NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

EE6601 Advanced Wafer Processing

Cleaning Technology

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Course Information

2018/2019 Semester 2 (Weeks 01 – 13)

Learning Objective

1. To study sub-micron front end process technology
2. To study sub-micron back end process technology
3. To study characterization techniques relevant to sub-micron process technology

Learning Outcome

The students will be exposed to state-of-the-art advanced CMOS process technologies. They will also be exposed to future technology. They will also become more familiar with the relevant diagnostic techniques for process related issues.

Course Information

2018/2019 Semester 2 (Weeks 01 – 13)

Grading

Continuous Assessment (20%)

- CA 1 - review (10%)
- CA 2 - review (10%)

Final Exam (80%)

Plagiarism report!

Location of EE6601 files: NTUlearn > EE6601 > Content > Part 2 (Wei Lei)

Text Books and References:

1. The science and engineering of microelectronic fabrication, Stephen A. Campbell, Oxford, 2001
2. Silicon VLSI Technology: Fundamentals, Practice, and Modeling, James D. Plummer, Michael Deal, and Peter B. Griffin, Prentice Hall, 2000
3. Silicon Processing for the VLSI Era Vol 4 – Deep-submicron Process Technology, S Wolf, Lattice Press
4. Semiconductor Materials and Device Characterization, Dieter K. Schroder, Wiley Interscience
5. Semiconductor Manufacturing Technology, Michael Quirk and Julian Serda Prentice Hall

Course Information

2018/2019 Semester 2 (Weeks 01 – 13)

Topic	Lecturer
Etching Process and Technology Interconnect Technology Process Integration Scaling	TAN Chuan Seng
Cleaning Technology Chemical and Mechanical Polishing Metrology and Analytical Techniques Dielectrics for CMOS technology	WEI Lei
Lithography and Resist Technology	TAY Beng Kang

2nd Part

Week	Date	Time/Room	Topic	Remarks
5	**Feb 12 (Tue)**	**6:30-9:30 pm LT27**	**Cleaning Technology**	**CA#2 Out NTULearn submission opens Turnitin Assignment CA2**
6	**Feb 19 (Tue)**	**6:30-9:30 pm LT27**	**Chemical and Mechanical Polishing**	
7	**Feb 26 (Tue)**	**6:30-9:30 pm LT27**	**Metrology and Analytical Techniques**	
		Recess Week		
8	**Mar 12 (Tue)**	**6:30-9:30 pm LT27**	**Dielectrics for CMOS technology**	
9	**Mar 19 (Tue)**	**6:30-9:30 pm LT27**	**Dielectrics for CMOS technology Revision, Q&A**	**CA#2 Due NTULearn submission closes**

Exercise/PYP questions during the lectures

CA #2

Notes:

1. Please write a review of at least 4 pages using CA 2 format (CA 2 template is available in NTULearn) on any of the following topics;
2. Your report must have a title, author, abstract, introduction, main discussion, summary, and references;
3. Submit your report by Mar 19 in NTULearn under "Assignment CA2". Late submission is not acceptable without a valid reason;
4. This report constitutes half of your total CA score (10%);
5. Any form of plagiarism is a serious matter and will not be tolerated. Citation is a must for any copyrighted and reported work.
6. **"Turnitin Assignment" allows to see the similarity checking results.**

Topics:

1. Recent development in advanced wafer cleaning technology;
2. Recent development in characterization tools, such as AFM, TEM, etc;
3. Recent development in technologies to enhance the reliability of SiO_2, or related topics on high or low k dielectrics, etc;
4. Your proposed topic related to lectures #5-8. If you are unsure, please discuss with me before working on it.

Wafer Cleaning Technology

- Wafer Processing Requires Cleaning
- Types of Contamination
- Wet Cleaning Process
- Wet Cleaning Equipment
- Alternative to RCA Clean

Effect of defect and contamination on semiconductor industry

Year of 1st DRAM Shipment	1997	1999	2003	2006	2009	2012
Minimum Feature Size	250nm	180nm	130nm	100nm	70nm	50nm
Wafer Diameter (mm)	200	300	300	300	450	450
DRAM Bits/Chip	256M	1G	4G	16G	64G	256G
DRAM Chip Size (mm^2)	280	400	560	790	1120	1580
Microprocessor Transistors/chip	11M	21M	76M	200M	520M	1.40B
Critical Defect Size	**125nm**	**90nm**	**65nm**	**50nm**	**35nm**	**25nm**
Starting Wafer Total LLS (cm^{-2})	**0.60**	**0.29**	**0.14**	**0.06**	**0.03**	**0.015**
DRAM GOI Defect Density (cm^{-2})	**0.06**	**0.03**	**0.014**	**0.006**	**0.003**	**0.001**
Logic GOI Defect Density (cm^{-2})	**0.15**	**0.15**	**0.08**	**0.05**	**0.04**	**0.03**
Starting Wafer Total Bulk Fe (cm^{-3})	**3×10^{10}**	**1×10^{10}**	**Under 1×10^{10}**	**Under 1×10^{10}**	**Under 1×10^{10}**	**Under 1×10^{10}**
Metals on Wafer Surface After Cleaning (cm^{-2})	**5×10^{9}**	**4×10^{9}**	**2×10^{9}**	**1×10^{9}**	**$< 10^{9}$**	**$< 10^{9}$**
Starting Material Recombination Lifetime (µsec)	**≥ 300**	**≥ 325**	**≥ 325**	**≥ 325**	**≥ 450**	**≥ 450**

LLS: localized light scatters (use laser to detect and count particles)

GOI: gate oxide integrity, by electrical measurement

Requirement different for DRAM and logic chip, due to greater gate insulator area on DRAM chip.

$10^9/cm^2$ ~ 0.0001% monolayer

DRAM: Dynamic Random Access Memory

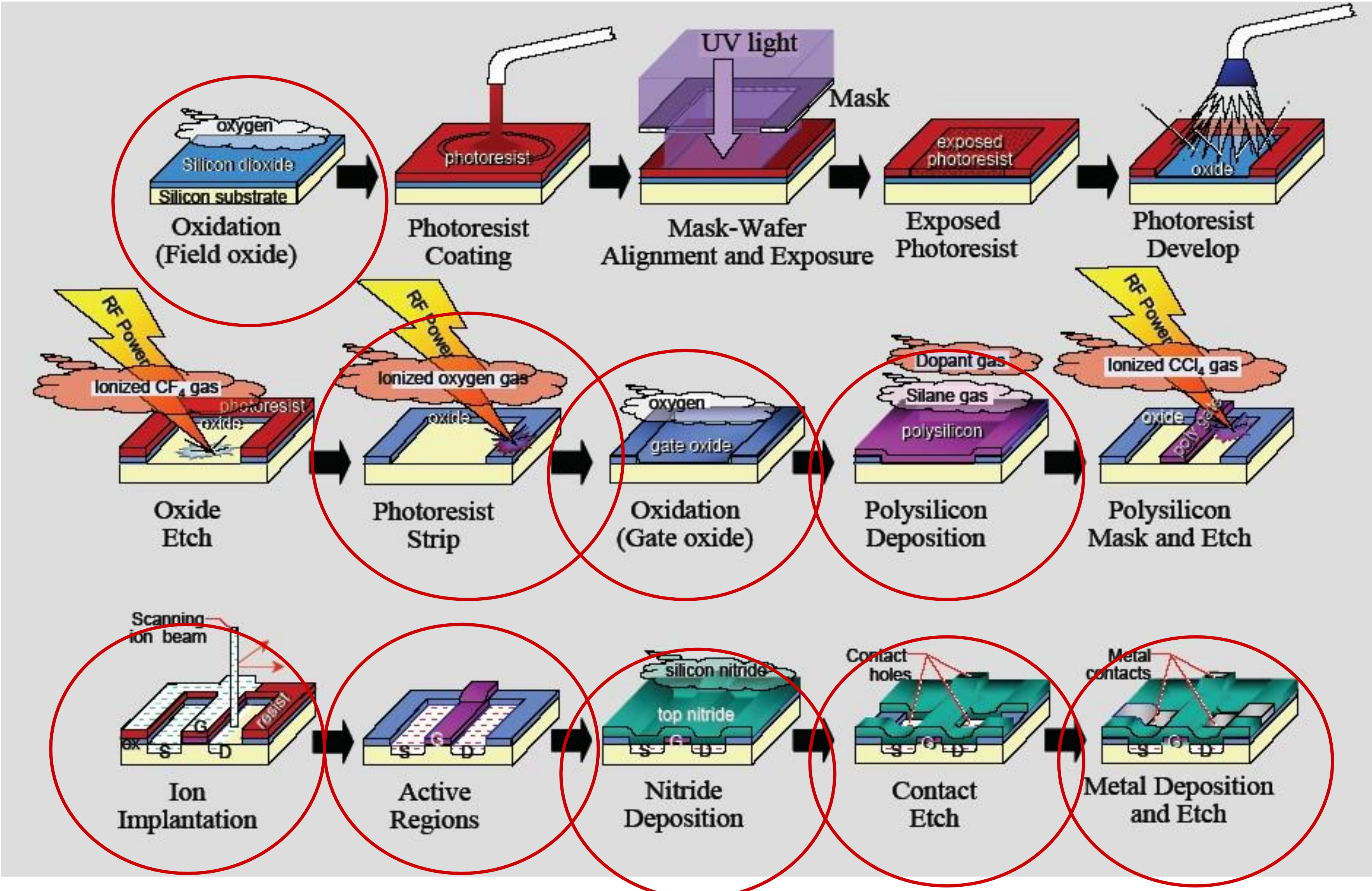
Importance of unwanted impurities increases with shrinking geometries of devices.

75% of the yield loss is due to defects caused by particles (1/2 of the min feature size).

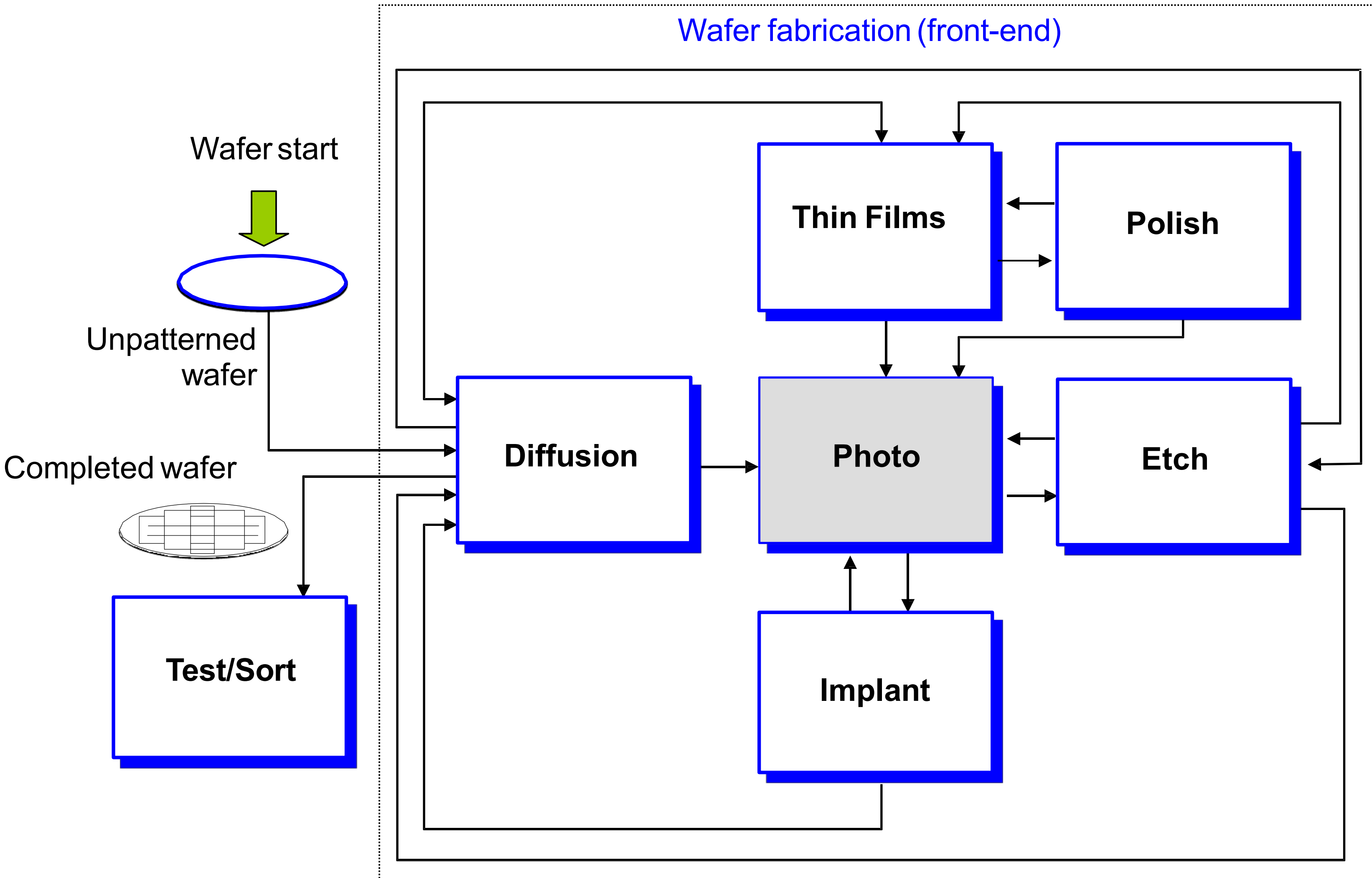
Wafer Cleaning Technology

- The objective of wafer cleaning and surface conditioning is the removal of particle and chemical impurities from the semiconductor surface without damaging or deleteriously altering the substrate surface.
- Most wet processes in wafer fab involve cleaning of wafer surfaces. Some of these cleans also involve etching.
- The number of cleaning steps in a process flow is typically 20-25% of the total steps in the process and involve all parts of the flow. At 0.18-micron design rules, 80 out of ~400 total steps will be cleaning.
- Cleans typically precede all diffusion steps and film deposition steps, and they follow all RIE or plasma etch steps and plasma strip processes.

