



Molecular Contamination Monitoring

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Agenda



- What is Molecular Contamination?
- Sources
- Surface Molecular Contamination “behavior”
- Monitoring Approaches
- Examples of Where to Monitor
- Summary

What is Surface Molecular Contamination?



- Surface Molecular Contamination (SMC) is:
 - Chemical contamination - gas-phase molecules interacting with product surfaces
 - Not particles
 - Often complex mixtures of chemical compounds that are highly variable
 - **Airborne Molecular Contamination (AMC) that forms very thin chemical films on surfaces**
 - **New understanding of AMC results in development of SMC monitoring standards (draft) by ISO Working Group 8**

SMC Impact



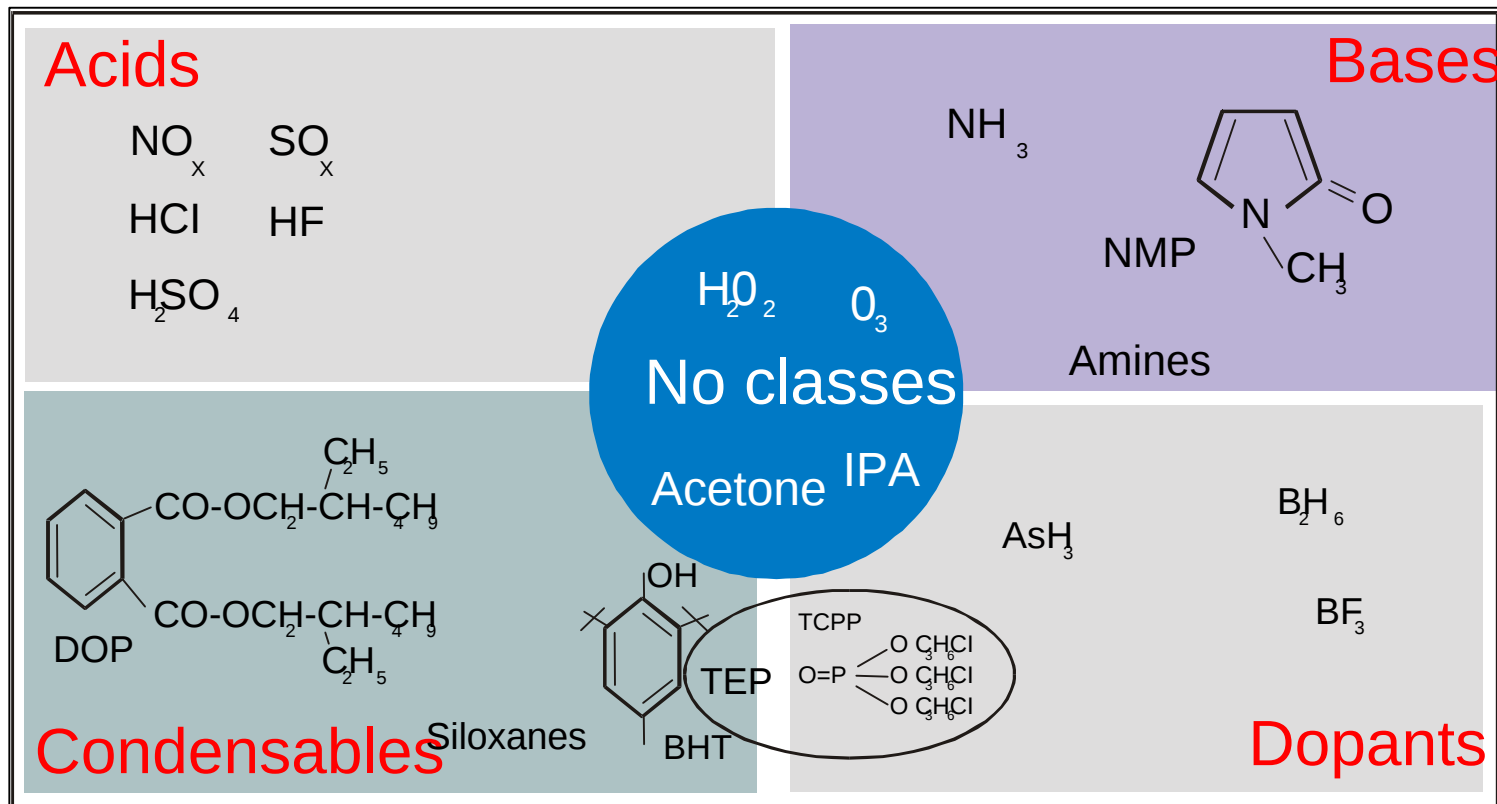
- Affects many industries, including:
 - Semiconductor (particularly line-widths <0.18 micron)
 - Hard disk drive
 - Flat panel display
 - Aerospace
- Critical molecular species and their specific impact vary across industries
- SMC found to cause yield losses, product degradation, or product failures in all these industries

Molecule vs. Particle Contamination - Class 1



	Molecule	Particle
Diameter	3 nm	100 nm
Number/m ³	3 x 10 ¹³ /m ³	29/m ³
(10 ¹² times more molecules than particles)		
Mass	5 ng/m ³	1 pg/m ³
(5,000 times more mass from molecular contamination than from particles)		

Typical AMC/SMC Compounds of Class A, B, C, D (according SEMI F21-95)



Sources of Molecular Contamination



- AMC/SMC from outdoor “make-up” air
 - Could be anything from anywhere
 - Auto exhaust
 - Industrial emissions
 - Smog, etc.
 - Should be chemically filtered if there are any molecular contamination concerns

Sources of AMC/SMC



- Contamination generated within a facility
 - Cross-process chemical contamination within a bay or across the facility
 - Recirculated air with inadequate filtration
 - Outgassing cleanroom materials (filters, gel sealants, construction materials, etc.) - especially new fabs
 - People/personal care products - exhaled ammonia ~5 - 25 ppbv
 - Equipment - pumps, motors, robots, containers, etc.
 - Accidents - chemical spills, temperature and humidity upsets
 - FOUP/Minienvironment construction materials

Constituents of SMC

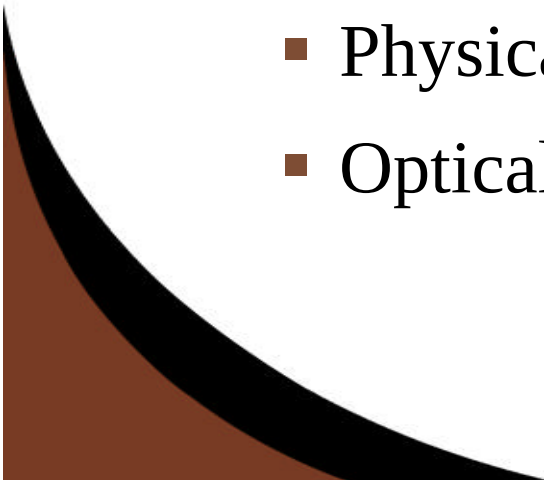


- Organophosphates
- Ammonia and Amines
- NMP
- Hydrocarbons
- Cresol
- Toxic chemicals

