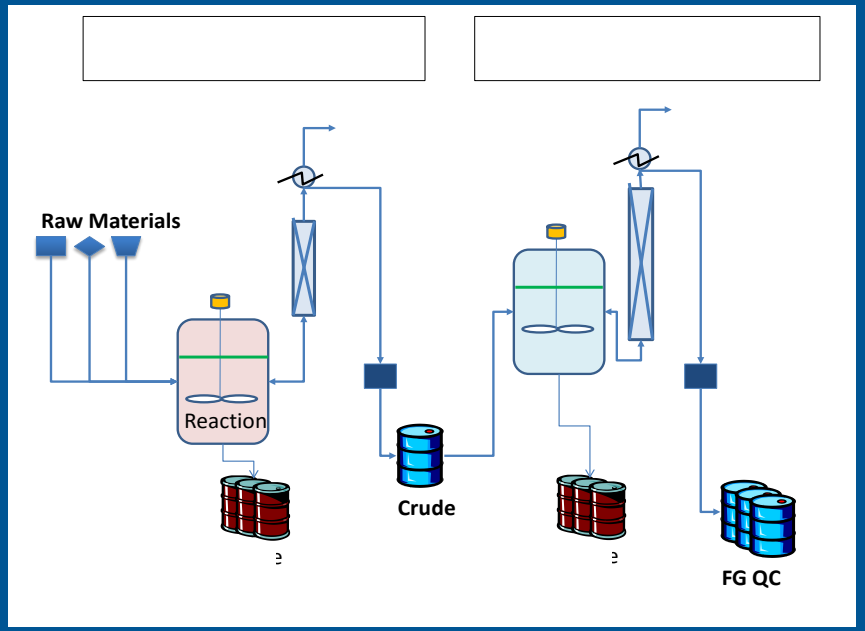
- ***Process Controls:*** Must have access to, and understanding of supply chain in order to develop FMEA and appropriate process control points
- ***Success requires collaboration*** among all supply chain partners
- ***Understanding & controlling variability*** risk is fundamental to delivering consistent material
- ***Advanced characterization*** paired with capable and stable metrology minimizes exposure

Improving Supply Chain Understanding

Increased Supply Chain Visibility Resulting in Improved Risk Management:

- Supplier Product / Process
  - Process flow diagram, raw materials (how many in product, batch sizes, frequency) , etc.
  - Dedicated process equipment?
- Raw materials
  - Batch size / frequency
  - Characterization info / plans
  - Process flows
  - Cherry picking? Single sourced?
  - Purchased directly or from a distributor?
- Supplier relationships with sub-suppliers: Contracts, BCP, audits, PCS reviews, change control agreements?