Major fabrication steps in process flow that require cleaning



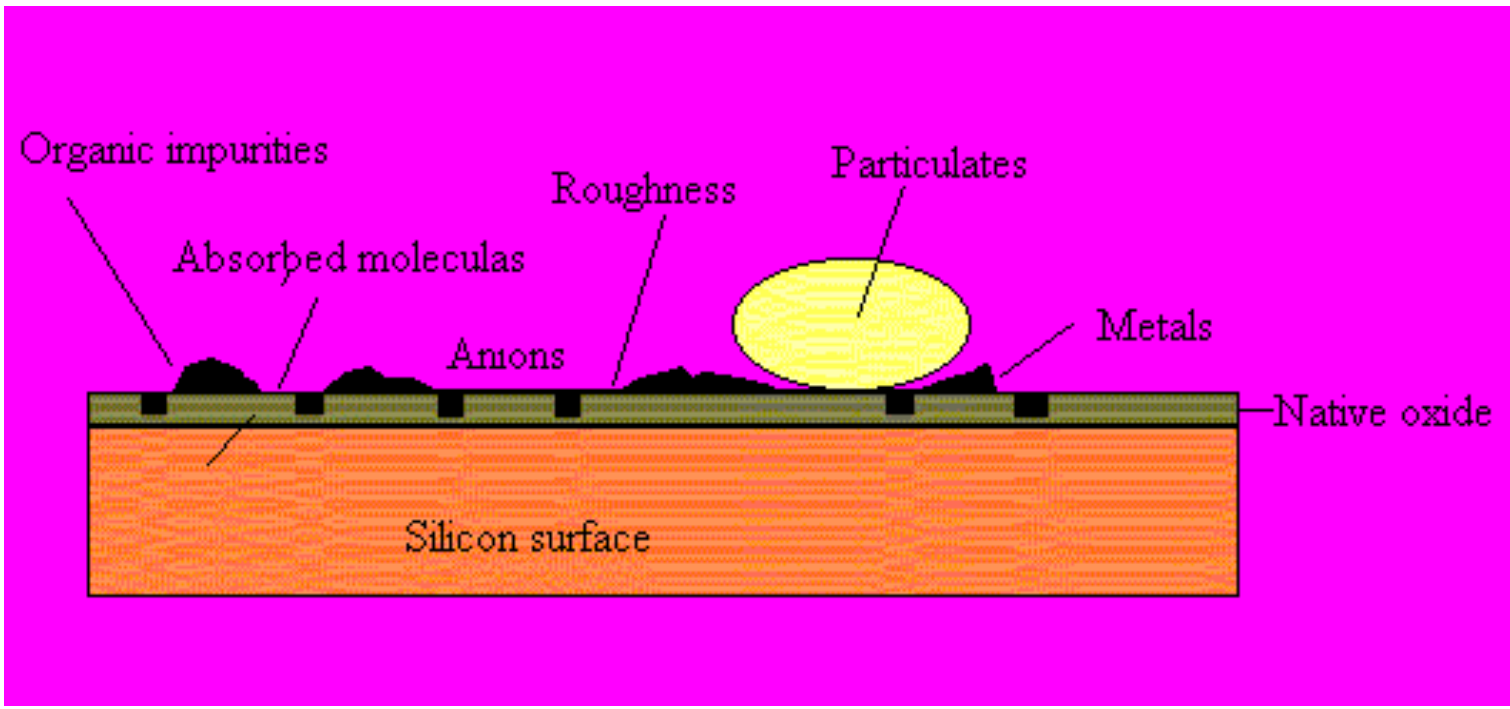
Wafer Fabrication Process Flow



Note: **wafer cleaning is required either before or after each processing step to ensure best wafer surface or prevent contaminations from affecting device performance**

Types of Contamination

- Particles
- Metallic Impurities
- Organic Contamination
- Native Oxides
- Electrostatic Discharge



Contamination on the silicon surface

Types and Sources of Contamination

Particles

dust, pollen, clothing particles, bacteria, etc. In ordinary room there are as much as 10^6 particles more then 0.5 micron in diameter per cu.ft. Particles with diameter more then 20 micron will settle down readily. Particles of diameter from 0.1 to 20 micron are the main problem.

Inorganic contaminants

salts, positive and negative ions in solution, heavy metal atoms. Inorganics are removed by cleaning the wafer in water recirculation systems and using special solutions.

Organic contaminants

smog, skin oil, fluxes, lubricants, solvent vapors, monomers from plastic tubing and storage boxes that can condense on substrate. They usually removed using strong oxidizers, gaseous or liquid.

Impurities

incorporated during the formation of substrates or overlayer films. Generally, they cannot be removed.

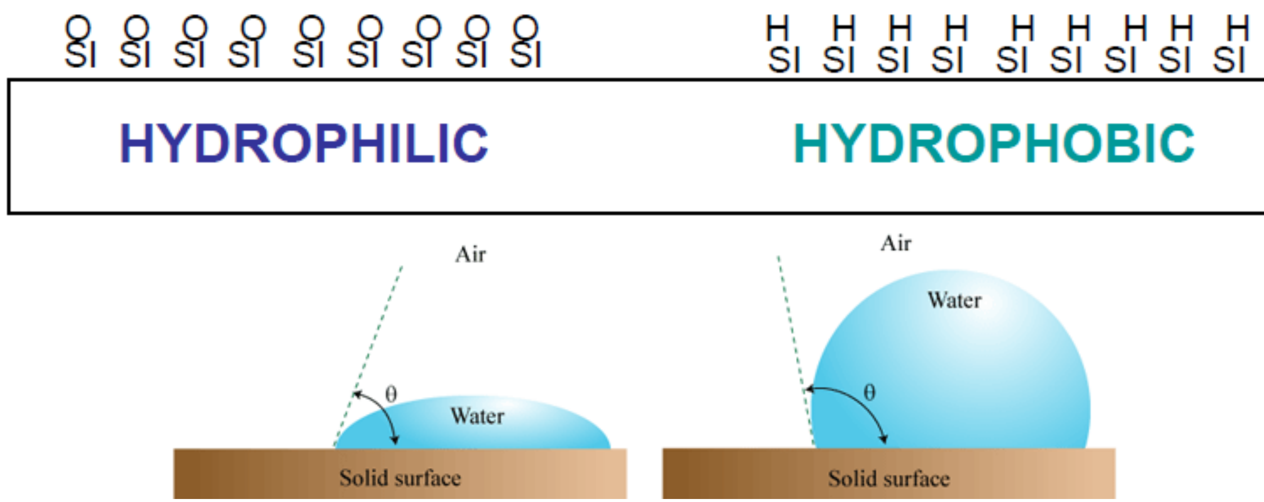
杂质

Sand → SiO_2 → Si

Silicon Wafer Surface

- Bare silicon surfaces - unstable
  - Hydrogen terminated
  - React with oxygen to form “native” oxide
  - Hydrophobic

- Native oxide - stable
  - Not equivalent to thermal oxide
  - Thickness = about 10Å
  - Self limiting
  - Grown by exposure to air or oxidizing solution
  - Hydrophilic

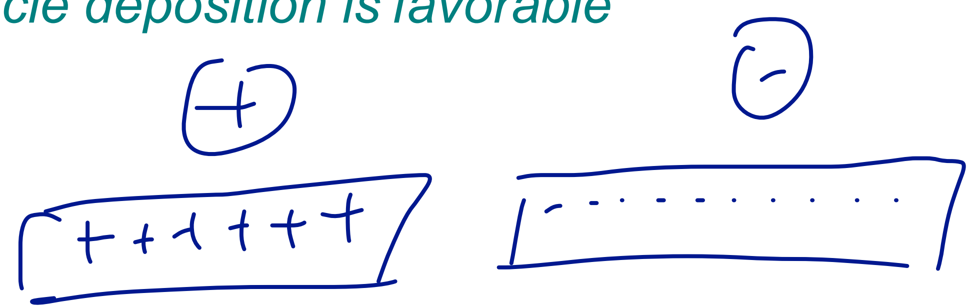


Adhesion of Particles to Surfaces

- Attractive Forces (AF)
  - van der Waals forces (short range)
  - 静电 Electrostatic (if the charge on the particles is opposite to the charge on the surface (typically longer range)

- Repulsive Forces (RF)
  - Electrostatic (charge on the particle has the same sign as that on the surface)
  - Steric forces (due to absorbed polymer layers on the surface of the particles and wafer) (short range)

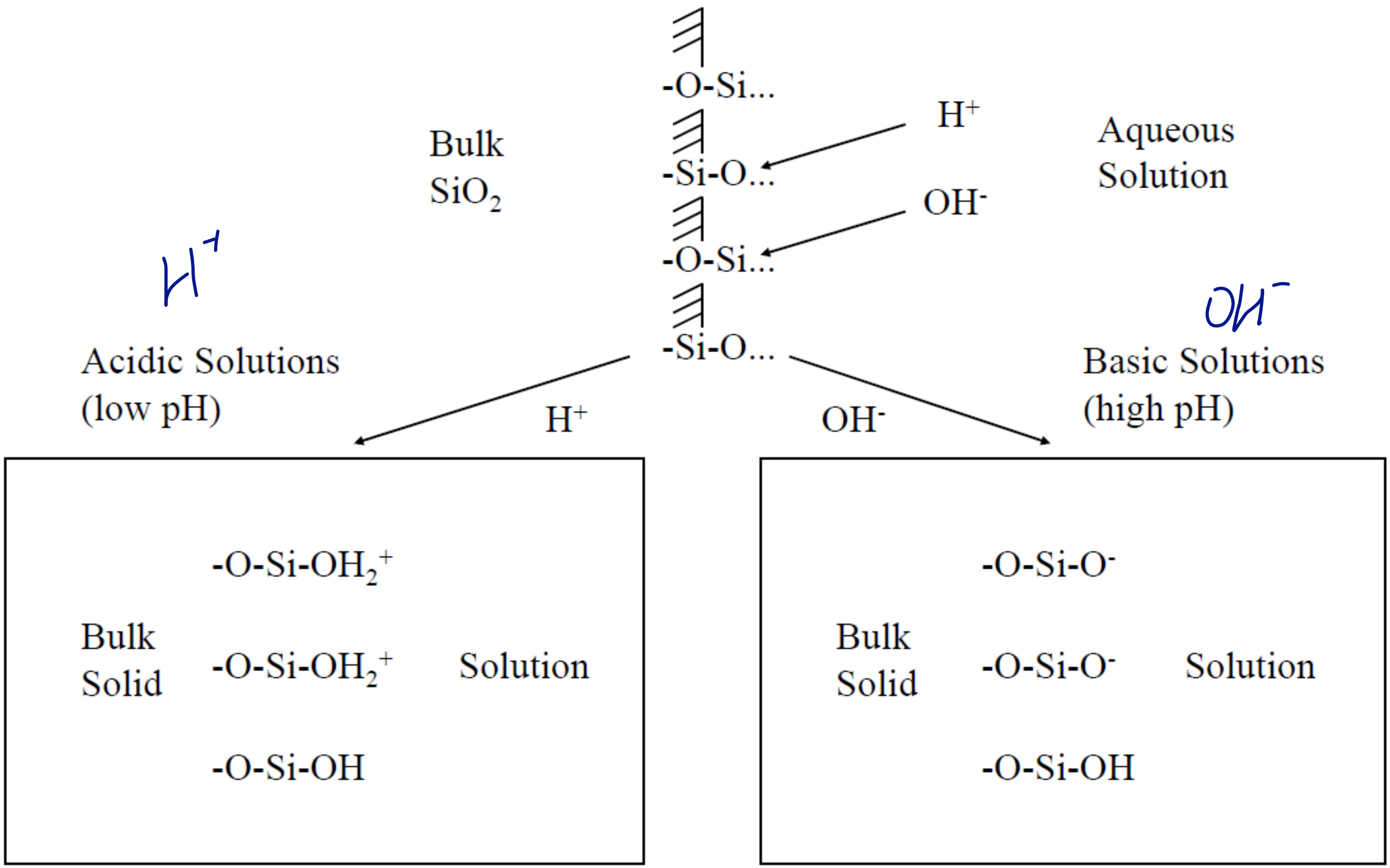
When AF > RF, particle deposition is favorable



Surface Charge and Surface Electricity

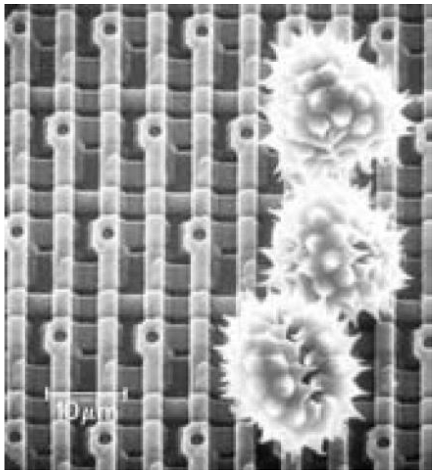
- Development of surface charge
  - Adsorption of H+ and OH- ions (oxides)
  - Selective adsorption of positive or negative ions (hydrophobic materials)
  - Ionization of surface groups (polymers such as nylon)
  - Fixed charges in the matrix structure exposed due to counter ion release
    - example: positively charged modified filters used in DI water purification

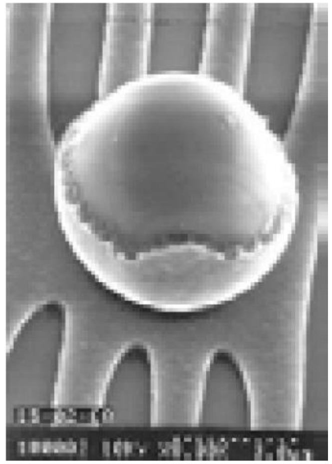
Surface Charge Development on SiO_2 Immersed in Aqueous Solutions



Particle Contamination

Causing Defects in Lithography Patterns

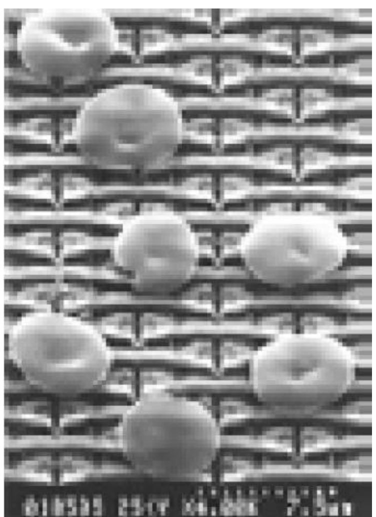


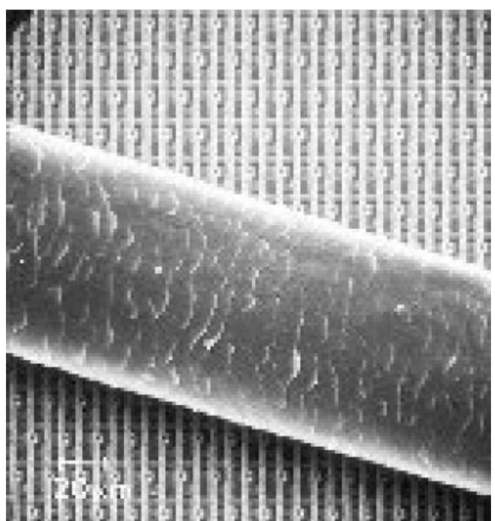


Particle sources: air, people, equipment and chemicals.
A typical person emits 5-10 million particles per minute.

