EE-527: MicroFabrication

De-Ionized Water

Clean Water as a Processing Chemical

- Water (H_2O) is the most prevalently used material in microfabrication processes, and is used mainly for rinsing and cleaning of wafers.
- Approximately 6000 gallons of de-ionized (DI) water are required for <u>each</u> 6” CMOS wafer.
- 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.

Size Ranges of Suspended Particles

- Macro Particle Range
  - > 25 μm, visible to the naked eye
- Micro Particle Range
  - 1 - 15 μm, visible with an optical microscope
- Macro Molecular Range
  - 0.1 - 1 μm, visible with a high power optical microscope
- Molecular Range
  - 1 - 100 nm, visible with a scanning electron microscope
- Ionic Range
  - 0.1 - 1 nm, not visible with current technology

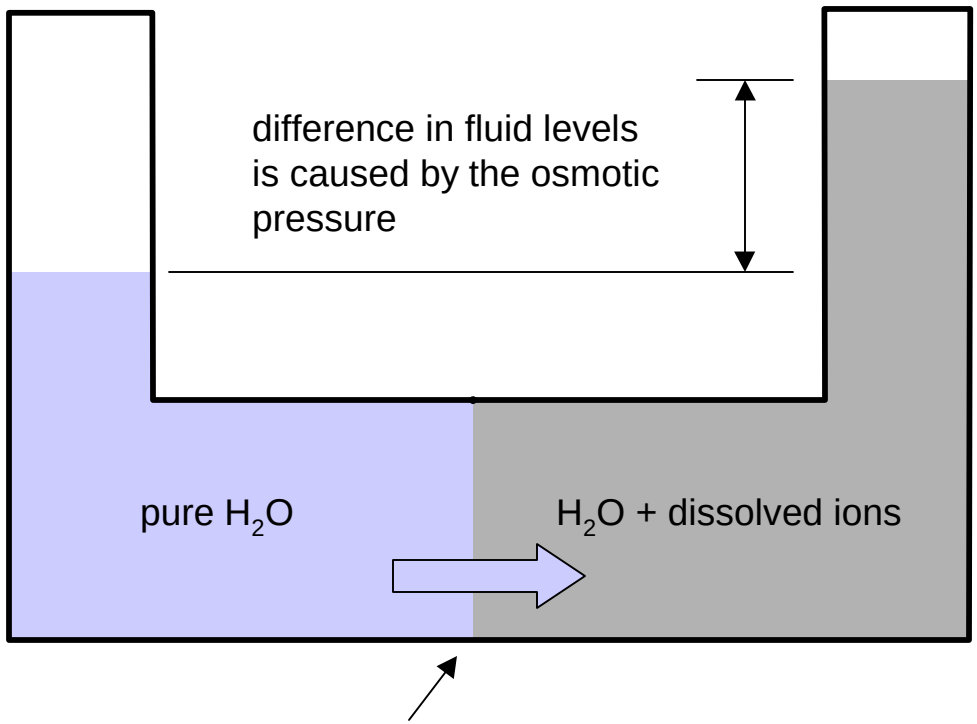
Size Range of Common Particles

Atomic Radii	1-6 Angstroms
Metal Ions	2-7 Angstroms
Aqueous Salts	2-20 Angstroms
Sugars	7-25 Angstroms
Pyrogens	20-250 Angstroms
Collodial Silica	6-250 nm
Albumin Protein	8-100 nm
Viruses	9-100 nm
Carbon Black	12-100 nm
Tobacco Smoke	20-1000 nm
Paint Pigment	0.1-5 μm
Bacteria	0.25-30 μm
Lung Damaging Dust	0.5-35 μm
Coal Dust	1.0-100 μm
Milled Flour	1.0-100 μm
Yeast Cells	2.0-50 μm
Red Blood Cells	5.0-9.0 μm
Pollens	10-100 μm
Human Hair (Diameter)	25-200 μm
Mist	70-200 μm
Beach Sand	100-10,000 μm

