FAB Optima™

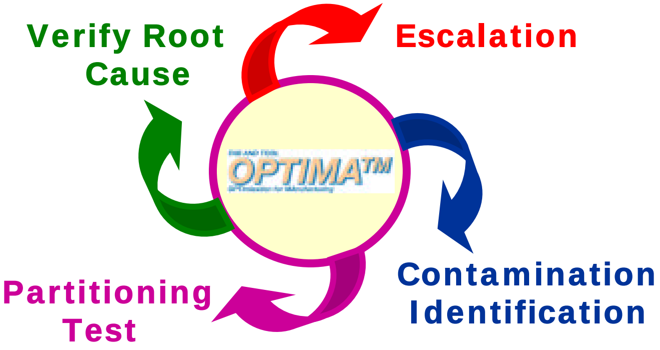
The Ultimate Program for Airborne Quality

Victor K.F. Chia, Ph.D.
victor.chia@balazs.com

Abstract

Fab Optima^{TM}: The Ultimate Program for Airborne Quality

The Fab airborne quality is an essential building block for clean manufacturing. The construction materials and all materials within the cleanrooms affect the fab airborne quality. Fab Optima is a Quality Control process that ensures the facility is capable of supporting clean manufacturing for increased production yields. This can only be achieved through collaboration between facility engineers, contamination control engineers and process engineers working in concert to lower the risk of contamination that often results in fab and tool escalations. This presentation reviews the key components of the program with examples of monitoring programs, Recommended Practices and test results.



Verify Root Cause

Escalation

Contamination Identification

Partitioning Test

Speaker Biography: Victor Chia is a Director of Air Liquide-Balazs Analytical Services. His responsibilities include advancing surface contamination technologies at Balazs, global sales and international business development. Victor has served in the semiconductor industry for over 20 years. He received his Ph.D. in Analytical Chemistry from the University of California, Santa Barbara and was a post-doctoral fellow at Lawrence Berkeley Laboratory. Victor has hands-on experience with AAS, Raman Spectroscopy and SIMS. He is the current chair of the IEST WG-031 for organic outgassing and is active with AVS at the National and Chapter level committees, as well as the standard committee of the ITRS. Victor has held positions at KLA-Tencor (Contamination Specialist) and at Charles Evans and Associates (11 years starting as SIMS analyst to Director). Dr. Chia was also the President of Cascade USA, a branch of Cascade Scientific and worked as a Consultant. Victor has published over 40 papers and co-authored several chapters on SIMS and contamination characterization. Victor is an experienced instructor and has presented several UC Berkeley Extension Courses.

Outline

- Introduction
  - ✓ AMC baseline, source and control
    - MA, MB, MC, MD, MM
    - Test methods
  - ✓ SMC baseline, source and control
    - SMO, SMD.SMM
- Fab Optima^{TM} (Optimization for Manufacturing)
  - ✓ Star★ALert programs for clean manufacturing
  - ✓ Personal behavior
  - ✓ Cleanroom practice
  - ✓ Cleanroom supplies
  - ✓ Cleanroom housekeeping
  - ✓ Cleanroom cleanliness validation
  - ✓ Cleanroom monitoring program
  - ✓ Case studies

Airborne Molecular Contamination (AMC)

MA Molecular Acids	HCl, HF, HNO_3, H_2SO_4
MB Molecular Bases	Ammonia, amines, amides
MC Molecular Condensables	Organics: silicones, plasticizers (bp >150°C)
MD Molecular Dopants	B, P, As compounds
MM Molecular Metals	Al, transition metals, alkali

- Volatility (vapor pressure)
  - AMC can pass through HEPA and ULPA filters into cleanrooms
- Boiling points
  - Typically, < ~ 450°C organics can eventually pass through ULPA or gas filters
- AMC can become SMC (Surface Molecular Contamination)
  - SMC can form many particles
  - If > monolayer, SMC can make films, homogeneous or islands
  - SMC is often < ML (~5Å) or approximately 10^{15} atoms or ions/cm^2

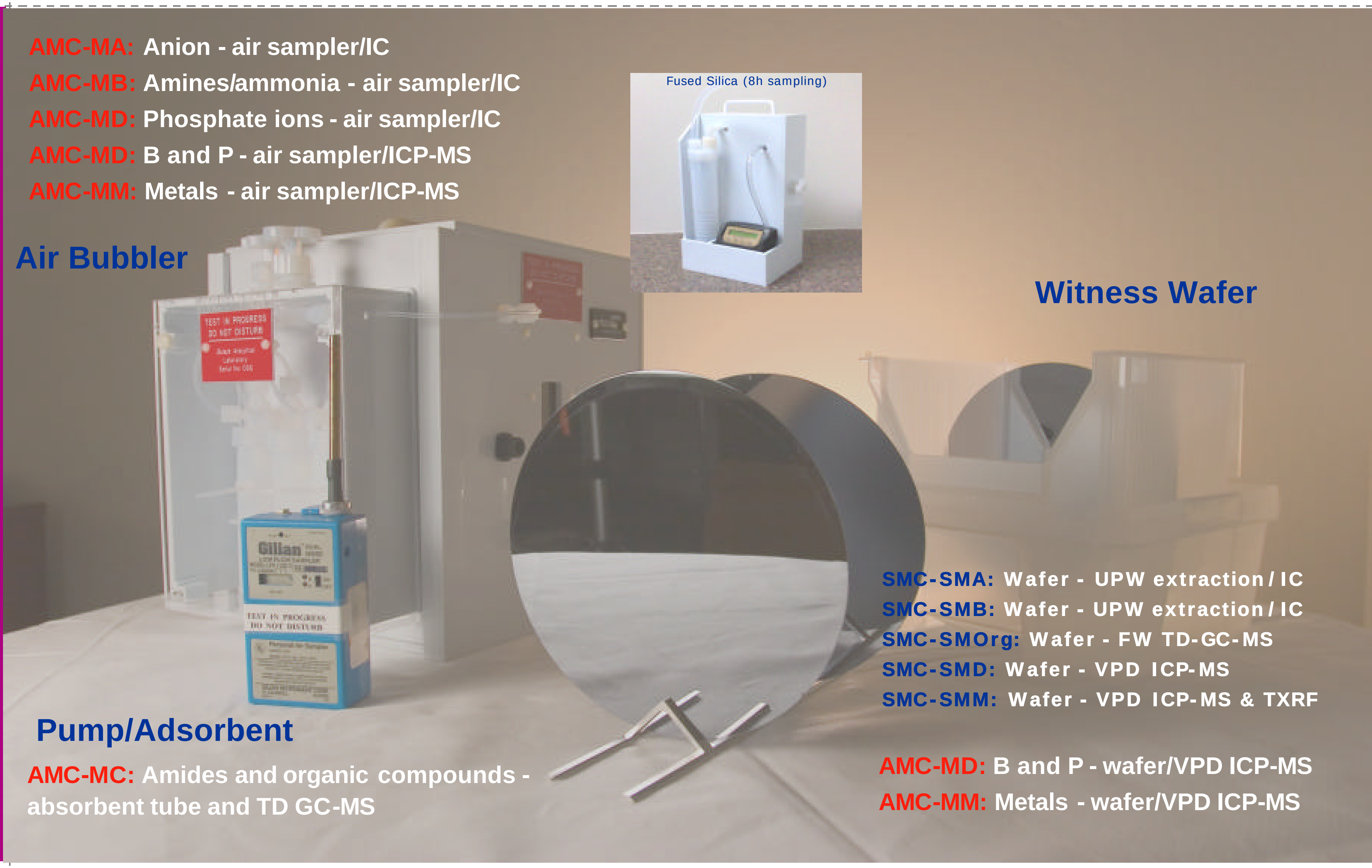
AMC Sources

- Outside air: autos, power plants, smog, industry, roofing, paving, fertilizers, pesticides, farming, sewers, fab exhaust, ocean/saline water
- Process chemicals (esp. hot), reaction by-products, reactor exhaust
- Wet cleaning, wet- and dry-etching, electroplating baths
- Solvents: lithography, cleaning solutions
- People: ammonia, sulfides, organics
- Equipment outgassing: robots, motors, pumps, fans, electronics, computers, heaters
- Materials outgassing into air or onto sealed products
- Disasters, internal or external:
    - ✓ Spills, leaks (coolants), accidents, fires, power outages
    - ✓ Failures of air handlers and scrubbers
- Recirculating air between areas
- FOUPs, Pods, shippers, carriers, minienvironments

AMC Effects

- DUV photoresist T-topping
- Uncontrolled boron or phosphorus doping
- Surface issues: adhesion, wafer bonding, delamination, electrical conductivity, high contact resistance, shorts, leakage currents, wetting, cleaning, etch rate shifts, spotting, particle removal, electroplating defects
- Wafer hazing: time dependent haze
- Optics hazing: hazing by adsorption, reactions, etching or photochemistry on lenses, lasers, steppers, masks, reticles, pellicles - especially for 157 and 193 nm lithograpghy
- Corrosion: process wafers (Al, Cu), flat panel displays, equipment, instruments, wiring and facility (over many years)
- SiC/Si_3N_4 formation following pre-oxidation clean
- Threshold voltage shifts
- Nucleation irregularities

AMC and SMC Sampling / Test Methods



AMC-MA: Anion - air sampler/IC
AMC-MB: Amines/ammonia - air sampler/IC
AMC-MD: Phosphate ions - air sampler/IC
AMC-MD: B and P - air sampler/ICP-MS
AMC-MM: Metals - air sampler/ICP-MS

Air Bubbler

Fused Silica (8h sampling)

Witness Wafer

SMC-SMA: Wafer - UPW extraction / IC
SMC-SMB: Wafer - UPW extraction / IC
SMC-SMOrg: Wafer - FW TD-GC-MS
SMC-SMD: Wafer - VPD ICP-MS
SMC-SMM: Wafer - VPD ICP-MS & TXRF

Pump/Adsorbent

AMC-MC: Amides and organic compounds - absorbent tube and TD GC-MS

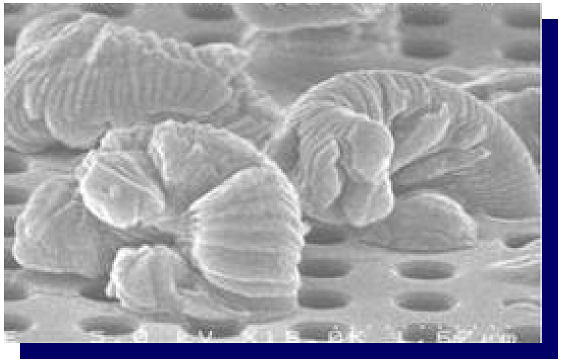
AMC-MD: B and P - wafer/VPD ICP-MS
AMC-MM: Metals - wafer/VPD ICP-MS

AMC Monitoring (I)

- Incoming wafers
  - ✓ Organics, condensables, dopants, and metals on the wafer surface
- New cleanroom materials (contruction and consumables)
  - ✓ Organic outgas testing (including organophosphate dopants)
- Make-up air (MUA)
  - ✓ Organics, acids, and bases prior to recirculation to check for outside environmental sources
- Stockers, mini-environments, wafer sort and storage areas
  - ✓ Acids and ammonium in air (amines if used in the fab)
  - ✓ Organics and dopants on wafers

AMC Monitoring (II)

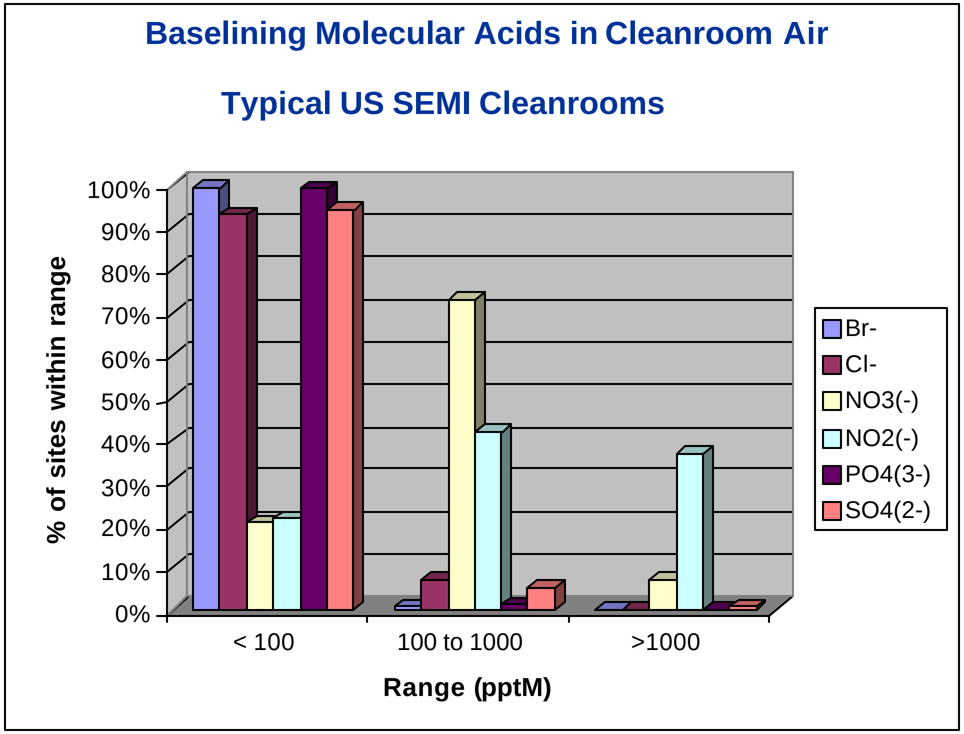
- Pre-diffusion, oxidation furnace, implant annealing process areas
  - ✓ Dopants, metals, and alkali on witness wafers
  - ✓ Acids in air (cause corrosion)
- Lithography process areas
  - ✓ Air and gases including CDA, N_2, Ar, O_2 and He
    - Acids, bases, and condensables
    - Up-stream and down-stream of carbon filters/purifiers
- Wet bench and bath areas
  - ✓ Bases, amines, amides and organics in air
  - ✓ Acids and ammonium in air (amines if in photoresist strippers)



Cl-induced corrosion of Al at the bottoms of vias.

Molecular Acids (AMC-MA)

- NO_x dominant MA and is not removed by filters. Not as detrimental as other acids. NO_x compounds often "smog" related
- Most acids are from SC-2, HF, BOE, SPM), RIE, CVD, dopants ($POCl_3$)
- PO_4^{3-} very rare since phosphoric acid not volatile. $POCl_3$ leaks can put P into air.
- SO_4^{2-} can come from inside air or outside air (SO_2) which can oxidize to sulfates



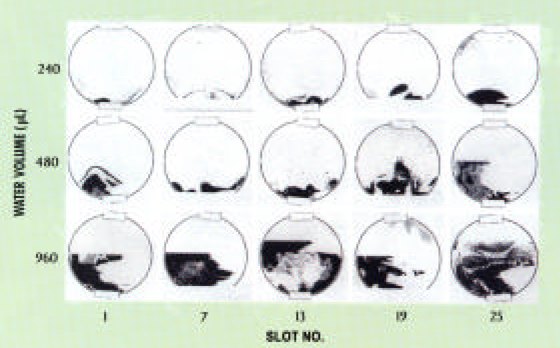
Sources of Molecular Acids

- Cleaning and acid etch baths (process lines and wet laboratories in fabs)
  - Vaporization of $H_2^+ SO_4^{2-}$, $H^+ Cl^-$, $H^+ F^-$, $H_3^+ PO_4^{3-}$, and $H^+ NO_3^-$
  - Problems occur when there is insufficient exhaust
  - Improper airflow setting of minienvironment used for acid sinks
  - Typical cleanroom H_2SO_4 concentrations are <1 ppb
- Leaks in HCl lines
- Outside environment
  - Fab may be situated in a heavily industrialized area
  - MUAH systems with insufficient filtering

Ionic Haze - Background

- Dominion Semiconductor was the first to report yield loss from ammonium sulfate haze around 1997, when the company lost some $25M in one day
- Since then, essentially every semiconductor fab has experienced some form of haze contamination
- In some cases, the loss actually outstripped revenue, with the largest loss reported to date being $100M
- The worst effects have been seen in Taiwan and Shanghai, China, where environmental factors figure prominently
- In addition to ionic haze, the surfactants that maskmakers use to clean the photomasks are a significant cause of haze

Ionic Haze

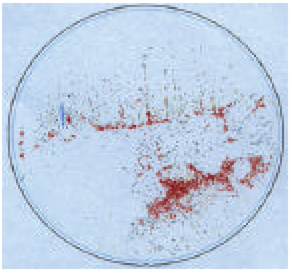


L.W. Shrive, R.E. Bank, and K.H. Lamb, MICRO, p. 59, March 2001

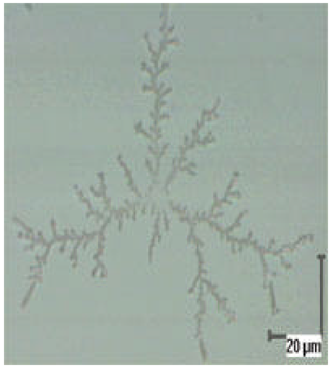
Experiment

- Different volumes of water was added to wafer carriers containing freshly cleaned wafers
- The total area of the wafers that is affected by haze can be related to the amount of water added
- Oxide thickness increased from 0.8 - 1.1 nm (clean wafer) to a chemical oxide thickness of 1.5 nm

Wafer maps at MEMC showed that packaging issues were causing the growth of haze on wafers placed in storage. In this case, a rough estimate puts particle density at more than a million defects per square centimeter.



- The causes of haze are generally from insufficient rinsing and AMC
- Stable Haze
  - ✓ Haze formation caused by a high concentration ($\geq 10^{14}$ - 10^{15} atoms/cm^2) of any anions and cations on the Si surface. For example ammonium chloride or ammonium sulfate residues.