Particle density (number/ml) for ULSI grade chemicals

	>0.2μm	>0.5μm
NH_4OH	130-240	15-30
H_2O_2	20-100	5-20
HF	0-1	0
HCl	2-7	1-2
H_2SO_4	180-1150	10-80





ULSI: ultra-large-scale integration

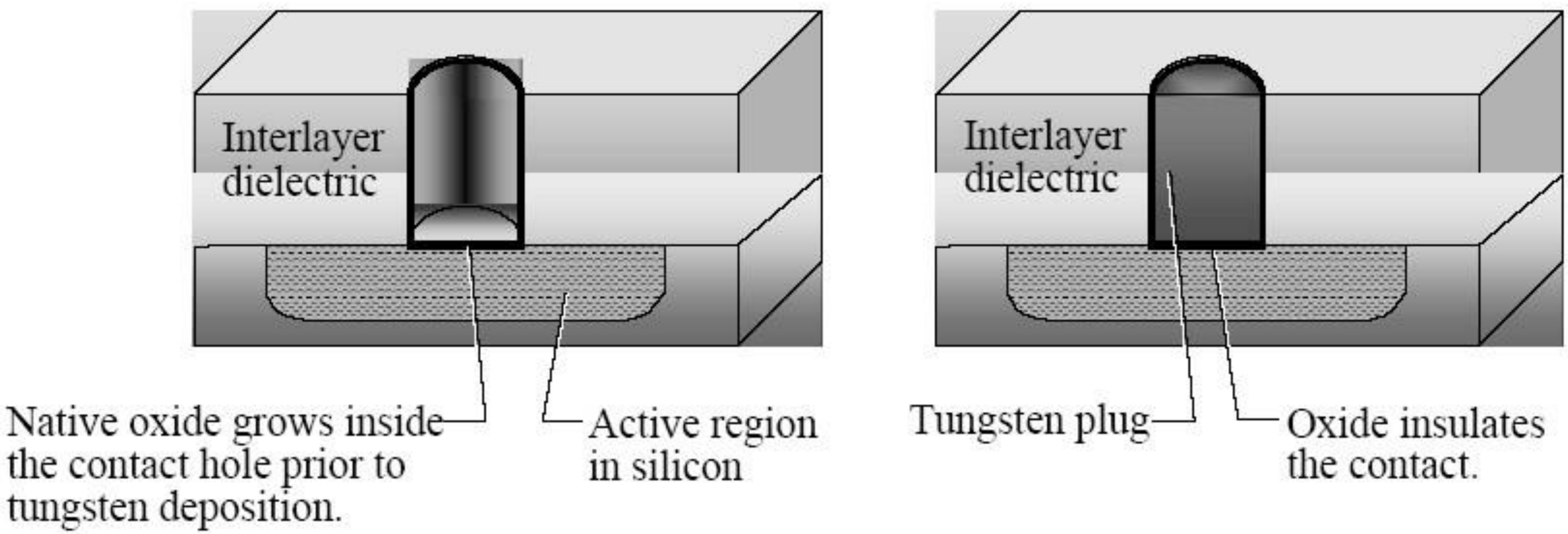
Typical Metal Impurities

Heavy Metals	Alkali Metals
Iron (Fe)	Sodium (Na)
Copper (Cu)	Potassium (K)
Aluminum (Al)	Lithium (Li)
Chromium (Cr)	
Tungsten (W)	
Titanium (Ti)	

Two ways: one is to bind on the surface (not easy to remove); the other is to form in oxide (easy to remove by stripping the oxide)

Native Oxide on Contacts

Native oxide lines the bottom of the contact hole, creating poor electrical contact between tungsten and the doped silicon region.



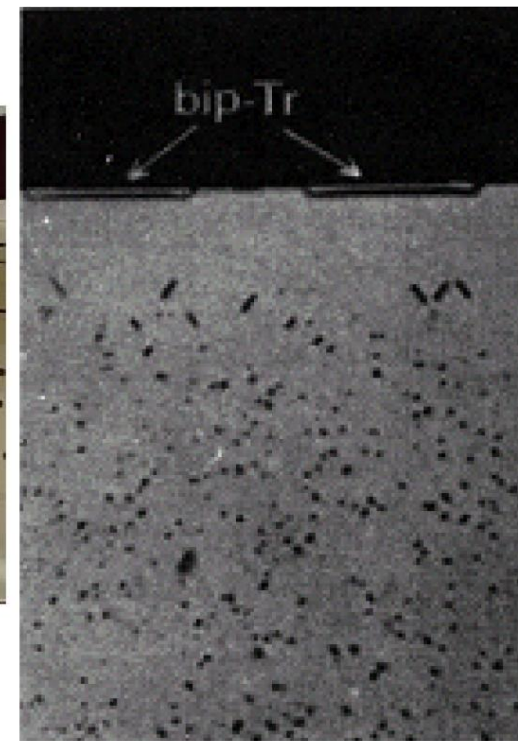
Clean factory is the first approach against contamination

Modern IC factories employ a three tiered approach to control unwanted impurities:

1. clean factories
2. wafer cleaning
3. gettering

Clean factory

Wafer cleaning



Gettering

Clean room

Factory environment is cleaned by:

- HEPA filters and recirculation for the air.
- “Bunny suits” for workers.
- Filtration of chemicals and gases.
- Manufacturing protocols.

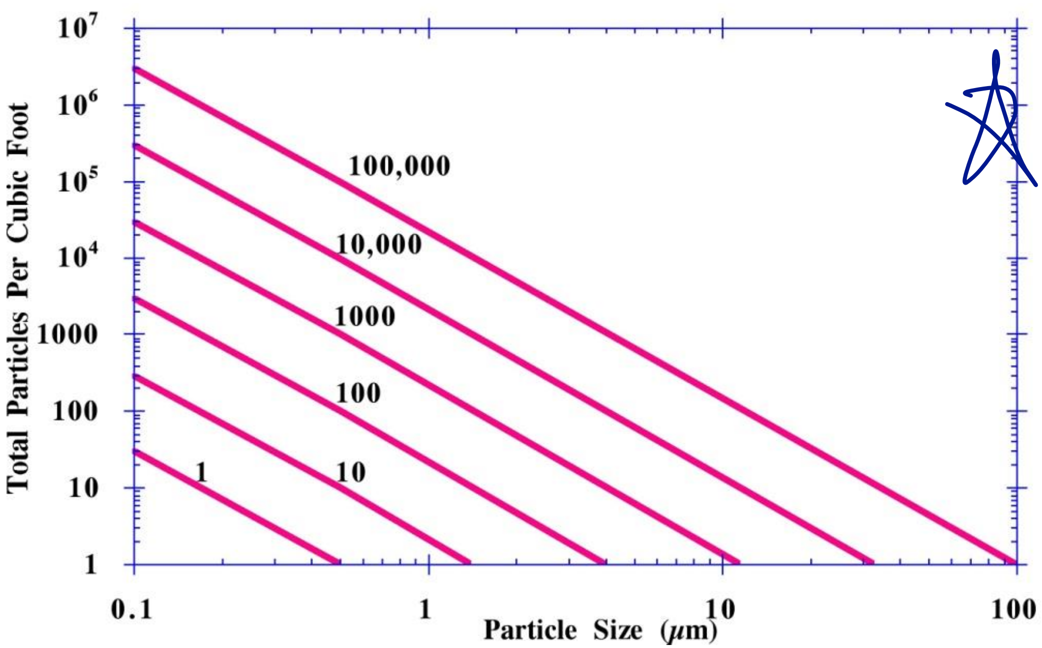
UV light

HEPA: High Efficiency Particulate Air

- HEPA filters composed of thin porous sheets of ultrafine glass fibers (<1μm diameter).
- It is 99.97% efficient at removing particles from air.
- Room air forced through the filter at 50cm/sec.
- Large particles trapped, small ones stick to the fibers due to electrostatic forces.
- The exit air is typically better than class 1.

Class of a clean room

- Air quality is measured by the "class" of the facility.
- Class 1-100,000 mean number of particles, greater than 0.5μm, in a cubit foot of air.
- A typical office building is about class 100,000.
- The particle size that is of most concern is 10nm – 10μm. Particles <10nm tend to coagulate into large ones; those >10μm are heavy and precipitate quickly.
- Particles deposit on surfaces by Brownian motion (most important for those <0.5μm) and gravitational sedimentation (for larger ones).



Particle diameter (μm)

Class	0.1	0.3	0.5	5.0
1	35	3	1	
10	350	30	10	
100		300	100	
1000			1000	7
10000			10000	70
100000			100000	700

by definition

Cleaning for Advanced Wafer Processing

Front-End-Of-Line (FEOL)

Individual devices are patterned in the semiconductor wafer

- Pre-Diffusion Cleaning
- Post Photolithography Photoresist Removal and Cleaning
- Post Gate Etch Photoresist Removal and Cleaning
- Post Ion Implant Photoresist Removal and Cleaning
- Post Shallow Trench Isolation (STI) CMP Cleaning

Back-End-Of-Line (BEOL)

Individual devices are interconnected with wiring on the wafer

- Pre Thin-Film Deposition Cleaning
- Post Contact and Via Etching Cleaning
- Post Metal Etching Photoresist Removal and Cleaning
- Post Metal and Low-k Dielectric CMP Cleaning

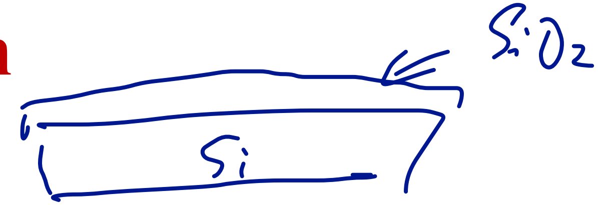
Modern Wafer cleaning

- Cleaning involves removing particles, organics and metals from wafer surfaces.
- Particles are largely removed by ultrasonic agitation during cleaning.
- Organics (photoresist) are removed in O_2 plasma or in H_2SO_4/H_2O_2 (Piranha) solutions.
- The "RCA clean" is used to remove metals and any remaining organics.

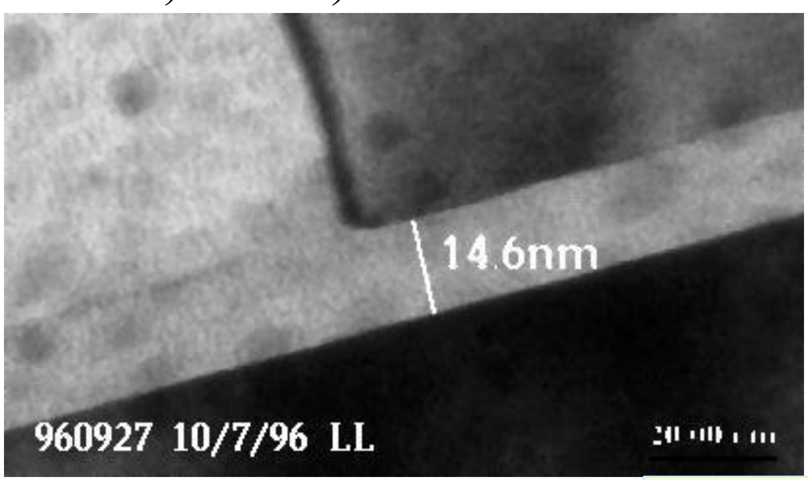
A cassette of wafers

Typical person emit 5-10 million particle per minute.
Most modern IC plants use robots for wafer handling.