Types of Water Filtration

- Particle Filtration
  - 1-75 μm cartridge filters: cellulose, fiberglass, or polypropylene fibers
- Microfiltration
  - 0.1-1.0 μm cartridge filters: ceramic or polymer membranes
- Ultrafiltration
  - 20-2000 Angstroms: chemically based
- Reverse Osmosis (Hyperfiltration)
  - 1-200 Angstroms: uses special membrane and high pressure to overcome osmotic pressure

Osmotic Pressure



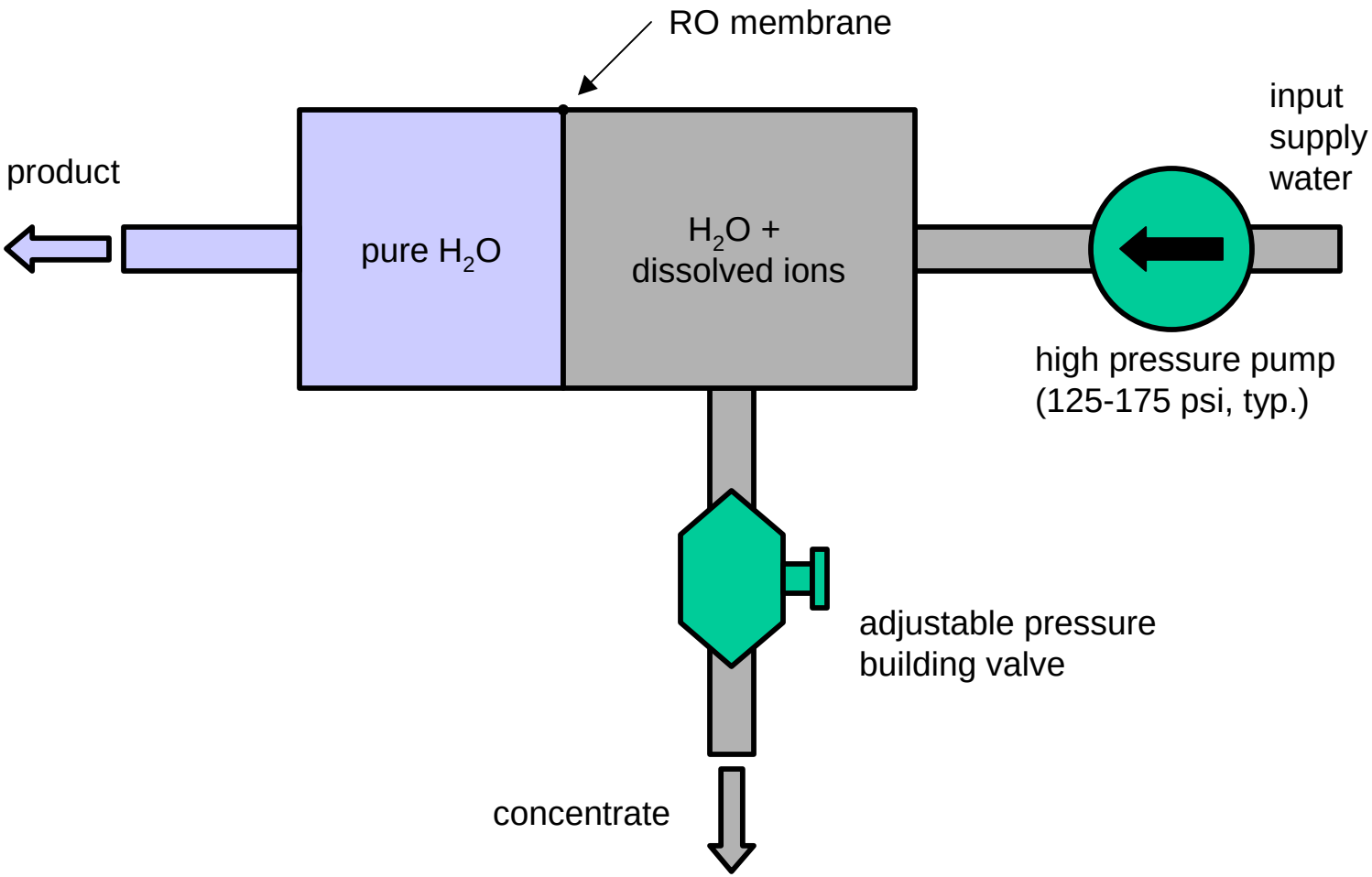
Semipermeable membrane allows water to pass, but not dissolved ions.

