Thin Films Lecture 2

Vacuum Technology

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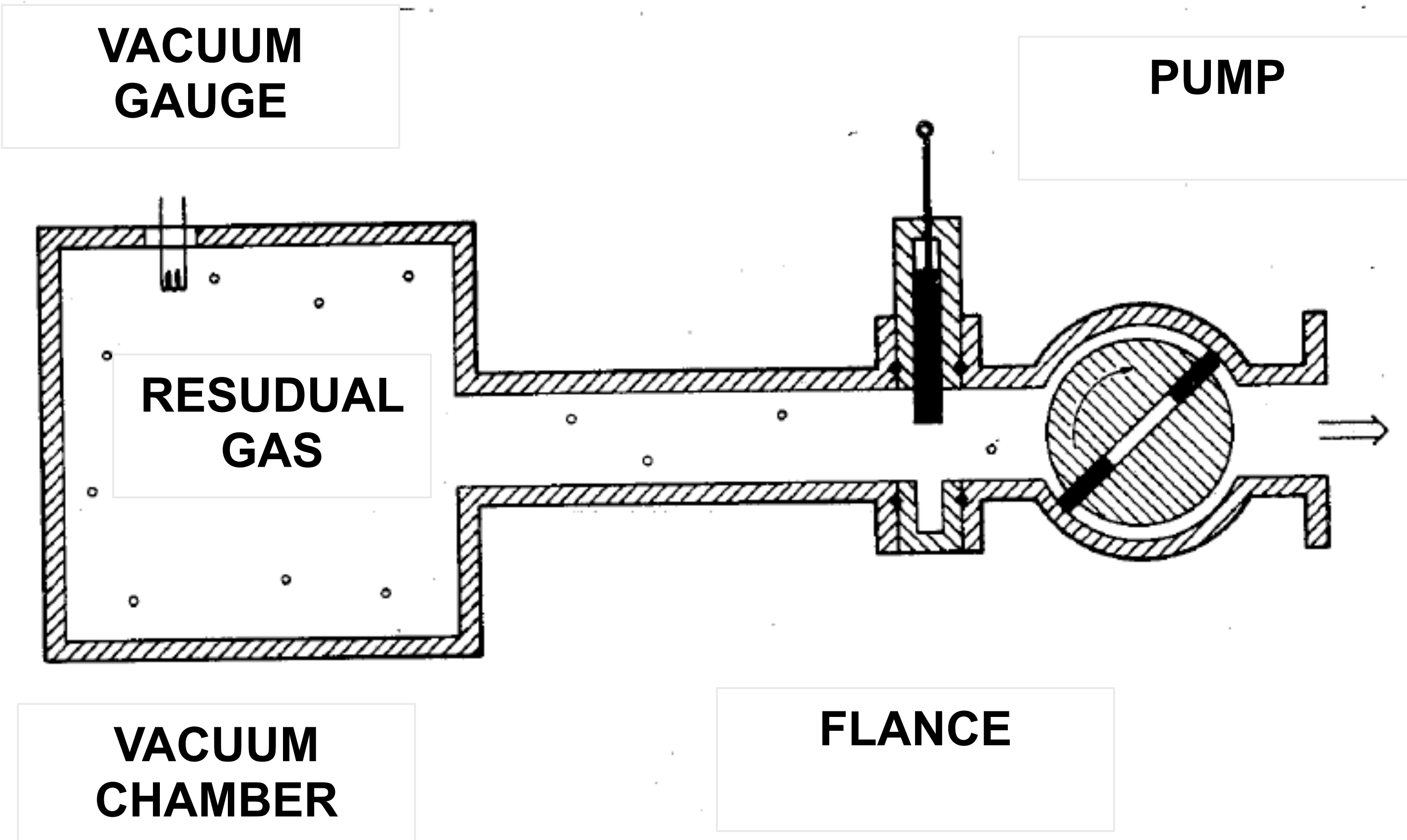
Aalto University
School of Chemical Technology

Vacuum system



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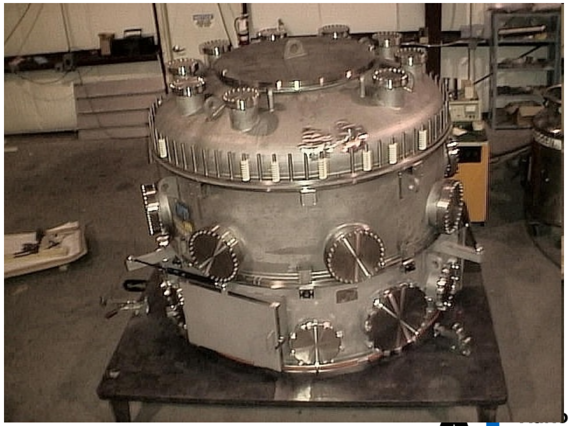
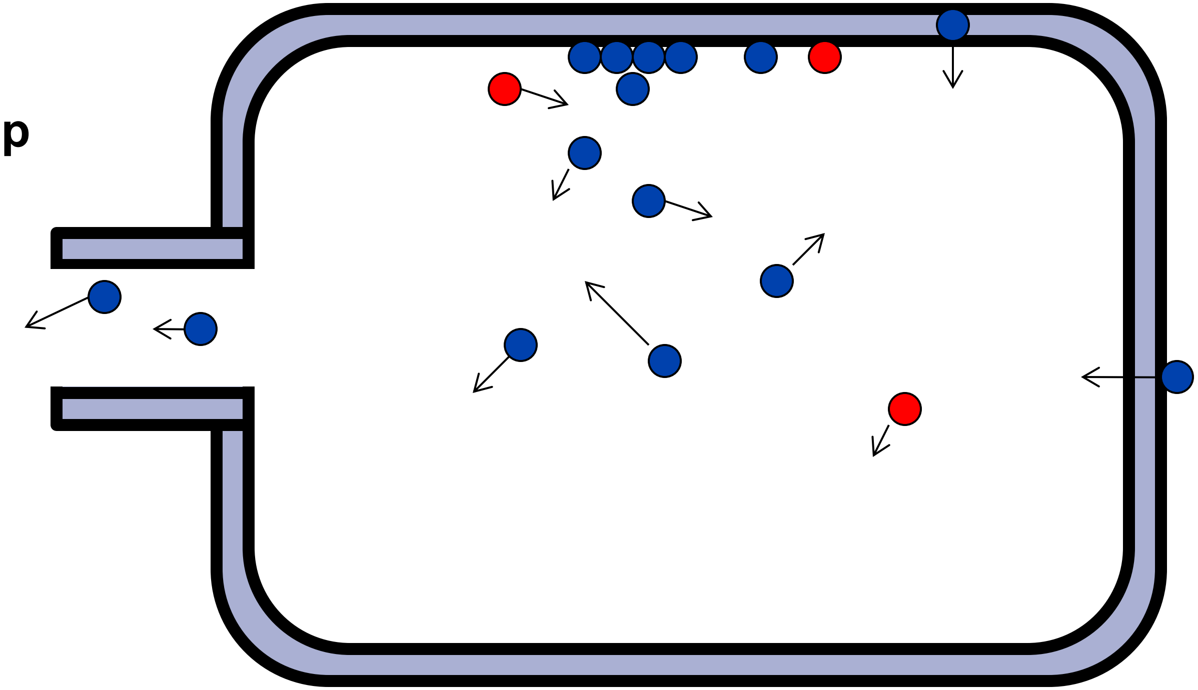