Sub Supplier Process Flow

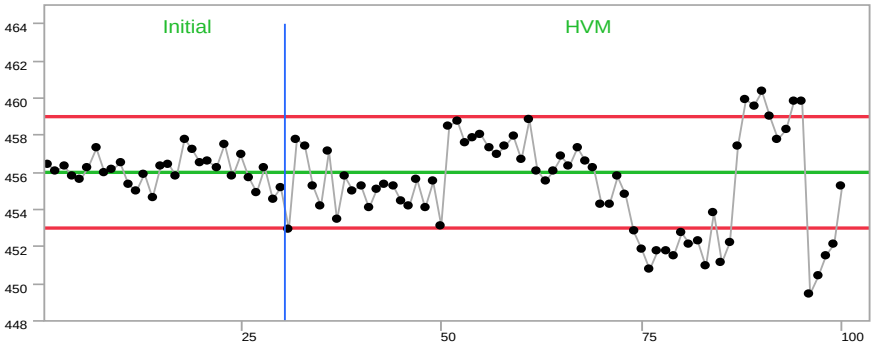


"Need-to-Know" teams established to protect supplier & Intel IP

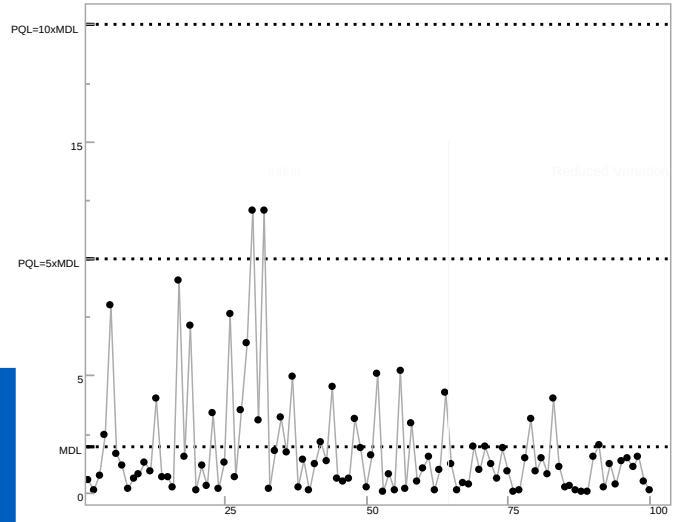
Process Control Challenges

Semiconductor Process Purity Requirements are Tightening

- Organic/trace impurity levels in “non-traditional” materials are becoming critical
  - ➢ Enabling raw material components are new to semiconductor industry
  - ➢ Existing industry standards for purity are insufficient



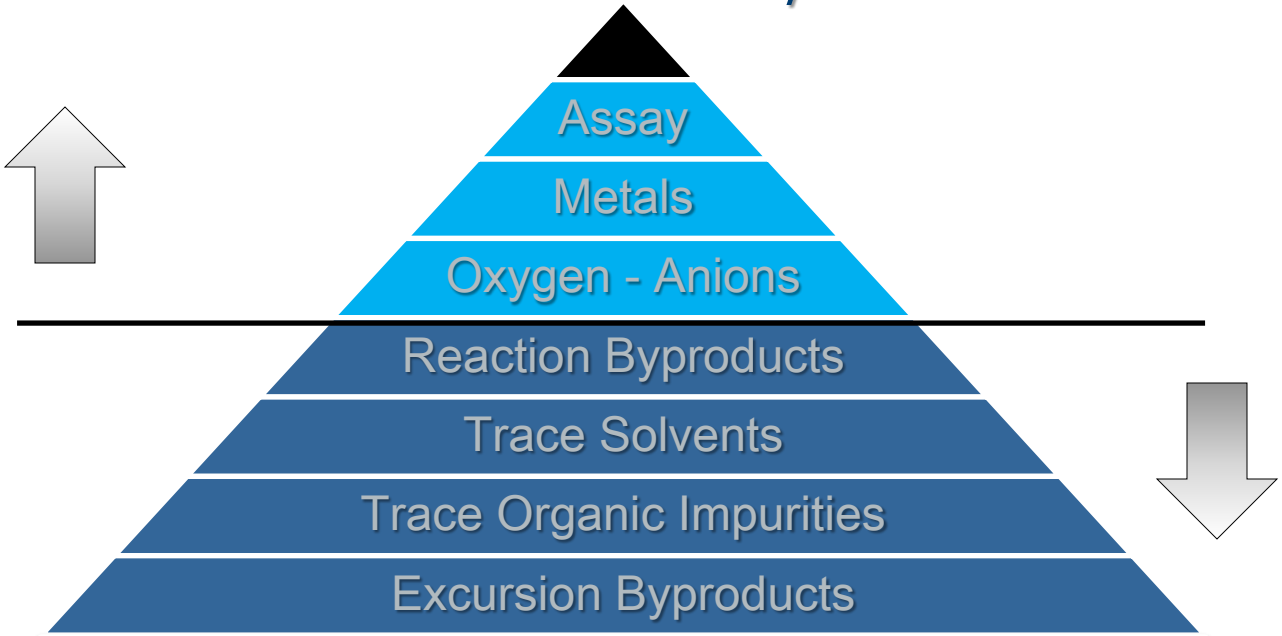
Understanding potential HVM shifts during development are critical – traditional HVM limit setting based on initial data no longer valid



Trace metal reporting limits >2-3xMDL will no longer meet industry needs

Broad Spectrum Characterization

Precursor Example



Most excursions now caused by trace species not on a traditional CoA – broad characterization vital to understanding normal process variability

