EE 527 MICROFABRICATION

Lecture 26

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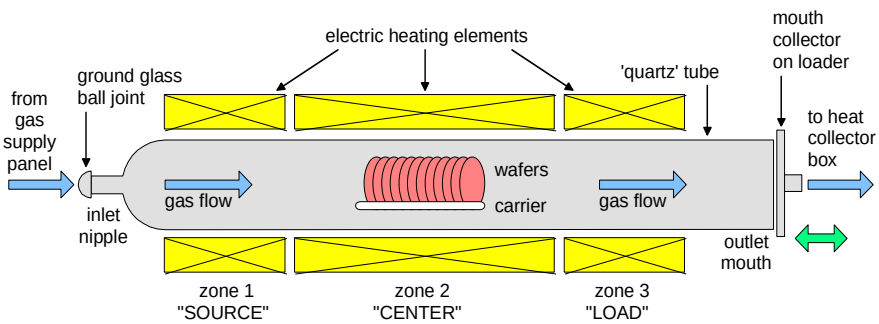
3-ZONE HORIZONTAL FURNACE TUBE - ATMOSPHERIC

Atmospheric pressure system:



3-zone tube furnaces are most common, but 5-zone tube furnaces also exist.

4-TUBE SEMI-PRODUCTION FURNACE STACK

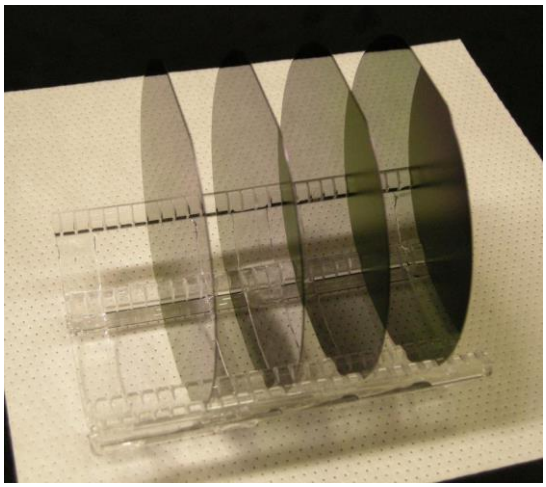
- Laminar bench loading area with automatic boat loaders:

TUBE FURNACE QUARTZWARE

- "Quartzware" is actually fused silica (SiO_2), a glass, not a crystal.
- Fused silica can normally withstand temperatures up to ~1800°C.
- The high purity of the silica allows it to introduce minimal contamination to wafers being processed in the furnace.
- However, at the high temperatures of a furnace, alkali cations can very rapidly diffuse through fused silica.
  - A single fingerprint on the outside of a fused silica tube can contribute enough Na^+ ion to completely contaminate a furnace tube.
  - A tube that has been contaminated in this way has to be discarded! ($$$)
  - The diffusion coefficient for Na^+, K^+, and Li^+ through SiO_2 at ~1000°C is high enough that it only takes ~30-60 seconds for these ions to diffuse through a 3 mm thick tube wall.
- All furnace quartzware MUST be handled ONLY with clean gloves.
- Small accessories are also often fragile and brittle, like any glass.

QUARTZWARE WAFER BOATS

- Boats usually hold up to one cassette of 25 wafers.
- Boats must be matched to the wafer size: 3, 4, or 6-inch.
- Boats are hand loaded, so care must be taken to insure each wafer is properly slotted.



HEATING MANTLES

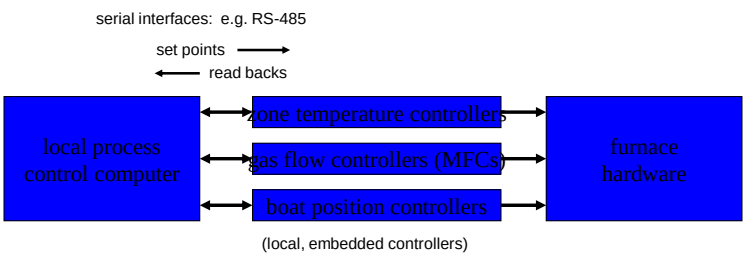
- Used for heating laboratory glassware, most commonly closed-top vessels with standard taper (ST) ground glass fittings.
- Commonly used in distillation apparatus and steam boilers.
- Must be sized to the flask being used.
- Must be used with a power controller or variac.
  - Never directly connect to 120VAC line power!