Large surfaces, upscaling

www.scheuten.com

Residual gas

Pumping of:
Residual gas:
- **Adsorption – Desorption**
- **Diffusion of dissolver or trapped gas**
- **Permeation trough materials**
- **Leaks**



Composition of atmospheric air

	% by weight	% by volume	Partial pressure mbar
N_2	75.51	78.1	792
O_2	23.01	20.93	212
Ar	1.29	0.93	9.47
CO_2	0.04	0.03	0.31
Ne	$1.2 \cdot 10^{-3}$	$1.8 \cdot 10^{-3}$	$1.9 \cdot 10^{-2}$
He	$7 \cdot 10^{-5}$	$7 \cdot 10^{-5}$	$5.3 \cdot 10^{-3}$
CH_4	$2 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	$2 \cdot 10^{-3}$
Kr	$3 \cdot 10^{-4}$	$1.1 \cdot 10^{-4}$	$1.1 \cdot 10^{-3}$
N_2O	$6 \cdot 10^{-5}$	$5 \cdot 10^{-5}$	$5 \cdot 10^{-4}$
H_2	$5 \cdot 10^{-6}$	$5 \cdot 10^{-5}$	$5 \cdot 10^{-4}$
Xe	$4 \cdot 10^{-5}$	$8.7 \cdot 10^{-6}$	$9 \cdot 10^{-5}$
O_3	$9 \cdot 10^{-6}$	$7 \cdot 10^{-6}$	$7 \cdot 10^{-5}$
	Σ 100 %	Σ 100 %	Σ 1013
50 % RH at 20 °C	1.6	1.15	11.7

Note: In the composition of atmospheric air the relative humidity (RH) is indicated separately along with the temperature. At the given relative humidity, therefore, the air pressure read on the barometer is 1024 mbar.

Units of pressure

	Pa (N m^{-2})	mbar	Torr (mm Hg at 0 °C)	Technical Atmospheres (at)	Physical Atmospheres (atm)
Pa (N m^{-2})	1	1.0×10^{-2}	7.5×10^{-3}	1.02×10^{-5}	9.87×10^{-6}
mbar	1.0×10^{2}	1	7.5×10^{-1}	1.02×10^{-3}	9.87×10^{-4}
Torr (mm Hg at 0 °C)	1.33×10^{2}	1.33	1	1.36×10^{-3}	1.32×10^{-3}
Technical Atmospheres (at)	9.80×10^{4}	9.80×10^{2}	7.36×10^{2}	1	9.68×10^{-1}
Physical Atmospheres (atm)	1.01×10^{5}	1.01×10^{2}	7.60×10^{2}	1.03	1

http://vacuumtech.blogspot.com/2009/06/in-international-system-of-unit-units.html

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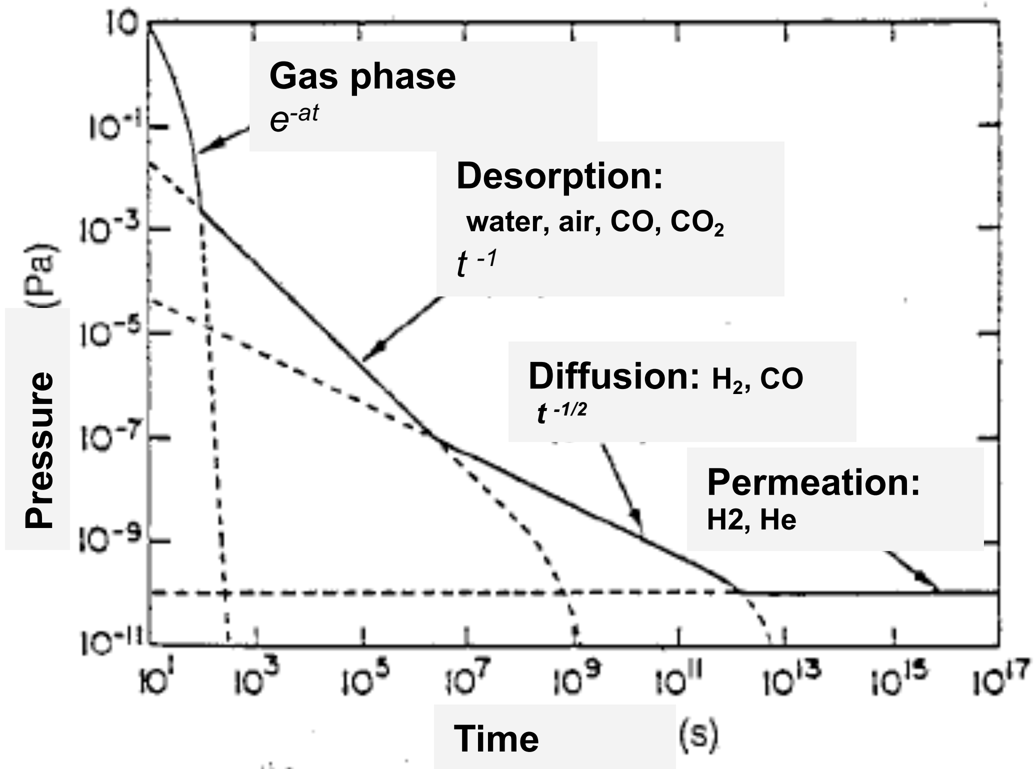
Sources of residual gas