Metrology Challenges

Chems, gasses & precursors

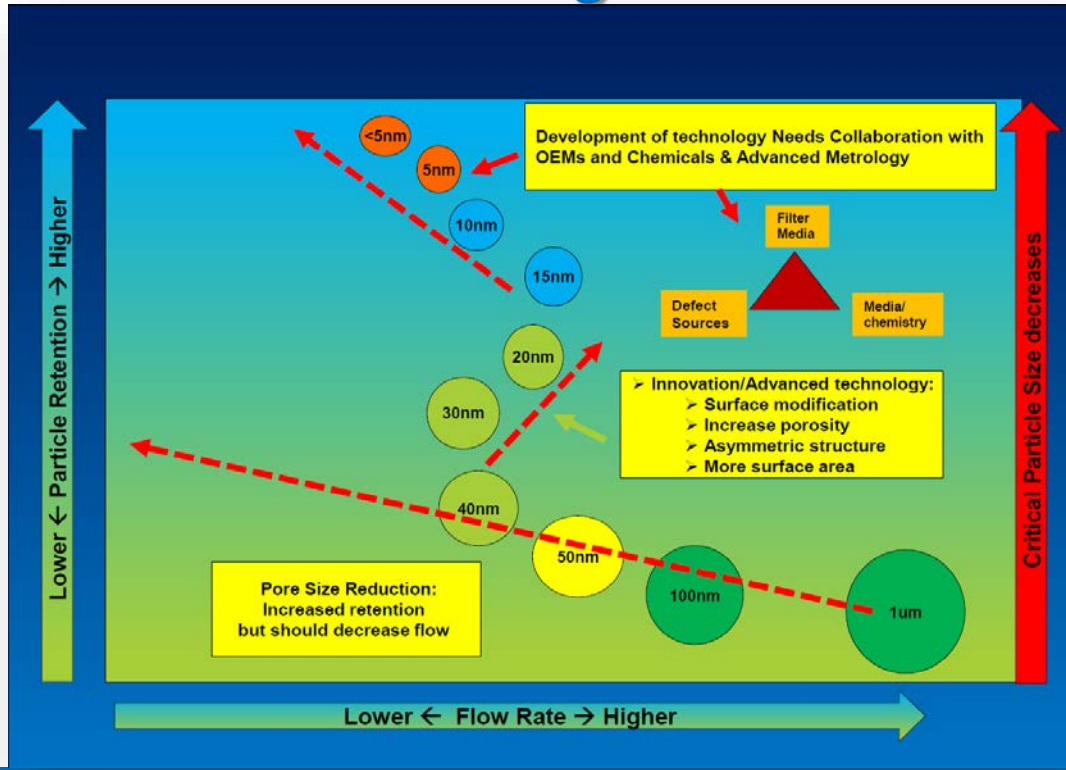
Material	Metrology for Control	New Requirements
Wet chems and formulated chems, Solvents	LPC, Trace metals, Anionic Impurities	LPC: monitor <30nm bin size. Currently available ≥30nm. Trace metals: sub ppt-ppq detectability in high matrix background Anionic impurities: sub ppb detectability in highly corrosive matrices
Precursors	Trace metals, residual solvents	Trace metals: ppb- sub ppb detectability in high matrix background. Residual solvents: head space GC techniques to obtain sensitivity and minimize column degradation
Blended Spec Gases	Assay	Binary gas analyzers with high accuracy and precision

Material	Metrology for Characterization	New Requirements
Wet chems and formulated Solvents	GC-MS (low and high res), LC-MS (low and high res), IC-MS (anionic and cationic (no TM) impurities, GC-FPD (phosphorus/sulfur compounds), Raman	MS techniques to provide better id capability. High resolution to help id the unknown. Specific detectors to enhance detectability
Precursors	GC/LC-ICPMS; XRPD (for solids)	GC/LC-ICPMS to characterize any volatile/non-volatile organometallic impurities. XRPD for solids to determine impurities (crystalline/amorphous)
Blended Spec Gases	GC-MS, GC-FTIR, RGA-MS	Identification of unknowns or functional groups

Filtration Technology

Keeping up with defect scaling

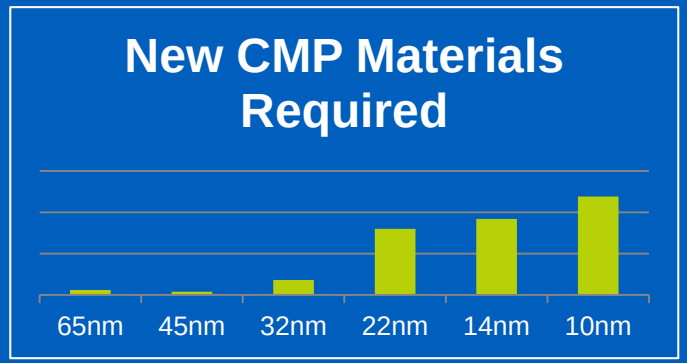
- Filtration must keep up with “Paradigm Shift” in Defect Tolerance for Next generation Tech Nodes
- Customized Filtration is needed to Aggressive Chemistry/Processes
- Innovation needed for <=5nm Metals/Particles/Organics/NVR removal for next generation need
- Filters should not add any of these contaminants