Effects of Surface Molecular Contamination



- Chemical film formation on surfaces
- Changes in surface properties
 - Chemical
 - Electrical
 - Physical
 - Optical



Effects of Surface Molecular Contamination

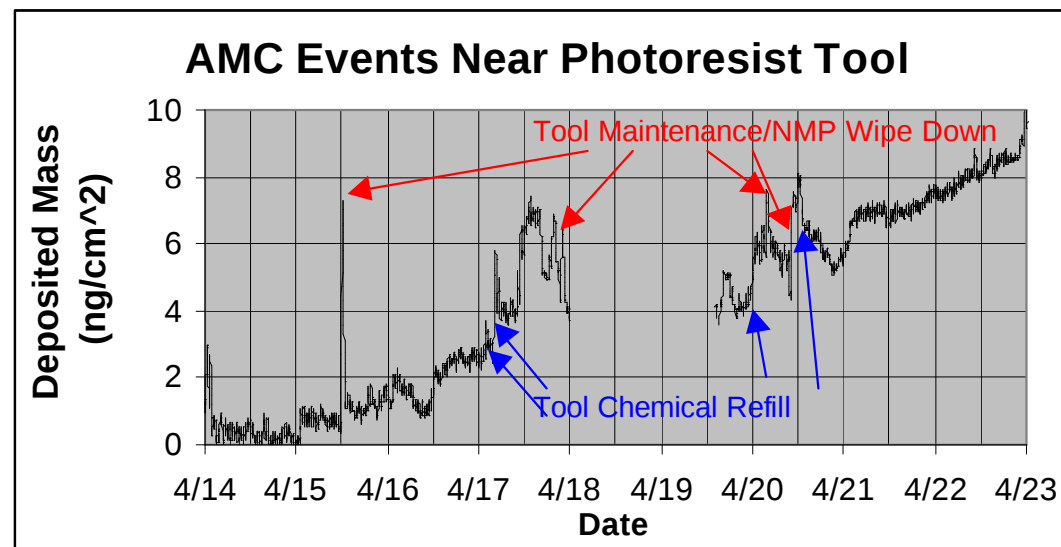


- Examples of Surface Property Changes
 - Wet-ability (chemical)
 - T-topping of photoresist by organic bases (chemical)
 - Unintentional doping (electrical)
 - Defective epitaxial growth (physical)
 - Hazing of optics (optical)
 - Uneven oxide growth (chemical/physical)
 - Corrosion (chemical/electrical)
 - Stiction (physical)

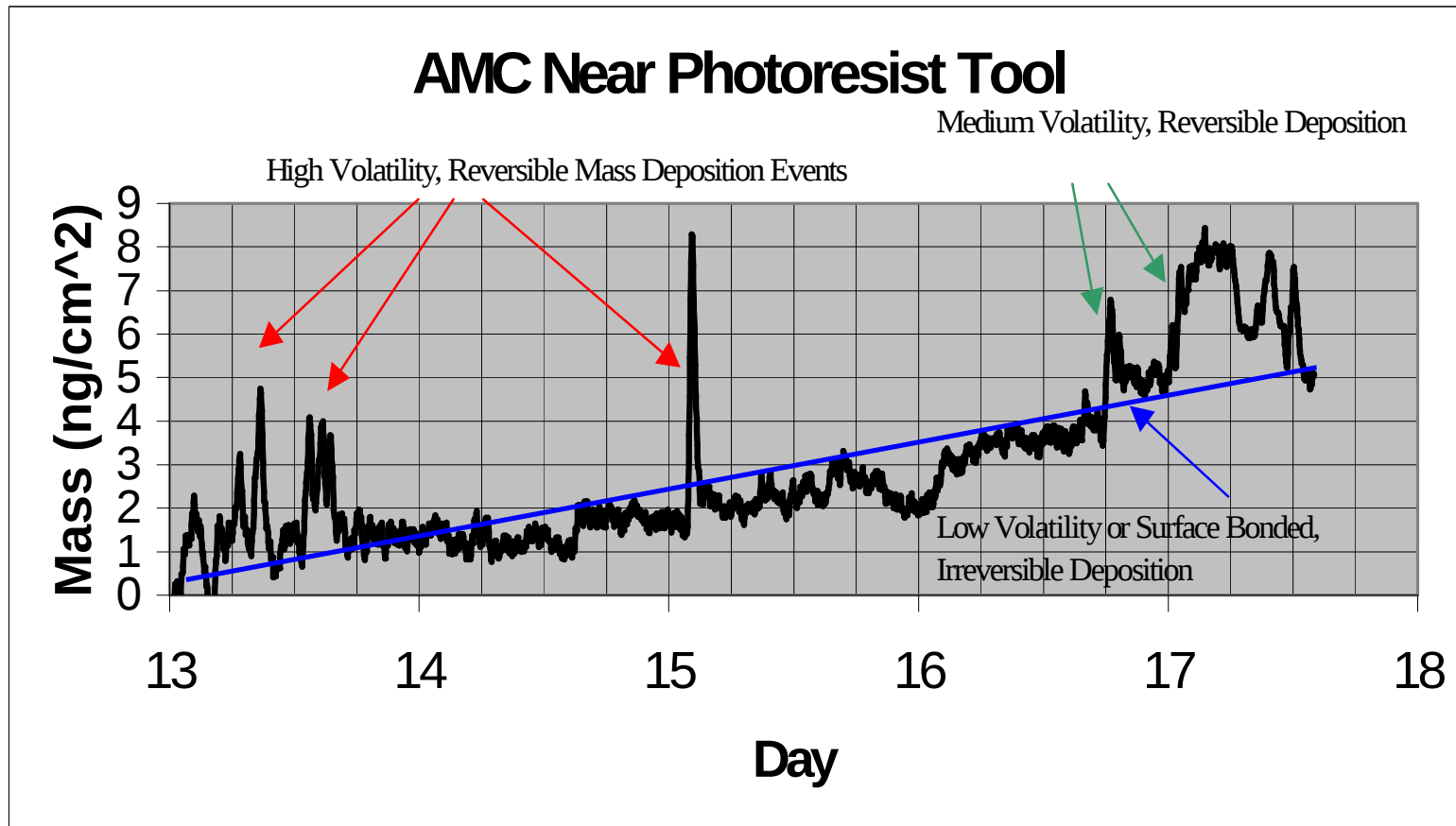
SMC “Behavior”