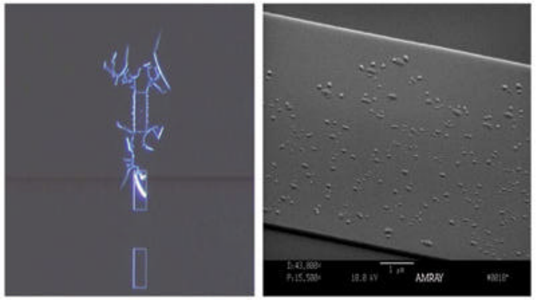


Ammonium sulfate haze

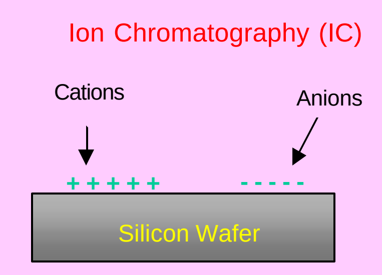
  - ✓ This haze is stable since there are equivalent amounts of anions & cations
  - ✓ The suspected causes are from poor rinsing of wafers after chemical cleans and inadequate exhaust at wet benches

Ionic Haze (cont'd)

- Time dependent haze (TDH)
  - These hazes are difficult to identify as they appear and disappear with time
  - It is due to excess NH_4^+ ions on a Si wafer; anions concentration do not balance the concentration of NH_4^+ ions detected
  - The excess NH_4^+ ions are probably present as a condensed film of NH_4OH or a solution NH_3 in H_2O
  - The haze is not stable since NH_4OH is extremely volatile and appears/disappears depending on the temperature and humidity of the Si wafer environment



Optical and SEM images show ammonium carbonate haze formation.



Ion Chromatography (IC)

Cations

Anions

\+ + + + +

\- - - - -

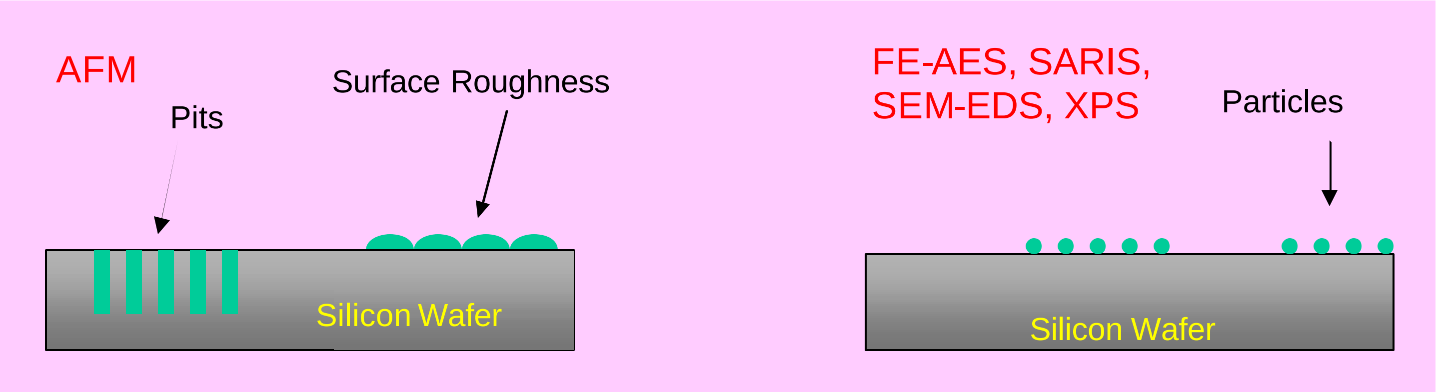
Silicon Wafer

Time-dependent haze (TDH), also known as degradation haze, is formed in the following way:

- The wafer is contaminated with water-soluble ions and organic molecules (other organic molecules also deposit on the wafer, making it more hydrophobic).
- A change in humidity causes water to condense on the wafer surface.
- The surface water dissolves the water-soluble contaminants
- The hydrophobic surface causes the water to form microscopic droplets.
- The micro-droplets evaporate and leave residual TDH defects.
- Without humidity, micro-contamination does not develop into haze. So one thing MEMC did was to implement measures to get the moisture out of its manufacturing

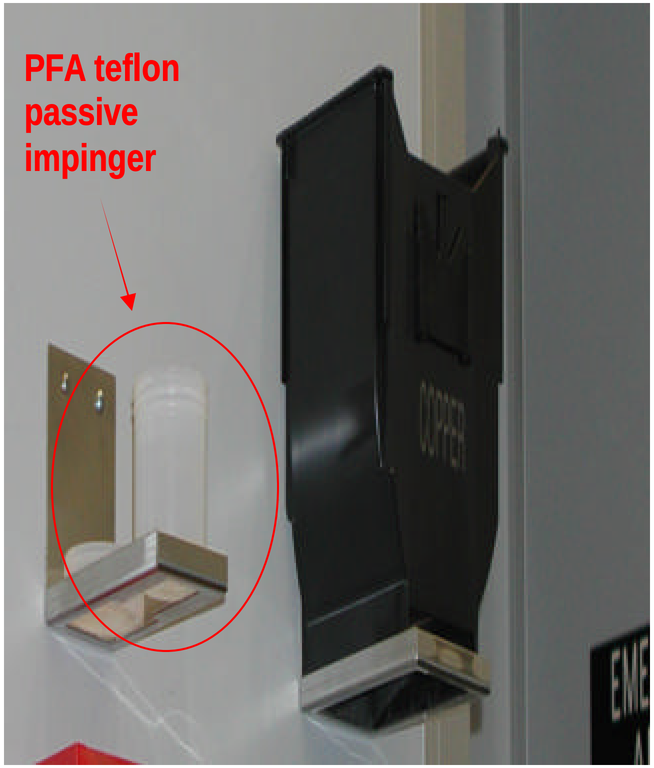
Ionic Haze (cont'd)

- Fluoride haze
  - ✓ High concentrations of fluoride ions can cause uneven etching of the native oxide and give the appearance of a haze
  - ✓ Potential contamination sources of F- ions are wafer carriers and boxes; either through direct contact or outgassed F- ions, from DI water or process chemicals with high F- ions concentration, and from F- ions leached from flouropolymer components



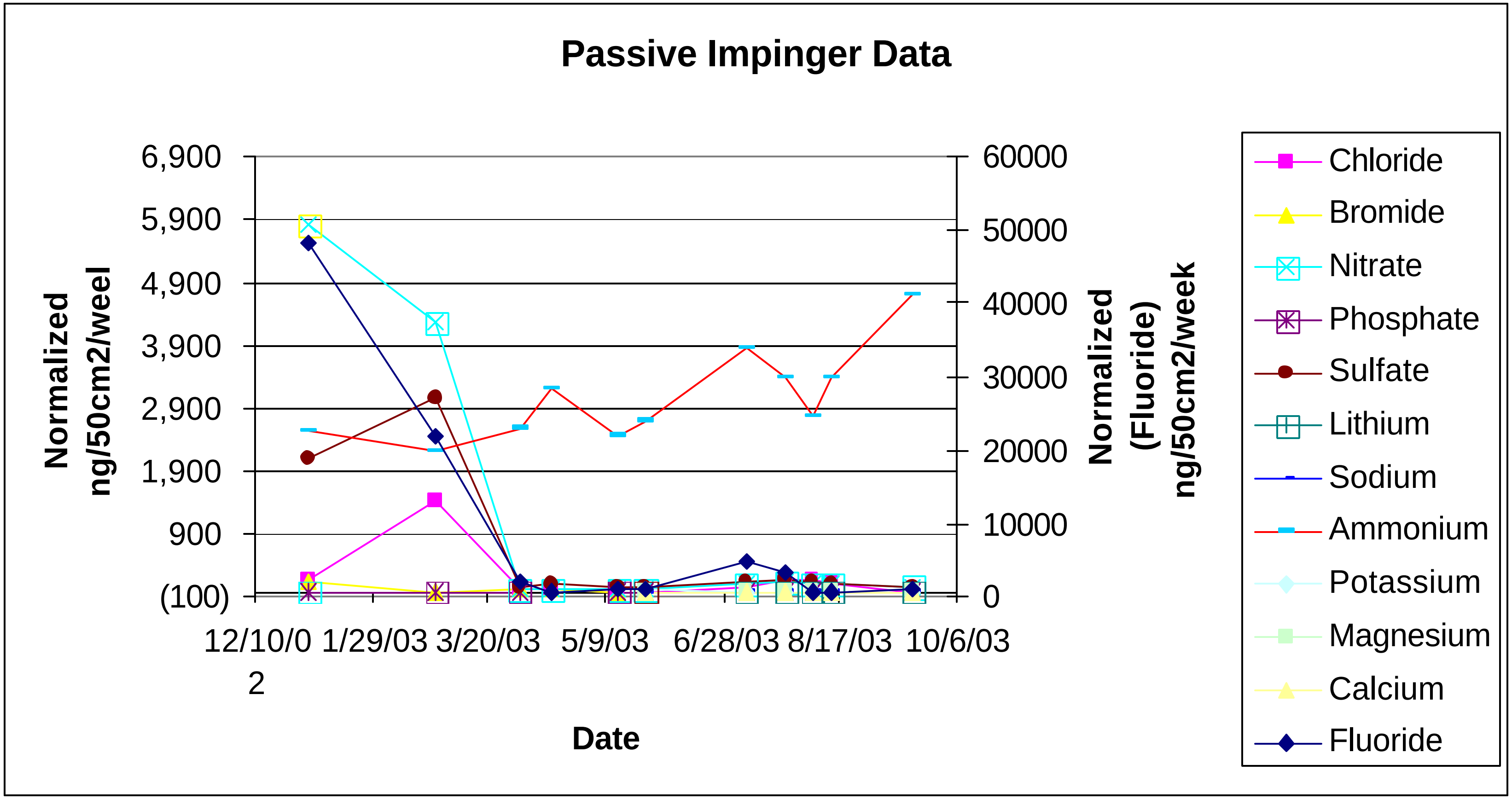
Passive Impinger

- Low Cost alternative ($30 for PFA Teflon Pot) to active impingers
- Impingers are filled with UPW that has undergone additional polishing with a Millipore Element system
- No acids or solvents are used as the collection media
- Impingers are placed in each process bay and left for 1 week period
- After 1 week PIs are collected, weighed and analyzed via ion chromatography (IC)



*Luke Lovejoy, Motorola,
2nd Annual SCCCM Conference, San Marcos, TX, 2003*

AMC-MA/MB/MM Using UPW Impinger



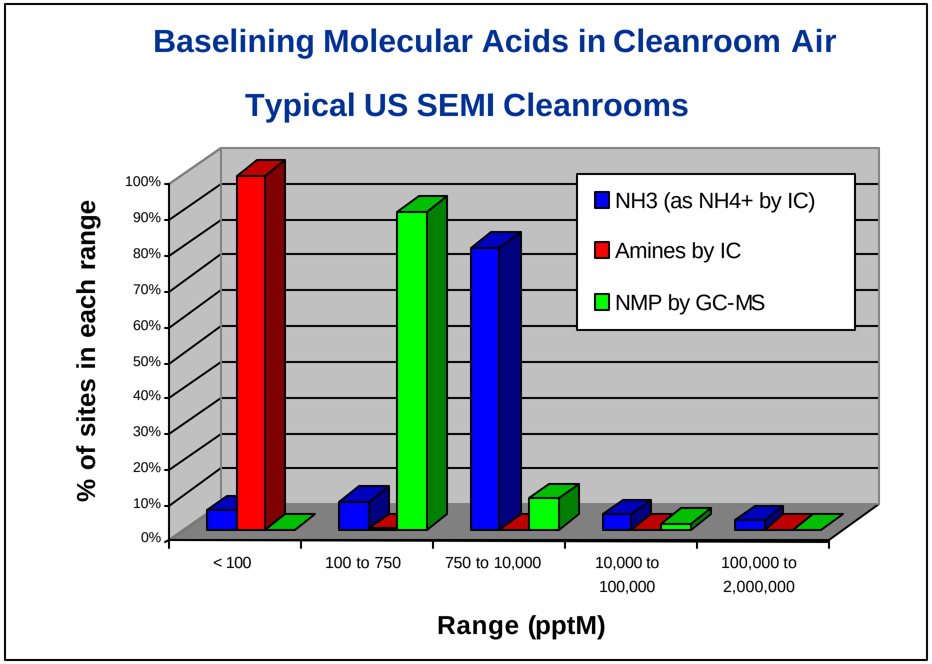
Luke Lovejoy, Motorola, 2nd Annual SCCCM Conference, San Marcos, TX, 2003

Controlling Molecular Acids

- Improved balancing of wet benches, reactors, exhaust
- Exhaust scrubbing, dilute chemistries, closed area cleans
- Gas phase adsorbers (e.g. Na_2CO_3, KOH, IX resins)
  - For outside air (NO_x, SO_x)
  - For recirculation air (to remove process acids)
- Isolation of processes (from cross-contamination)

Molecular Bases (AMC-MB)

- Amines are seldom observed, unless used (e.g. photoresist stripper, humidifiers)
- Ammonia still remains the dominant base in fabs
- Amides as NMP sometimes seen if used
- “Water spotting” has been observed to result from excessive base ambient
  - ✓ Probably results from caustic etching causing increased microroughness from sodium silicate formation



Sources of Molecular Bases

- Ammonia (NH_3)
  - ✓ HMDS, CMP slurries/wafer polishing, wafer cleaning (SC-1, APM), Si_3N_4 and TiN deposition, people, outside air (especially fertilizer, sewers, farms)
- Amines (NR_3)
  - ✓ Photoresist strippers
  - ✓ Cleaning solutions
  - ✓ Anion exchange resin regeneration (Me_3N) epoxies
  - ✓ Air humidifiers (corrosion inhibitors)
- Amides (R-C=O(-NR_2)
  - ✓ Photoresist strippers
  - ✓ Solvents for polymers, including polyimides, epoxy
  - ✓ High-temperature solvent baths
  - ✓ Paints and paint removers (NMP, 1-methyl-2-pyrrolidine)

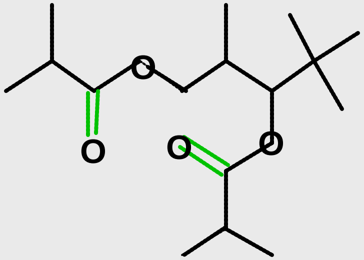
Controlling Molecular Bases

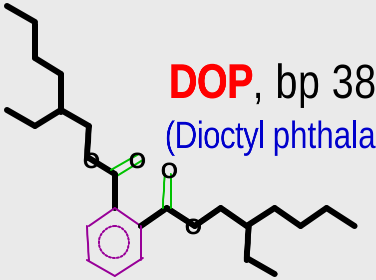
- Source reduction
    - Improved venting of baths and scrubbing of exhaust
- Amine/base removal
    - Appropriate gas phase or carbon adsorber cells (molecular filters) in lithography area. Such as, citric acid, phosphoric acid, acidic polymers and Activated Carbon to remove NMP & high boiling organics
    - Need to test kinetics (breakthrough), capacity (lifetime), shedding (contamination)
- Isolation
    - Purge tracks and minienvironments (MENV) with base filters or purified gases
- Modify process
    - Shorter process windows prior to resist coat and post exposure
    - Pre-exposure bakes to densify/harden resist and reduce base penetration or diffusion

Molecular Condensable (AMC-MC)

Plasticizers

TXIB, bp 280 °C
(Texanol isobutyrate)

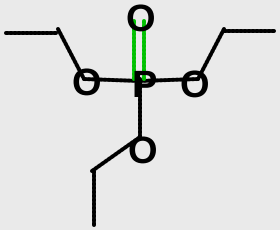




DOP, bp 384 °C
(Dioctyl phthalate)

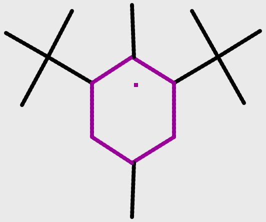
Phosphates

TEP, bp 215°C
(Triethyl phosphate)



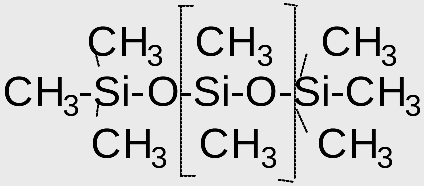
Antioxidants

BHT, bp 233 °C
(Butylated hydroxytoluene)



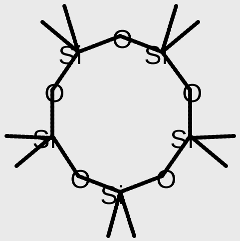
Silicones / Siloxanes

PDMS
Poly(dimethyl silicone)



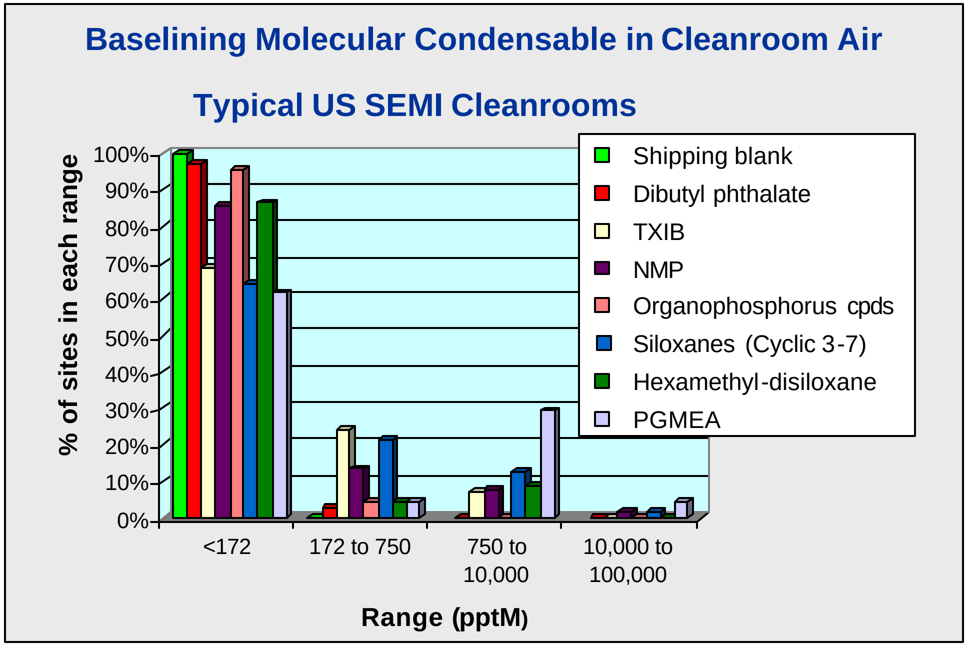
$$\mathrm{CH_3\text{-}\overset{CH_3}{\underset{CH_3}{Si}}\text{-}O\text{-}\left[\overset{CH_3}{\underset{CH_3}{Si}}\text{-}O\text{-}\right]\overset{CH_3}{\underset{CH_3}{Si}}\text{-}CH_3}$$