Chemical Mechanical Polish

Enabling leading-edge technology

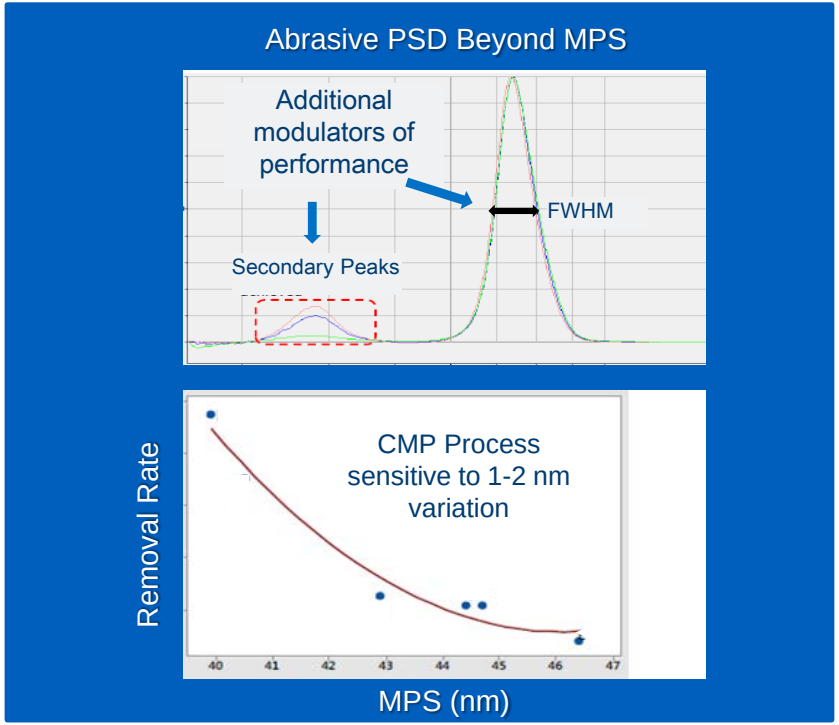
- CMP critical to the advanced integration schemes required for Moore's Law
- Complex interactions between chemicals/consumables are now common
  - Performance-based monitors may be required
- Normal impurity profile variation of commonly used Industrial-grade additives no longer acceptable
  - Additional purification and/or higher purity sources required
- Raw material batch variation of slurries, pads and conditioners are easily detected in CMP modules
  - Non-FIFO raw material management required
- Traditional CofA parameters are not sufficient to predict performance
  - Advanced material characterization required during material development to ensure adequate controls are proactively implemented



Chemical Mechanical Polish

Abrasive Requirements Beyond 3-Sigma

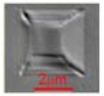
- Abrasive Mean Particle Size (MPS) no longer adequate to predict required performance
  - ➢ Particle Size Distribution (PSD) control required
- Process sensitivity to 1-2nm variation well within material normal variation
  - ➢ 3 sigma limits no longer sufficient
- Abrasive customization across the supply-base has reduced supply-line stability and increasing BCP risks
- Consolidation of abrasive supply-base has reduced competition and further increasing BCP risks



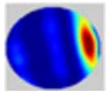
Si supplier chain metrology development & management