- SMC Events
 - Duration -- minutes to weeks
 - Typically, several simultaneous events
 - Multiple sources
 - Multiple molecular species
 - Real-time data helpful in identifying process steps and events that create SMC



SMC Volatility and Trend



Molecular Contamination Monitoring



- **Molecular contamination measurements characterize:**
 - Cleanroom air
 - Process tools
 - Minienvironments
 - Chemical filters
 - Process gases
- **Molecular Contamination Monitoring - Gas or Surface?**
 - Gas-Phase (where transport occurs)
 - Surface (where impact to product occurs)
- **SMC measurements are used to prevent, detect, and correct AMC/SMC problems -- Key factors are:**
 - Time resolution
 - Mass sensitivity

Molecular Contamination Monitoring Technologies



Technology	Real-time	Time Resol.	Specific	Maint.	Mass Sensitivity*	Direct Surface Meas.
Sorption/GCMS	No	20+ min	Yes	High	Very good - with preconcentration	No
Impinger-IC	No	20+ min	Yes	High	Very good - with preconcentration	No
IMS	Yes*	< 1 min*	Limited	Med	$< 1 \times 10^{-6} \text{ g/m}^3$	No
Chemiluminescence	Yes	< 1 min	Limited	Low	$< 1 \times 10^{-6} \text{ g/m}^3$	No
Test Wafer	No	3+ days	No*	Low	$2 \times 10^{-10} \text{ g/cm}^2$	Yes
QCM Sensor	Yes**	15 min**	No*	Low	$6 \times 10^{-9} \text{ g/cm}^2/\text{Hz}$	Yes
SAW Sensor	Yes	1 min	No*	Low	$2 \times 10^{-11} \text{ g/cm}^2/\text{Hz}$	Yes

SMC Monitoring Technologies

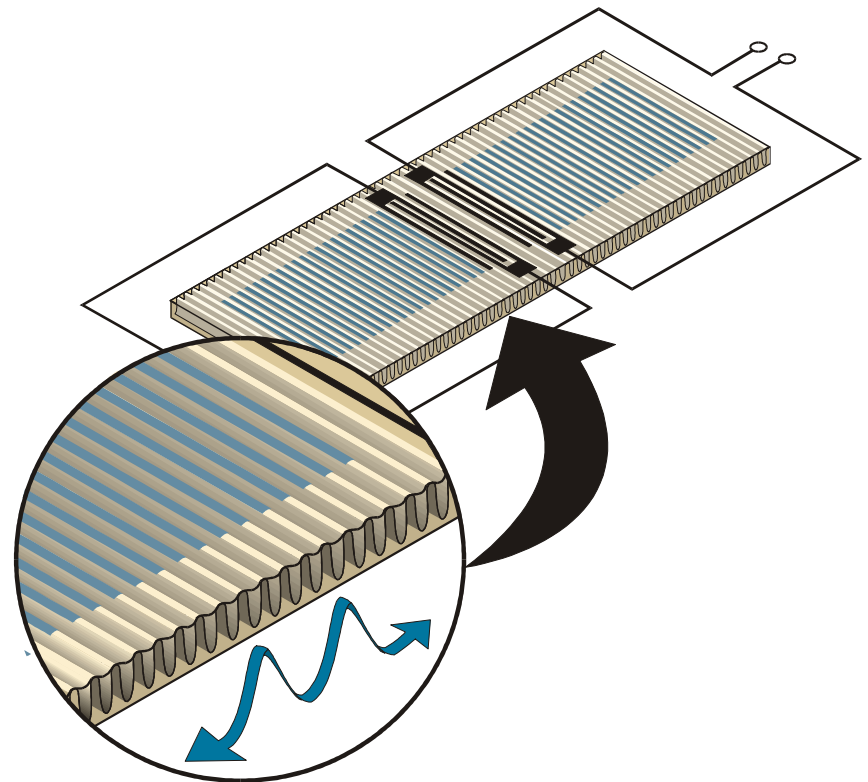


- Surface Molecular Contamination Monitoring
 - Test Wafer
 - Combine with analytical techniques for speciation
 - No real-time data
 - 0.2 ng/cm² sensitivity
 - QCM
 - Crystal surface mimics critical product surface
 - Combine with analytical techniques for speciation
 - Real-time data
 - 6.0 ng/cm²/Hz sensitivity
 - SAW
 - Crystal surface mimics critical product surface
 - Combine with analytical techniques for speciation
 - Real-time data
 - 0.02 ng/cm²/Hz sensitivity

Surface Acoustic Wave (SAW) Sensor Technology



- Quartz Crystal SAW Sensor
 - Piezoelectric
 - Electrical pulses create acoustic waves on crystal surface
 - Mass deposition on surface reduces frequency of acoustic waves
 - Exposed crystal referenced to sealed crystal
 - Surface Molecular Contamination mass calculated from frequency difference between exposed and sealed crystals



Sensor Surface Considerations



- Create a Surface that Mimics the Product Surface
 - SiO_2 -- Wafer and Lithography Optics
 - Cu -- Copper Interconnects
 - Silver -- General Metallic Corrosion
 - Permalloy -- HDD Read/Write Head Corrosion
- Contamination Levels in the Air
 - Chemical and physical characteristics of the surface
 - Environmental conditions (temperature, humidity, pressure, etc.)

Common Applications



- Ultra-clean manufacturing areas
- Chemical filter monitoring
- Make-up air characterization
- Process monitoring
- FOUPS / SMIFS