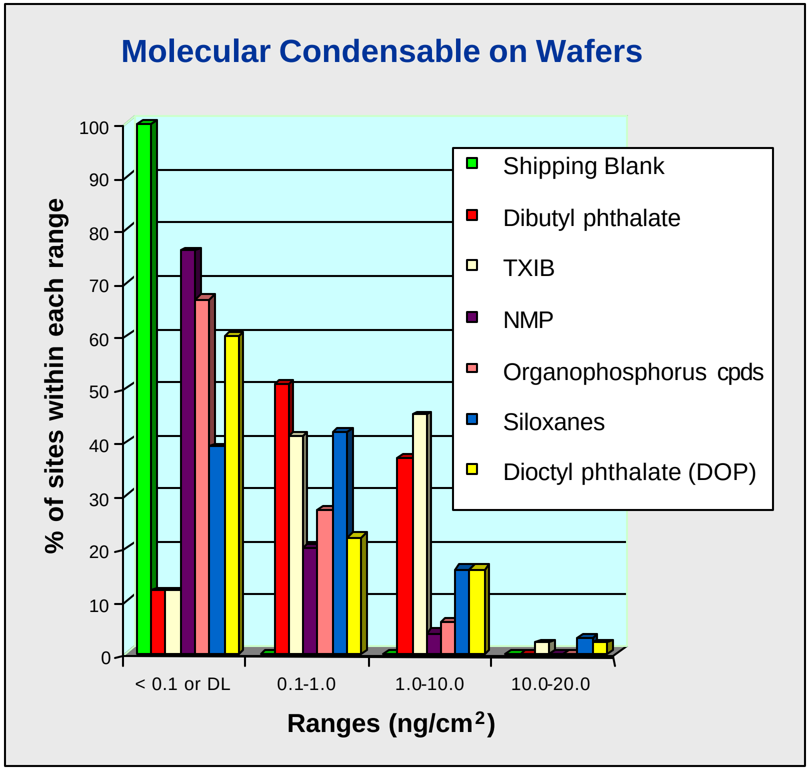
Decamethylpentasiloxane



bp 211°C

Molecular Condensables in Air and Wafers





BALAZS nanoanalysis
Reducing Contamination

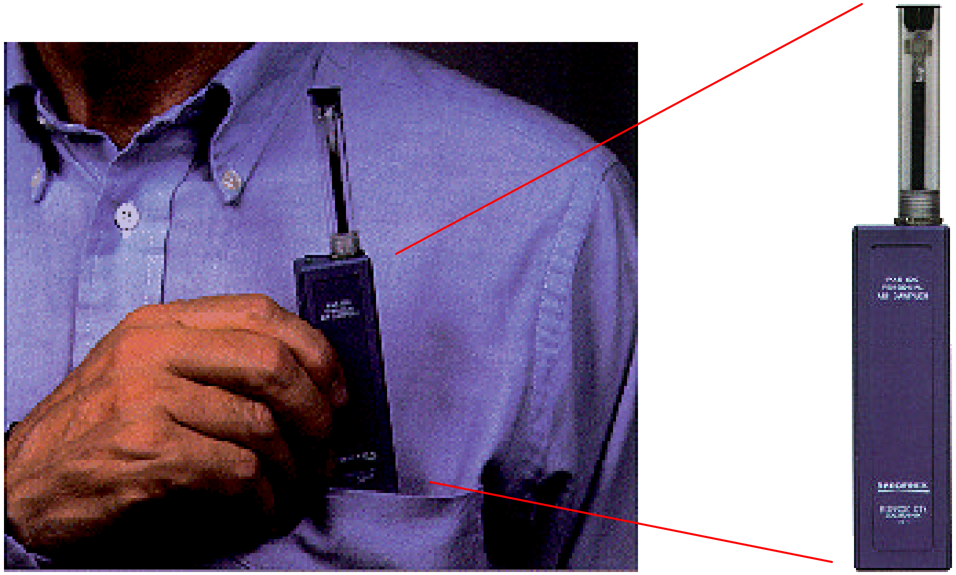
FAB AND TOOL OPTIMA™ OPTimization for MAnufacturing

Sources of Molecular Condensables

- Plasticizers, such as DOP and TXIB, are used in flooring material, vinyl curtains, flexible duct connectors, wafer carriers
  - TXIB, chemical name is trimethylpentanediol diisobutyrate.
  - TXIB is a Eastman trademark and is a common plasticizer found in PVC (polyvinyl chloride)
- Anti-oxidants, such as BHT (butylated hydroxytoluene) for polymers are used in adhesives, wafer carriers, and PVC polymers
- Phosphates, such as TEP (triehtyl phosphate) is a fire retardant used in construction materials and sealants of HEPA filters
- NMP, N-methylpyrrolidone is a common paint thinner
- Silicone, such as PDMS (polydimethylsiloxane) is a releasing agent used in silicon-based gels and machine lubricant

Organic AMC Air Sampler

- Flow range: 5 - 200 cc/minute
- Full flow regulation. A constant voltage is applied to pump as battery voltage drops
- Accommodates 6mm diameter (single and double) and 8mm diameter charcoal Tenax tubes, Perkin-Elmer adsorber tubes, and other absorber tubes



PAS-500 micro air sampler

Material Outgassing

- Any cleanroom material has the potential to outgas organic compounds
  - Coatings
  - Paints
  - Wall coverings
  - Sealants
  - Caulking and curing agents
  - Adhesives
  - Tapes
  - Gel seals (potting agents)
  - Floor covering
  - Cables
  - Pipes, bearings, solder/fluxes
  - Tubing (flexible membranes and hoses)
  - Labels
  - Gaskets
  - O-rings
  - Plastic curtains
  - Packaging
  - Light fixtures
  - Insulation (thermal, electrical, acoustic)
  - Cleanroom materials
  - Wafer carriers
  - Filter systems (high efficiency particulate air and ULPA)
- Assembled products requiring bonding should be tested in both raw and assembled form
- Vinyl floor covering bonded to aluminum tile with an adhesive

Material Outgassing Test Standards

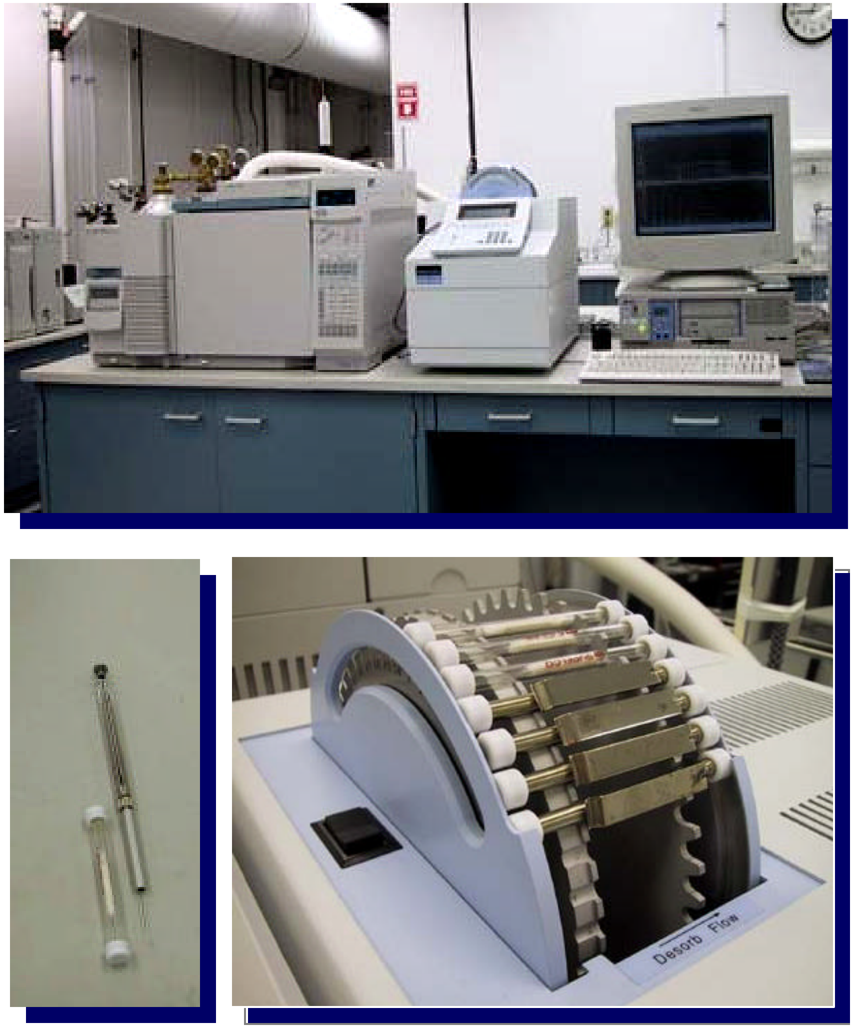
- Dynamic Headspace GC-MS (IEST WG CC31)
  - ✓ Method for semi-qualitative analysis of outgassed compounds from cleanroom materials and components
- IDEMA M11-99 DHS GC-MS method
  - ✓ Approved for disk drives and used for cleanrooms
  - ✓ Good for detecting high boiling compounds outgassed from cleanroom components, disposables
- ASTM F1982-99: Analysis for organics on a silicon wafer by TD-GC-MS

Assorted materials for outgasssing characterization

Outgassing onto a substrate of interest

- SEMI E46: Outgassing of pods onto wafers, then IMS analysis
- SEMI E108: Outgassing onto wafer method, GC-MS analysis by ASTM 1982-99

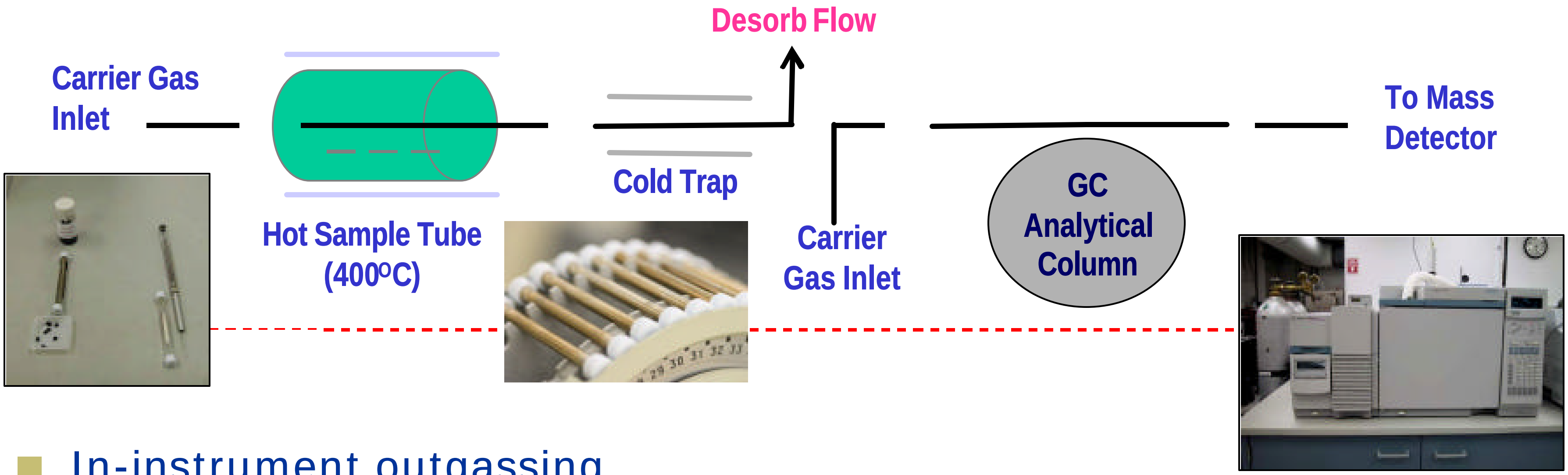
IEST WG CC31



Victor Chia and Jim Ohlsen, IEST WG-CC031.1, ESTECH 2006

- GC with temperature programming
  - ✓ 50º, 75º, 100º, or 150º C for 30 minutes
  - ✓ Helium carrier gas flow rate 3 mL/min
- MS with mass detector range 33-550 amu
- GC column
  - ✓ Non-polar fused silica open tubular capillary column with a film of poly(dimethylsiloxane)
  - ✓ HP-1, DB-1, DB-5 (1-10mg/g min. sens.); HP-5 MS (1-10 ng/g min. sens.)
  - ✓ 30 meter length

Thermal Desorption Gas Chromatography Mass Spectrometry (TD-GCMS)



Primary (Tube) Desorption

Desorb Flow

Carrier Gas Inlet

Hot Sample Tube (400^{o}C)

Cold Trap

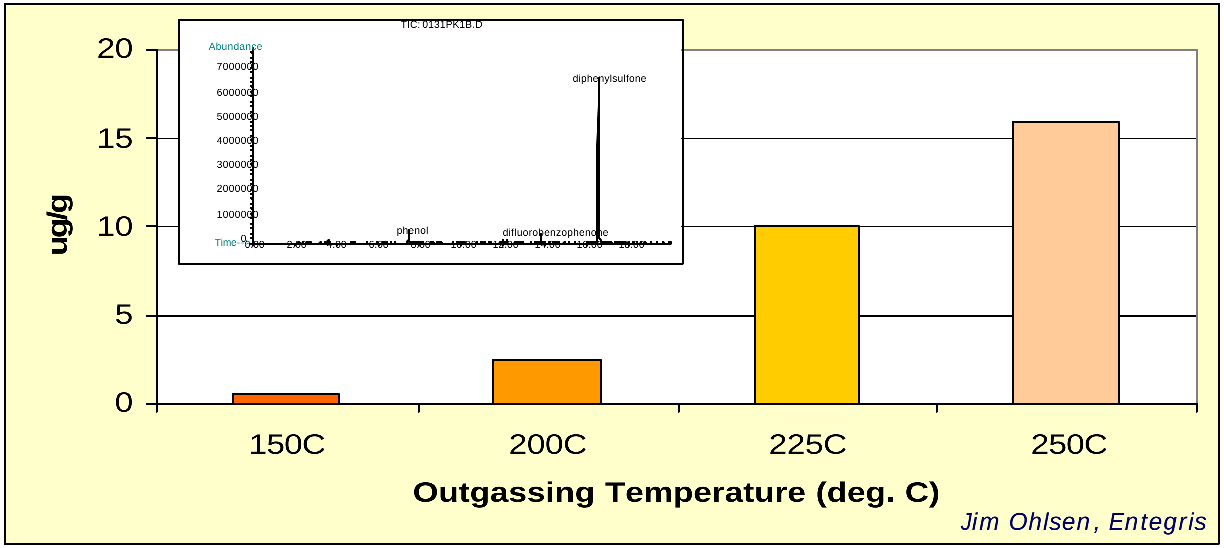
Carrier Gas Inlet

GC Analytical Column

To Mass Detector

- In-instrument outgassing
  - Tenax tube
  - For medium to high outgassing material
- Off-line outgassing
  - Quartz tube
  - Larger sample to increase detection limit
  - For low outgassing material

PEEK Outgassing Results



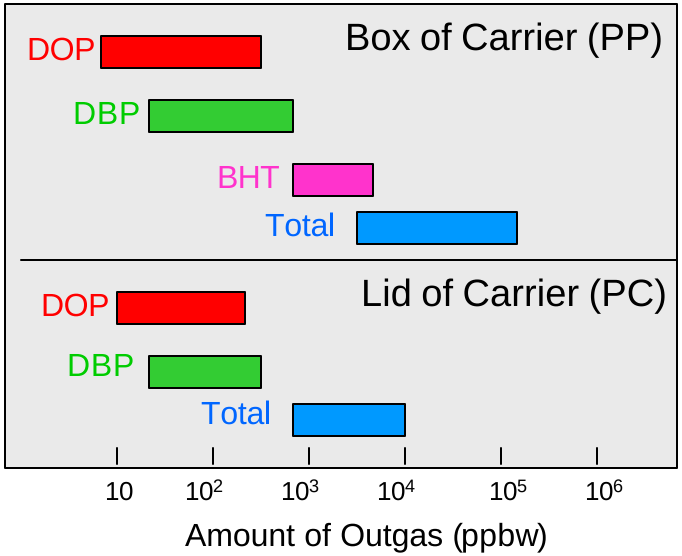
Jim Ohlsen, Entegris

- Outgassing increases with increasing outgassing temperature from 150^{o} - 250^{o}C
- Mass spectral libraries
  - John Wiley
  - NBSK
  - Jossey-Bank
  - Analytical Chemistry Handbook
  - Atlas of Spectral Data and Physical Constants for Organic Compounds