Metrology Development

- LLS: Killer Defect Classification



- Geo: New Metrics for Advanced Litho

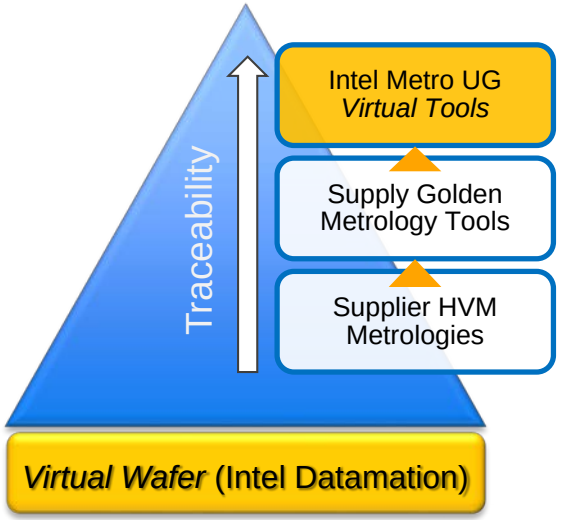


- Metals: Epi Layer Metal

- Crystal Characterization

Enable NextGen Wafers

Supplier HVM Metrology Alignment



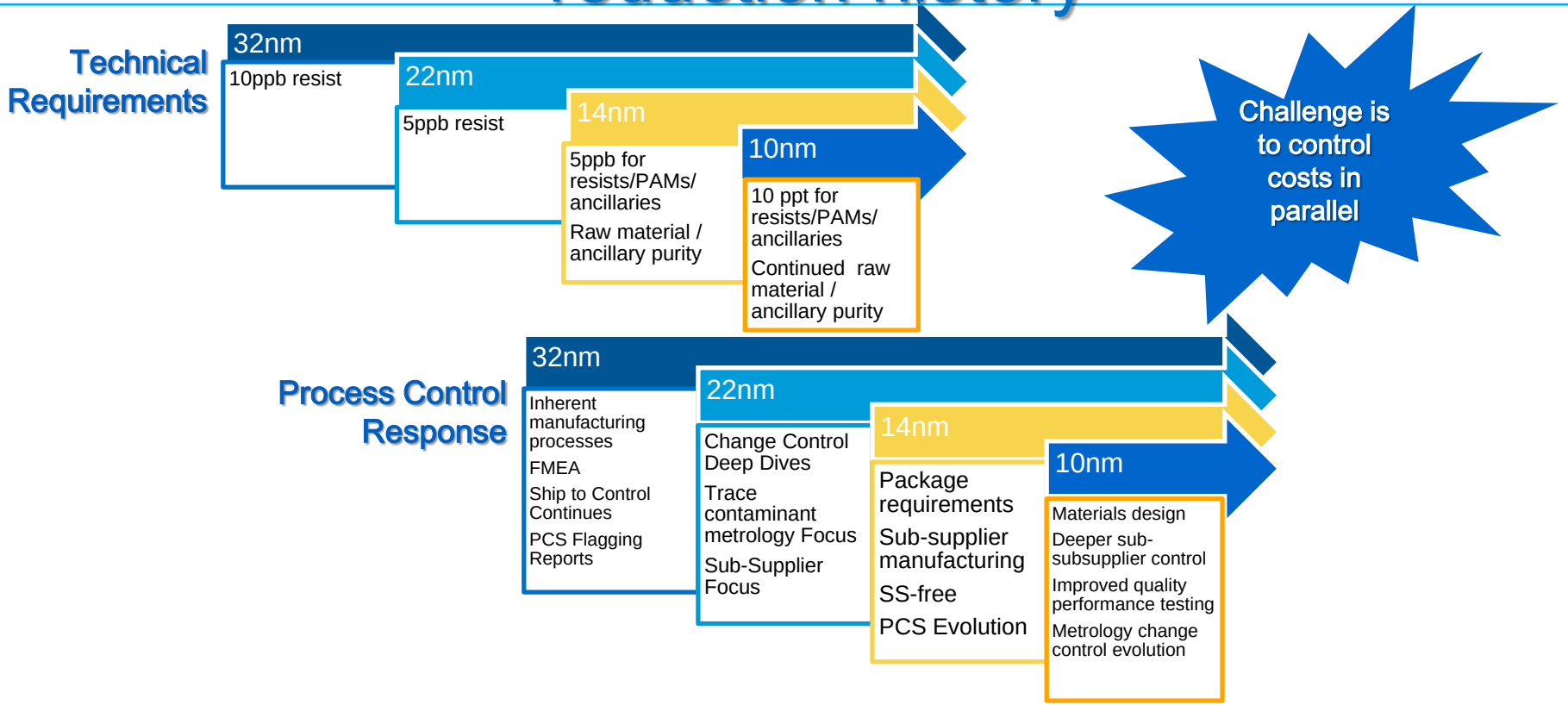
Enable Wafer Quality Control/Improvement