Water flows in a direction so as to aid diffusion and dilute itself as much as possible.
This produces the osmotic pressure.

Reverse Osmosis (RO)

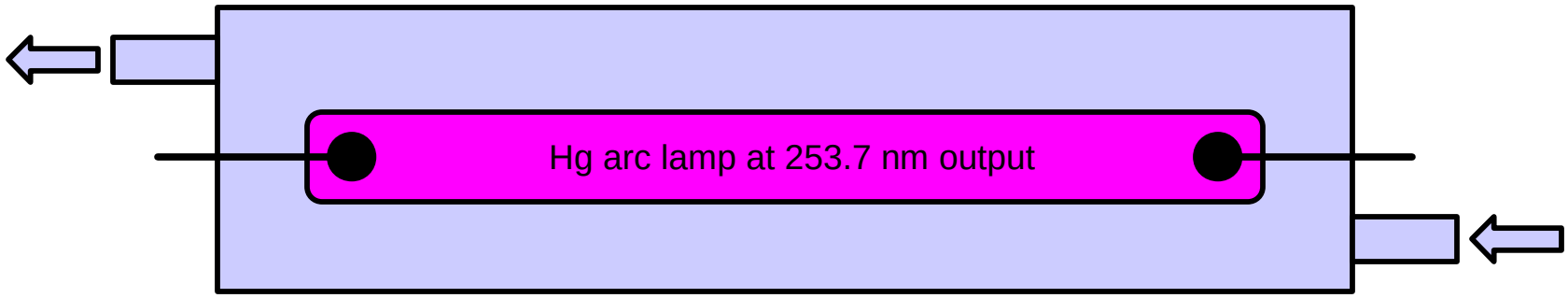
- By applying a pressure greater than the osmotic pressure, water can be driven backwards through the membrane for purification (reverse osmosis process).
- Terminology:
  - TDS = total dissolved solids
  - “product” = pure water produced by RO
  - “concentrate” = rejected water which contains concentrated dissolved material
  - “recovery” = ratio of product to input water, typically about 75 %
  - “rejection” = fraction of TDS that is retained by the RO filter membrane, typically about 90-95 %
- Rejection and recovery are optimized by RO operating pressure and the type of RO membrane.
  - Higher pressures increase recovery, but decrease rejection.

Reverse Osmosis (RO) System



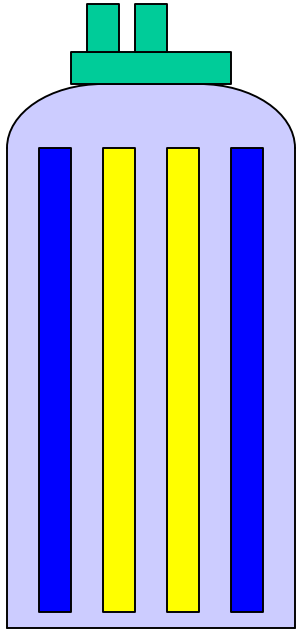
Ultraviolet Sterilizers

- Standard is 25 mW-sec @ 253.7 nm; strongest Hg arc line.
- This bursts the cell membranes of bacteria and renders their DNA incapable of reproduction.
- Exploded remains of bacteria are called “pyrogens” and must be collected by a 0.2 μm filter downstream from the sterilizer.