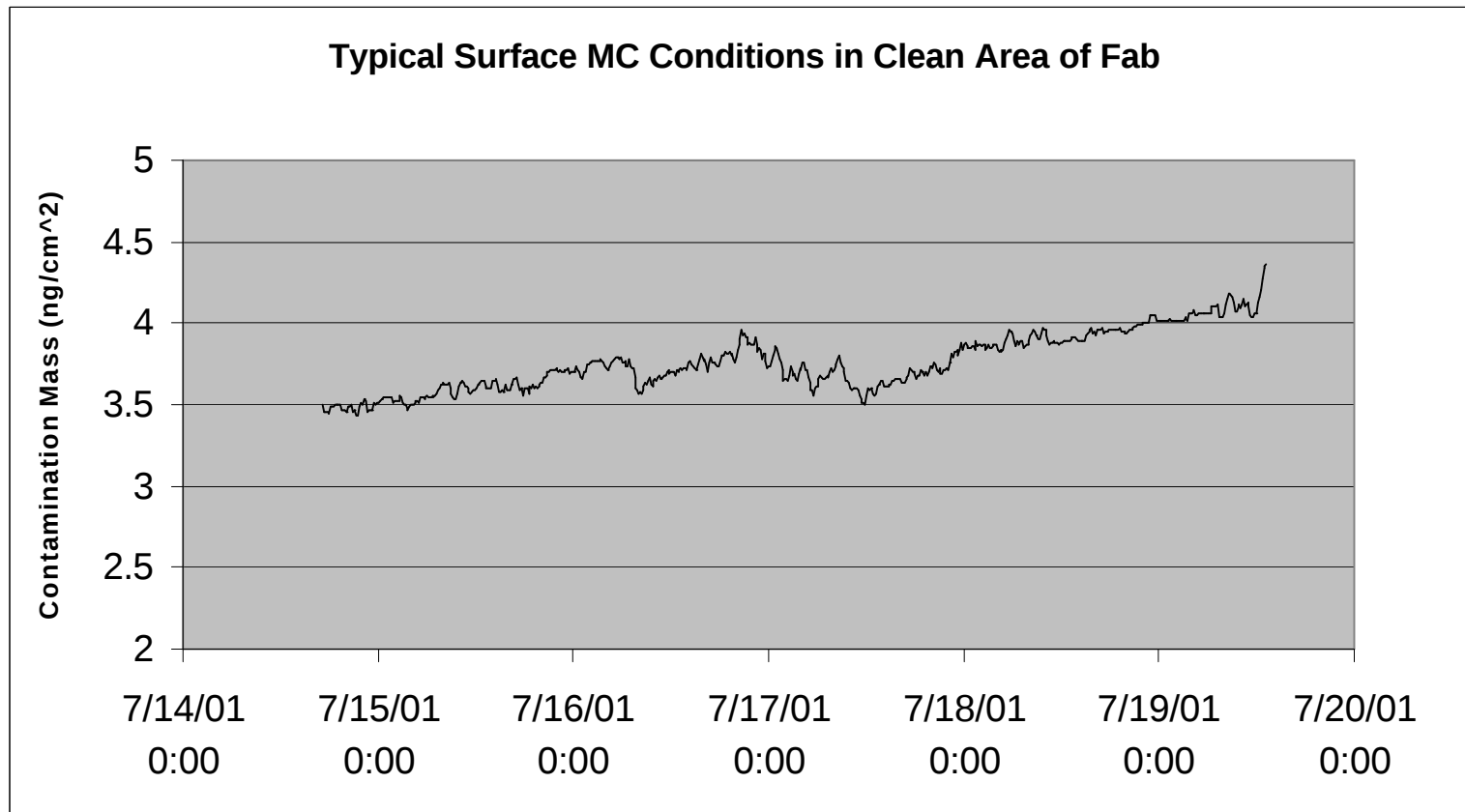
Molecular Contamination Guidelines for Ultra-clean Manufacturing Areas



- 1 - Clean $< 0.2 \text{ ng/cm}^2/\text{day}$
- 2. - Moderate $0.2 - 0.6 \text{ ng/cm}^2/\text{day}$
- 3. - Dirty $> 0.6 \text{ ng/cm}^2/\text{day}$

* on Silicon Dioxide Surfaces

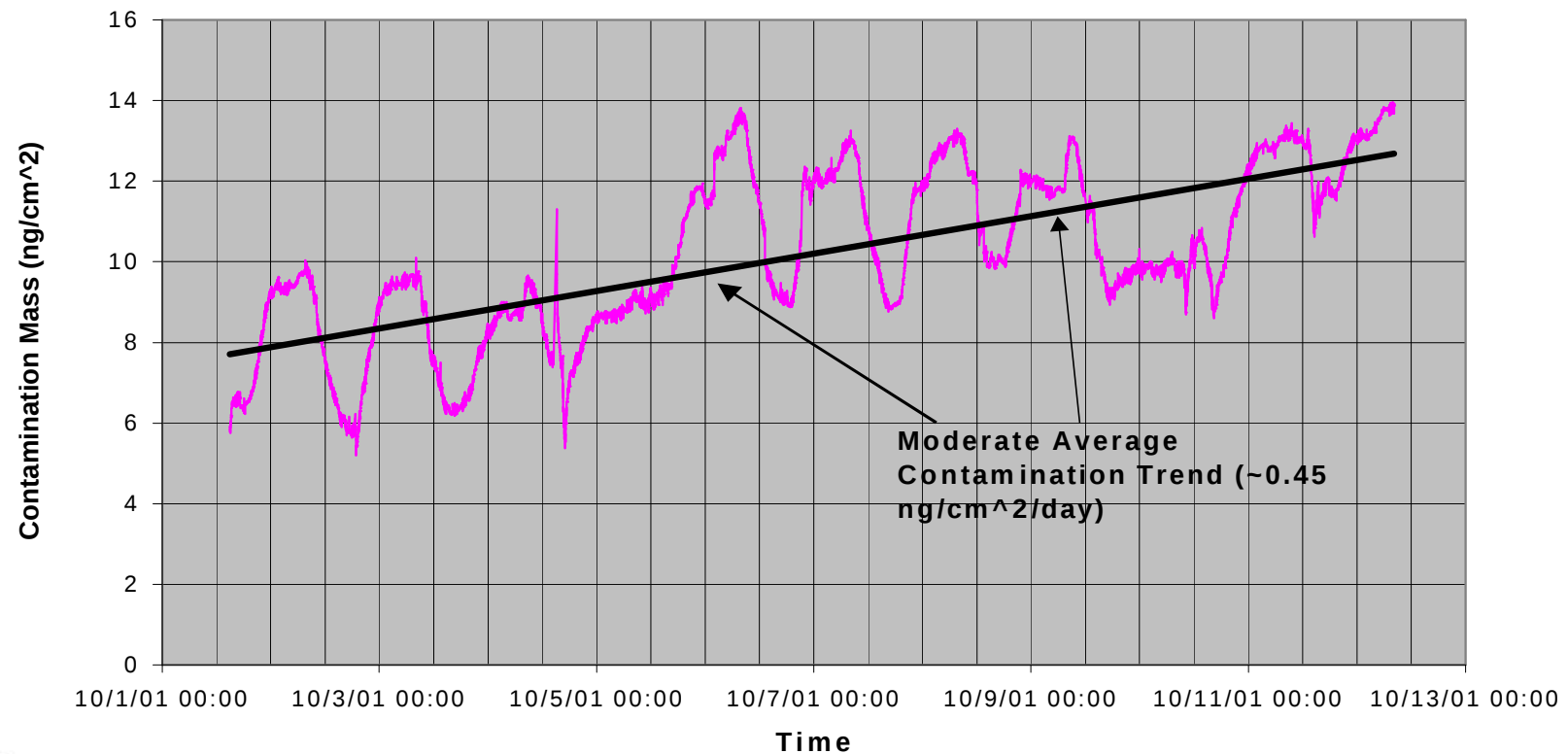
Example of Clean Area ($<0.2 \text{ ng/cm}^2/\text{day}$)