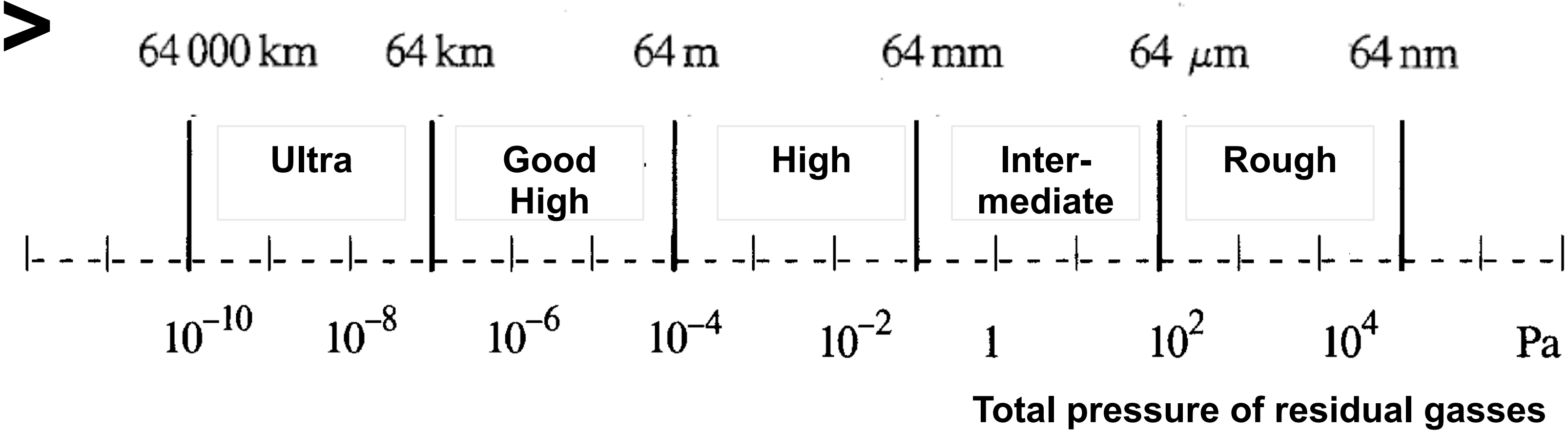
Limiting factors

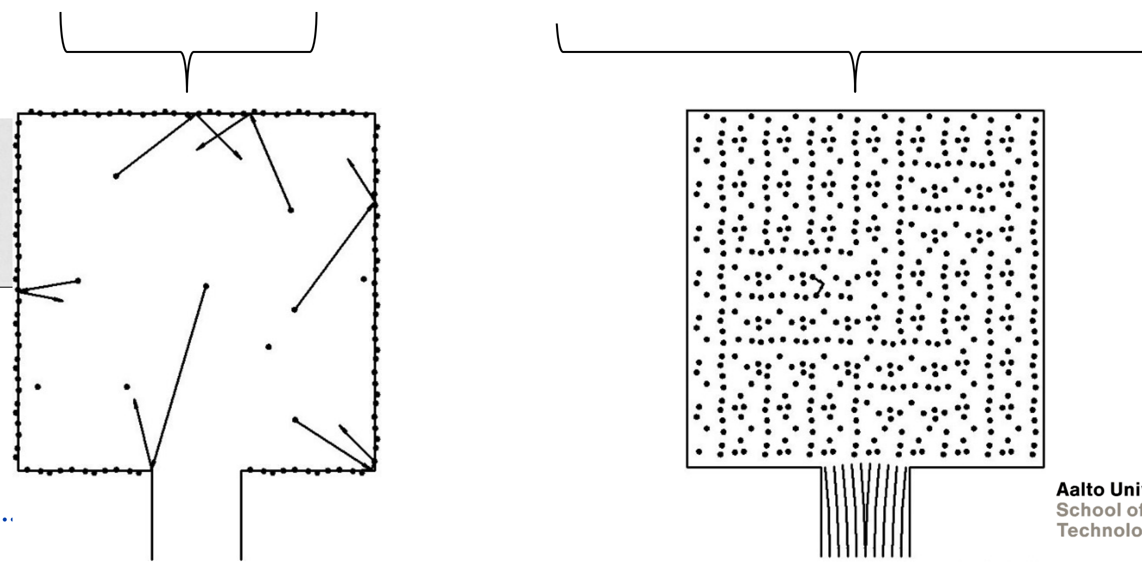
- **High vacuum**
  - **pumping speed**
  - **leak**
- **Good High vacuum**
  - **desorption from walls**
  - **baking**
- **Ultra high vacuum**
  - **impurities**
  - **internal leaks**
  - **material selection**
  - **diffusion**
  - **permeation**



Average mean free path (distance between collission) in nitrogen residual gas

$\langle\lambda\rangle$





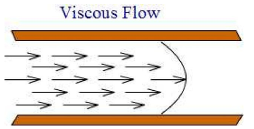
$$\langle\lambda\rangle = \frac{k \cdot T}{\pi \cdot \sqrt{2} \cdot P \cdot \xi^2}$$

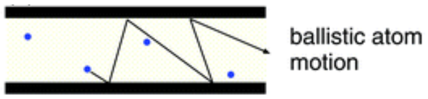
$\rho_N = N/V$

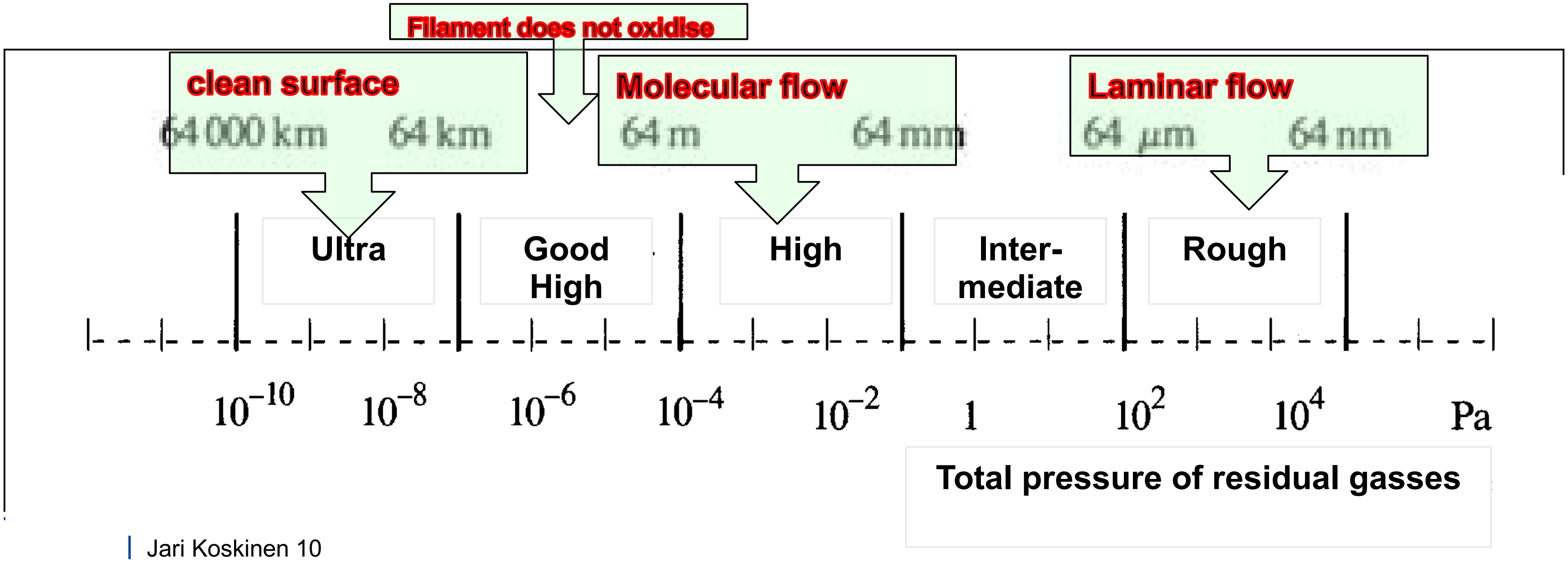
Phases of residual gas

d = diameter of chamber

- **Viscotic** $\langle\lambda\rangle < d/100$
- **Intermediate**
- **Molecular** $\langle\lambda\rangle \gg d$