Controlling Molecular Condensables

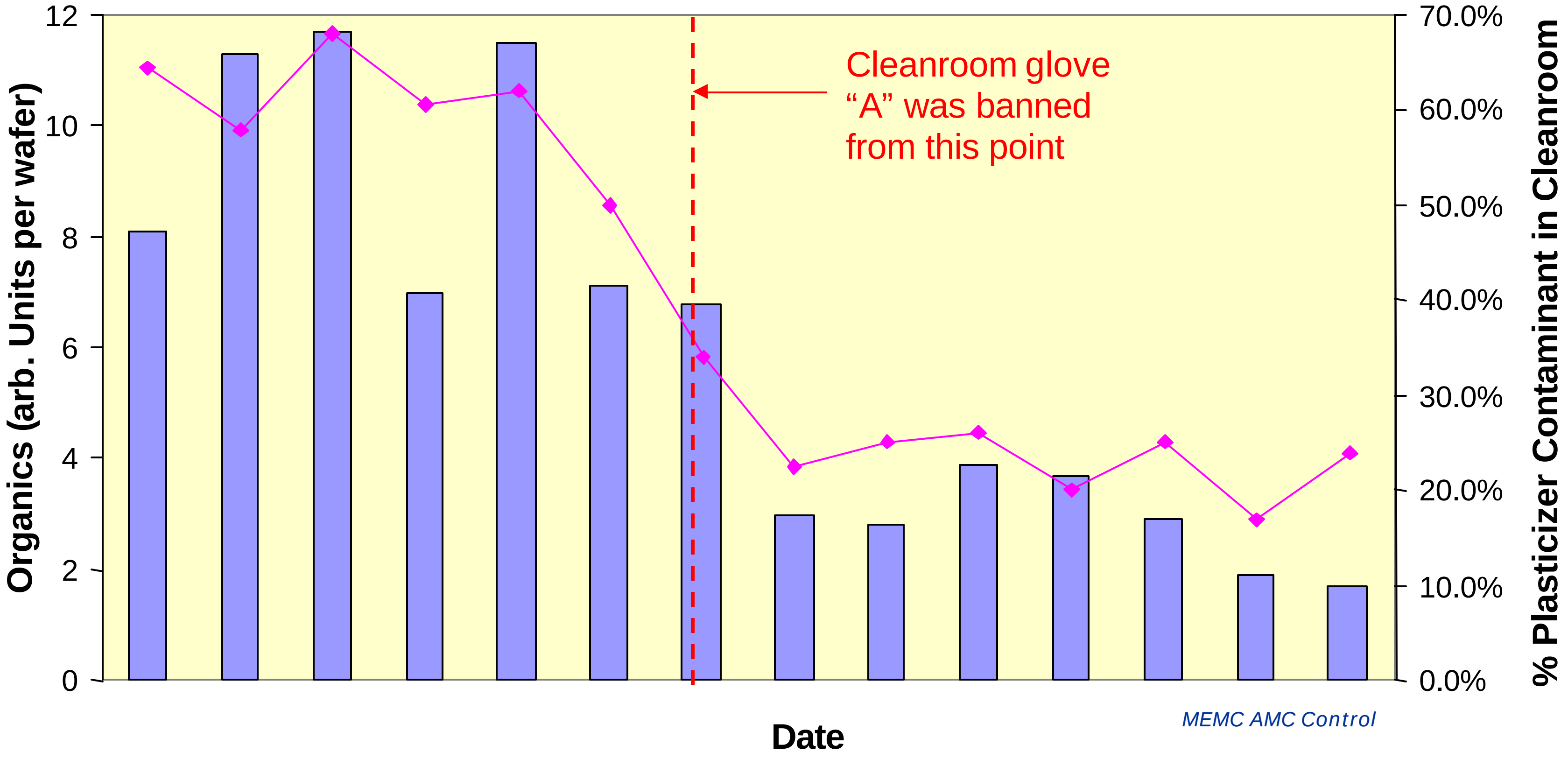
Limit Outgassing

- Sealants, paints, coatings, adhesives, epoxies, urethanes, elastomers, gaskets
- Plastics: vinyls, PP, PE, PVC, fluoropolymers, mold releases
- Insulation, flooring, curtains, hoses, pipes, tubing, o-rings, walls, ducts, ceiling tiles, light fixtures, containers
- ULPA and HEPA filter systems: potting compounds and gel seals
- Wafer shippers, carriers, FOUPs, Pods, compacts, cassettes, minienvironments
- Integrated products: Instruments, computer terminals, chairs, process tools, people, motors, bearings, heaters, lubricants
- Consumables: garments, gloves, masks, wipes, booties, adhesives, tapes, bags, tacky mats, cleaners



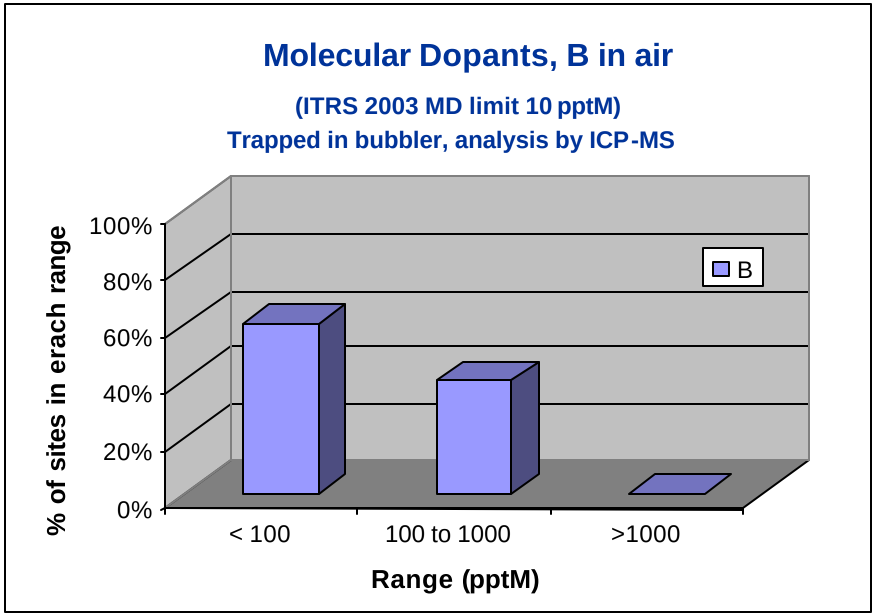
Kikuo Takeda et al, Proceedings of the IEST, p. 556, 1998

Careful Selection of Material Reduces AMC



Molecular Dopants (AMC-MD)

- Many fabs have B much above roadmap and DLs of test methods
- High B in air or on wafers may be acceptable for back-end-of-line process
- High B in cleanroom air is acceptable for FEOL processes if
  - Wafer is cleaned prior to processing
  - Wafer is not exposed to air (e.g. N_2 purge box, cluster tools)



Sources of Molecular Boron

- Degradation of HEPA/ULPA filter media
  - Typically borosilicate glass. Reacts with HF (alcohols, moisture) to form volatile B compounds, such as BF_3 (bp 100 ^{o}C), $B(OiPr)_3$ (bp 140 ^{o}C)
  - Particulates also emitted, includes Ti, Zn, Al, Ca, Mg, Na, Si, B, K, and Ba
- Process chemicals
  - CVD, B_2H_6, TMB (trimethyl borate), kilograms used
  - Reactive ion etching exhaust (BF_3, BCl_3, BBr_3)
  - Ion implantation dopants (BF_3), grams used
- Wafers exposed to ambient boron, such as boric acid, at a concentration level of 118 pptM or ~300 ng/m^3 will result in
  - Approximately 3.7×10^{11} atoms/cm^2 for a 15 minute exposure
  - Approximately 1×10^{13} atoms/cm^2 after 24 hours exposure

Sources of Molecular Phosphorus

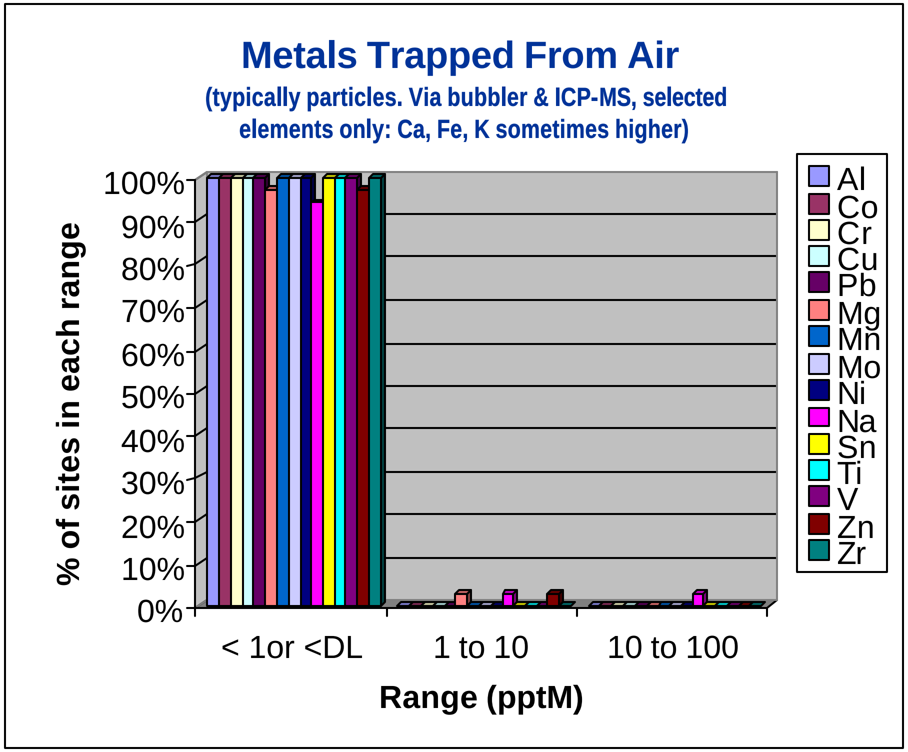
- Phosphorus dopants used for CVD, ion implantation, and maybe RIE by-products
  - ✓ PH_3 and POF_3
  - ✓ $POCl_3$ (dopant for poly-Si)
  - ✓ Trimethyl phosphate or trimethyl phosphite (CVD for PSG, BPSG)
- Common flame retardants, such as TEP (triethylphosphate) and Fyrol PCF [tri(β-chloroisopropyl) phosphate], plasticizers (especially urethanes and may be used in some carriers), lubricants, and hydraulic fluids
- Wafer correlation
  - ✓ For example, 0.1 pptM of airborne organophosphate correlates to about 2.5 - 5×10^{10} P atoms/cm^2, based on a 4 hour sit time
  - ✓ 5 - 50 pptM of airborne organophosphate results in a wafer doping level of 1×10^{18} P atoms/cm^2, following <1 hour exposure time

Controlling Molecular Dopants

- Convert to using borosilicate filters
- Control HF in air
- Use boron-free ULPA (Ultra Low Penetration Air) filters
  - Use PTFE filters
  - Use B-free fused silica
- Install additional HF- or B-removal filters
- Add gas phase adsorbers for makeup or recirculation
- Avoid or minimize wafer exposure to air by using cluster tools and nitrogen environments

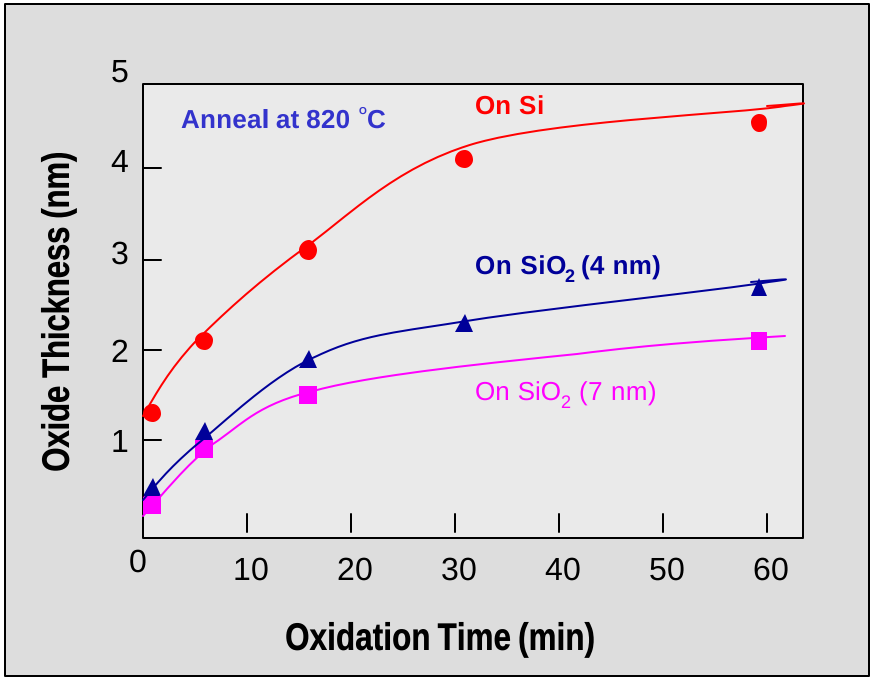
Molecular Metals (AMC-MM)

- Metals in air may be molecular in some cases,
    - $AlCl_3$ (bp 183 °C)
    - WF_6 (bp 18 °C, used for W plugs)
- In the future, more metal problems are likely
    - Organometallics (organo-Cu, Al, Ti, Ga, As, Ge, In, Ba, Sr, Ta, Zr, Hf, Bi, Nb, La) and hydrides for MOCVD are volatile
    - Some etch by-products may also be volatile
    - Cu in air: ITRS 2003 limit is 0.15 pptM for wafer environment



Accelerated Oxide Growth

- Experiments by Ohmni has shown that 100 ppb Al residue on a wafer surface after a SC1 (or APM) (NH_4OH : H_2O_2 : DIW) cleaning process can accelerate oxidation of bare silicon wafers



T. Ohmori, N. Yokoi, and K. Sato, UCPSS, p. 25, 1996

Sources of Molecular Metals

- Most metals still originate as particulates
  - From tools, floors, spills, ECP, CMP, ULPA leaks, corrosion, robotics
  - Metals may transport via air or surface contact
  - In the future, more metals/oxides may be used for contacts, salicides, electrodes, gates. Hence, greater awareness to Co, Ni, Ru, RuO_2, Pt, Ir, Hf, Zr, Gd, Sc, and La
- Degradation of air ducts
  - Corrosion of passivated (chromium oxide films) stainless steel by HCl resulting in emission of Fe, Cr, and Ni into the airstream
  - Corrosion of galvanized (Zn coated) stainless steel by H_2SO_4 resulting in Zn and Fe emission in airstream

ITRS adds SMC limits in 2003

Why there is a shifting emphasis from AMC to SMC?

- 200- and 300-mm wafers have less exposure to air
  - Wafers spend less time in laminar flow or cleanroom air
  - Fewer open cassettes - still some exposure to air in tools
  - Wafers mostly enclosed in FOUP’s, pods, minienvironments
- Outgassing or carryover of contaminants in FOUPs/Pods an issue
  - But AMC (MC, MD) levels not well correlated between SMC on wafers and process effects
- Cleanroom AMC testing still critical for Litho (MA, MB and MC)
- Contact transfer of contaminants to wafer surfaces a major concern
  - Especially for acids, bases, organics and Cu (copper metallization)
- Need identical SMC analysis methods (as for AMC) to characterize what adsorbs onto the wafer from the air, storage or process steps, and control all contaminants within process specifications

ITRS SMC Deposition Limits

- 3 new SMC classifications
- Tests: Si witness wafers exposed 24 hr
  - ✓ Closed FOUP, Pod
  - ✓ Minienvironment, or flowing air
  - ✓ Can also compare with process SMC

Test	**2005 SMC**	
SMC Organics, "SMOrg"	2 ng/cm^2 (for 2005-2009) *~ 0.1 monolayer* 1E14 C atoms/cm^2	*~ 0.1 ML*
SMC Dopants, SMD	2E12 atoms/cm^2 1E12/cm^2 for 2006-9	*~ 0.001 ML*
SMC Metals, SMM	2E10 atoms/cm^2 to 2008 1E10 atoms/cm^2 for >2009	*~ 0.00001 ML*

Same tests to compare FOUP's, Pods, minienvironments, air or process!

1 organic/polymer monolayer is =*1E15 atoms/cm^2 on bare Si <100>*

ITRS Surface Preparation Requirements

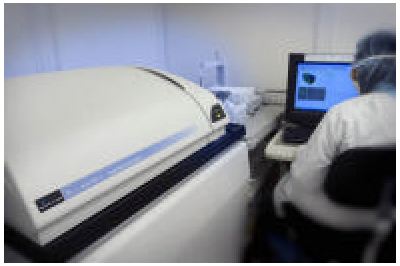
YEAR OF PRODUCTION	2007	2008	2009	2010	2011	2012	2013
	65nm	57nm	50nm	45mm	40nm	36nm	32nm
Surface carbon (10^{13} at/cm^2)	1.2	1.0	0.9	0.9	0.9	0.9	0.9

- The surface concentration of carbon atoms after cleaning is based on the assumption that a 10% (7.3×10^{13} atoms/cm^2) carbon atom coverage on a bare silicon <100> surface can be tolerated during device fabrication
- Surface organic levels are highly dependent on wafer packaging, on hydrophobic or hydrophilic wafer surface conditions, and on wafer storage conditions such as temperature, time and ambient

SMC Sampling and Analysis Methods

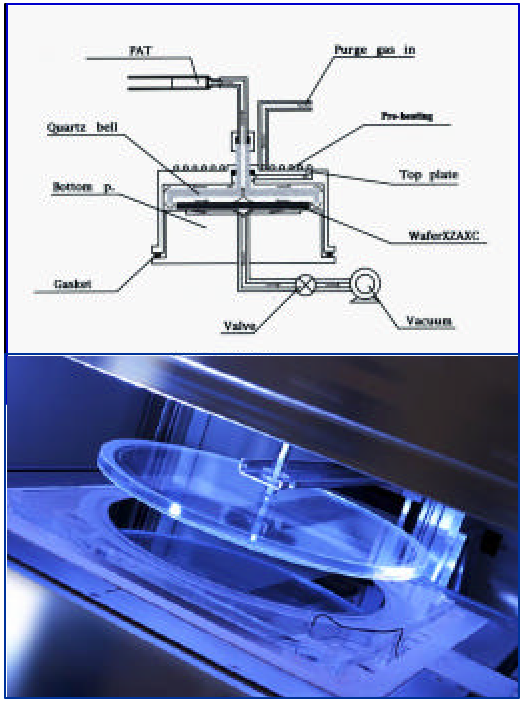
Analyte	Sample Collection	Sample Analysis
Organics, SMOrgs	Exposed Witness Wafers for 24 Hours	Full Wafer Thermal Desorption-GC-MS, SEMI MF1982-1103
Dopants (B, P, As, Sb)	Exposed Witness Wafers for 24 Hours	Drop Scan & ICP-MS Analysis
Trace Metals	Exposed Witness Wafers for 24 Hours	VPD - ICP-MS

ICP-MS: Inductively coupled plasma-mass spectrometry

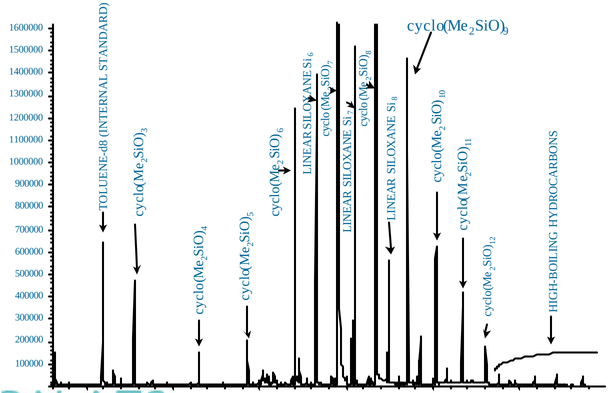


- Detection limits well below the ITRS limits; start with clean wafers!
- Need to apply these new ITRS SMC tests since they solve problems!
- Test size wafer up to 300 mm
- Other tests also available and can be helpful in some cases:
  - ✓ *Smaller spots, mapping, particle ID: TOF-SIMS, TXRF, SIMS, FTIR, Raman, Auger*
  - ✓ *Trending SMC weight on surface: SAW (Surface Acoustic Wave)*