Pre-Diffusion Clean



- Cleans before furnace operations are critical
  - Defects or contamination will be incorporated into the wafer if not removed prior to high temperature furnace operation
- Most important steps - those where bare silicon is present
  - Pre-initial
  - Pre-sac gate
  - Pre-gate
- Typically full cleans (Piranha+BOE (Buffered Oxide Etch, HF) +SC(standard clean)1+SC2)

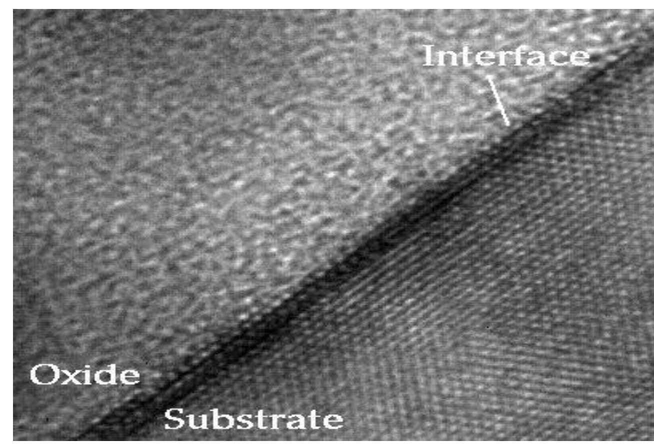


Polysilicon

Gate Oxide

Silicon

Gate Oxide Stack



Silicon Oxide Interface

Wafer Wet-Cleaning Chemicals --- Pre-Diffusion Clean

Contaminant	Name	Chemical Mixture Description (all Cleans are followed by a DI Water Rinse)	Chemicals
Particles	Piranha (SPM)	▪ Sulfuric acid/hydrogen peroxide/DI water	$H_2SO_4/H_2O_2/H_2O$
	SC-1 (APM)	• Ammonium hydroxide/hydrogen peroxide/DI water	$NH_4OH/H_2O_2/H_2O$
Organics	SC-1 (APM)	• Ammonium hydroxide/hydrogen peroxide/DI water	$NH_4OH/H_2O_2/H_2O$
Metallics **(not Cu)**	SC-2 (HPM)	• Hydrochloric acid/hydrogen peroxide/DI water	$HCl/H_2O_2/H_2O$
	Piranha (SPM)	▪ Sulfuric acid/hydrogen peroxide/DI water	H_2SO_4/H_2O_2
	DHF	• Hydrofluoric acid/water solution (will not remove copper)	HF/H_2O
Native Oxides	DHF	• Hydrofluoric acid/water solution (will not remove copper)	HF/H_2O
	BHF	• Buffered hydrofluoric acid	$NH_4F/HF/H_2O$

Wet-Cleaning Chemicals

- **PIRANHA or SPM (Sulfuric Acid-Hydrogen Peroxide)**
  - Sulfuric acid/hydrogen peroxide/ deionized water (SPM, $H_2SO_4/H_2O_2/H_2O$)
  - Temperature range of 110-130°C
  - H_2SO_4 (98%) and H_2O_2 (30%) in different ratios
  - Used for removing organic contaminants and stripping photoresists
  - Will grow an oxide on bare silicon but will *not* grow oxide on oxidized surfaces
  - Peroxide has a limited lifetime, replenished by spiking with added peroxide

  - **Sulfuric acid disadvantages**
    - Difficult to remove from surfaces
    - Water used for rinsing is usually very hot
    - Amount of sulfur left on surfaces is very high.
    - Removed easily with a brief HF dip

Wet-Cleaning Chemicals

- **APM (SC-1) --- NH_4OH-H_2O_2**
  - Ammonium hydroxide/hydrogen peroxide/DI water mixture ($NH_4OH/H_2O_2/H_2O$).
  - Temperature range of 60-80°C
  - Standard solution is $NH_4OH/H_2O_2/H_2O$ = 1:1:5
  - APM oxidizes the bare silicon to form native (chemical) oxide
  - slightly etches oxides at a low rate (~1Å/min) and can etch silicon
  - slightly etches to undercut and remove particles from the surface
  - it also removes organic and metal contaminants.
  - Typically used with a Megasonic unit for particle removal
  - **Problems**
    - Peroxide is unstable in basic solution, especially in the presence of metallic impurities.
    - Ammonia has high volatility.
    - Metallic impurities readily adsorb onto surfaces:
      - Al and Fe contamination - typical problem
      - Other transition metals can also deposit
    - Can also result in surface roughening
    - Presence of the oxidant is critical!
      - If lost, solution will etch silicon

Wet-Cleaning Chemicals

- **APM (SC-1) --- NH_4OH-H_2O_2** (…continue)

  - Dilutions down to 1:1:50 probably as effective, may have other problems:
    - Control of the concentration is critical
    - Tradeoffs to be considered with lower concentrations:
      - higher changeout frequency/shorter bath life
      - lower particle removal efficiency
      - metallic contamination
      - ammonia evaporation and peroxide decomposition

- **DHF** following SC-1
  - Hydrofluoric acid or diluted hydrofluoric acid (HF or DHF @ 20-25 degrees C).
  - Removes oxides from area of interest, etches silicon oxides and dioxides,
  - Reduces metals contamination of the surface.
  - Sometimes buffered oxide etch(BOE or BHF, NH4F/HF/H_2O @RT) is used in place of DHF in some processes, but may lead to NH4F precipitation and contamination.

Wet-Cleaning Chemicals

- **HPM (SC-2)**

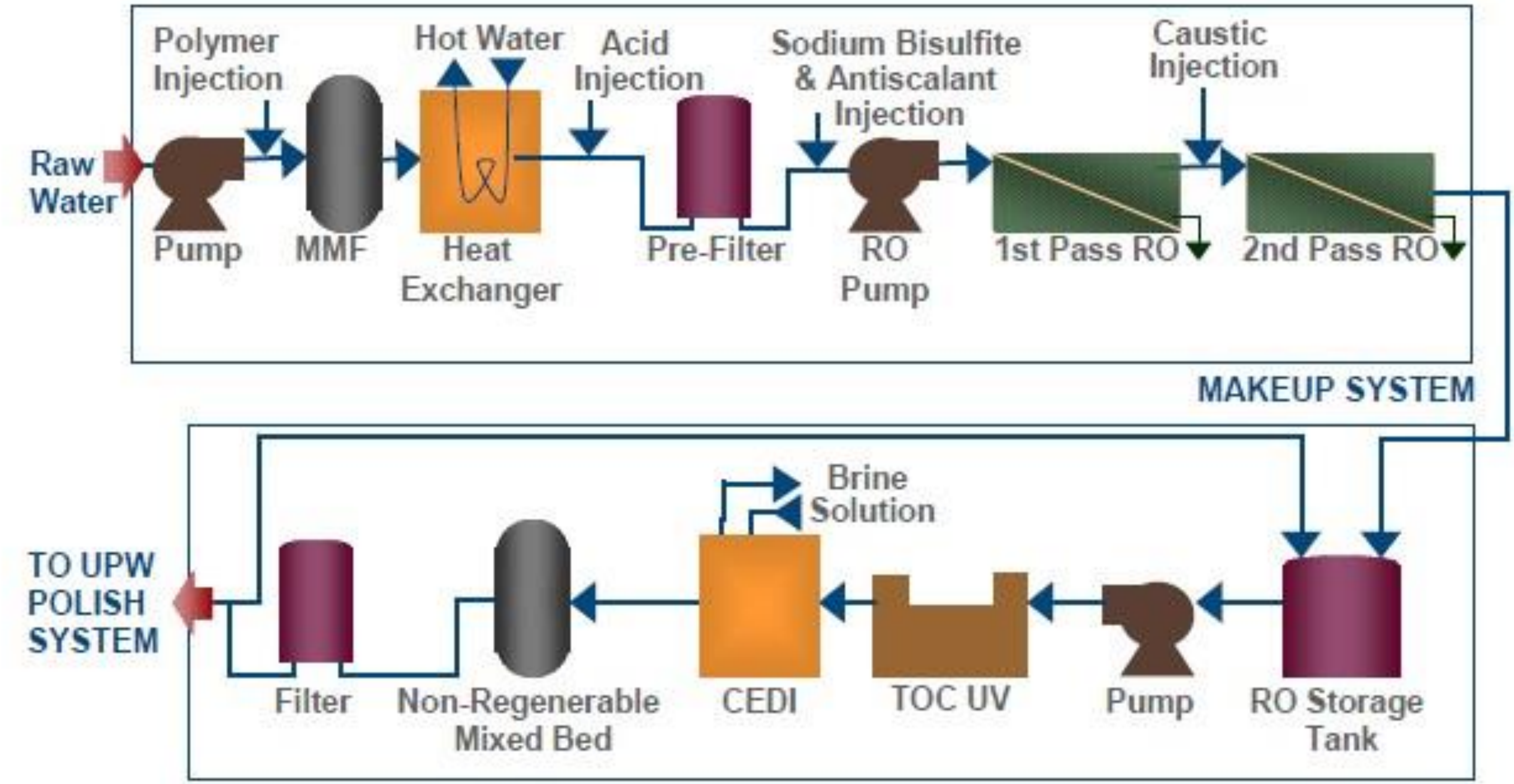
  - **Hydrochloric acid/hydrogen peroxide/DI water (HPM, $HCl/H_2O_2/H_2O$ (1:1:5) @ 60- 80degrees C)**
  - Temperature range of 60-80°C
  - Standard solution is $HCl/H_2O_2/H_2O$ = 1:1:5
  - **HPM removes metallic contaminants from substrate and acts as oxidizing agent.**
  - Mechanism for operation - chlorides of most metallic contaminants are soluble in an acidic solution
  - Peroxide may not be needed at low metallic contamination levels.

Wet-Cleaning Chemicals

- **UPW as Processing Chemical**

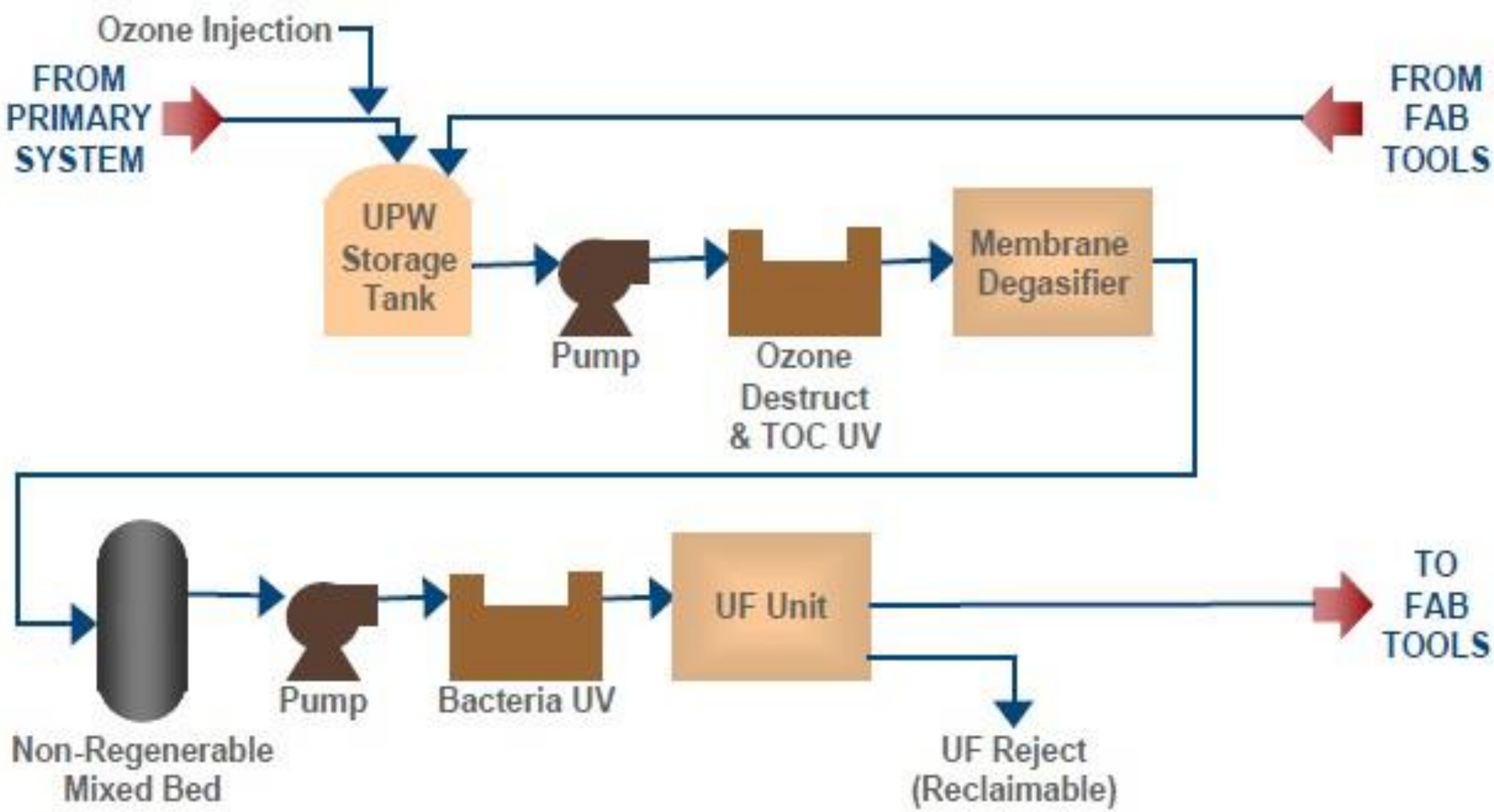
  - Ultra-pure water (UPW). Commonly called as DI water.
  - Most heavily used chemical in wafer fabrication > 6000 gal/8"CMOS wafer .
  - it dilutes chemicals and rinses solutions after chemical cleans.
  - Rinse multiple times until solution reaches high resistivity in given time period
  - DI water must be manufactured on site to achieve the quality and purity levels required by modern microfabrication.
  - Each gallon of DI water may require as much as 4-6 gallons of raw city grade water to manufacture.
  - DI water must be continuously recirculated in order to achieve the quality and purity levels.