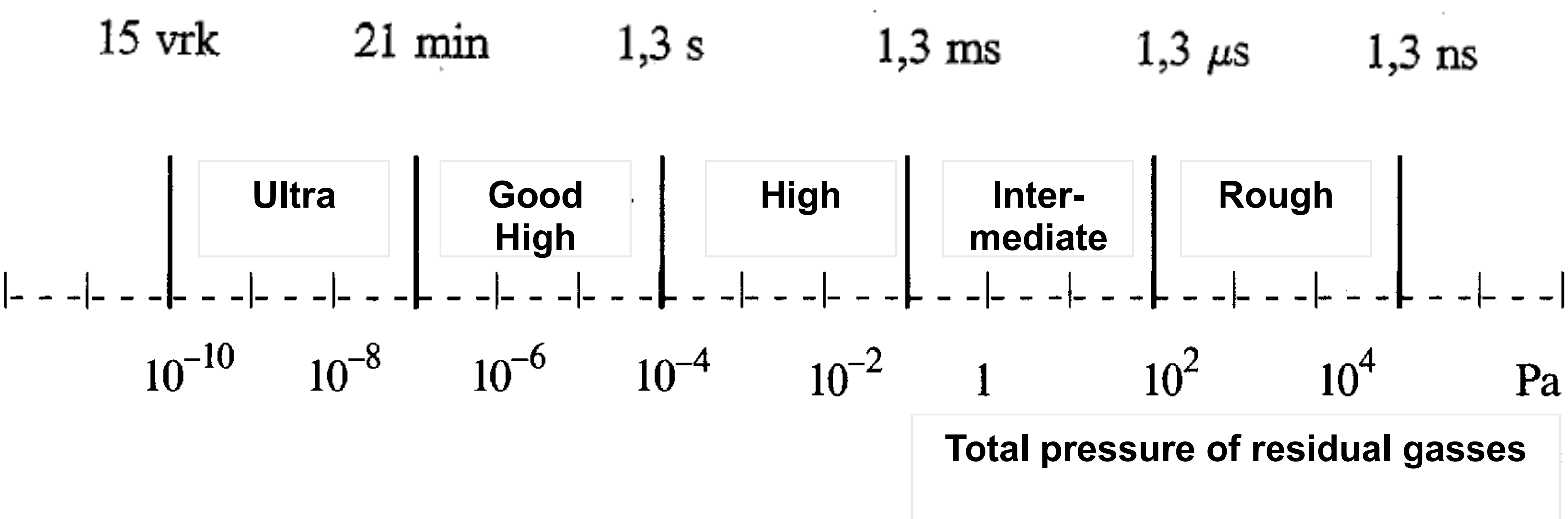




Time to form one molecular layer on surface

m	average molecule mass
ζ	diameter of molecule

$$\tau = \frac{(2 * \pi * m * k * T)^{1/2}}{\zeta^2 * P}$$

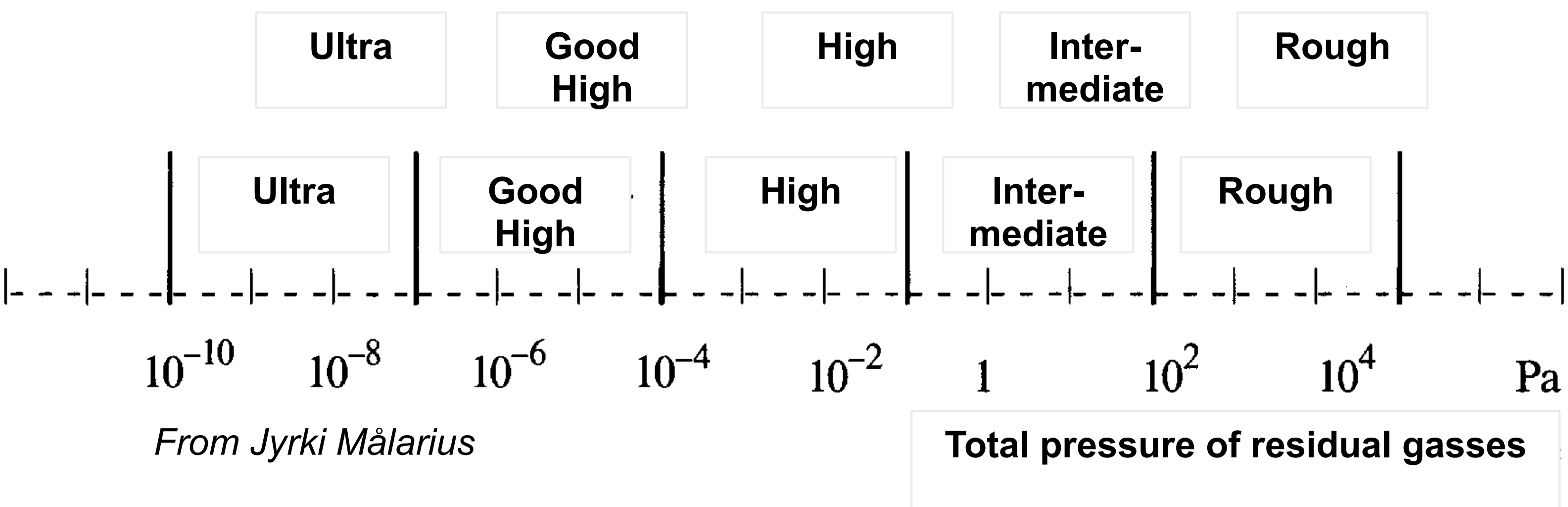


Use of High Vacuum

- Ultra High vac. UHV $\tau \sim$ hour
    - Clean surface during slow experiment
    - Atomic clean surface
  - Ion accelerators
  - MBE-processes
  - Surface analysis
    - XPS, ESCA
    - SIMS

- Good High Vacuum $\tau \sim$ min
    - Sufficient for electron gun
    - Clean surfacea during slow process
  - Several thin film processes
  - Crystal growth
  - Electron microscopy
  - Mass spectroscopy
  - Lithography

- High vacuum $\tau \sim$ s
  - Clean surface during process
  - Several thin film processes
  - Ion implantation



From Jyrki Målarius

Critical temperatures for some residual gasses

Gas or vapor		T_c (°C)
Helium	He	—268
Hydrogen	H_2	—240
Nitrogen	N_2	—147
Carbon monoxide	CO	—140
Argon	Ar	—122
Oxygen	O_2	—118
Methane	CH_4	—82
Carbon dioxide	CO_2	31
Chlorine	Cl_2	144
Ether	$(C_2H_5)_2O$	195
Ethanol	C_2H_5OH	243
Carbon tetraclor.	CCl_4	283
Water	H_2O	374