Full Wafer TD-GCMC for SMC-SMOrg



GL Science SWA 256, Balazs Analytical Services



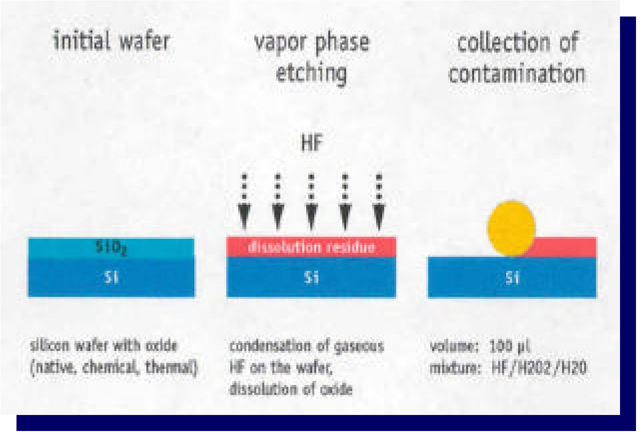
SEMI MF1982-1103

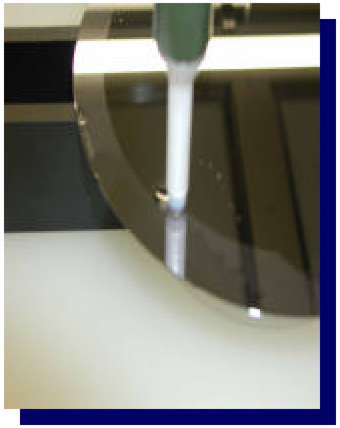
- The whole wafer is heated in a quartz chamber to ≤700ºC and the organic compounds outgassing from the selected side are collected and analyzed by GC-MS
- Recommended fab areas/locations to place witness wafers are make-up air, stockers, minienvironments, wafer sort and storage areas, wet benches, pre-diffusion, oxidation furnace and implant anneal areas, and lithography
- ITRS guidelines for 2005-2009
  - 2 ng/cm^2 for 24 h exposure and reducing to 0.5 ng/cm^2
  - 2 ng/cm^2 is approx 0.1 monolayer)

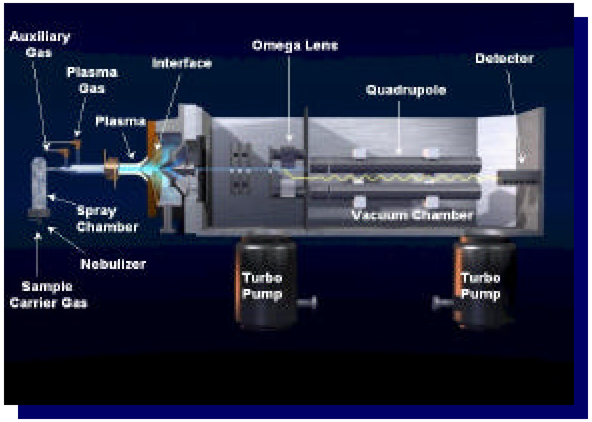
BALAZS nanoanalysis
Reducing Contamination

FAB AND TOOL OPTIMA™
OPTimization for MAnufacturing

Vapor Phase Decomposition ICP-MS (VPD ICP-MS)







Lovejoy, Motorola, 1st Annual SCCCM Conference, San Marcos, TX, 2002

Technical Summary

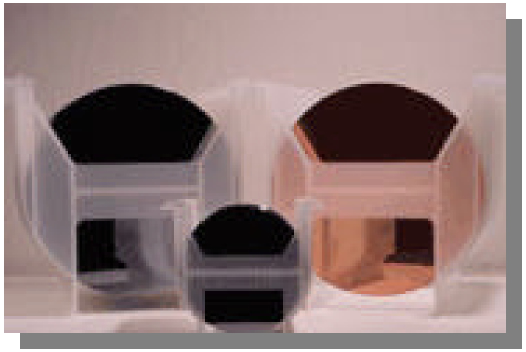
- Li to U
- Survey method
- 10^7 - 10^{11} at/cm^2
- Quantitative
- Native oxide
- Whole wafer
- Total wafer surface
- 300 mm wafers

- VPD ICP-MS is widely used because of its merit of detection limit and capability to provide full wafer surface and local analysis
- It is a survey method and provides detection sensitivity at the 10^7-10^{10} atoms/cm^2 range
- The scanning droplet may alternatively be analyzed by TXRF, referred to as VPD TXRF

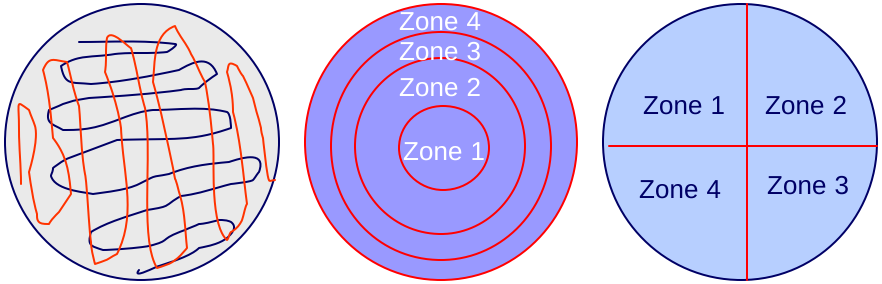
Advanced VPD Methods

Advanced VPD laboratory
300 mm handling in a Class 10 environment at Balazs

- Radial Analysis
  - ✓ Scan concentric bands
  - ✓ Reactor (CVD, ech tools) and wafer stage evaluation
- Bevel/Edge Analysis
  - ✓ Scan bevel or edge of the wafer
  - ✓ Edge grip chuck, CMP, wafer carrier
- Quadrant Analysis
  - ✓ Specific quadrant on the wafer
  - ✓ Tool configuration optimization



VPD can analyze bare, oxide, Si_3N_4, TanOx, BPSG, SiOC, HfSiO, and Al_2O_3



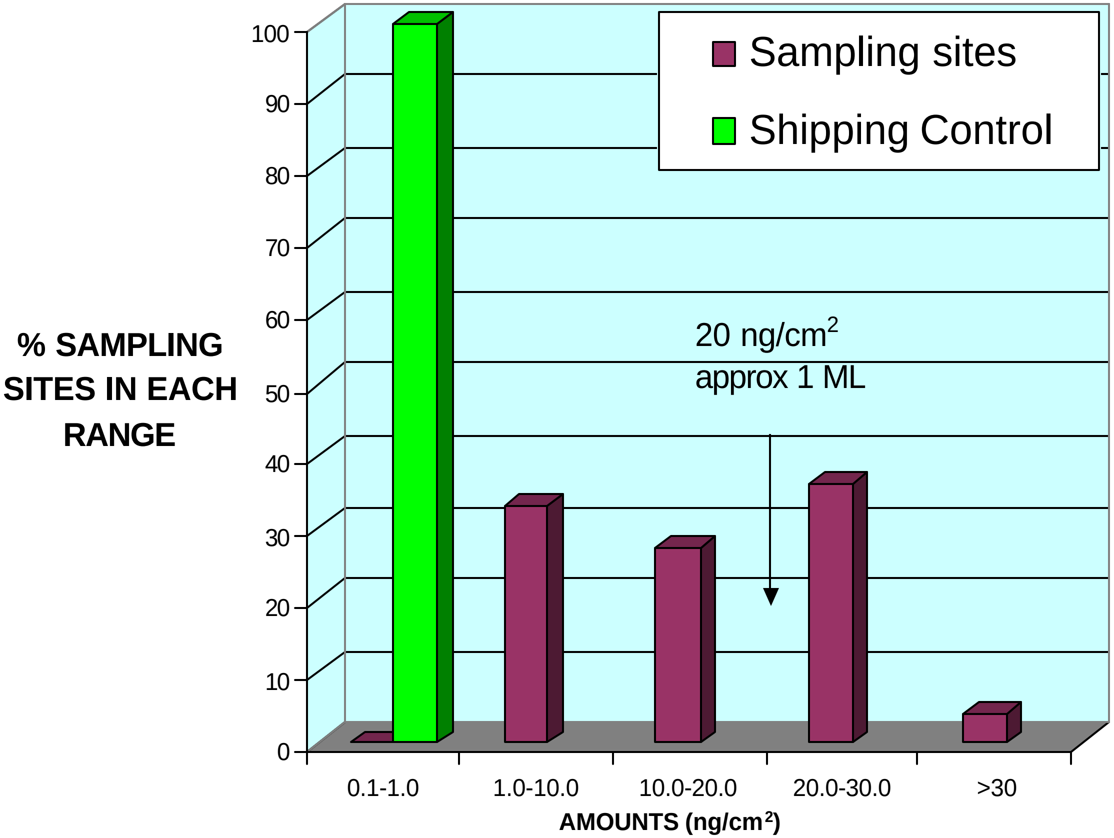
Advanced VPD scanning for localized information

SMC-SMOrg (Organic)

- Comprised of
  - Esp. organics with boiling points 250 – 450°C (or NVR’s)
  - Silicones, phthalates, antioxidants, hydrocarbons, organophosphates…
- AMC to SMC sources
  - Outside air and air handling system components
  - Outgassing (thousands of materials have been tested)
    - Standardized test, IEST RP-031
    - Should test existing compounds or materials
    - Also: new compounds/materials, or new uses
    - Esp. Foups, pods, mask compacts, minienvironments, ULPA’s, floors, sealants, walls
- Liquid sources include process chemicals, solvents, UPW or additives to slurries, rinses
  - Impurity residues for strippers, edge bead removers, IPA, MeOH
- Contact transfer sources
  - To wafer edges from FOUPs, Pods, shippers, chucks, wafer holders, boxes
  - Installation and maintenance cleaning via gloves, wipes, swabs
  - Shipping bags for parts

SMC-SMOrg (Organic)

Histogram: TYPICAL TOTAL ORGANICS (>C_7) FROM WHOLE WITNESS WAFERS BY SEMI MF 1982-1103, METHOD B (TD-GC-MS), WAFER EXPOSURE: 24 HOURS

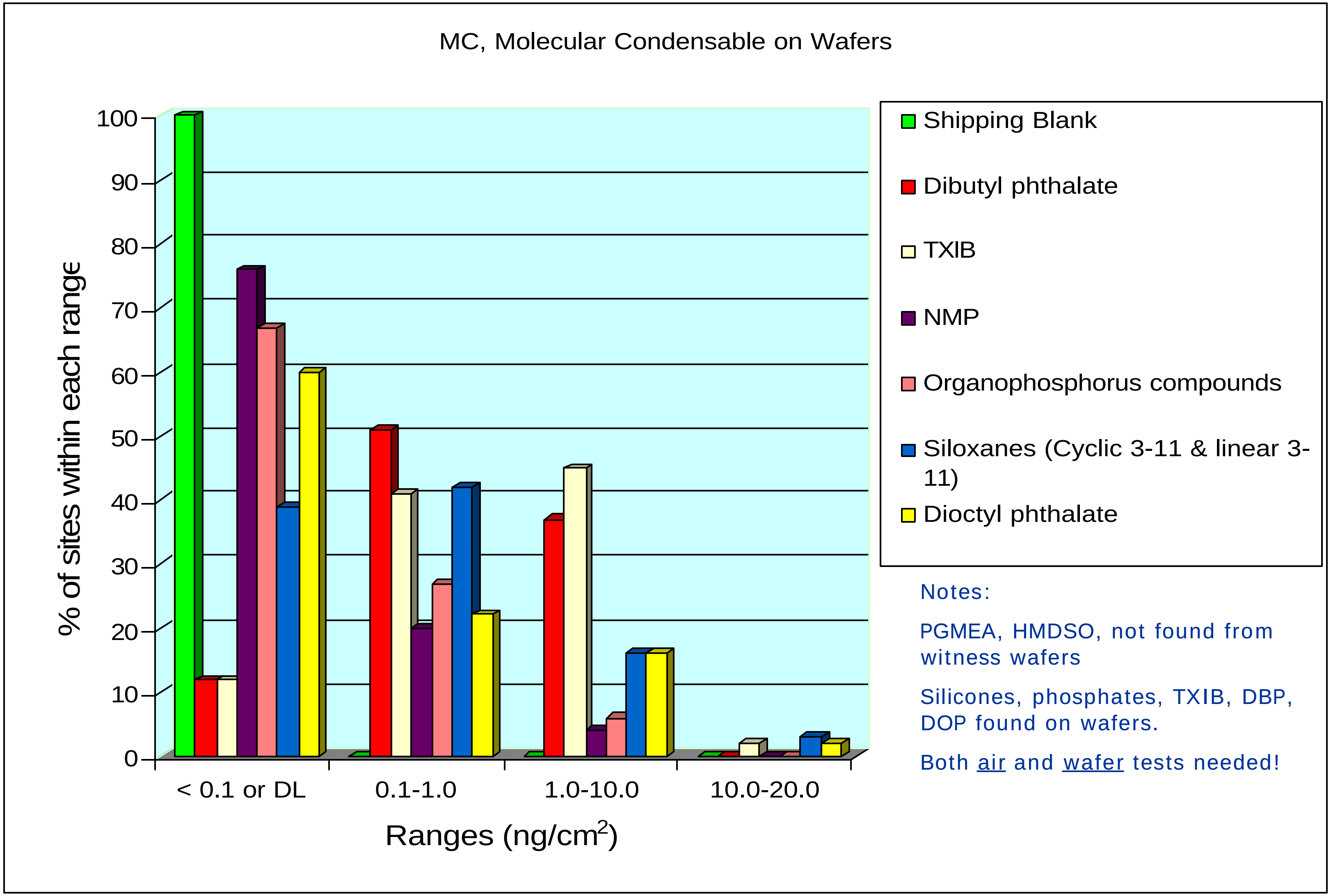


Increasing delamination of resists & other layers →

Possible GOI, SiN, polysilicon errors, depending on compound & process

Ellipsometry errors →

SMC-SMOrg (Organic)



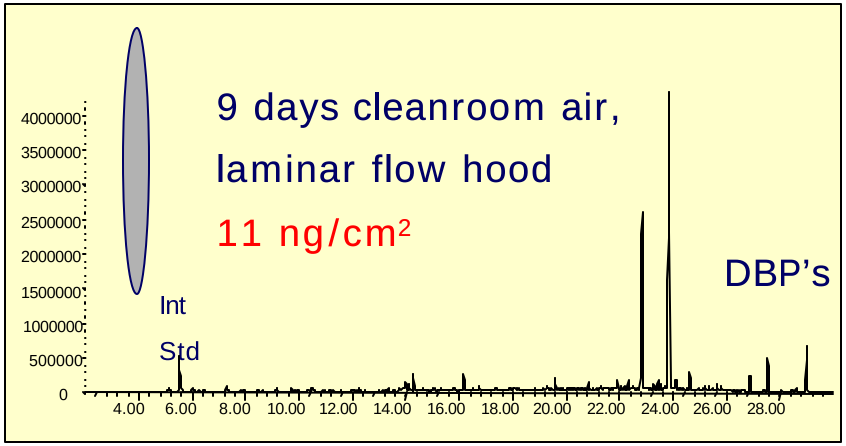
Notes:

PGMEA, HMDSO, not found from witness wafers

Silicones, phosphates, TXIB, DBP, DOP found on wafers.

Both air and wafer tests needed!

SMC-SMOrg: 300mm Wafer Exposure

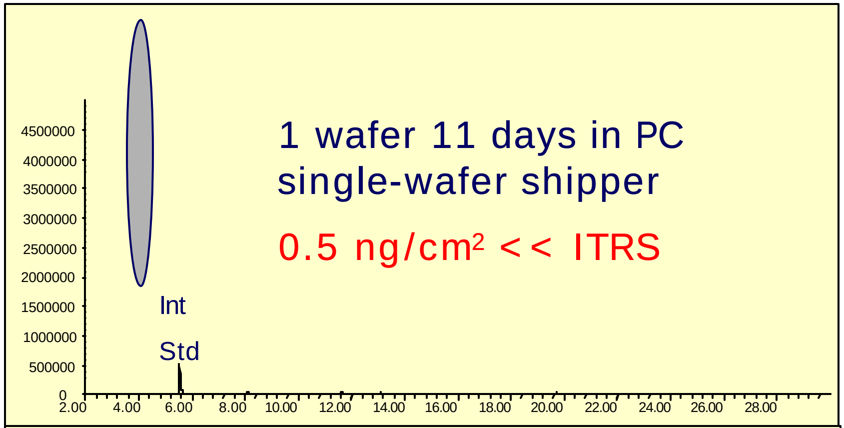

9 days cleanroom air, laminar flow hood

11 ng/cm²

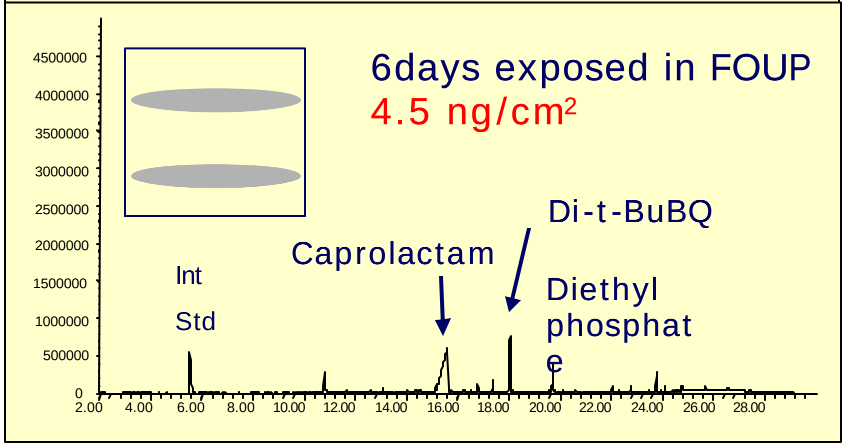
DBP's

Conclusion

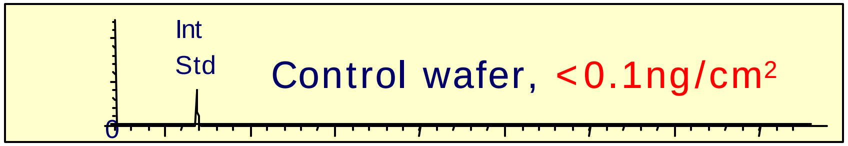
- Exposure to cleanroom air often results in SMC > ITRS recommended concentration of 2 ng/cm²
- Shippers provide excellent protection from outside AMC
- FOUP outgassing/carryover issues
- Beware of hot wafers too!