Metrology COO

- Promoting Metro Competition
- Cost Effective NextGen or New Metrology Design
- Effective Metro SPCs
- HVM Sampling Efficiency

Improve Wafer Affordability

Lithography Material contaminant reduction history



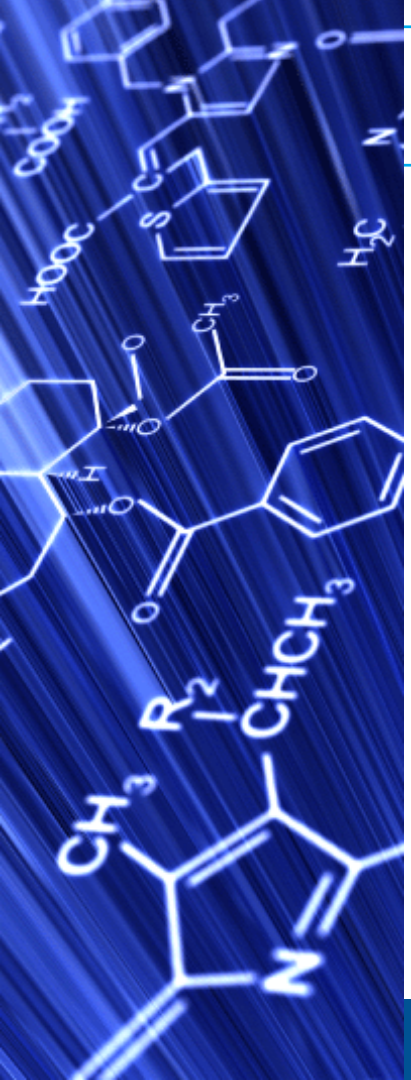
Metals Targets

- Multi component target compositions and increasing purity requirements are driving unique metrology challenges
- Non-uniformity is inherent due to various parameter gradients c to casting and thermal mechanical processing methods
- Binary or Multiphase compositions make grain size calculations complicated
- Analyzing submicron defects embedded in solid state matrices difficult to isolate and techniques are supplier specific (lack of commercially available or established industry methods)
- Lack of predictive non-destructive target metrology methods necessitate the use of manufacturing process control data as predictive of material performance

“commodity” wet chemicals

Custom high-purity process chemicals

- Major volume growth driven by technology (multi-patterning, etc.)
- High utilization; frequent capacity constraints
- Highly re-entrant in process → high sensitivity
- Constantly tightening requirements (particles, filtration, SPC)
- Deep supply chain understanding & raw material control is critical
- Difficulty matching multiple facilities or production lines
- Need improved metrology sensitivity for particles & purity



Specialty cleans chemicals

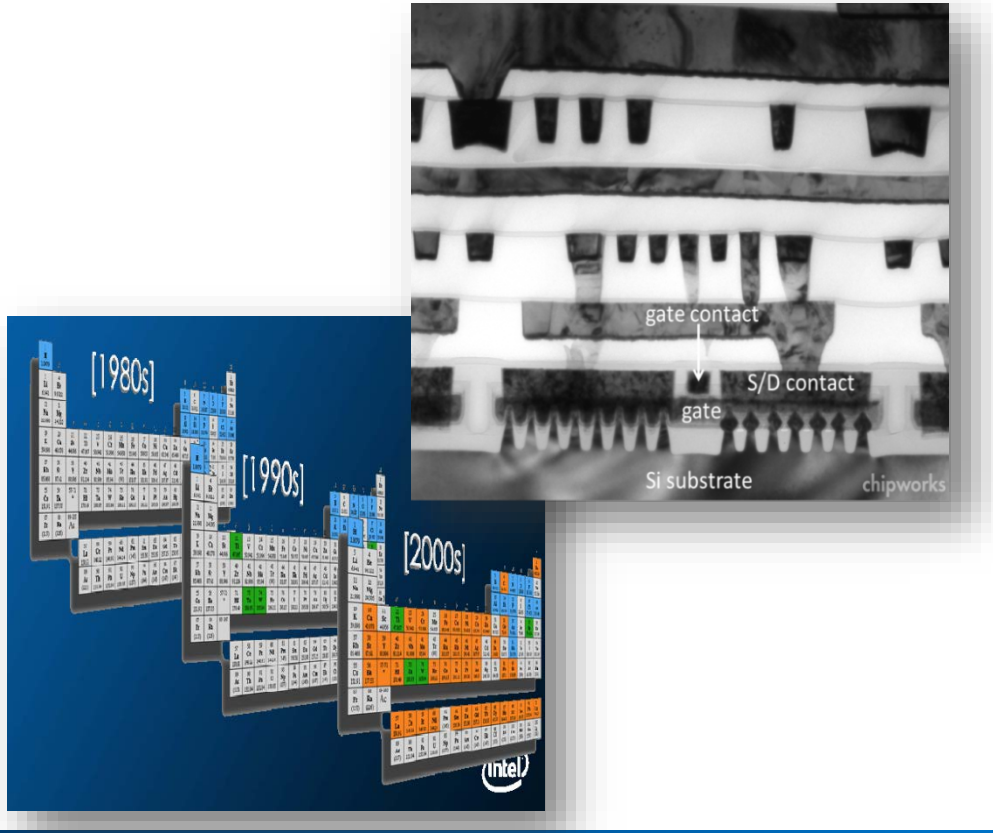
Formulated blends for custom applications