above T_c no liquid

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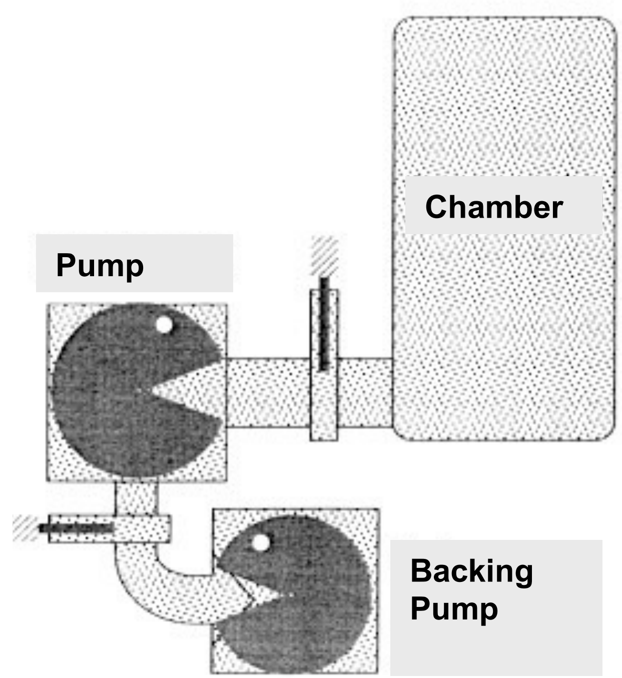
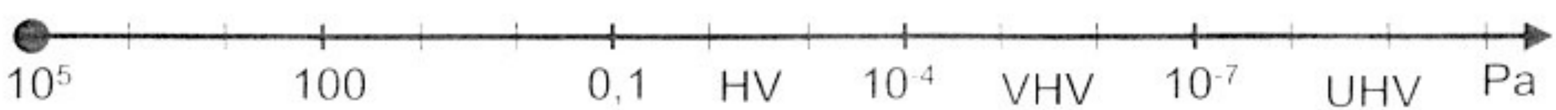
Vacuum Pumping

- **Mechanical pumping → 0.1 Pa**

- **High Vacuum pumps with backing pump → HV, Good HV (VHV)**

- **High Vacuum closed → UHV**





From Jyrki Målarius

Vacuum

- **Pump throughput**
  Pa m³/s

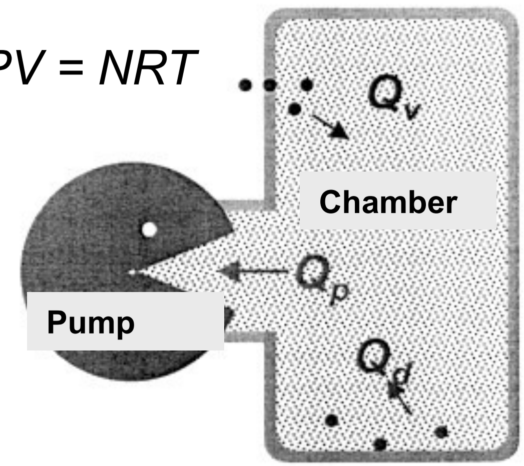
$$Q_p = p\frac{\Delta V}{\Delta t}$$

- **Pumping speed**
  m³/s, l/s, m³/h

$$S = \frac{\Delta V}{\Delta t}$$

$$Q_p = Q_d + Q_v$$

PV = NRT



- **Final pressure**

$$p = \frac{Q_d + Q_v}{S}$$

- m^3/s
- l/s
- m^3/h

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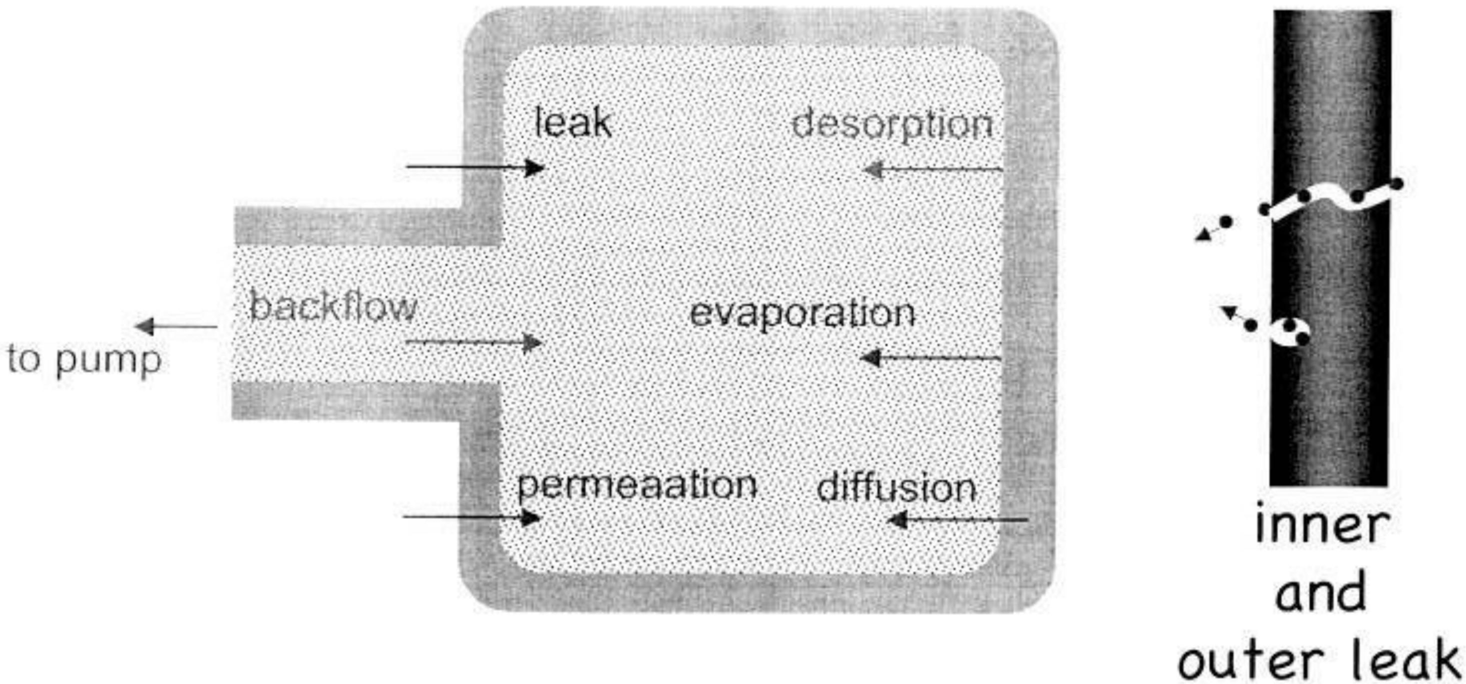
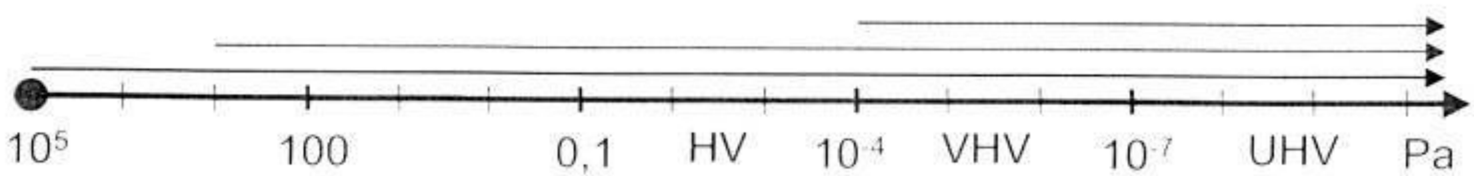
Pumping speed and the ultimate pressure