1 wafer 11 days in PC single-wafer shipper

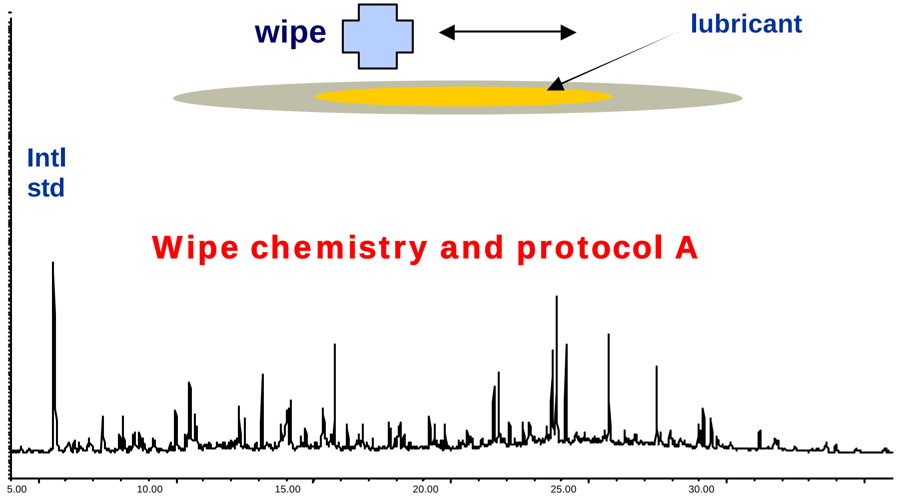
0.5 ng/cm² << ITRS

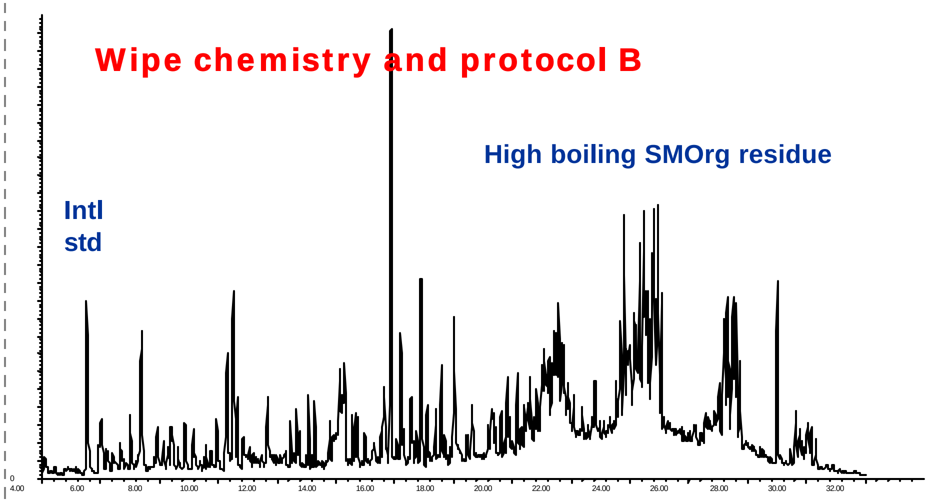

6days exposed in FOUP

4.5 ng/cm²

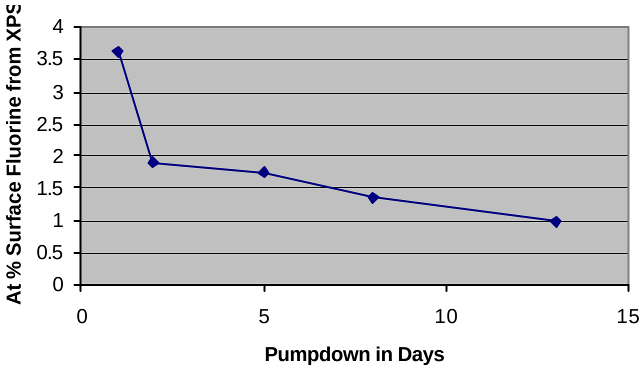

Control wafer, <0.1ng/cm²

Lubricant Decontamination





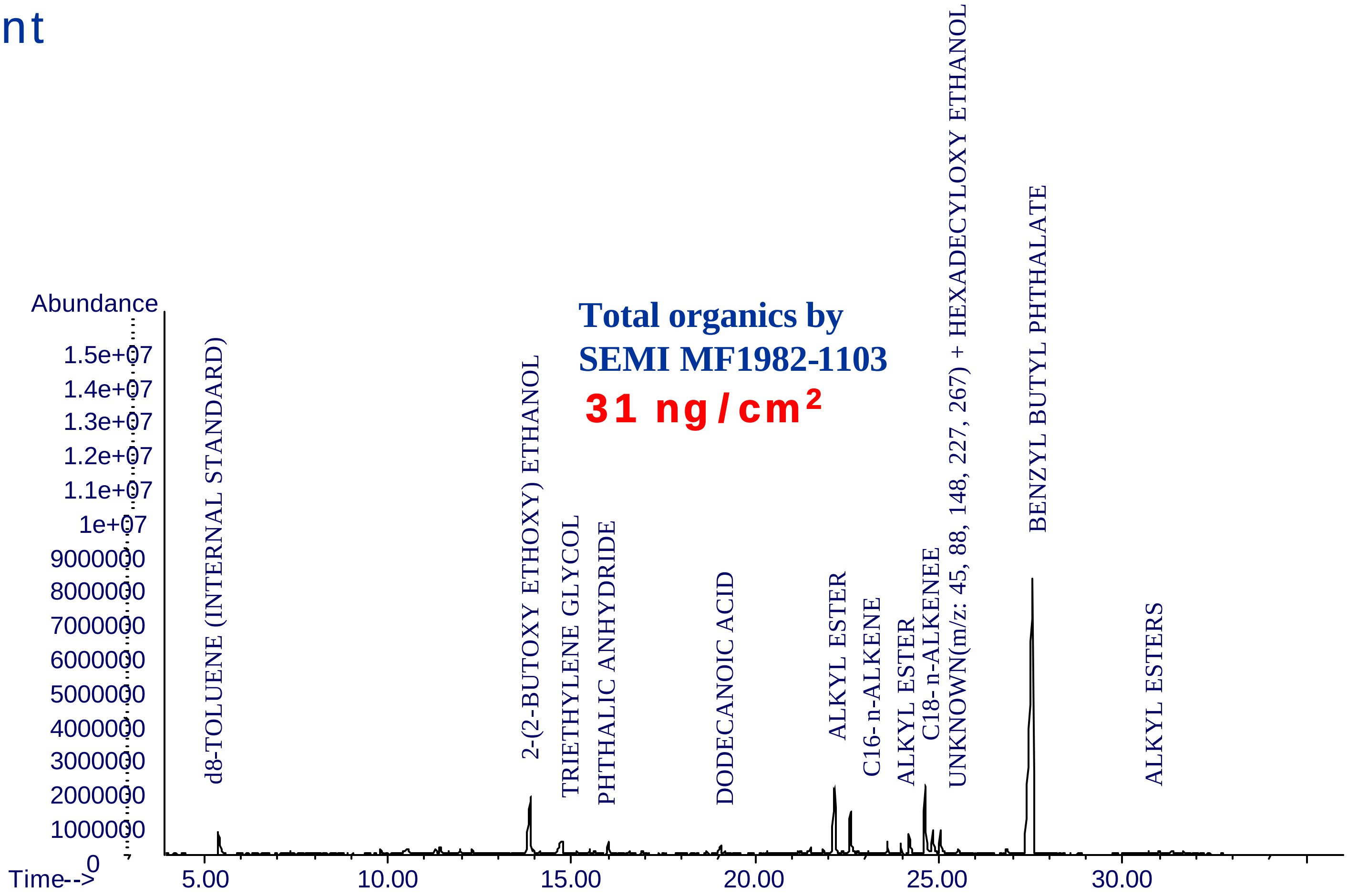
- Evaluate cleaning methods for different lubricants
  - ✓ Brayco 815Z
  - ✓ Brayco 600EF
  - ✓ Brayco 1624
  - ✓ Krytox 16256
  - ✓ Kytox 1525
- Outgas residue on wafer after wiping using FW TD-GCMC
  - ✓ Precaution: gloves and wipes may contribute organics
  - ✓ Use only high purity solvents
- Evaluate tool cleanliness using XPS



Wafer Proximity Test

- Cleanroom material
- GelPak and membrane box
- Anti-static and “pink” bag
- Lubricant
- Paint
- Epoxy
- Tape
- Foam

Wafer above 3.5-years-old vinyl flooring, post cleaning, under glass cover



Total organics by SEMI MF1982-1103

31 ng/cm^2

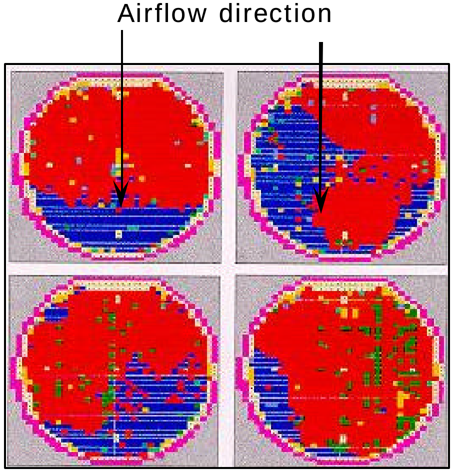
BALAZS nanoanalysis

Reducing Contamination

FAB AND TOOL OPTIMA™ OPTimization for MAnufacturing

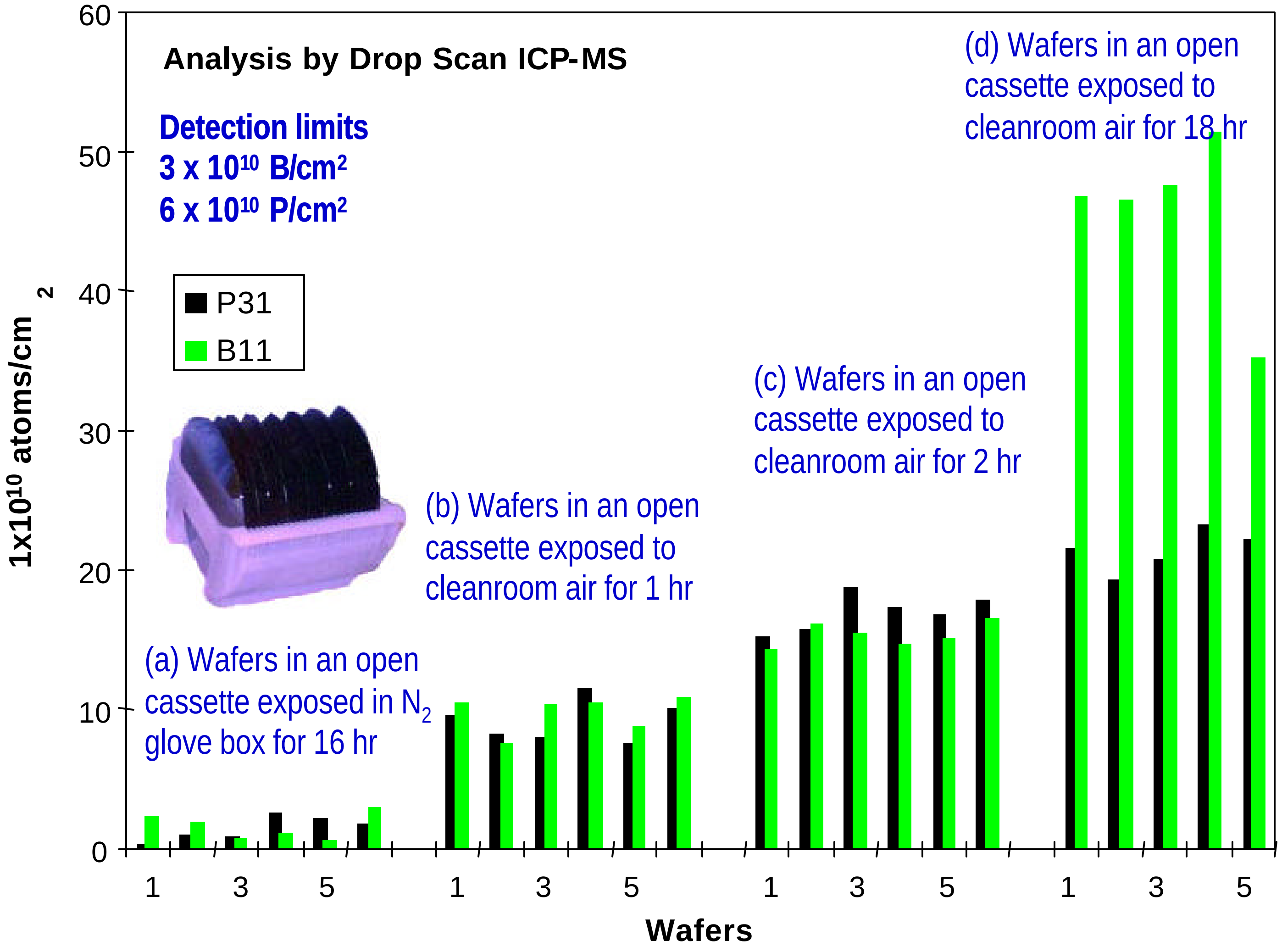
SMC-SMD (Dopant)

- Comprised of:
  - Boron: contamination from HEPA filters has been one of the most common yield-impacting effects of MD
  - Phosphorus (including organo-phosphates)
    - Example of yield maps for P AMC to SMC →
  - Arsenic
  - Antimony
- Sources
  - Outside air
  - HEPA or ULPA filters (borosilicate glass)
  - Reactive ion etch, Implant, EPI & CVD exhaust
  - Outgassing: Flame retardants, plasticizers
  - Cross contamination via recirculation
- Dopants mainly an issue for front end Si processes
  - MD affect: resistivity, V_t, V_{fb}, leakage currents



Blue die: passed.
Red die: n^+-doped by P, failed.

SMC-SMD Using Witness Wafer Monitoring



Analysis by Drop Scan ICP-MS

Detection limits
3×10^{10} B/cm^2
6×10^{10} P/cm^2

(a) Wafers in an open cassette exposed in N_2 glove box for 16 hr

(b) Wafers in an open cassette exposed to cleanroom air for 1 hr

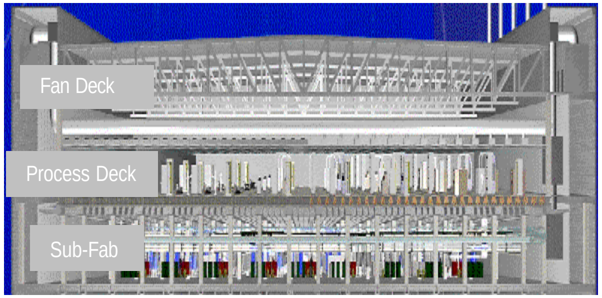
(c) Wafers in an open cassette exposed to cleanroom air for 2 hr

(d) Wafers in an open cassette exposed to cleanroom air for 18 hr

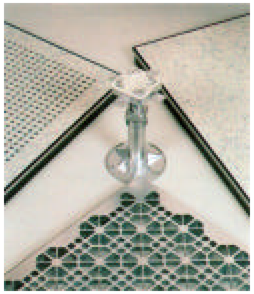
SMC-SMM (Metal)

- Metals on surfaces for witness wafers and process wafers
  - ✓ Usually determined by VPD-ICP-MS
    - Average over whole wafer, per ITRS.
    - Front-side, backside, edge (2mm) or bevel: can test individually
    - Shows location of transfer, esp. from backside contact, edge residues, FOUP/Pod/cassette contacts, robotics
  - ✓ Sometimes TXRF, < 1 cm spot
    - not sensitive for light elements (Li, Na,Mg, Al)
  - ✓ Sometimes TOF-SIMS
    - Can be hard to quantify: sometimes complex to interpret
    - Very localized: good for small defects, may not be representative
- More issues coming - volatile CVD, high K, barriers, ALD
- Copper contamination from air, pods, also contact transfer
- Metal contamination often due to particles: seldom AMC

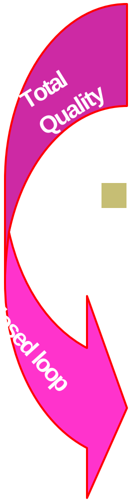
Fab Optima™



The FAB is the foundation for clean manufacturing



Fab Optimization for **Ma**nufacturing



- **AMC and SMC baseline**
  - Manufacturing process floor
  - Tool manufacturing floor
- **Optimize performance by reducing contamination**
  - Particles
  - Metals
  - Anions (Cl, F) and cations (NH_4)
  - Organics
- **Optimize materials and components**
  - Material design and selection – material compatibility to function and cleanliness
  - Packaging – bag, container
  - Consumables - UPW, HP chemicals
  - Gas – CDA, N_2
  - People – clean manufacturing
- **Certificate of Cleanliness (CoC)**
  - Independent analyses customized to meet cleanroom specifications
    - Fab or supplier sites (Gap Analysis)

Fab Optima™

ACTIVITIES/ RESPONSIBILITES

Test for particles and organics in environment/on components

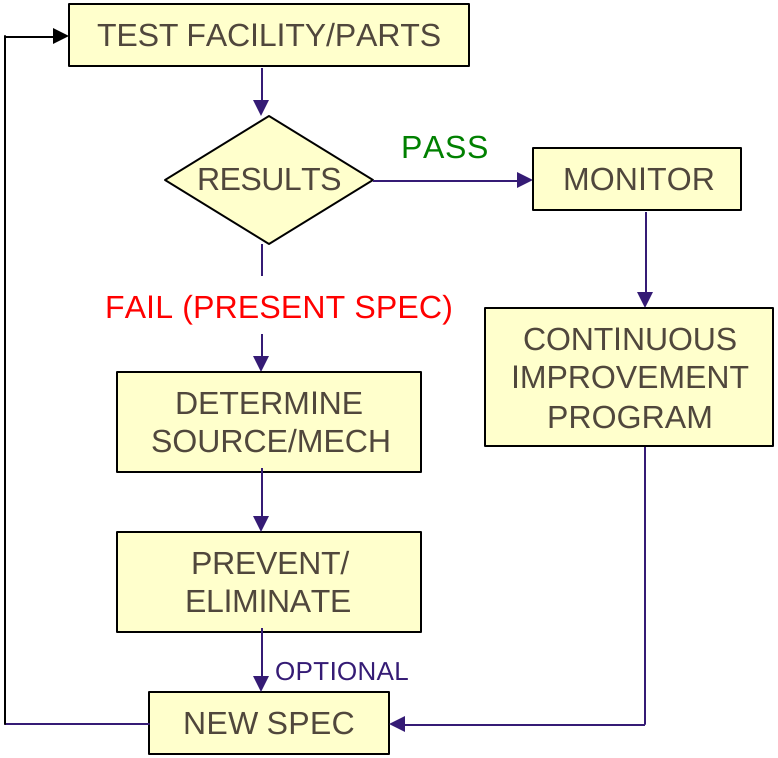
Contamination Controller and Mfg Eng

Testing and monitoring; cleanroom, assembly, cleaning, packaging, procedure

Implement change, improvement, and control; facility, tool material/design, procedure