Typical UPW System



Raw and Primary Supply System

Typical UPW System



Polishing System

Typical UPW System

Incoming raw water quality

Parameter	Quality Level
Conductivity	250 microsiemens/cm
Total Oxidizable Carbon (TOC) UV/Resistivity	2.2 ppm
Silica (total)	12.6 ppm
Dissolved Oxygen	10.5 ppm
Turbidity	0.65 NTU
Sodium	53 ppm
Chloride	22 ppm
Iron	0.05 ppm

Typical Specifications for DI Water suitable for wafer fab

Max ions (ppb)		Max metals (ppb)			
Na^+	0.05	Li	0.03	B	0.05
K^+	0.1	Na	0.05	Al	0.05
Cl^-	0.05	K	0.05	Mn	0.02
Br	0.1	Mg	0.02	Fe	0.10
NO_3^-	0.1	Ca	2.00	Ni	0.02
SO_4^-	0.1	Sr	0.01	Cu	0.02
total	0.5	Ba	0.01	Zn	0.02
				Pb	0.05

Parameter	Specification
Resistivity In-Line Cell	> 18.2 MOhm-cm
Total Oxidizable Carbon (TOC) UV/Resistivity	< 2 ppb
Bacteria, 48-Hour Culture	< 1 cfu/Liter
Reactive Silica	< 1 ppb
Dissolved Oxygen	1 to 20 ppb
Particles–Laser Cell > 0.05 Micron > 0.10 Micron > 0.50 Micron	 < 500/Liter < 50/Liter < 1/Liter
Sodium, IC	50 ppt
Chloride, IC	50 ppt
Metals, Each, ICPMS	50 ppt
Metals, Total, ICPMS	< 1 ppb

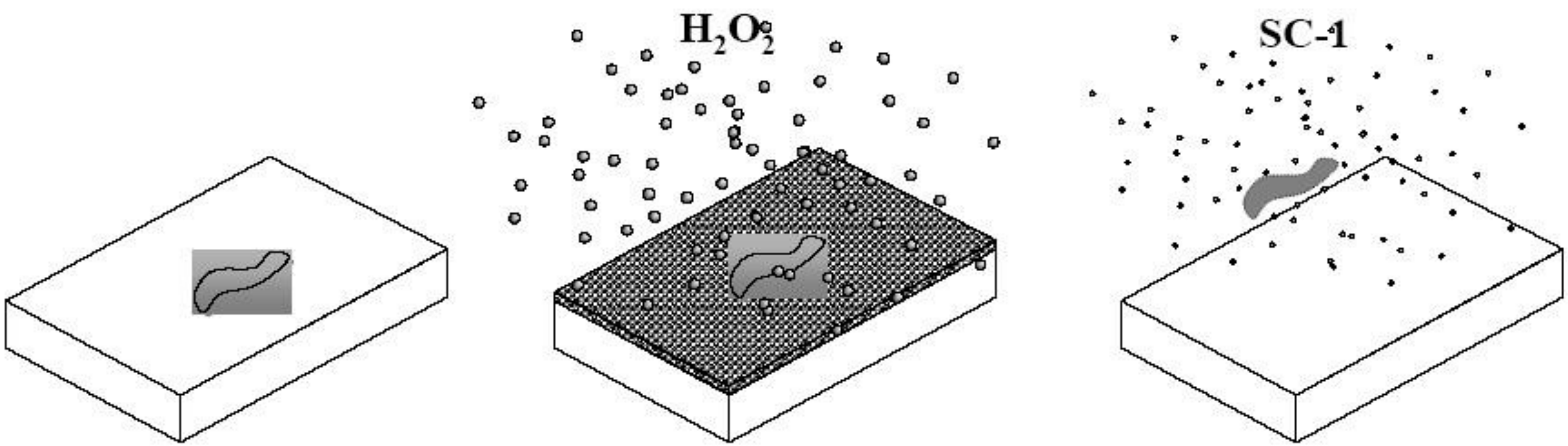
Deliver

DI Water System

- Water must flow continuously recirculation loops at > 10 linear feet per minute to keep bacteria from forming on walls.
- Dead-legs must be avoided in plumbing-- stagnant regions will provide culture zone for bacterial growth.
- Distance from loop to taps must be minimized.
- All piping must be PVDF (teflon) with fusion welded joints.
- No metal parts must be in contact with loop, except for a few stainless steel parts around the UV sterilization units which are unavoidable.
- Resistivity monitor reads > 18 MOhm-cm.
- DI Water system must be sterilized with injected H2O2 to kill any bacteria/fungi culture in the loop from time to time and then restarted. H2O2 is reduced to H2O and O2 upon passing through UV sterilizer. (Turn the UV unit off for system sterilization.)

Action of SC-1 (APM – NH4OH/H2O2)

Oxidation and Solubility of Particle in SC-1

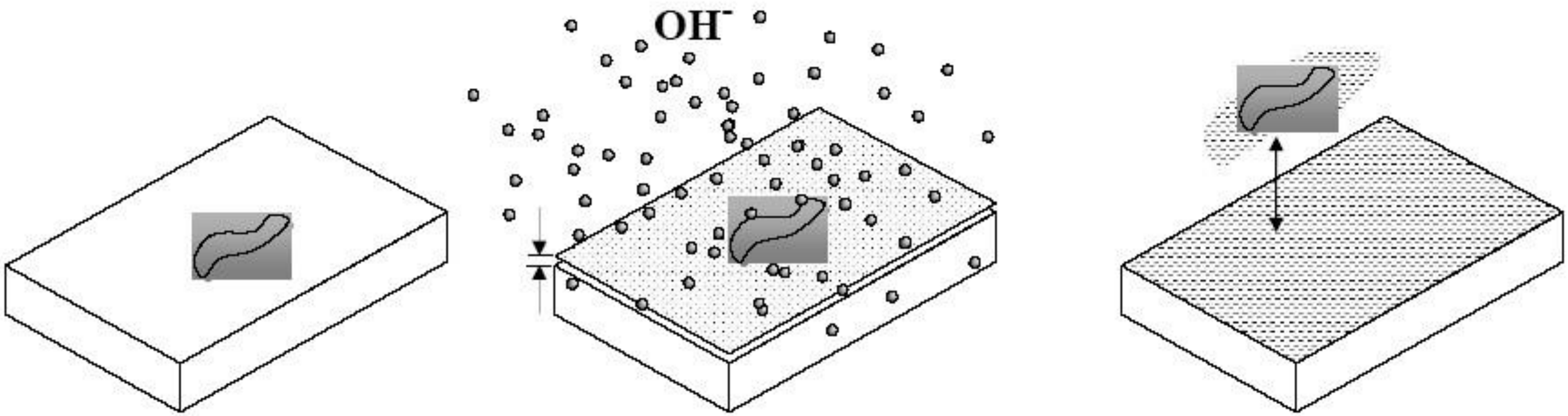


(1) Particle attaches to silicon.

(2) Oxidation of silicon by H_2O_2 helps lift particle.

(3) Particle dissolves in SC-1 solution.

Particle Removal Through Negative Charge Repulsion



(1) Particle attaches to silicon.

(2) OH^- from NH_4OH etches surface.

(3) HO^- builds up a negative charge on the surface that repels the particle away.

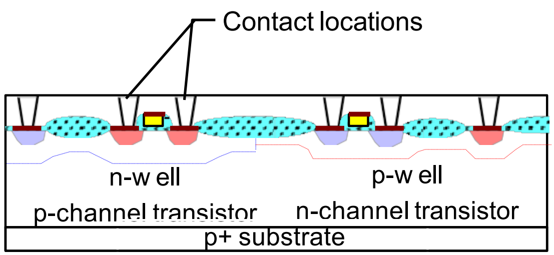
Typical Wafer Wet-Cleaning Sequence

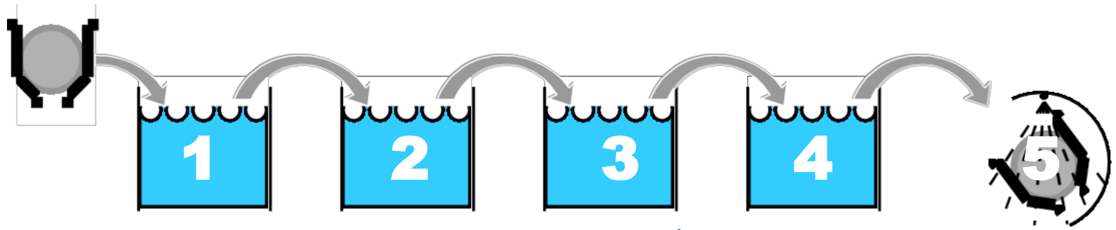
Cleaning Step	What it Cleans
H_2SO_4/H_2O_2 (piranha)	**Organics & metals**
UPW rinse (ultrapure water)	Rinse
HF/H_2O (dilute HF)	Native oxides
UPW rinse	Rinse
$NH_4OH/H_2O_2/H_2O$ (SC-1)	**Particles**
UPW rinse	Rinse
HF/H_2O	Native oxides
UPW rinse	Rinse
$HCl/H_2O_2/H_2O$ (SC-2)	**Metals**
UPW rinse	Rinse
HF/H_2O	Native oxides
UPW rinse	Rinse
Drying (SRD or IPA)	Dry

Modified steps

RCA Clean

Typical Wafer Wet-Cleaning Sequence





IC-1 IC-2

1 Organics
H_2SO_4 +
H_2O_2
H_2O Rinse

2 Oxides
HF +
H_2O
H_2O Rinse

3 Particles
NH_4OH +
$H_2O_2 + H_2O$
H_2O Rinse

4 Metals
HCl +
$H_2O_2 + H_2O$
H_2O Rinse

5 Dry
H_2O or IPA +
N_2

Process Conditions

Temperature: Piranha Strip is 130 degrees C.

RCA Clean
- **SC1 Clean ($H_2O + NH_4OH + H_2O_2$)** *
- * **SC2 Clean ($H_2O + HCl + H_2O_2$)** *

Piranha Strip
- * **$H_2SO_4 + H_2O_2$** *

Nitride Strip
- **H_3PO_4** *

Oxide Strip
- **$HF + H_2O$** *

Dry Strip
- **N_2O**
- **O_2**
- **$CF_4 + O_2$**
- **O_3**

Solvent Cleans
- **NMP**
- **Proprietary Amines (liquid)**

Dry Cleans
- **HF**
- **O_2 Plasma**
- **Alcohol + O_3**

Solvent Based Cleaning (Post-Etch and BEOL)

Before etching

Mainly used for Post-Etch Cleaning to remove phtoresist and etch residues. For BEOL cleaning in the presence of Metal layers

- Resist strippers - proprietary mixtures of organic solvents and active ingredients
  - The solvents are typically NMP (N-methyl pyrrolidone)
  - NMP is water soluble and neutral in aqueous solution
  - "Active ingredients" are typically amines
  - Attack the resist and dissolve into the solvent media.

- New strippers - "semi-aqueous", containing both organic solvents and water along with "active ingredients" and corrosion inhibitors

clean / etch → clean

Resist Strip

- Resist removed by *ashing* - a plasma process which "burns" the resist off the surface
  (Note - Resist contains measurable amounts of impurities such as sodium.)
- Ashing concentrates impurities on the surface.
  - Must be followed by a wet process to remove contaminants
- Sulfuric acid-hydrogen peroxide used before metal is present on the wafer (FEOL)
- Solvent strippers used after metal deposition (BEOL)

Post-Etch Clean

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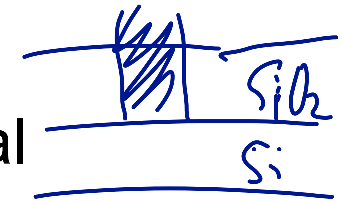
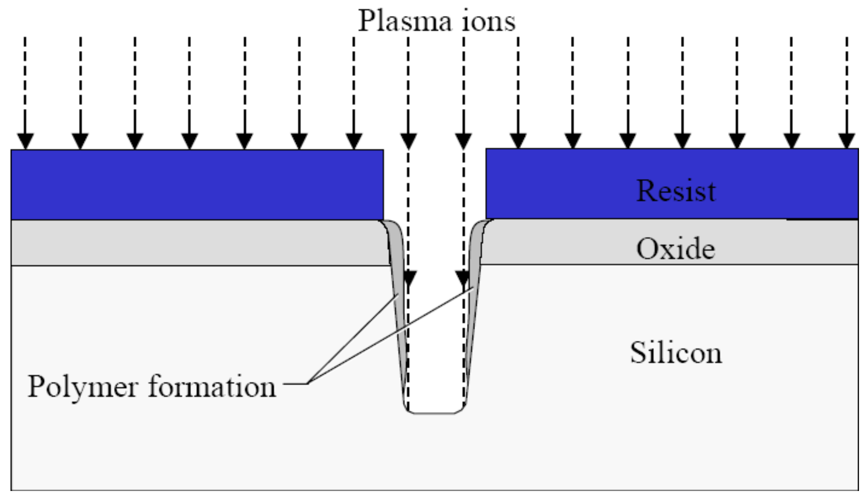


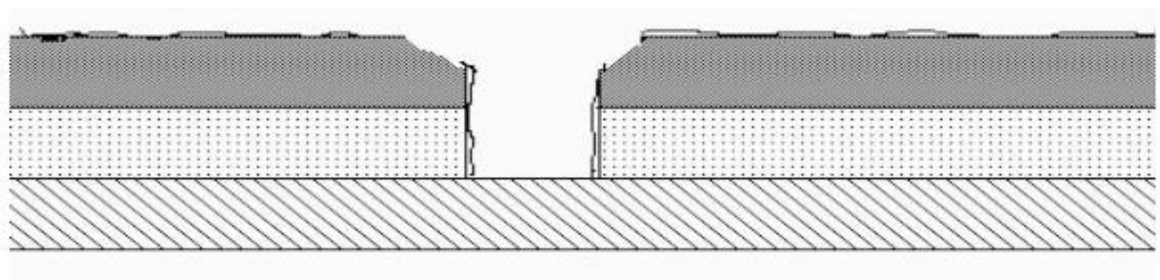
- Reactive ion etching (RIE) = a physical-chemical process which can leave residues (or polymer)
- RIE uses chemically reactive plasma to remove material deposited on wafers. The plasma is generated under low pressure (vacuum) by an electromagnetic field. High-energy ions from the plasma attack the wafer surface and react with it.
- Difficult to remove (can be fluorinated polymers) so both ash and wet clean are usually used
  - Residues are created to inhibit attack of the plasma on the sidewall of the etched film
  - Changes in the etch process or the material being etched can require changes in the clean
- Solvent based cleanings are required for different post etch cleaning process