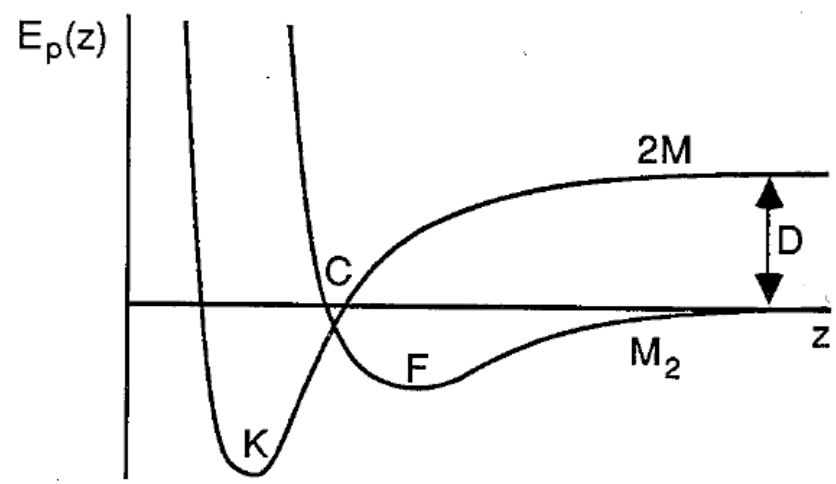
Balance $Q_p = Q_{leak} + Q_{des} + Q_{evap} + Q_{diff} + Q_{per} - Q_{ads}$



From Jyrki Målarius

Adsorption

- Physisorption
- Chemisorption

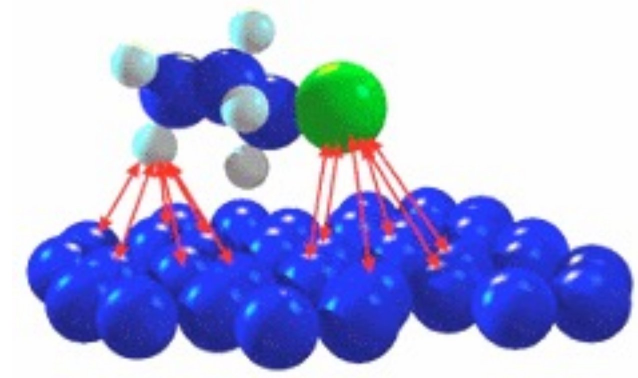


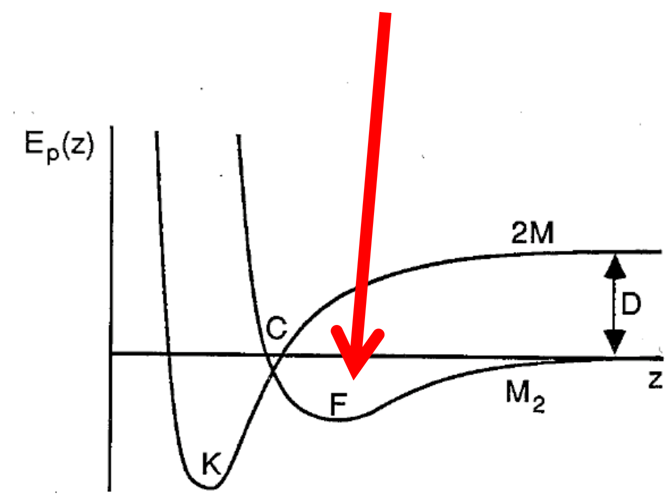
Kuva 12.1. *Lennard-Jones-diagrammi.*

Adsorption

Physisorption

- Chemical bonding:
  - polaroization (van der Waals)
- Bonding energy ≈ 0.001 – 0.5 eV
- Bond length ≈ 3 – 10 Å
- For example: nobel gas or molecules on materials
- Possibly precursion state before chemisorption



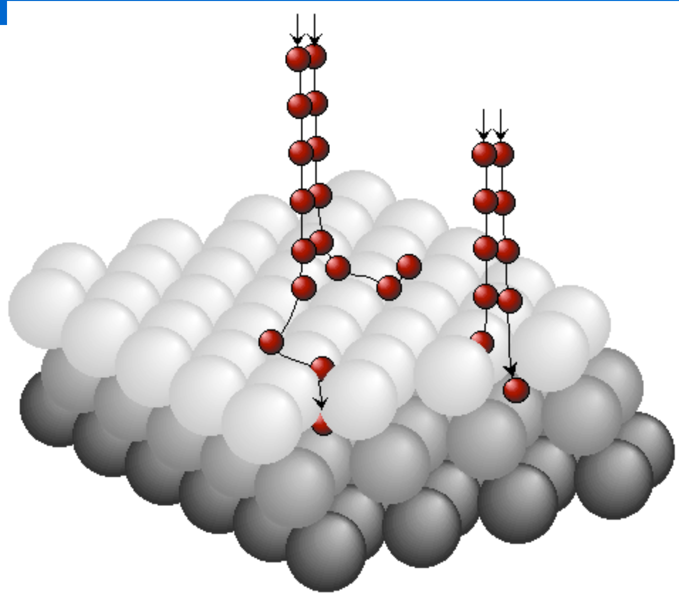


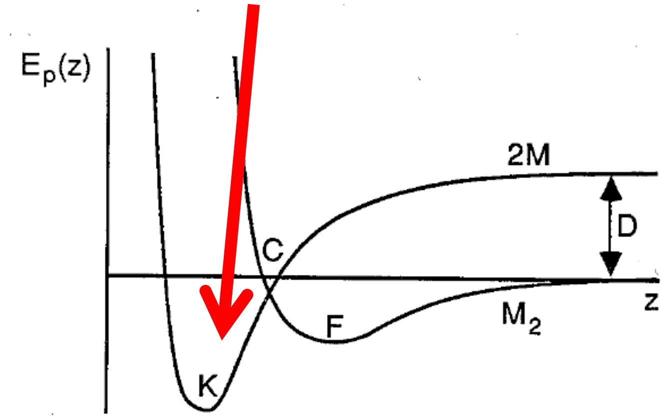
Kuva 12.1. *Lennard-Jones-diagrammi.*

Adsorption

Chemisorption

- Chemical bonding:
  - charge exchange
- Bonding energy ≈ 0.5 – 5 eV
- Bond length ≈ 1 – 3 Å
- For example: H, O, N, CO on metals
- Dissociation of molecule
- Final absorption