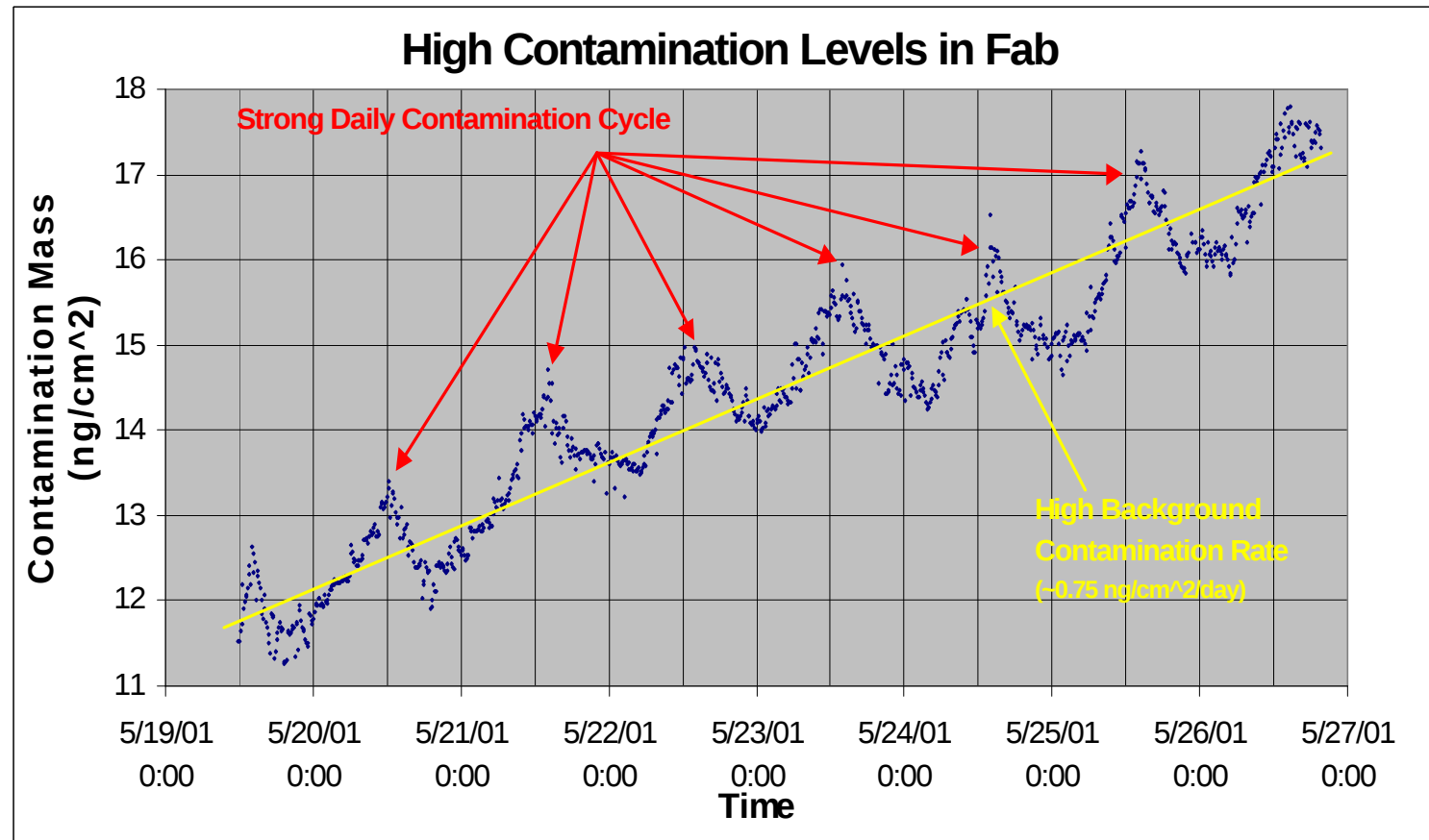
Example of a Moderately Clean Area



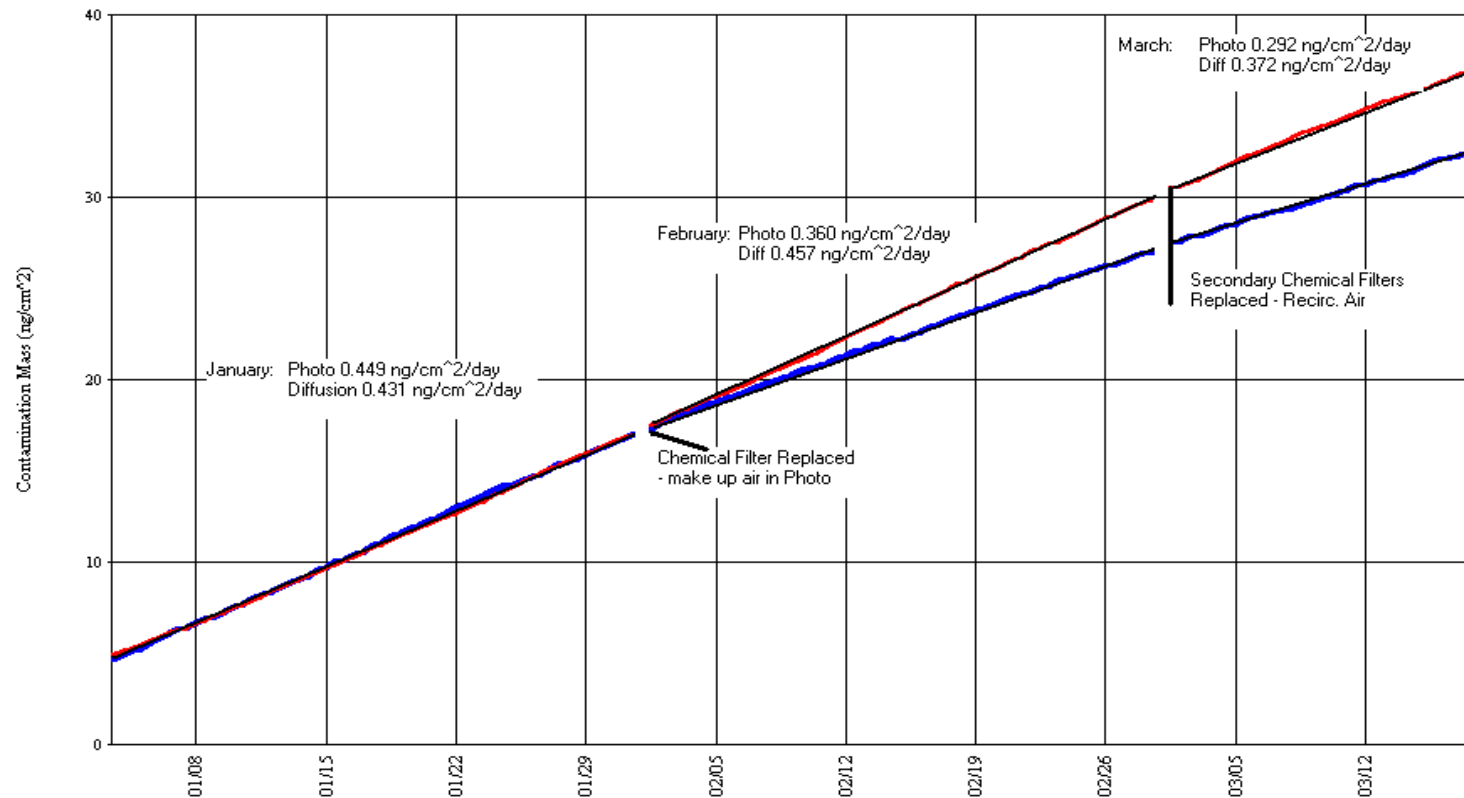
Moderate Average Contamination Trend with Strong Daily Pattern