Contamination Controller and Mfg Eng/Design

STRATEGY



NOTES

Note:
Do not make procedural changes before testing

Note:
Contamination improvements shall be correlated to yield and performance

Note:
Contaminants and their sources that are detrimental to the process must be identified and eliminated

Note:
Important to set a specification that is achievable and within the corporate cost/production goals

BALAZS nanoanalysis
Reducing Contamination

FAB AND TOOL OPTIMA™
OPTimization for MAnufacturing

Fab and Tool Optima™ "Building Block"

Leadership, Image, and Profitability

ACTIVITIES/ RESPONSIBILITES

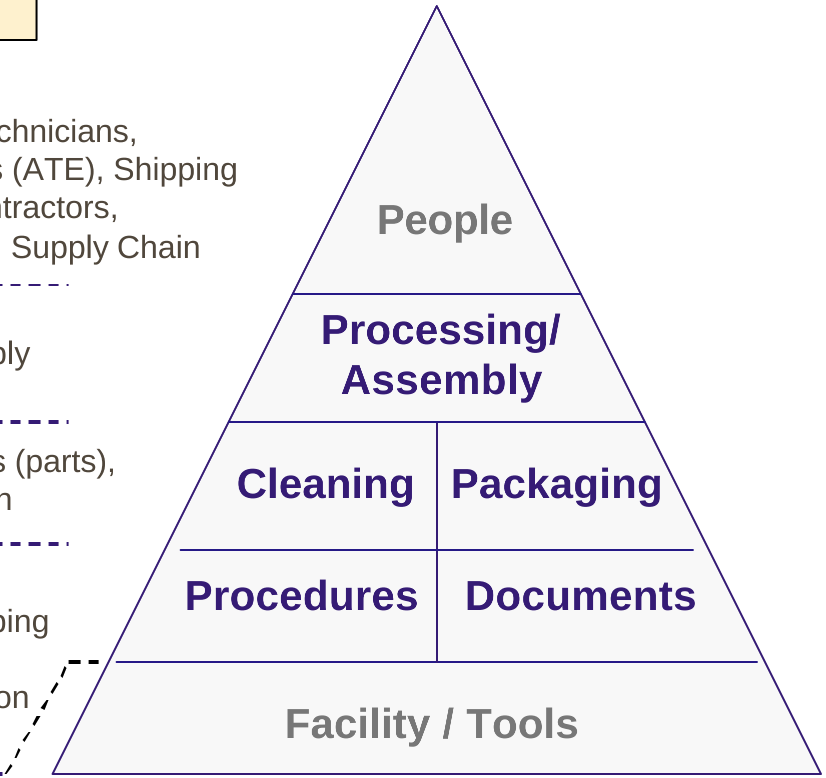
Engineers, Assembly Technicians, Associate Test Engineers (ATE), Shipping & Receiving, Facility, Contractors, Contamination Controller, Supply Chain

Engineers, Assembly Technicians, ATEs, Supply Chain

Housekeeping, Engineers (parts), Contractors, Supply Chain

Engineers, Assembly Technicians, ATEs, Shipping & Receiving, Facility, Contractors, Contamination Controller, Supply Chain

Facility, Contractors, Contamination Controller, Supply Chain



NOTES

Root Cause

Note

Pe r;

s on.

a s,

bet

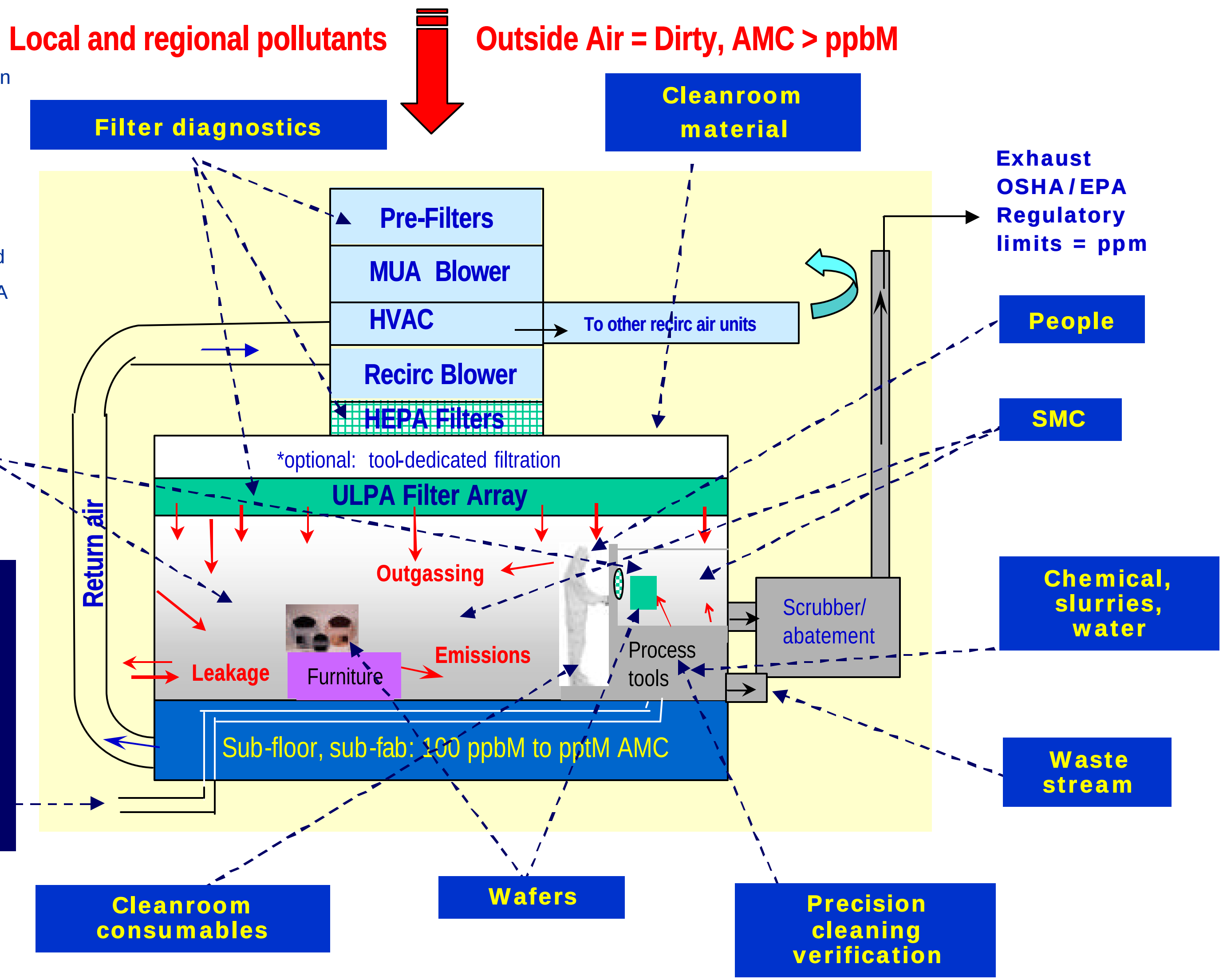
proce

Root Cause

Complex Synergy in the Fab

FILTER DEFINITION

- HVAC: Heating, Ventilation & Air Conditioning system
- MUA: Makeup air - air added to fab to make up for that lost to exhaust & leakage
- HEPA: High Efficiency Particulate Air filter
- ULPA: Ultra Low Penetration Air filter, used in cleanest cleanrooms. More efficient than a HEPA filter

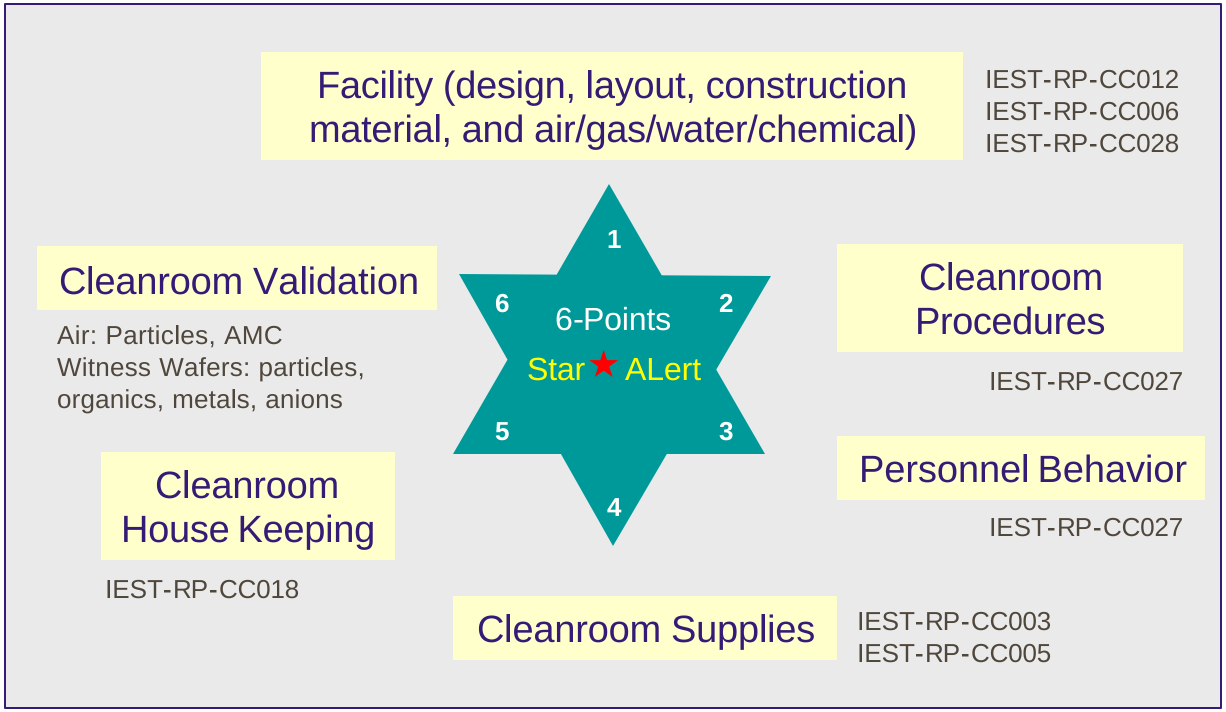


Inline chemical analyzers

Cu-Spec 257, Inline corrosion inhibitor analyzer (Air Liquide)

ChemPulse, Inline slurry characterization (Air Liquide)

Star★ALert: Clean Manufacturing Program



Facility (design, layout, construction material, and air/gas/water/chemical)

IEST-RP-CC012
IEST-RP-CC006
IEST-RP-CC028

Cleanroom Validation

Air: Particles, AMC
Witness Wafers: particles, organics, metals, anions

Cleanroom Procedures

IEST-RP-CC027

Cleanroom House Keeping

IEST-RP-CC018

Personnel Behavior

IEST-RP-CC027

Cleanroom Supplies

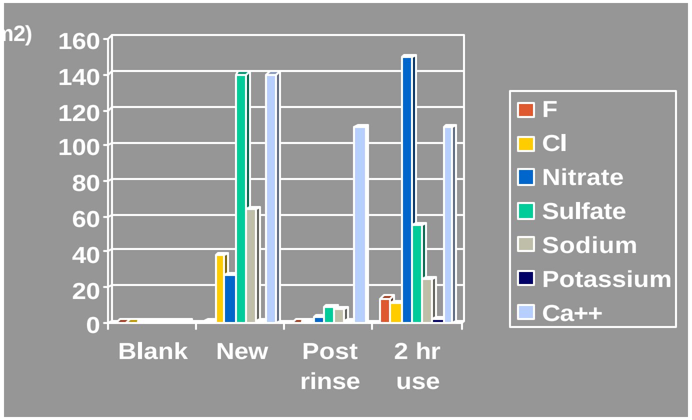
IEST-RP-CC003
IEST-RP-CC005

- This program requires ALL the basic 6-Points of the Star★ALert to be conducted properly at all times
- Disruption of any one of these basic Star★ALert programs will jeopardize the entire Cleanroom Program
- If such an excursion occurs the other Star programs may or may not be adequate enough to compensate for a disruption of the cleanroom balance
- Training is an essential component for Clean Manufacturing

Star★ALert Program: Personnel Behavior

Personnel Behavior During Tool PM

- Maintenance procedures requiring contact with ESCs, wafer holders, optics, reactor parts, shields, furnace tubes, etc. requires clean manufacturing procedures to be followed
  - ✓ Contact transfer of ionics, organics (lubricant), metals
  - ✓ Final wipe downs with solvents, wipes, gloves, can leave residues
  - ✓ Gloves leave organics, particles, ionics, metals
  - ✓ Particle shedding of new and used products



Cleanroom Practices

Walk slowly

- In a static situation the filtered air travels unimpeded in a vertical flow
- A turbulent air pattern called a vortex is created whenever anything is put in the path of the air flow, including equipment or people
- Particles are drawn into these turbulent areas and resettle
  - ✓ In this case particles are drawn towards the tool

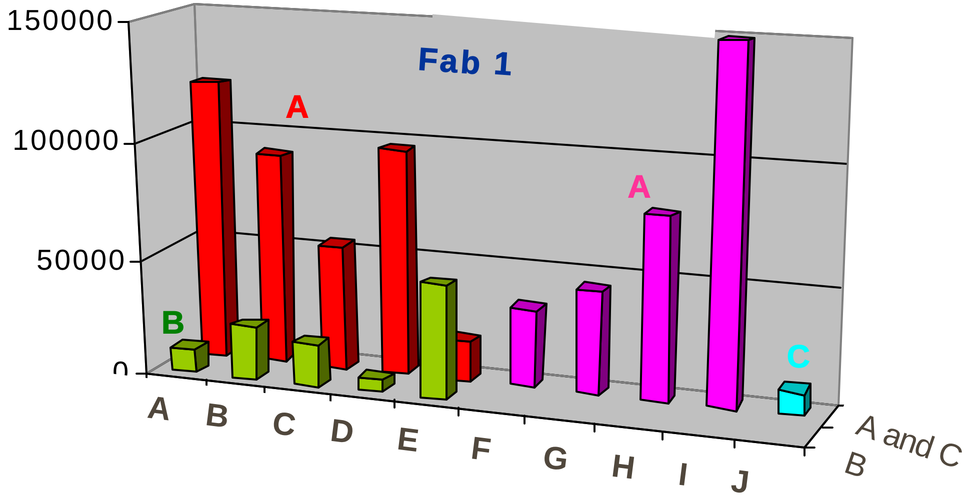
Wipe down working surface

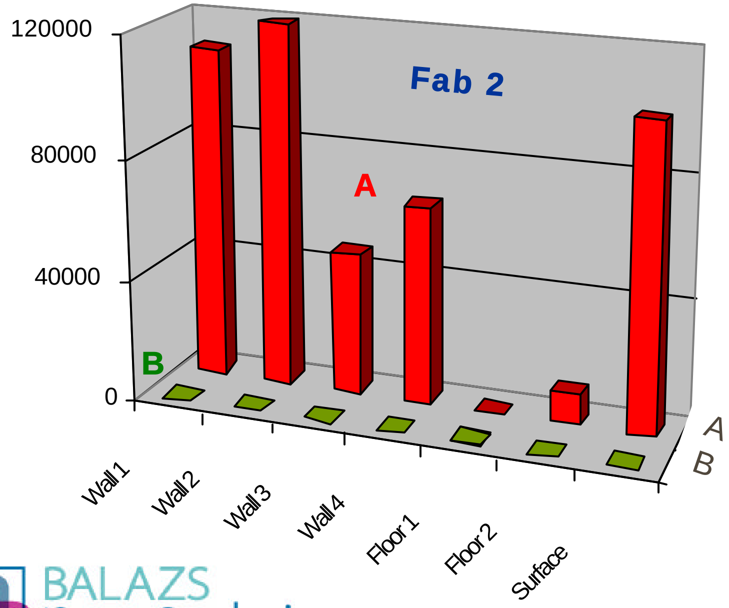
- Always from back-to-front and from top-to-bottom
- Fold wipe to new surface frequently

Star★ALert Program: Cleanroom Supplies

- RP–CC005.3: Gloves and Finger Cots Used in Cleanrooms & Other Controlled Environments
- RP–CC020.2: Substrates and Forms for Documentation in Cleanrooms
- WG–CC025: Evaluation of Swabs Used in Cleanrooms
- WG–CC032: Packaging Materials for Cleanrooms
  - ✓ Characteristics and test methods for evaluating flexible packaging for cleanroom products & supplies
  - ✓ Need to protect products from contamination and ESD