Post-Etch Residues from RIE Processes

Polymer formation during plasma etching

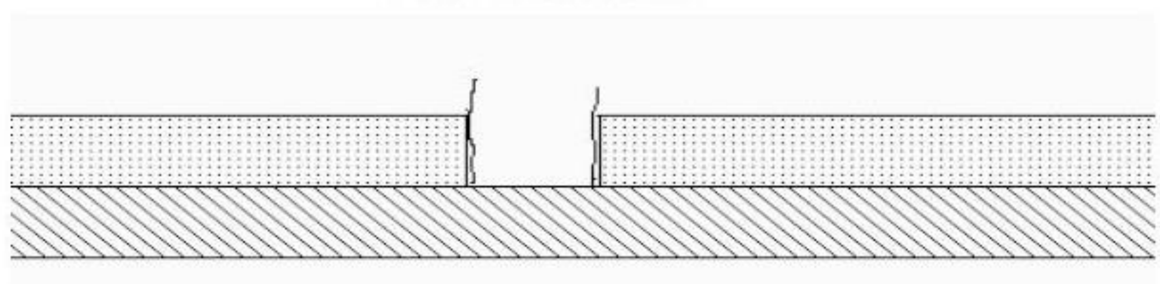


Post Etch Residue on sidewall of etch pattern



Post Etch Residue

Post Ash Residue - residue(Veils) on sidewall of pattern after plasma ashing to remove the bulk of photoresist



Post Ash Residue

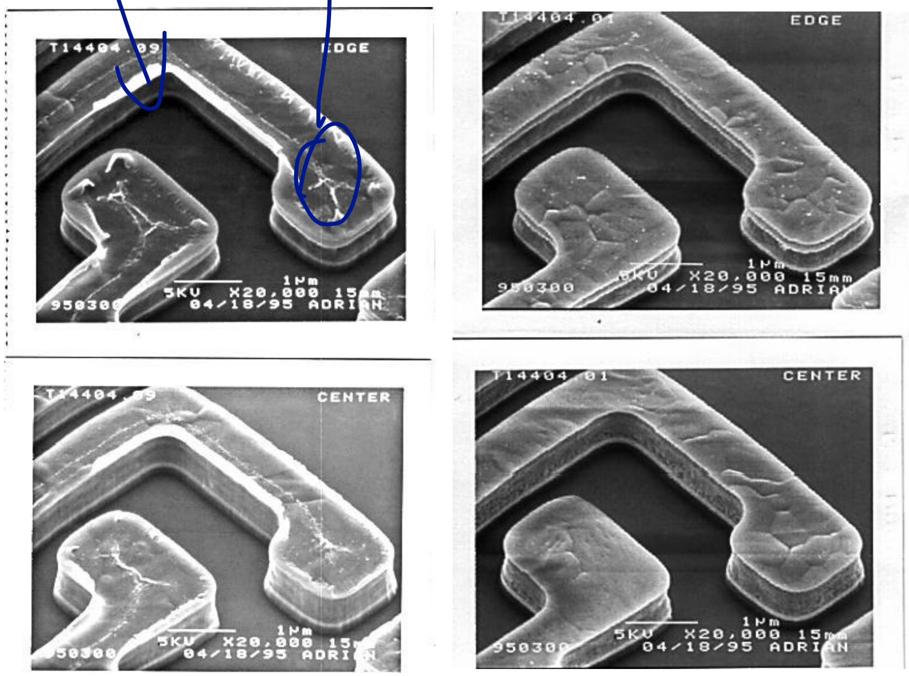
Post-Etch Residues Clean

poly layer

photo resist

Post Etch

Post Clean



Post Metal Etch Residues -- Veils

Fig. 1. Metal hardmask etch residues (65nm wafer, before chemical treatment)

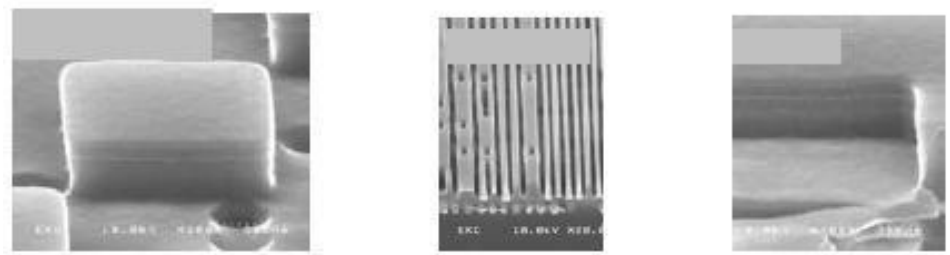
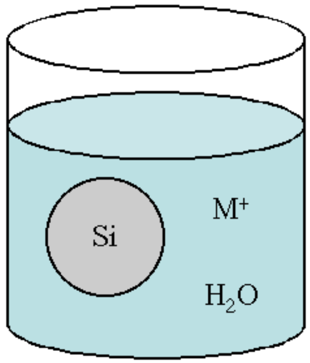


Fig. 2. Residues are removed by treatment with HCX010 (65nm wafer, 35°C, 5mins.)

Post Via Etch Residues

Principles of Metal Cleaning

If we have a water solution with a Si wafer and metal atoms and ions, two reactions take place.



$$\mathbf{Si + 2H_2O \leftrightarrow SiO_2 + 4H^+ + 4e^-} \qquad (1)$$

$$\mathbf{M \leftrightarrow M^{z+} + ze^-} \qquad (2)$$

The two reactions will proceed in opposite directions, one providing electrons, which will then be consumed by the other (forming an oxidation/reduction couple). In this couple, the stronger reaction will dominate.

Generally, (2) is driven to the left and (1) to the right so that SiO_2 is formed and M plates out on the wafer.

Good cleaning solutions drive (2) to the right since M^+ is soluble and will be desorbed from the wafer surface.

Principles of Metal Cleaning

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The strongest oxidants are at the bottom (H_2O_2 and O_3). These reactions go to the left, grabbing electrons and forcing (2) in previous slide to the right.

Fundamentally the RCA clean works by using H_2O_2 as a strong oxidant.

Oxidant/ Reductant	Standard Oxidation Potential (volts)	Oxidation-Reduction Reaction
Mn^{2+}/Mn	1.05	$Mn \leftrightarrow Mn^{2+} + 2e^-$
SiO_2/Si	0.84	$Si + 2H_2O \leftrightarrow SiO_2 + 4H^+ + 4e^-$
Cr^{3+}/Cr	0.71	$Cr \leftrightarrow Cr^{3+} + 3e^-$
Ni^{2+}/Ni	0.25	$Ni \leftrightarrow Ni^{2+} + 2e^-$
Fe^{3+}/Fe	0.17	$Fe \leftrightarrow Fe^{3+} + 3e^-$
H_2SO_4/H_2SO_3	-0.20	$H_2O + H_2SO_3 \leftrightarrow H_2SO_4 + 2H^+ + 2e^-$
Cu^{2+}/Cu	-0.34	$Cu \leftrightarrow Cu^{2+} + 2e^-$
O_2/H_2O	-1.23	$2H_2O \leftrightarrow O_2 + 4H^+ + 2e^-$
Au^{3+}/Au	-1.42	$Au \leftrightarrow Au^{3+} + 3e^-$
H_2O_2/H_2O	-1.77	$2H_2O \leftrightarrow H_2O_2 + 2H^+ + 2e^-$
O_3/O_2	-2.07	$O_2 + H_2O \leftrightarrow O_3 + 2H^+ + 2e^-$

Reaction goes to the left

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Solvent Based Cleaning Solutions

-- Post Dual Damascene Via Etch Solvent Cleaning for Cu Interconnect

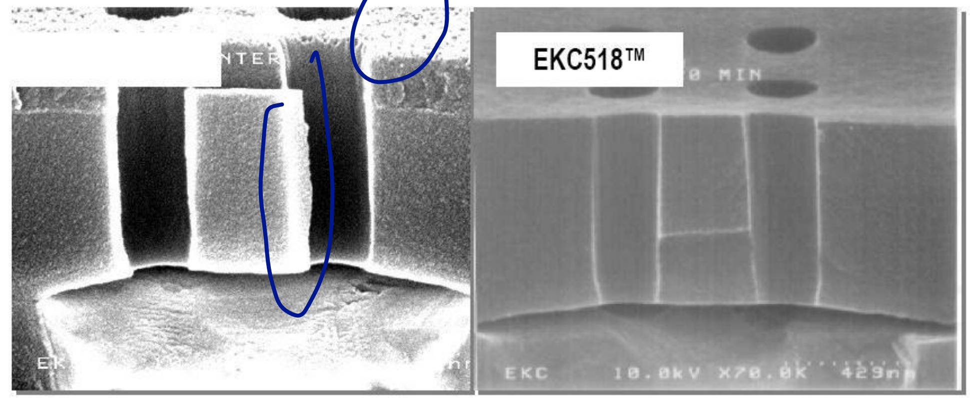
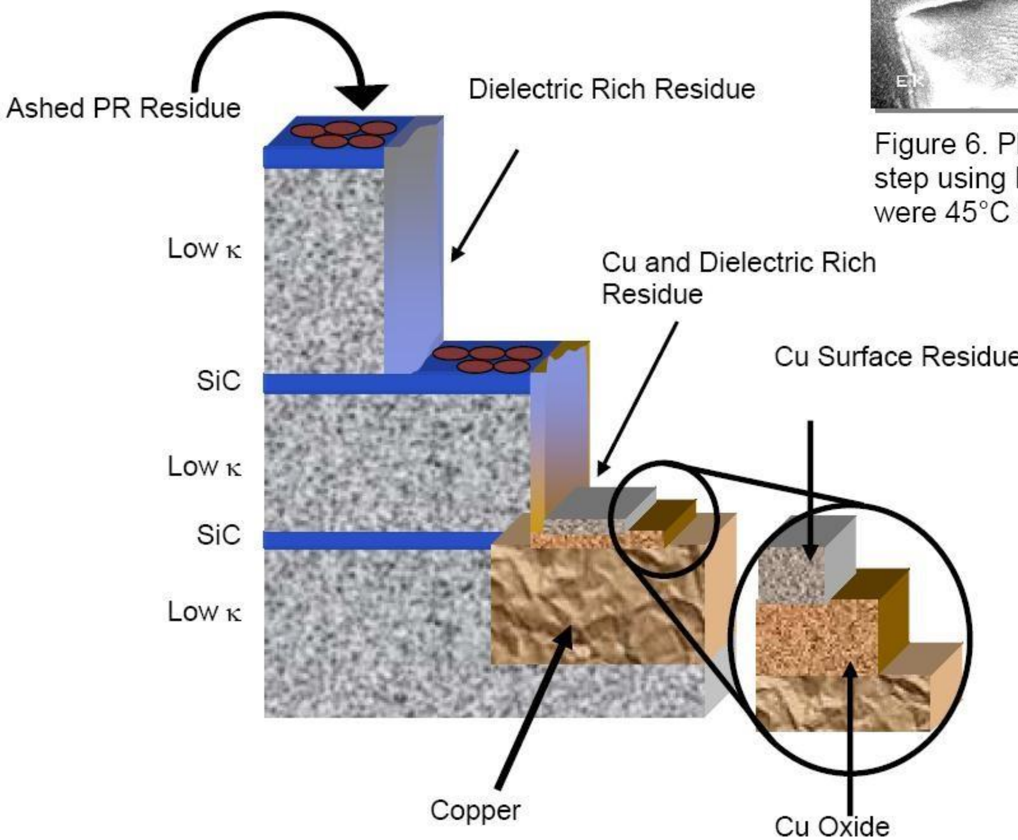
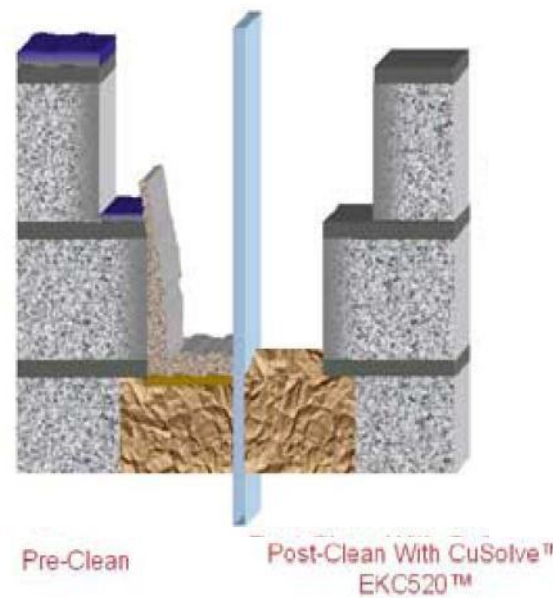


Figure 6. Photoresist and post etch residue removal in a single process step using EKC518™ on an SiOC dielectric film. Process conditions were 45°C for 20 minutes.