Example of Dirty Area



Chemical Filter Monitoring



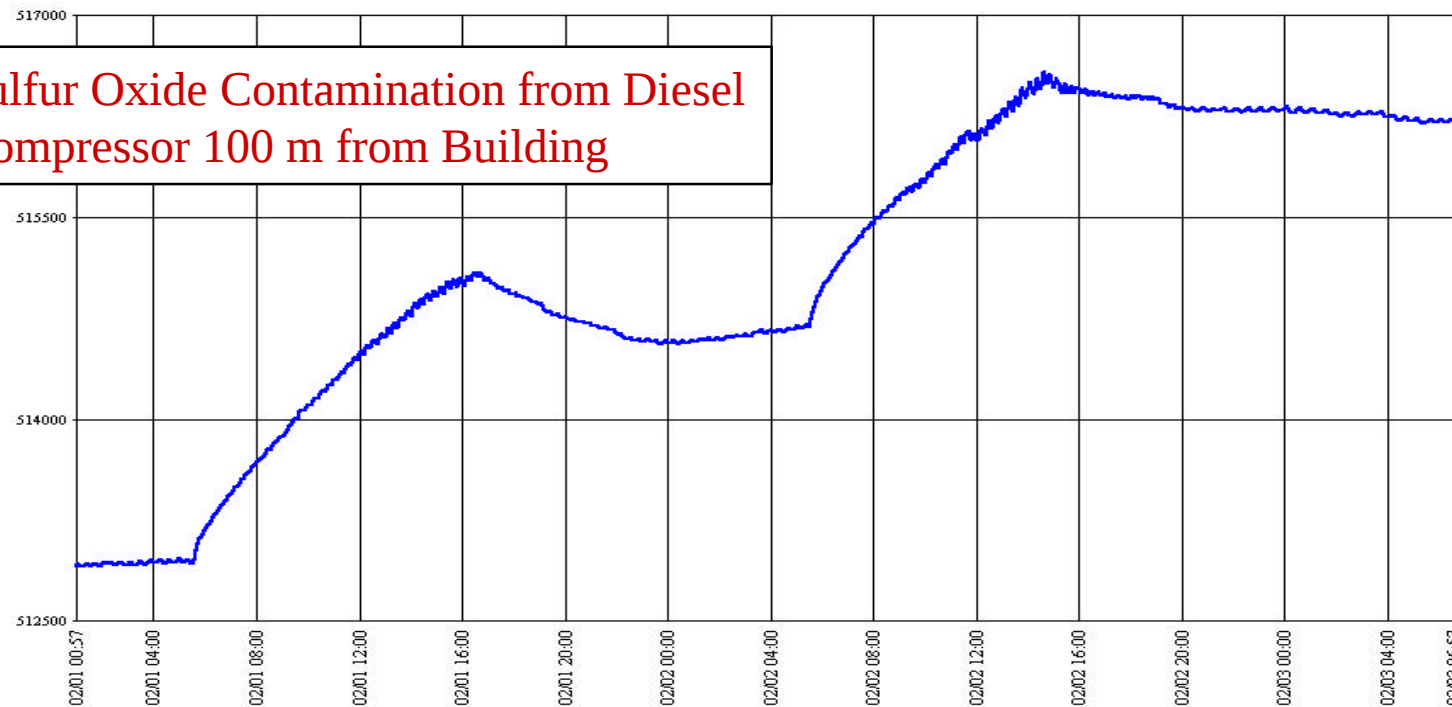
Item	Plot	Data Type	Minimum	Maximum	Average	Std Dev
Photolithography	ng/cm ²	Avg(12 hours)	4.694	32.720	19.76	8.13
Mass 2	ng/cm ²	Avg(12 hours)	4.939	37.027	17.08	8.82

Outside Air Contamination

- Corrosion on a Silver Surface



Sulfur Oxide Contamination from Diesel Compressor 100 m from Building



Item	Plot	Data Type	Minimum	Maximum	Average	Std Dev
f2	Hz	Avg(5 samp	512183.406	516581.813	514714.23	1252.31

Process Monitoring - Photolithography



- **“Optics contamination is a huge issue for DUV”** - Kim Dean, International SemaTech, *Molecular Contamination Issues for Lithography*, Sept. 2001
- **Use of shorter wavelengths makes optics more sensitive to contamination**
 - 248 nm (200 mm)
 - 193 nm (200 & 300 mm)
 - 157 nm (300 mm)
- **Contamination Sources**
 - Purge gas
 - Materials in the tool and fab
 - Photoresist fragmentation due to exposure to UV