Star★ALert Program: Housekeeping





Evaluate Cleanliness

Data Collection

- Swipes were taken from the floor and walls of the cleanroom

Results

- Metal wipe concentration lowest for vendors B and C

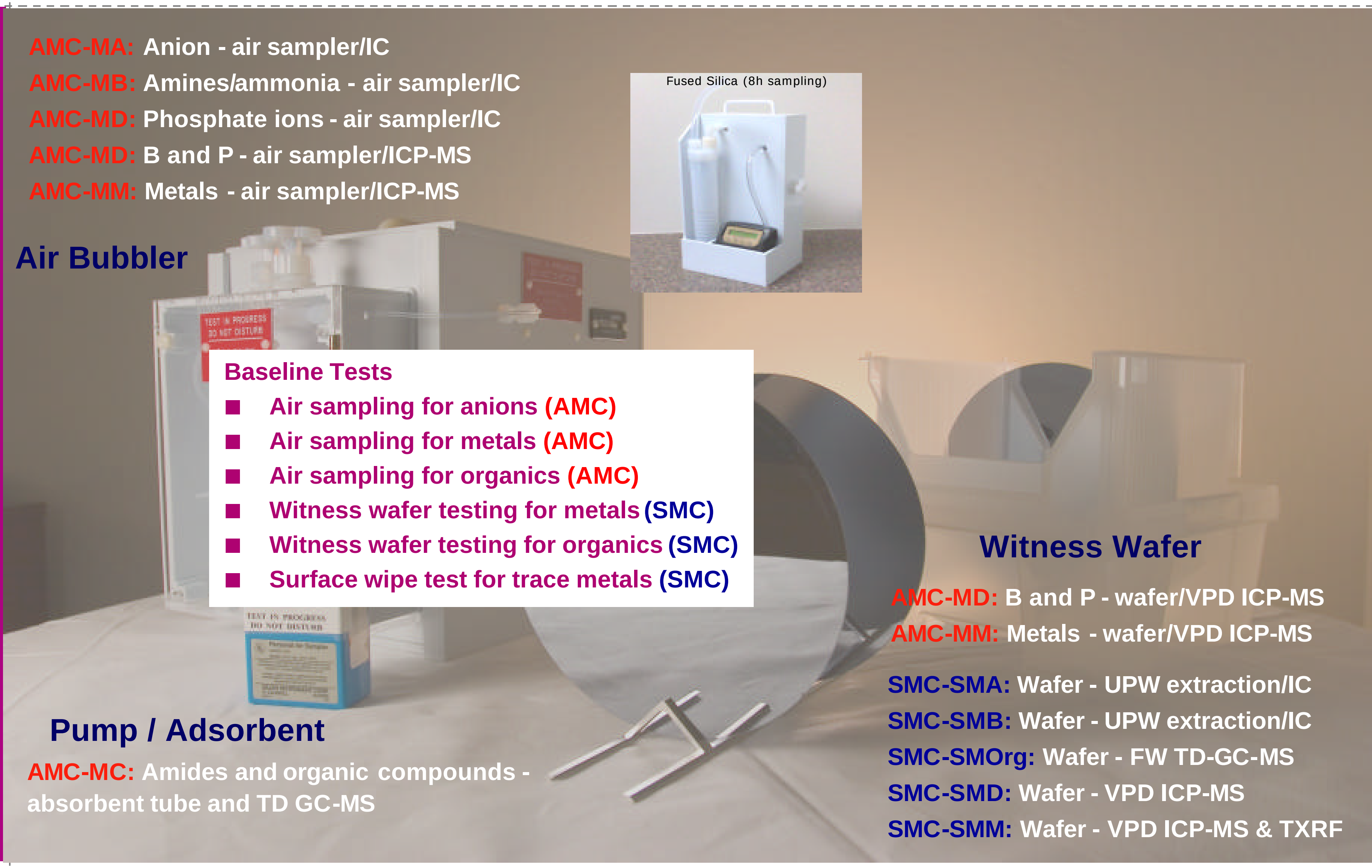
Inference

- Vendor B and C perform efficient housekeeping
- Vendor A is poor

Solution

- Retain vendors B and C

Star★ALert Program: Cleanroom Validation



AMC-MA: Anion - air sampler/IC
AMC-MB: Amines/ammonia - air sampler/IC
AMC-MD: Phosphate ions - air sampler/IC
AMC-MD: B and P - air sampler/ICP-MS
AMC-MM: Metals - air sampler/ICP-MS

Air Bubbler

Baseline Tests

- Air sampling for anions (AMC)
- Air sampling for metals (AMC)
- Air sampling for organics (AMC)
- Witness wafer testing for metals (SMC)
- Witness wafer testing for organics (SMC)
- Surface wipe test for trace metals (SMC)

Witness Wafer

AMC-MD: B and P - wafer/VPD ICP-MS
AMC-MM: Metals - wafer/VPD ICP-MS

SMC-SMA: Wafer - UPW extraction/IC
SMC-SMB: Wafer - UPW extraction/IC
SMC-SMOrg: Wafer - FW TD-GC-MS
SMC-SMD: Wafer - VPD ICP-MS
SMC-SMM: Wafer - VPD ICP-MS & TXRF

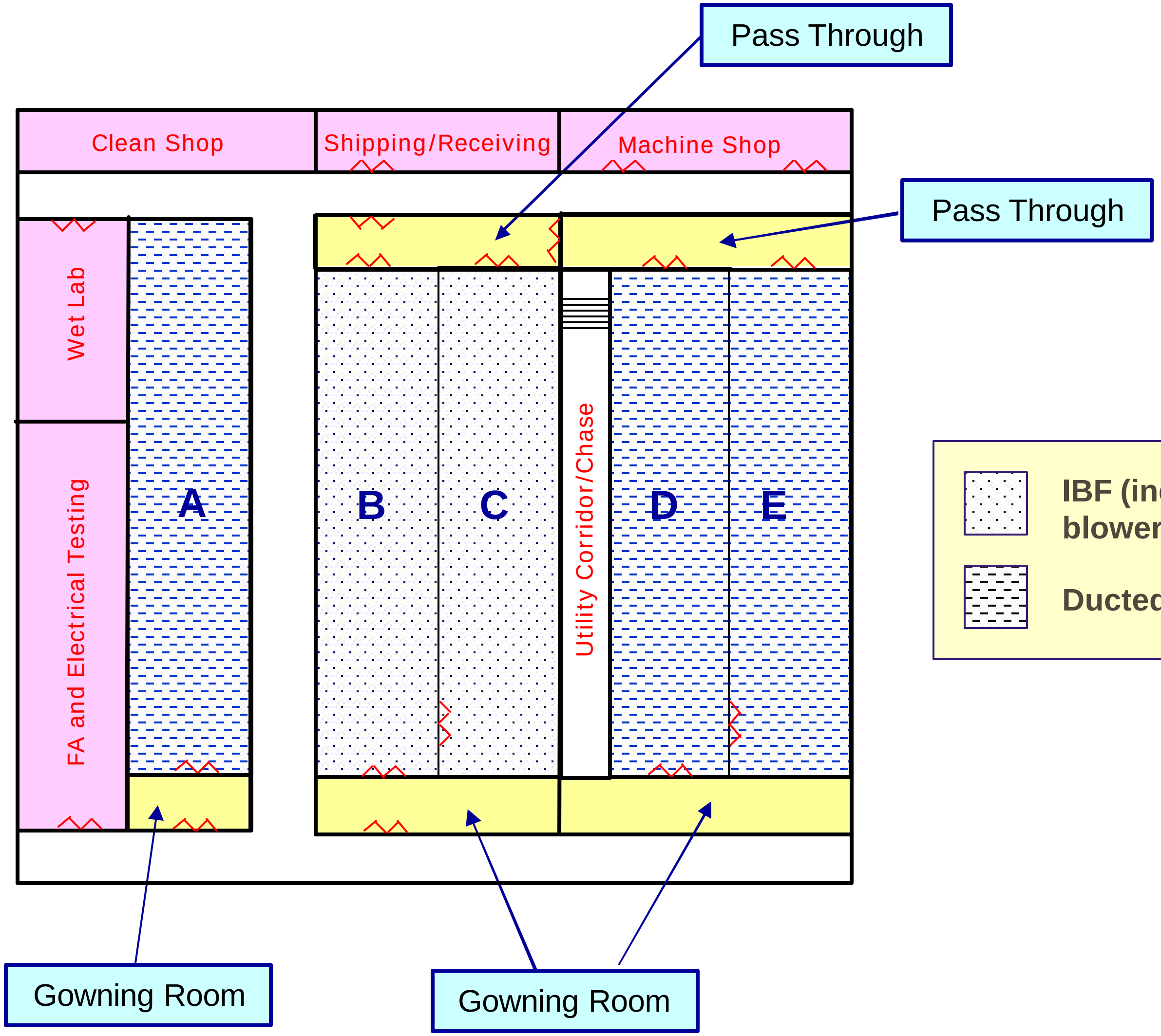
Pump / Adsorbent

AMC-MC: Amides and organic compounds - absorbent tube and TD GC-MS

Cleanroom Monitoring Program

Test Method	Procedure	Comments / Specifications	Suggested Frequency
Particle Count	ISO 14644-2	Test should be performed by a 3rd party	Quarterly
Air Flow	ISO 14644-2	Test should be performed by a 3rd party	Annually
Air Pressure Difference	ISO 14644-2	Test should be performed by a 3rd party	Annually
Metal wipe test (wipes and ICP-MS)	Balazs	Floor: Al, B, Cr,F e, Ni = 3,000 ng/wipe Cu = 500 ng/wipe Ca, Mg = 30,000 ng/wipe K, Na =20,000 ng/wipe	1X monthly
Molecular Acids (MA) (anions with impinger and IC)	Balazs	Nitrile = 6 ng/L air	1X monthly
Molecular Condensables (MC) (full wafer out gassing and GC-MS)	Balazs	Sum >= C7 =20 ng on wafer	1X monthly
Molecular Dopants (MD) (boron on wafer by VPD ICP-MS)	Balazs	Boron = 2 X 10^{12} atoms/cm^2	1X monthly
Molecular metals (MM) (metals on wafer for VPD ICP-MS)	Balazs	Cu = 1.0 X 10^{10} atoms/cm^2	1X monthly
QIII surface particle measurements	Pentagon	All work surfaces	2X/day
Surface wipe down of working areas	Balazs	All work surfaces	2X/day

Typical Cleanroom Layout



⠿	**IBF (individual blower filter) packs**
▤	**Ducted systems**

AMC-MA Baseline

Data Collection

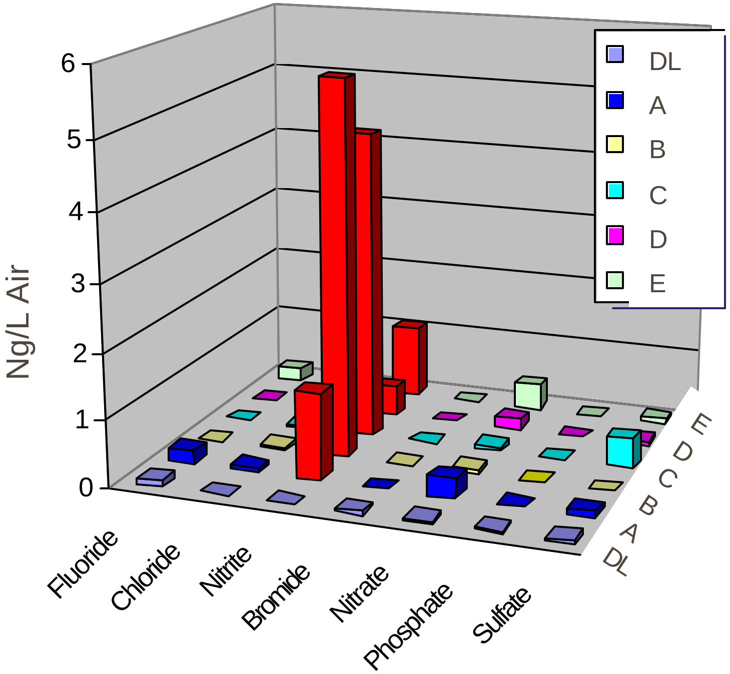
- Air sampling using impingers

Results

- Nitrite values significantly higher than other anions
- Highest nitrite observed in bays B and C
- Nitrite is indicative of smog and car exhaust

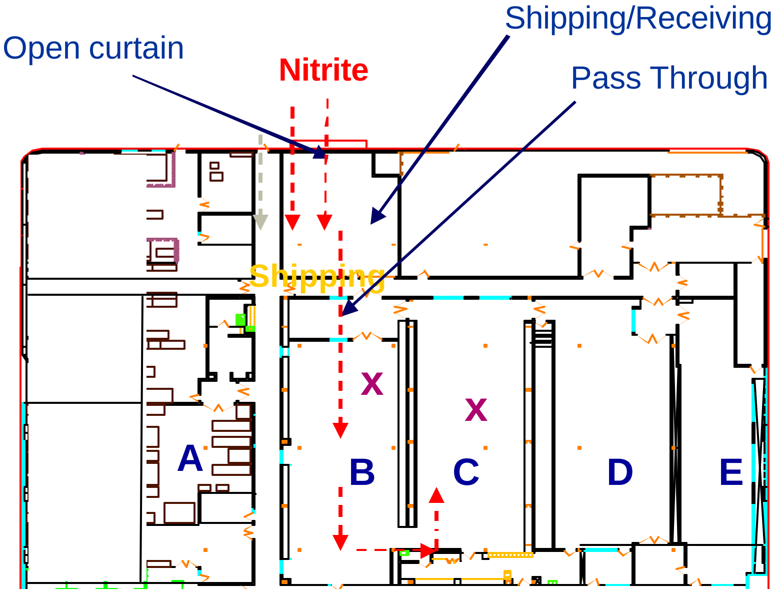
Inference

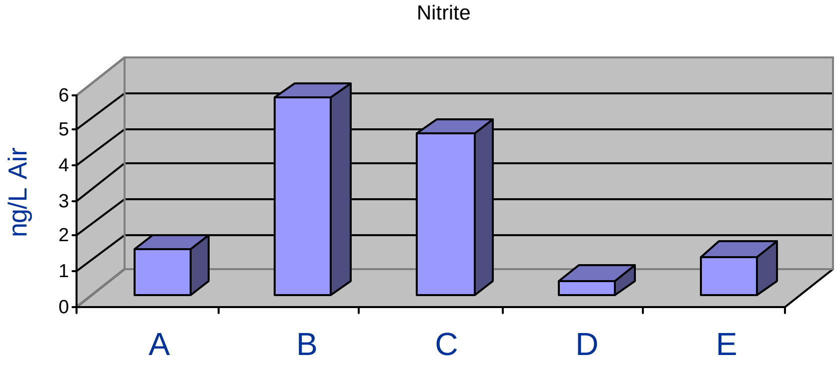
- Source of nitrite contamination is from outside air and is not removed by filters



What is the mechanism for contamination?

AMC-MA Baseline (for Nitrite)





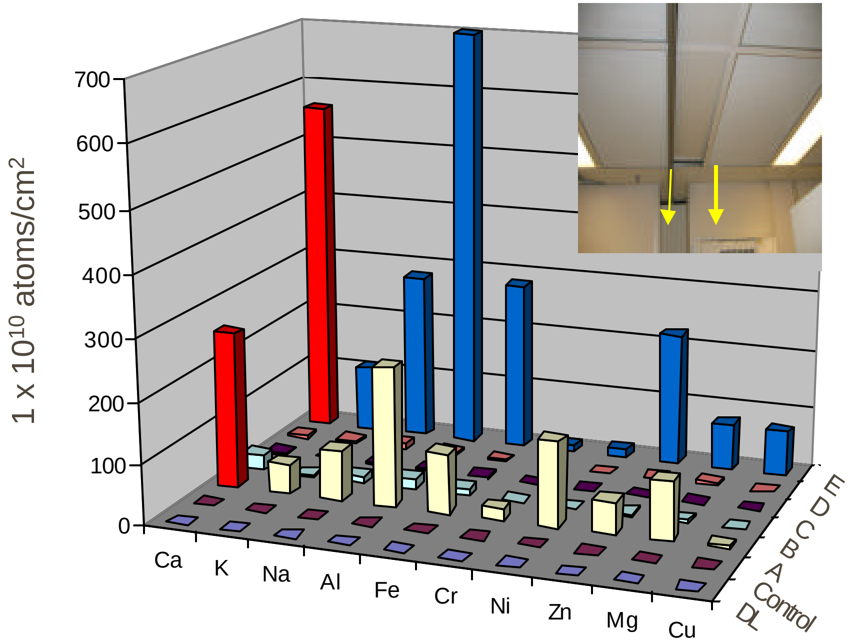
Mechanism

- The anions contamination transport mechanism is from the Shipping Dept with open curtains to the exterior, through the pass through room, and into the cleanroom
- Both doors of pass through are open

Solution

- Install interlocking doors in the pass through room so only one door can be opened at a time
- Invest in charcoal pack filters
- Training

AMC-MM Baseline (for Metals)



Data Collection

- Witness wafer exposure for 24h

Results

- High metal contamination levels observed in bays A and E and has been increasing over a period of time

What is the mechanism for contamination?

Discussion

- The metal signature (envelope of Ca, Na, Al, Fe, Zn, Mg) is the same for all bays
- Fe is not from SST but as a constituent of gypsum
  - Gypsum is composed of $CaSO_4$, NaCl, FeS_2, and $CaCO_3$

Inference

- Source is from damaged ceiling tiles (edge)

Mechanism

- Metals migrate through unsealed paths (voids) via Brownian’s motions against the pressure differential - gaps between the ceiling tiles and T-bar system

Solution

- Seal ceiling, replace tiles or upgrade t-bar system

Swipe Test of Critical Working Surface

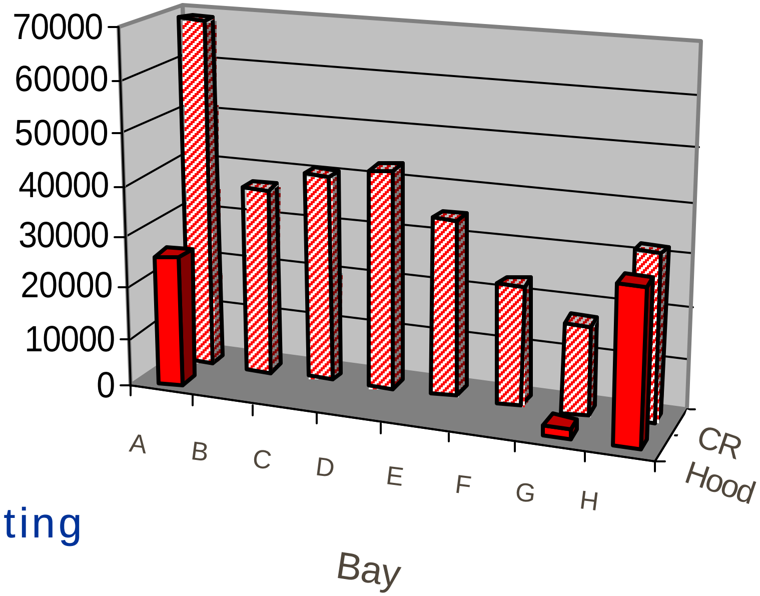
Data Collection

- ✓ Swipes were taken from the mini-environment surface

Results

- ✓ High metal level observed in the laminar flow hood in bay H

What is the mechanism for contamination?



Inference

- ✓ All laminar flow hoods are operating correctly
- ✓ Observation indicates high level from contamination carry over; audits confirm this

Solution

- ✓ Re-train engineer in cleanroom practices focusing on wipe down protocols

Conclusion

- The Fab airborne quality is an essential foundation for clean manufacturing
- Fab Optima™ and Star★ALert Programs incporporate many quality programs and disciplines to ensure the fab is capable of supporting contamination-free manufacturing
- The construction materials and all materials and products within the cleanrooms, including people, can affect the airborne quality
- Wipe test complements the standard air monitoring program to provide valuable information about the dynamic condition of the cleanroom and how engineers and housekeeping are affecting it
  - ✓ Swipe test results can reveal poor adherence of clean manufacturing protocols in selected areas on the fab floor
- Cleanroom training is required for anyone entering the cleanrooms – process engineers, visiting VIPs, facility engineers and suppliers
- A dedicated contamination team is required to enforce cleanroom practices and to interface between manufacturing and facility