- Selectivity requirements increasing as features shrink
- Rapid cleaning required for high throughput
- Raw material control is critical
- Novel materials and processes drive need for novel cleaner components
- High volumes drive significant cost pressure -> Formulation restrictions
  - Aqueous based cleaners desired; Solvents can be cost-prohibitive
- EHS and Green initiatives prevent use of some legacy cleaners (nMP, etc.)

Specialty gasses

- Assay control becoming more critical
- Increased consumption resulting in more multi-cylinder packs, tonners, isotainers.
- Package reliability issues for corrosive gases
- Gases can react in package → Need metrology that is sensitive to by-products.
- Supply chain shortages highlight need for robust BCP and sourcing strategies
- Need capture/reclaim from waste stream for expensive/rare gases

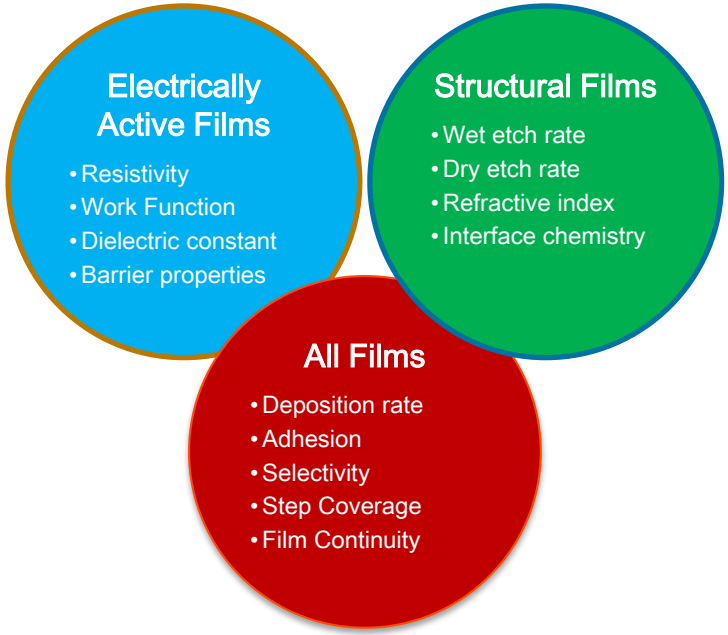
CVD & ALD Precursors



- Elements used in semiconductor processing has skyrocketed because of the demands of Moore's Law
- Each new element brings unique requirements and challenges
- Exist in all three phases of matter – solid, liquid, or gas – process and package flexibility is required

Key precursor challenges

- Precursor and co-reactants should be stable and volatile at delivery temperature
- Target Film must be generated predictably and reproducibly
- Key film properties depend on consistent precursor quality
  - ➢ Robust controls required on incoming materials and precursor manufacturing process
  - ➢ Higher purity precursors are not always “better”



Conclusions

- Establishing a foundation of robust quality systems and new material selection processes is key to supporting advanced materials
- Innovations in metrology, filtration and purification technologies needs to keep pace with the materials process control and characterization needs
- Additional purification and control requirements need to be applied to the raw material supply chains in order to meet final product process control requirements