Process Monitoring - Photolithography



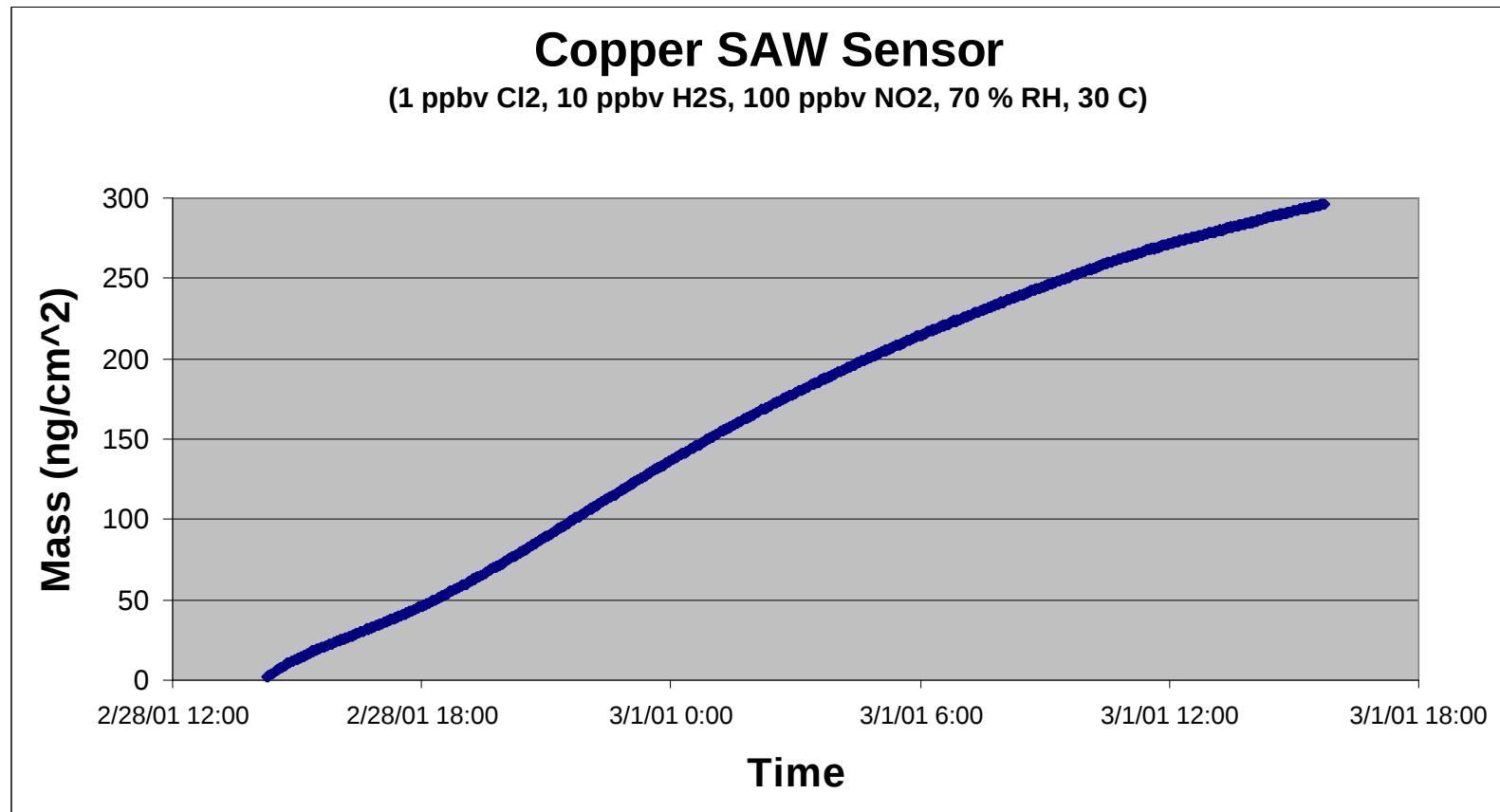
- **Hydrocarbon contamination adsorbs on optical components**
 - Photopolymerization occurs when optics exposed to short wavelength radiation causing hazing
- **Same hydrocarbon photopolymerization can result in chemical reactions producing particles**
- **Amines can react with acidic gases also causing haze on optics**

Copper Process Monitoring



- Real-Time Monitoring of Contamination on Copper Wafer Surface
 - Detects difference in molecular contamination conditions between high and low yield tools
 - Wet-ability (prior to wet etch process)
 - Reactive Acidic Gases
 - Monitor combined effects of multiple species and environmental conditions