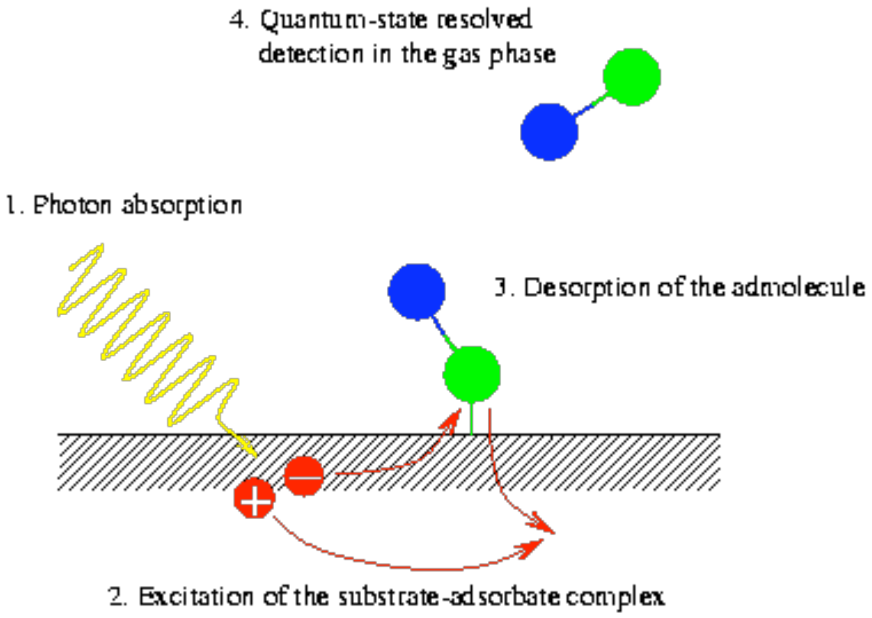


Kuva 12.1. *Lennard-Jones-diagrammi.*

Desorption

Adsorbed molecule must receive energy E_D in order to leave surface

- thermal
- radiation
  - photons
  - electrons
  - ions
  - electric field



Vacuum pumps

- **Positive displacement (mechanical pumps)**

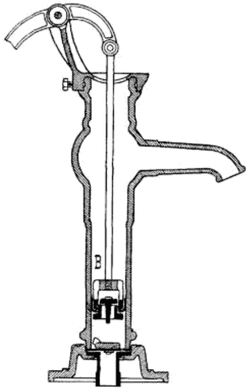
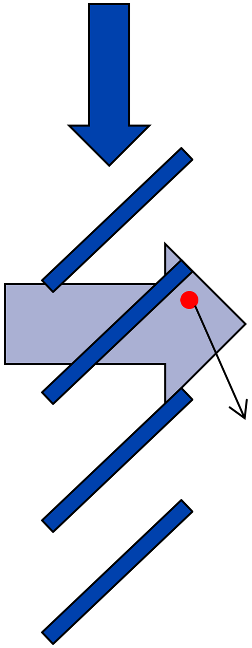
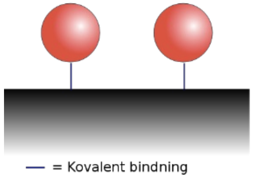


Fig. 9.

- **Momentum transfer (molecular pumps)**



- **Entrapment**



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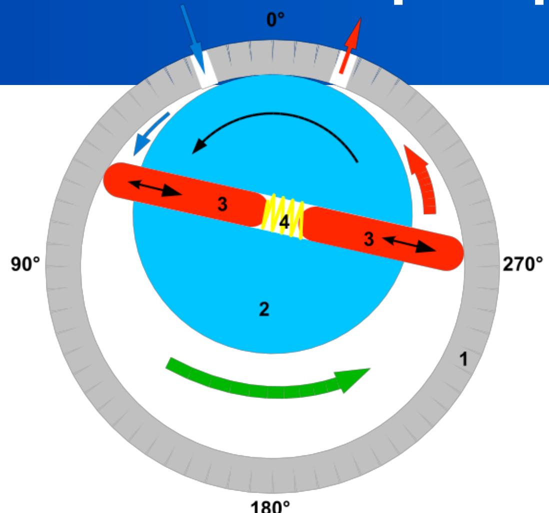
Mechanical pumps

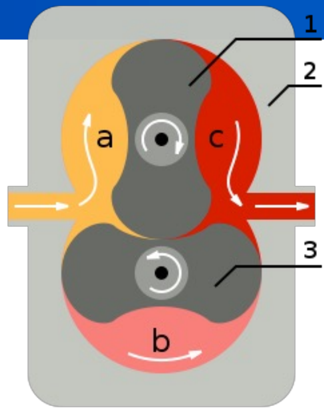


Rotary vane

Very common fore vacuum-and general vacuum pump.
- Typically 1 or 2 stage configuration.
- Gas is moved by rotating vanes.
- Oil is used as seal, lubricant, and coolant.

+ High capacity from 10^3 to ~10^{-2}mbar.
- Potential back streaming of oil into vacuum chamber.

Mechanical pumps



Roots

ZJP-1200C

Counter rotating blades moves gas volume.

•No contact between surfaces →oil free operation.

•Runs very hot without fore vacuum pump.

+ High capacity from 10 to ~10^{-4} mbar.
(Medium capacity from 1000 to ~10 mbar)
+ Oil free
- Works best together with fore vacuum pump.

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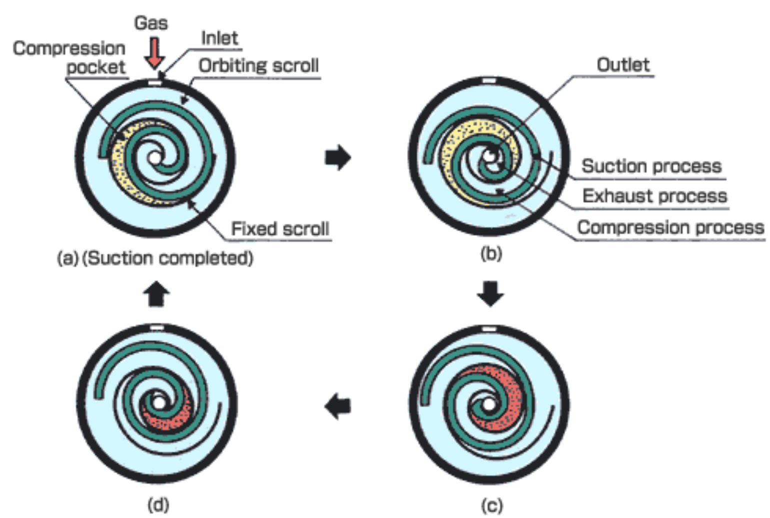
Mechanical pumps

Scroll pump

Moving scroll orbiting a fixed scroll.

•Compressed gas volume pushed towards center outlet.

+ Oil free
+ Reliable, low maintenance.
- Low to medium capacity ($10^3$to ~10^{-2}mbar)



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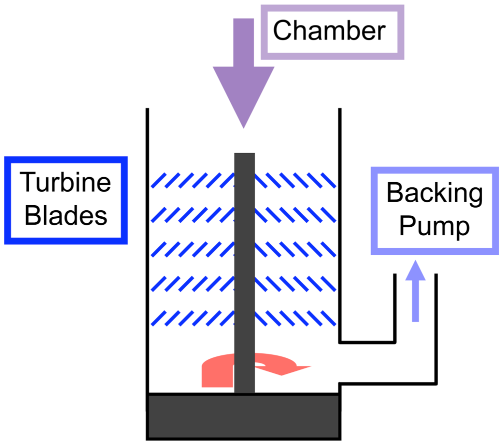
Momentum transfer - Turbo pump



Turbo molecular

•Fast moving rotor (30k to 90k rpm) with several stages and many blades per stage.

•High efficiency in the molecular regime where gas molecules collide with rotor blade and not each other.

•Some modern pumps have magnetic, non-contact, bearings.

+ High capacity from 10^{-3} to ~10^{-8} mbar.
+ Low maintainance.
- Sudden large gas loads may cause severe, expensive damage.