HEATING MANTLE STEAM BUBBLER FOR OXIDATION FURNACE

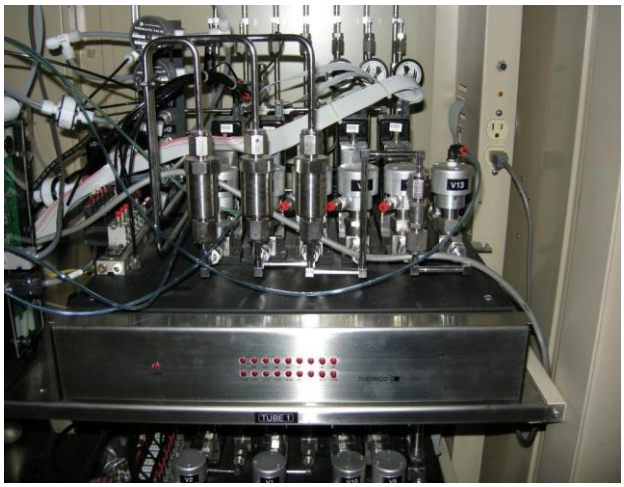
- This system uses standard taper glassware with teflon valves and tubing connections.
- Note temperature sensor in the thermometer well for closed-loop control of water temperature.
- The bypass line around the bubbler allows both wet and dry oxidation to be performed using the same furnace tube system.

FURNACE CONTROL SYSTEM

- Typical of most fabrication process control systems:



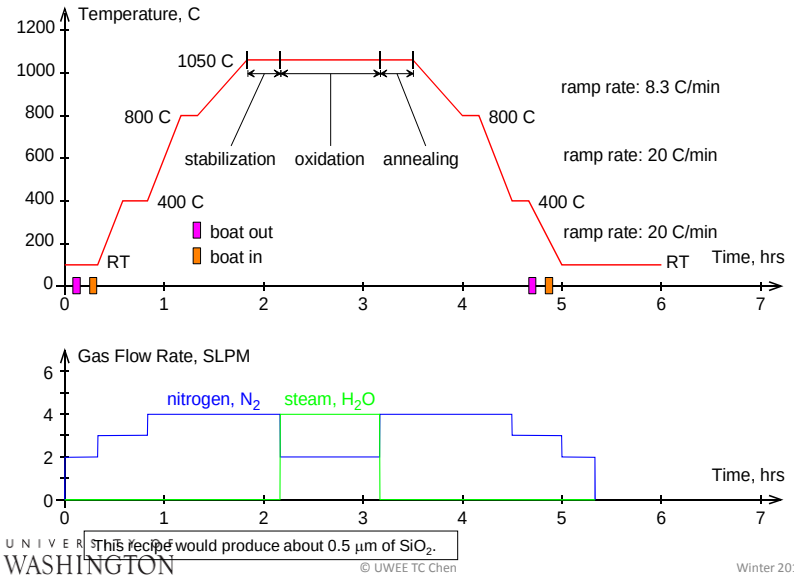
AUTOMATIC TUBE FURNACE GAS PANEL



TIME – TEMPERATURE PROFILES

- All thermal processing steps need to be engineered around a time – temperature schedule which forms the core recipe.
- Elements of a time – temperature schedule:
  - Ramps – periods of controlled heater power increase or decrease to move the temperature up or down at a prescribed rate
  - Stabilization periods to allow equilibration of temperatures and thermally induced stresses; maximum rates are needed to avoid thermal shock
  - Processing periods, e.g. oxidation, nitridation, reducing; often switched on and off by gas flow changes
  - Ramps (down)– periods of controlled heater power increase or decrease to move the temperature up or down at a prescribed rate.
  - Load / unload periods and timing within the schedule

TYPICAL TUBE FURNACE WET OXIDATION RECIPE

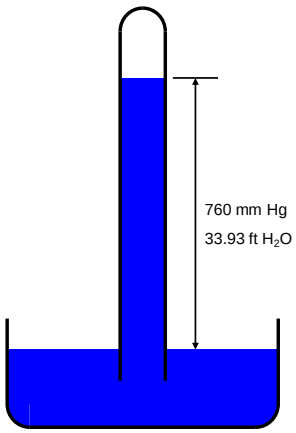


USES OF VACUUM IN MICROFABRICATION

Rough Vacuum	High Vacuum	Ultra-High Vacuum
wafer chucks	evaporation	surface analysis
load locks	ion implantation	molecular beam epitaxy (MBE)
sputtering		
reactive ion etching (RIE)		
low pressure chemical vapor deposition (LPCVD)		

UNITS OF PRESSURE MEASUREMENT

- 1 atmosphere =
  - 760 mm Hg = 760 torr
  - 760,000 millitorr or microns
  - 29.9213 in. Hg
  - 14.6959 psi
  - 1.01325 bar
  - 1013.25 millibar
  - 101,325 pascals (Pa)
  - 407.189 in. H_2O
  - 33.9324 ft. H_2O