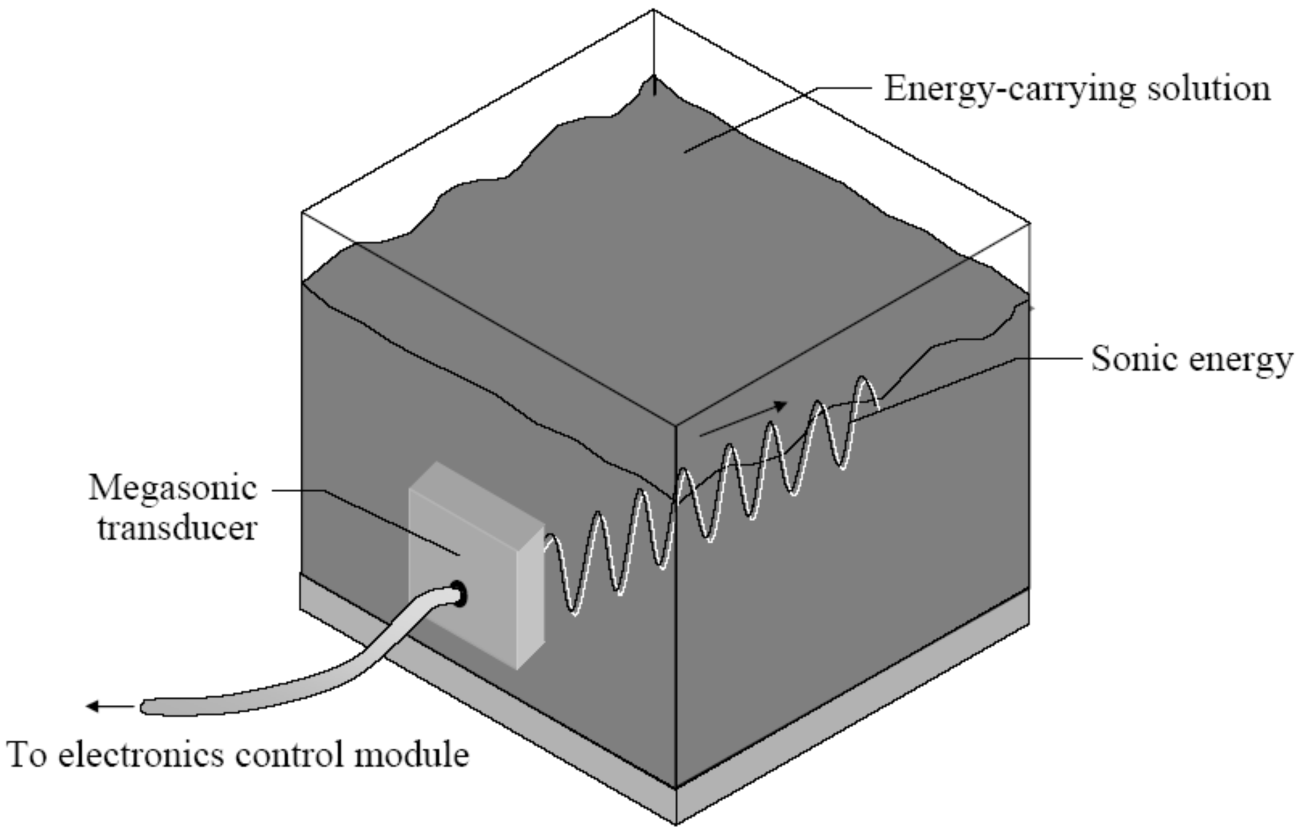




Wet-Cleaning Equipment

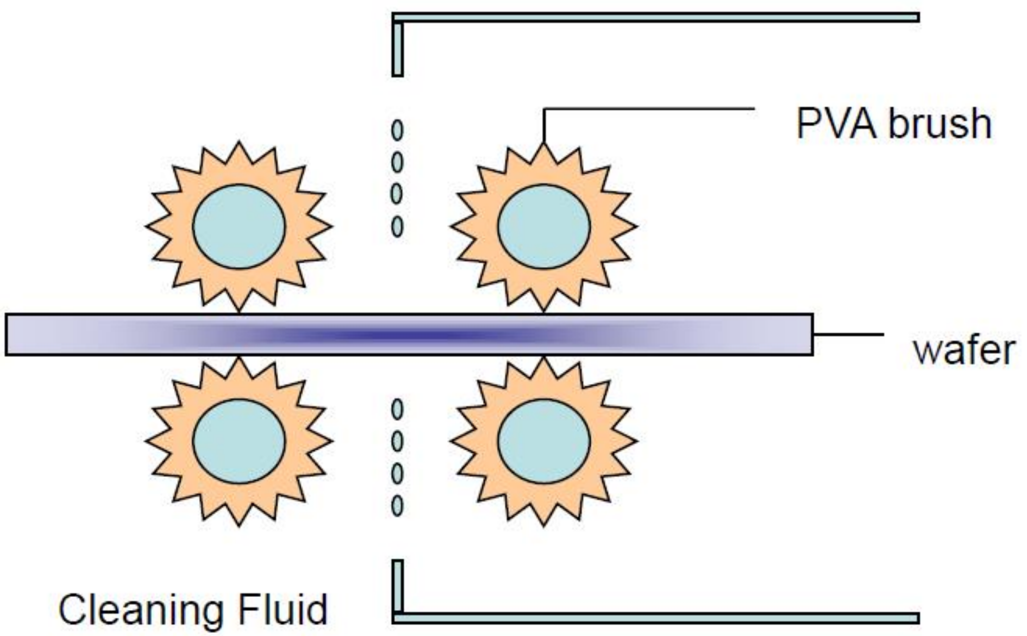
- Megasonics
- Spray Cleaning
- Scrubbers
- Wafer Rinse
  - Overflow Rinsers
  - Dump Rinse
  - Spray Rinse
  - Hot DI-Water Rinsing
- Wafer Drying
  - Spin Dryers
  - IPA Vapor Dry

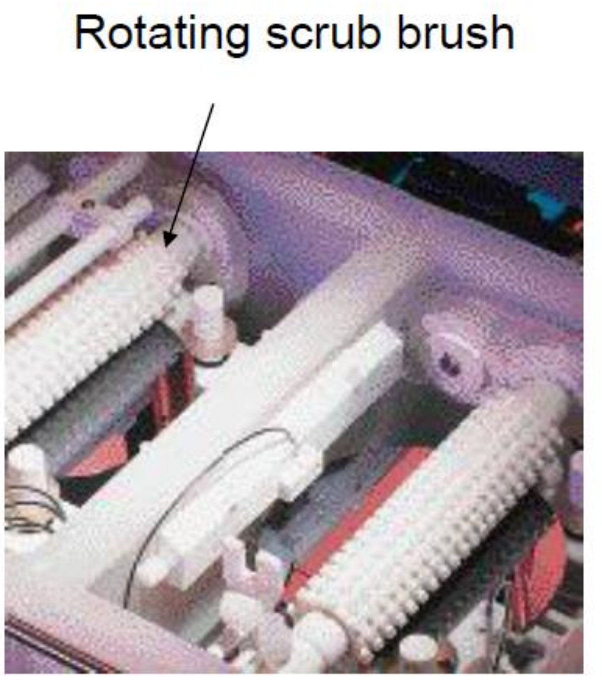
Megasonic Cleaning



Megasonic agitation is the most widely used approach to adding energy (at about 800kHz and 100,000g) to the wet cleaning process.

Post-CMP Scrubbing





Water Rinsing

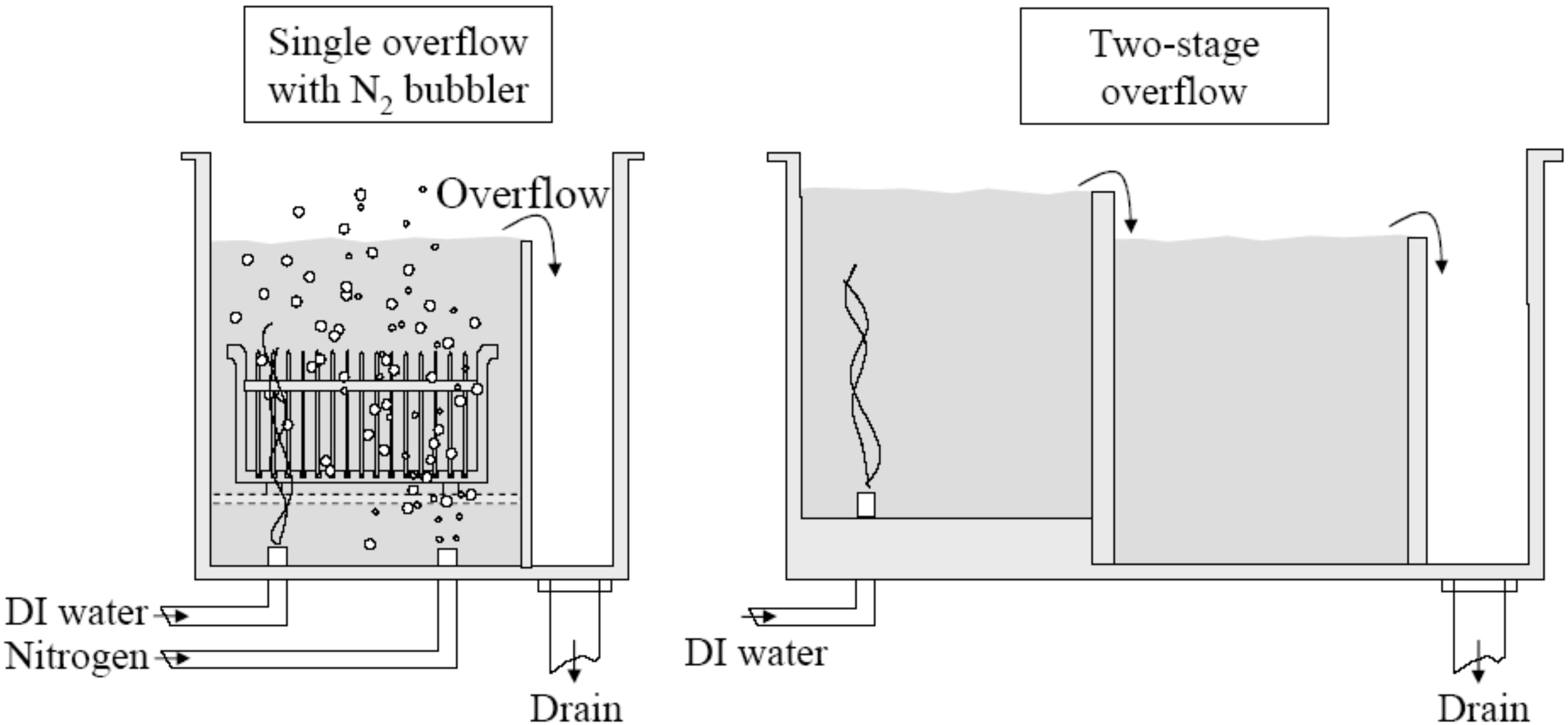
- Continuous flow of water passing through wafer surface

- Completion of rinse is determined by measuring the resistivity of the water

    (Resistivity = very sensitive method of determining the presence of ions in solution)

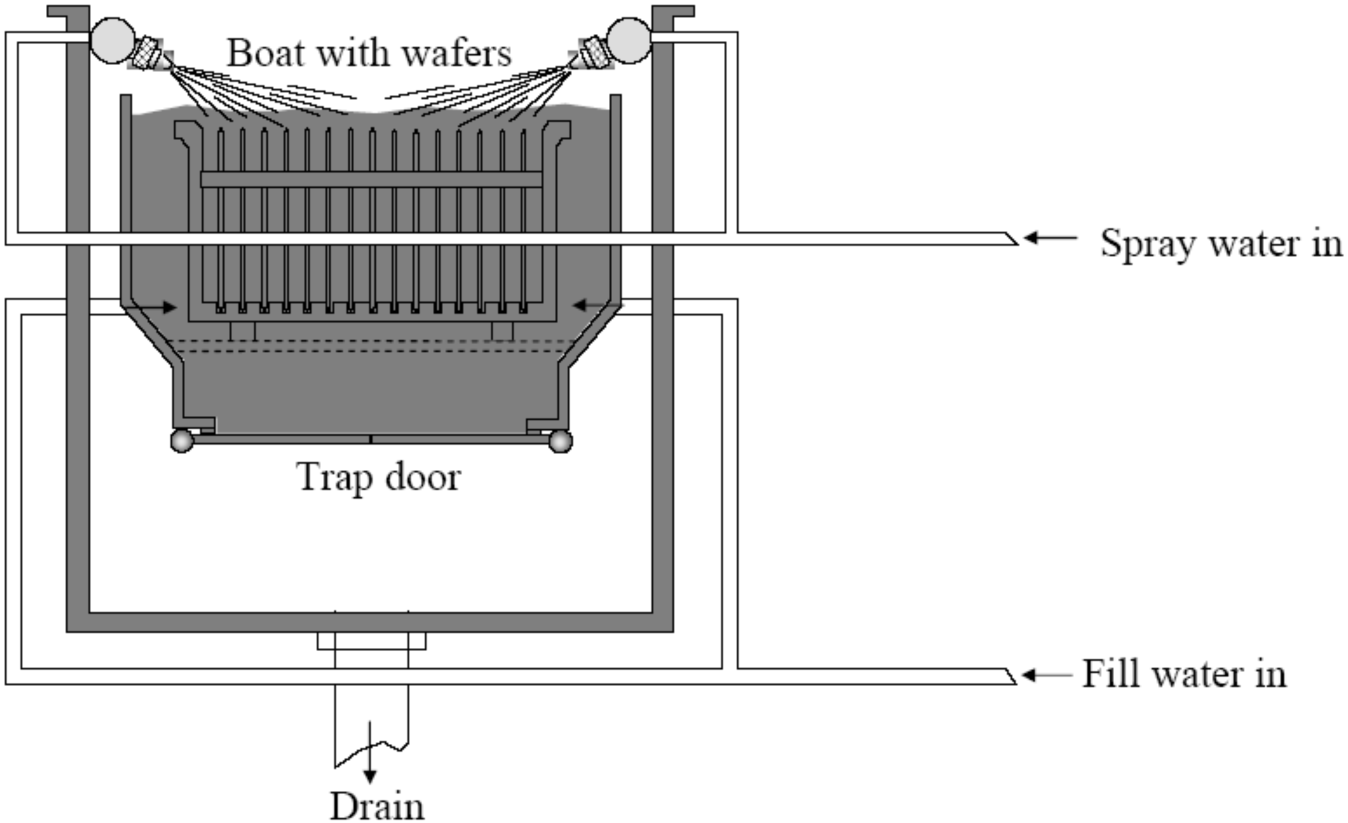
- Dump rinsing - used for wafers that are hydrophilic
- Hot water - used after some processes (but not HF treated surfaces)

Overflow Rinser



Also known as Cascade Rinsing

Dump Rinse



When overflow is complete, the bottom quick dump door opens and the rinse water drains from the tank in a matter of seconds while nozzle sprayers on the top of tank keep the product wet with fresh, clean DI water during the dumping process.