Corrosion of Copper Surfaces - in real-time

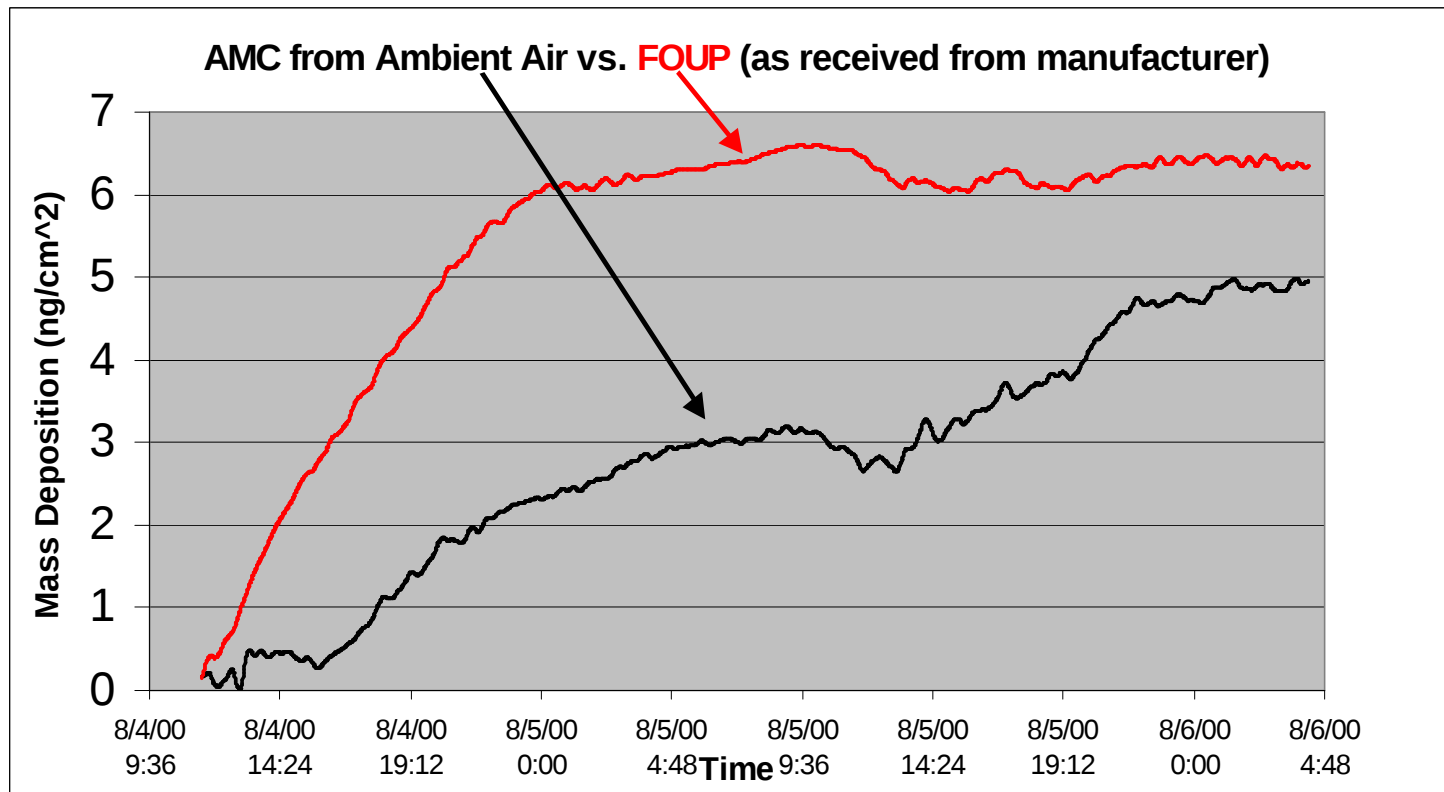


FOUP / SMIF Monitoring

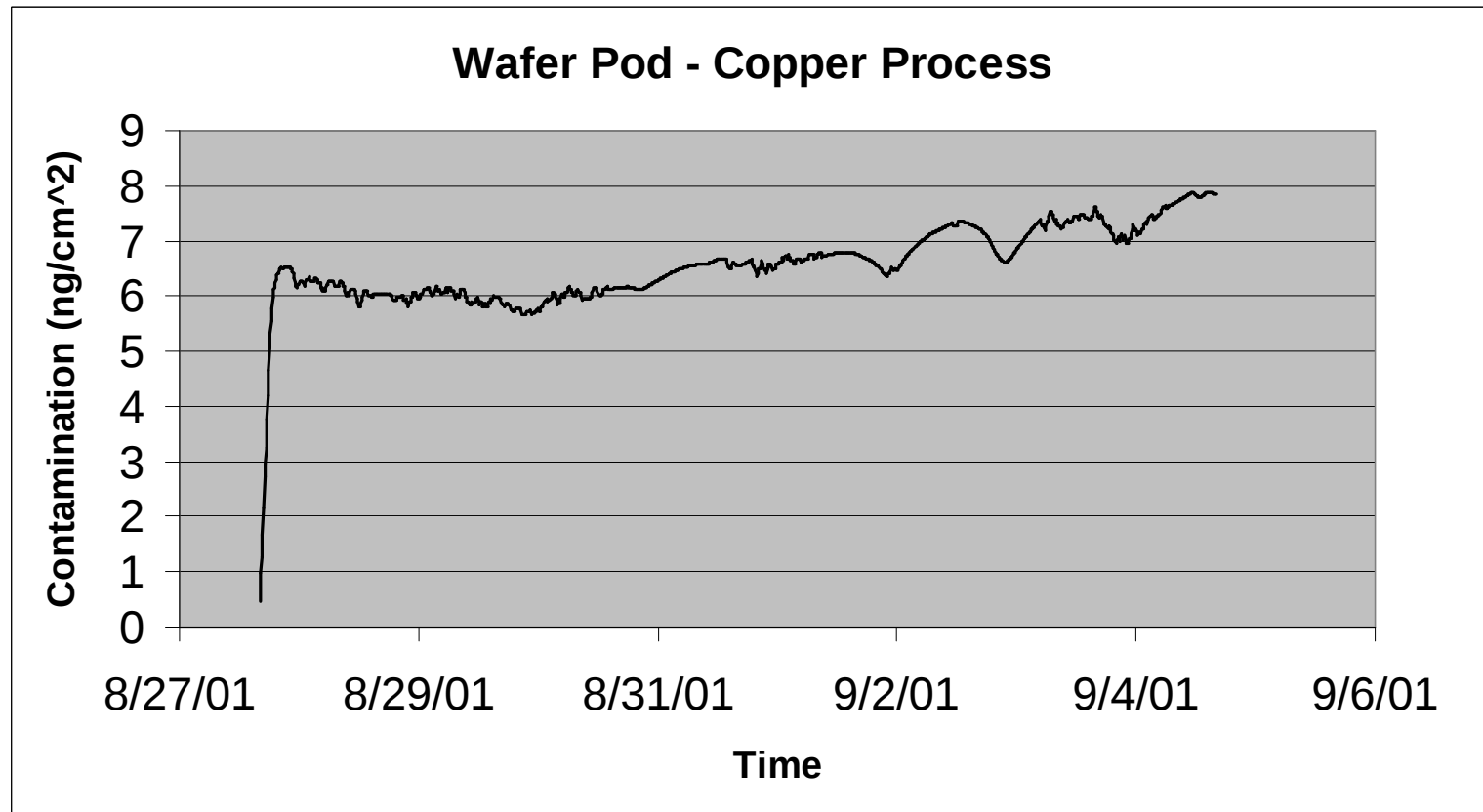


- Wafer Pod Monitoring
 - **Hydrocarbon Outgassing**
 - Construction Material - polycarbonate, etc.
 - Seal Material
 - **Effects of Ambient Air Contamination**
 - Closed pods “breathe” ambient contamination
 - Pods designed to protect wafers from particles, not molecules
 - **Secondary Contamination**
 - Wafers outgas contamination that can later desorb from FOUP and adsorb on wafer surface
 - Residual contamination from FOUP cleaning process

FOUP Monitoring



Monitoring Inside Wafer Carrier



General Guidelines for Mini-Environment Monitoring



- **Monitor Where Critical Surfaces are Most Exposed to Contamination**
 - Exposure Time
 - Contamination Levels
 - Sensitivity to Contamination
- **Locate Surface Molecular Contamination Monitor as Close to the Exposed Surface as Possible**
 - Sensor Surface Mimics Product Surface Material Properties
 - Sensor Exposure Mimics Product Exposure to Contamination
- **Understand background contamination conditions so new contamination events can be identified**

Summary



- Molecular contamination causes damage by changing the chemical, optical, physical, or electrical properties of a product surface
- Molecular contamination monitoring required to prevent, detect, and correct Surface Molecular Contamination events
- Molecular contamination impacts ultra-clean manufacturing
- Many monitoring techniques available, each with strengths and weaknesses
- No universal “best monitor”