1 Pascal = 1 N/m^2
1 torr = 1 mm Hg
1 micron = 1 μm Hg

VACUUM RANGES

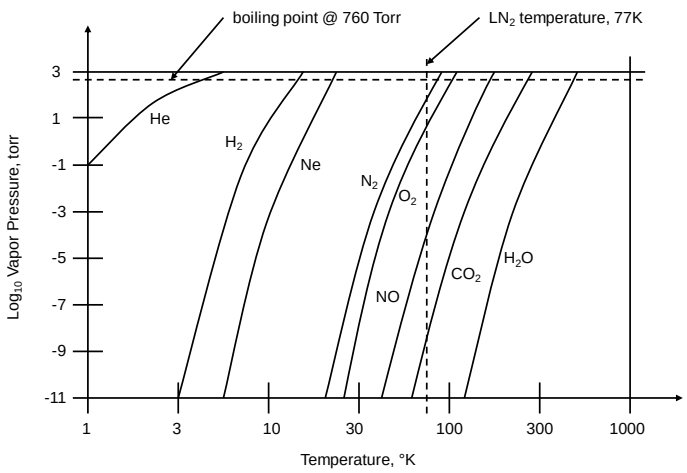
- Low or Rough Vacuum (LV)
  - 760 to 1 torr
- Medium Vacuum (MV)
  - 1 to 10^{-3} torr
- High Vacuum (HV)
  - 10^{-3} to 10^{-7} torr
- Ultra-High Vacuum (UHV)
  - 10^{-7} to 10^{-12} torr

PARTIAL PRESSURES OF GASES IN AIR AT STP

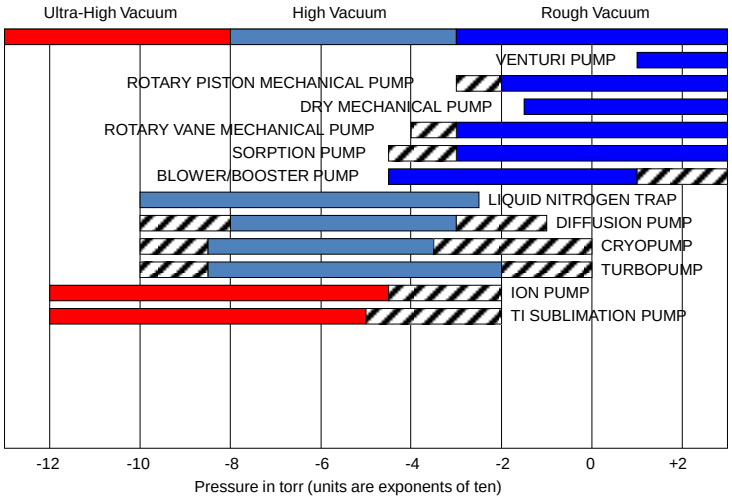
Gas	Symbol	Volume Percent	Partial Pressure, Torr
Nitrogen	N_2	78	593
Oxygen	O_2	21	159
Argon	Ar	0.93	7.1
Carbon Dioxide	CO_2	0.03	0.25
Neon	Ne	0.0018	1.4×10^{-2}
Helium	He	0.0005	4.0×10^{-3}
Krypton	Kr	0.0001	8.7×10^{-4}
Hydrogen	H_2	0.00005	4.0×10^{-4}
Xenon	Xe	0.0000087	6.6×10^{-5}
Water	H_2O	Variable	5 to 50, typ.

Standard Temperature and Pressure (STP): 0°C and 1 atm.

VAPOR PRESSURES OF GASES



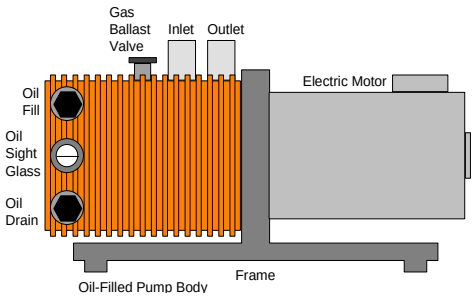
VACUUM PUMP PRESSURE RANGES

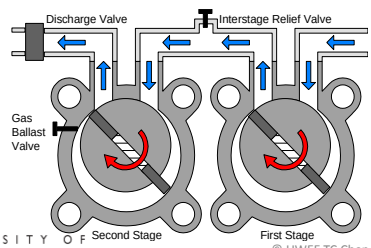


VACUUM PUMPS

- Two fundamental types:
  - Concentration pumps
    - Gas entering the inlet is compressed and expelled out an outlet
    - Can run continuously
  - Entrainment pumps
    - Gas entering the inlet is trapped inside (no outlet!)
    - Must be regenerated to empty the trapped gas

ROTARY VANE MECHANICAL PUMPS - 1





ROTARY VANE MECHANICAL PUMPS - 2

- Gases are removed by compressing them slightly above atmospheric pressure and then forcing them through a check valve.
- The rotary vane modules are immersed in an oil bath.
- The purpose of the oil is to:
  - cool the pump
  - lubricate the rotary vanes
  - provide a lip seal for the vanes
  - open the second stage exhaust valve at low inlet pressures
- They are powered by an electric motor:
  - Belt drive: 250 to 400 rpm
  - Direct drive: 1725 rpm (most common type)