Problems with DI Water Rinsing

- All DI systems contain bacteria, which can grow and contaminate systems if nutrients are provided.

- Ozonation or hydrogen peroxide (oxidizing agent) is typically employed to keep down bacterial levels.

- Once bacterial contamination is established, it is difficult to remove since the bacteria form colonies which are difficult to completely destroy with oxidant solutions.

Drying

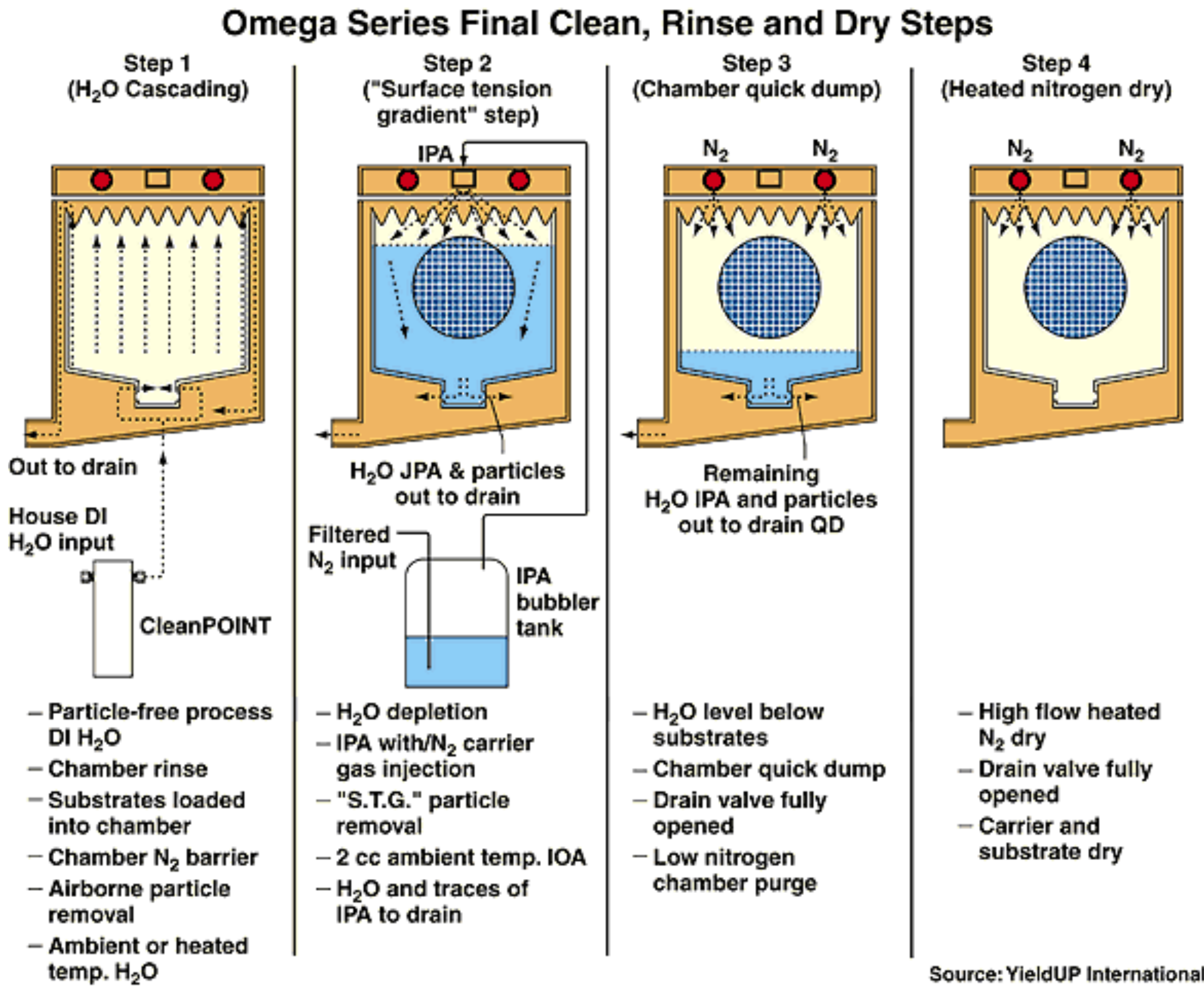
- Critical step in cleaning
- Objective - remove as much of the water as possible before it can dry on the surface and leave residues from any impurities in the water
- Two types of dryers
  - Spin rinse dryer (SRD) - throw off as much water as possible
  - IPA vapor - displace water with IPA
    - IPA vapor dryer styles
      - Tank
      - Vapor jet (VJD)
      - Marangoni-type

Spin Rinse Dryer (SRD)

- wafers put into a cassette and the cassette rotates at few thousand RPM
- throw off as much water as possible
- Hot N2 purge helps to dry wafer faster

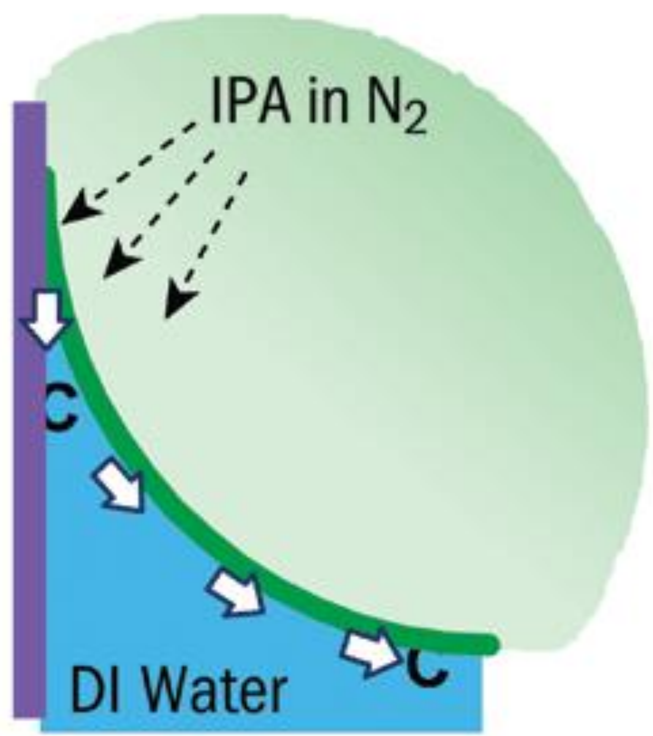
Marangoni Wafer Drying in IPA ambient after cleaning

The Marangoni principle involves the slow withdrawal of wafers from a DI water bath(or DI water level moving down the wafer surface) to an environment of isopropyl alcohol (IPA) and nitrogen such that only the portion of the surface that is at the interface of the liquid and vapor phases is "drying" at any one time.



Marangoni Wafer Drying in IPA ambient after cleaning

The Marangoni principle involves the slow withdrawal of wafers from a DI water bath to an environment of isopropyl alcohol (IPA) and nitrogen such that only the portion of the surface that is at the interface of the liquid and vapor phases is "drying" at any one time. In this way, uncontrolled evaporative drying on the wafer is prevented. IPA drying provides a great advantage in hydrophobic cleaning steps such as pre-gate, pre-silicide and pre-contact cleans.



As the wafers are withdrawn slowly from the water, the IPA layer displaces the water.
The IPA evaporates from the wafers and they are dried.

Spin Rinse Dryers (SRD)	*IPA Vapor Dryer*	*Marangoni Dryer*
Wafers in a cassette are spun at high speeds. Water is removed by centrifugal force.	A chamber with some liquid IPA is heated. Heat combined with a cooling coil causes the liquid IPA to form a cloud. Wafers exposed to this vapor cloud are dried.	Wafers submerged in water are slowly passed through a thin layer of IPA liquid. The wafers are dried by the surface tension gradient between IPA & H2O.
Benefits: • Low capital cost • No IPA consumed **Drawbacks:** • Water Marks • Vias may retain moisture (okay for low tech drying) • Rough mechanical wafer handling occasionally breaks wafers • No cassetteless option	**Benefits:** • Gentle wafer handling • Good drying results • Dries wafer carriers well • Integrates nicely with bench **Drawbacks:** • More expensive than spin drying • Process time is longer than Marangoni • Consumes more IPA than Marangoni • Limited availability	**Benefits:** • Gentle wafer handling • Accepted as the industry's best drying method. No watermarks. • No exposure to air during dry • Insitu -HF last is possible • Integrates nicely to a wet bench • Best cassetteless **Drawbacks:** • Most expensive • Consumes IPA, but very little

PYP 2017-2018 Semester 2

PYP 2017-2018 Semester 2

(c) Answer the following questions about cleaning, polishing and characterization.

(i) Explain the particle removal mechanism in the wafer cleaning processes.

(ii) Explain the role of slurry in the chemical mechanical polishing (CMP) process. What are the requirements in the selection of chemicals in the slurry to polish oxide films and metal films separately?

(iii) Briefly describe the effects on the wafer if the following CMP process variables are increased.

Variable	**Effect on Removal Rate and Planarity**
Downforce is increased	
Platen speed is increased	

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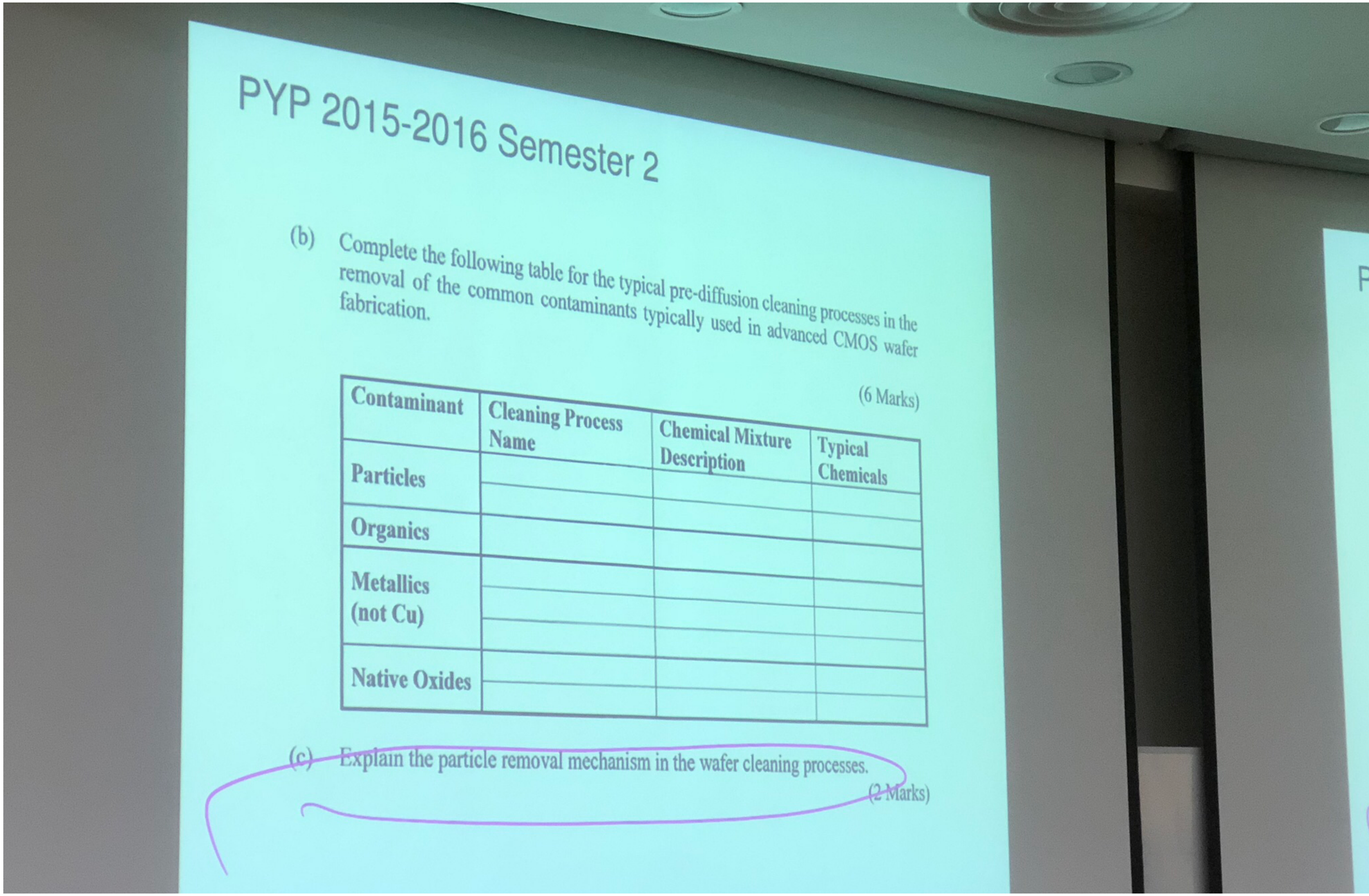

PYP 2015-2016 Semester 2

(b) Complete the following table for the typical pre-diffusion cleaning processes in the removal of the common contaminants typically used in advanced CMOS wafer fabrication.

(6 Marks)

Contaminant	Cleaning Process Name	Chemical Mixture Description	Typical Chemicals
Particles			
Organics			
Metallics (not Cu)			
Native Oxides			

(c) Explain the particle removal mechanism in the wafer cleaning processes.

(2 Marks)

PYP 2013-2014 Semester 2