Ion Exchange Columns

- Based upon ion exchange resins:
  - Cation exchangers: $H^+ \leftrightarrow Na^+, K^+, Ca^{++}$, etc.
  - Anion exchangers: $OH^- \leftrightarrow Cl^-, Br^-, F^-$, etc.
  - Both cation and anion exchange resins are built into a coaxial cartridge assembly. Exchanged H^+ and OH^- ions combine to form H_2O.



Features of DI water systems - 1

- Water must flow continuously through recirculation loops at approximately 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.
- Let DI faucets run until resistivity monitor reads > 18 MΩ-cm.
- High usage during day may require make-up system to run overnight to replenish supply in recirculation tank.
- If system “goes green” it must be sterilized with H_2O_2 and then restarted. H_2O_2 is reduced to H_2O and O_2 upon passing through UV sterilizer. (Turn the UV unit off for system sterilization.)

Features of DI water systems - 2

- Because of its zero ion and mineral content, DI water is a powerful leaching agent for metals. Metals in contact with DI water are often eroded in very short periods of time. Metal pump impellers last only a few months if they are not teflon coated.
- Molecular chlorine (Cl_2) and chloride ion (Cl^-) are removed differently from incoming water.
  - Cl^- is removed via the ion exchange columns
  - Cl_2 is removed via an activated carbon filter
  - Cl_2 must be removed prior to the RO, or it will destroy the membrane
- Final polishing is performed with 0.2 μm filters.
- Breach of an upstream filter often sends particles and debris down stream in sufficient quantity to damage subsequent filters.
- Change cartridge filters when the pressure difference across them exceeds more than about 10 psi.

Integrated Circuit Processing Requirements

Mass Production Started	1980	1984	1987	1990	1993	1996	1999	2004
Wafer Size (mm)	75	100	125	150	200	200	200	300
DRAM Technology	64K	256K	1M	4M	16M	64M	256M	1G
Chip Size (cm^2)	0.3	0.4	0.5	0.9	1.4	2.0	3.0	4.5
Feature Size (μm)	2.0	1.5	1.0	0.8	0.5	0.35	0.25	0.2-0.1
Process Steps	100	150	200	300	400	500	600	700-800
Cleanroom Class	1,000-100	100	10	1	0.1	0.1	0.1 mini environment	0.1 mini environment
Utility Purity (ppb)	1,000	500	100	50	5	1	0.1	0.01

Data from Chang and Sze, *ULSI Technology*.

Water Purity Measures

- Resistivity (ρ), measured in MΩ-cm
  - Perfectly pure water at 20ºC has ρ = 18.2 MΩ-cm
  - Perfectly pure water at 20ºC has pH = 7.00
- Total Organic Carbon (TOC), measured in ppm
- Total Dissolved Oxygen (TDO), measured in ppm
  - Pure water in equilibrium with air has TDO of around 20 ppm, depending upon agitation conditions
- Total Heavy Metals (THM), measured in ppm
- Bacteria, measured in colony forming units (CFU) per liter per day

ASTM D-1193-91 Type 1 Reagent Water

- Specifications:
  - $\rho > 18$ MΩ-cm
  - TOC < 100 ppb
  - $Na^+ < 1$ ppb
  - $Cl^- < 1$ ppb
  - Silica < 3 ppb
- Basic de-ionized water available at taps in EE MicroFab Lab.
- De-ionization is different from distillation!!
  - De-ionization removes charged ionic species, not neutral molecules.
  - Distillation removes molecules of differing vapor pressure, such as alcohols and other solvents, but does not de-ionize.
  - Distillation is more commonly used in biological applications.

SEMI recommended DRAM1 pure water guidelines

- $\rho > 18.2\ M\Omega$-cm
- TOC < 5 ppb
- THM < 1 ppb
- TDO < 20 ppm
- < 200 particles 0.3-0.5 μm/L
- < 1 particle > 0.5 μm/L

Semiconductor Equipment and Materials International (SEMI) is a standards organization for the microelectronics industry

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