Momentum transfer in turbo molecular pump

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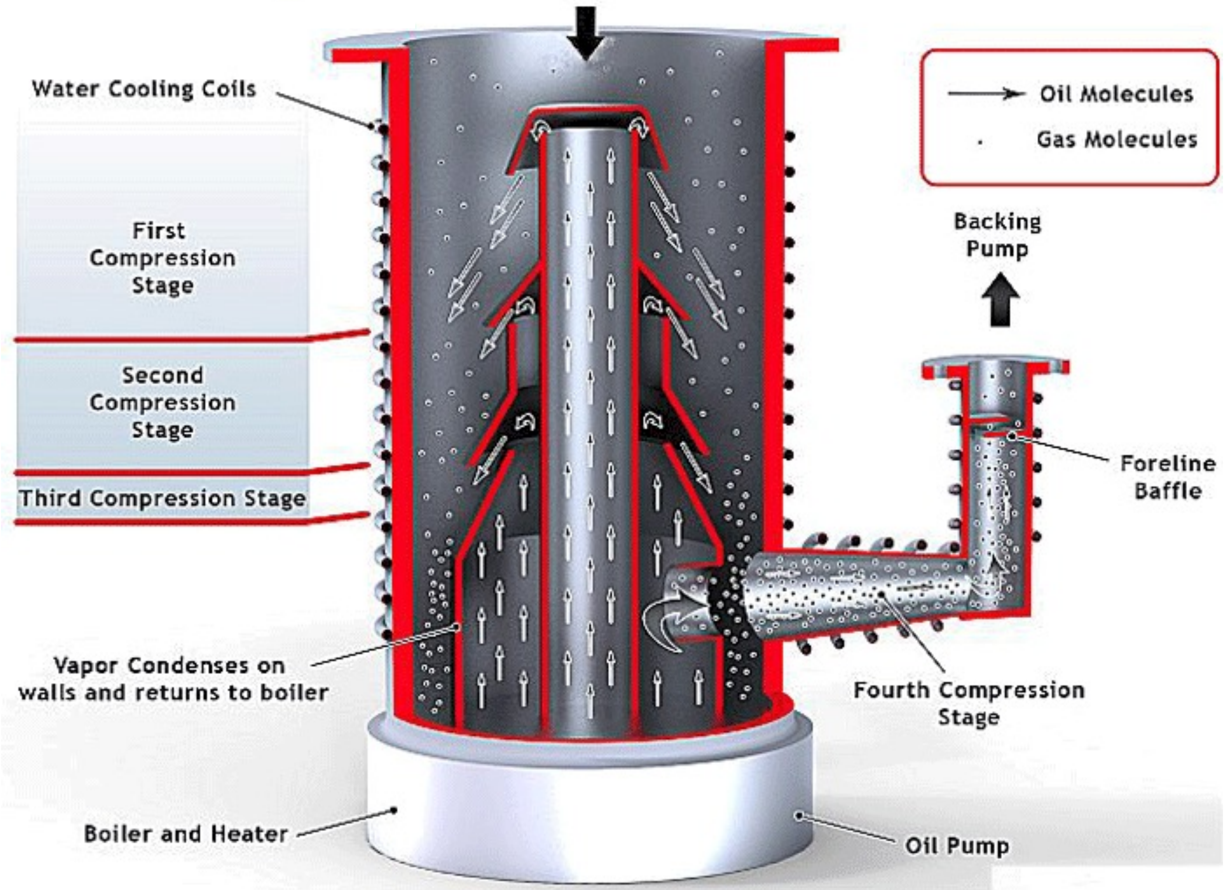
Momentum transfer – oil diffusion pump

Liquid nitrogen trap
(https://www.idealvac.com/Varian-362-6-ASA-Liquid-Nitrogen-Cryotrap-For-Varian-VHS-6-Diffusion-Vacuum-Pumps/pp/P10385)



- Hot dense oil vapor is forced through central jets angled downward to give a conical curtain of vapor.

- Gas molecules are knocked downwards and eventually reach the backing vacuum pump.

\+ Simple pump without moving parts.
\+ High capacity from 10^{-3} to ~10^{-8} mbar.
\+ Low maintenance.
\- Needs cooled baffle to reduce oil contamination of vacuum chamber.

https://vacaero.com/information-resources/vac-aero-training/170466-the-fundamentals-of-vacuum-theory.html

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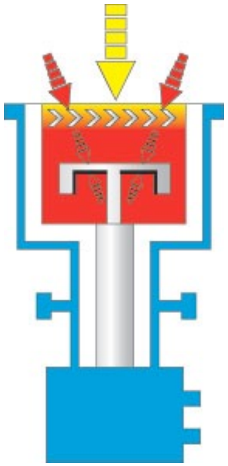
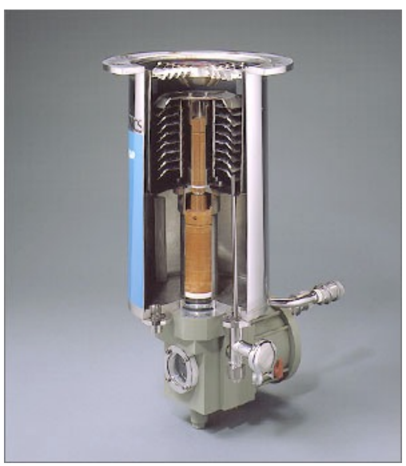
Entrapment



cryo pump



Cool head with several plates (stages).

The metal top side of the cool (12K) plates traps gas molecules by cryocondensation.

The bottom side of the plates are coated with active charcoal and traps gas molecules by cryo-adsorption.

The cooling is done with a Helium filled refrigerator loop.

+ Very High capacity down to ~10^{-9} mbar.
+ No backflow contamination.

- Pump saturates if exposed to high pressure or continuous gas flow.
- Need periodic regeneration of cool head.

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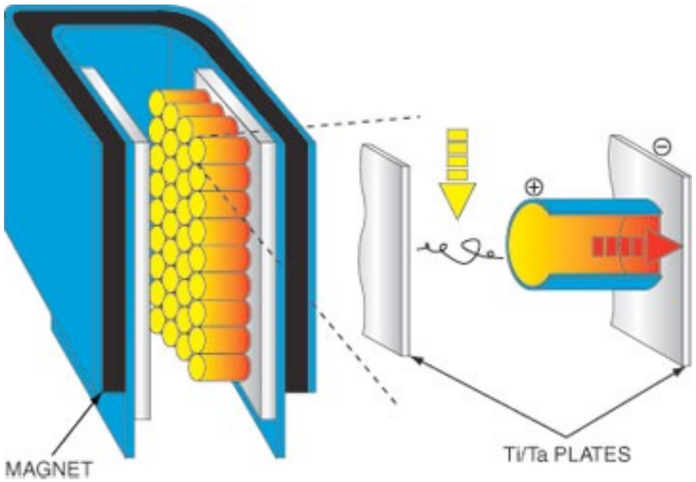
Entrapment



ion pump

Free electrons move in helical trajectories towards the anode, ionizing gas molecules upon collisions.

•Gas ions strike the Ti cathodes and some get buried.

•Sputtered Ti deposits inside the tubes and getters gas molecules through chemical reactions.

+ Simple pump without moving parts.
+ Can work at very low pressure ~10^{-11}mbar.
+ Oil free.
- Not suitable for gas loads.

Pumps and vacuum ranges

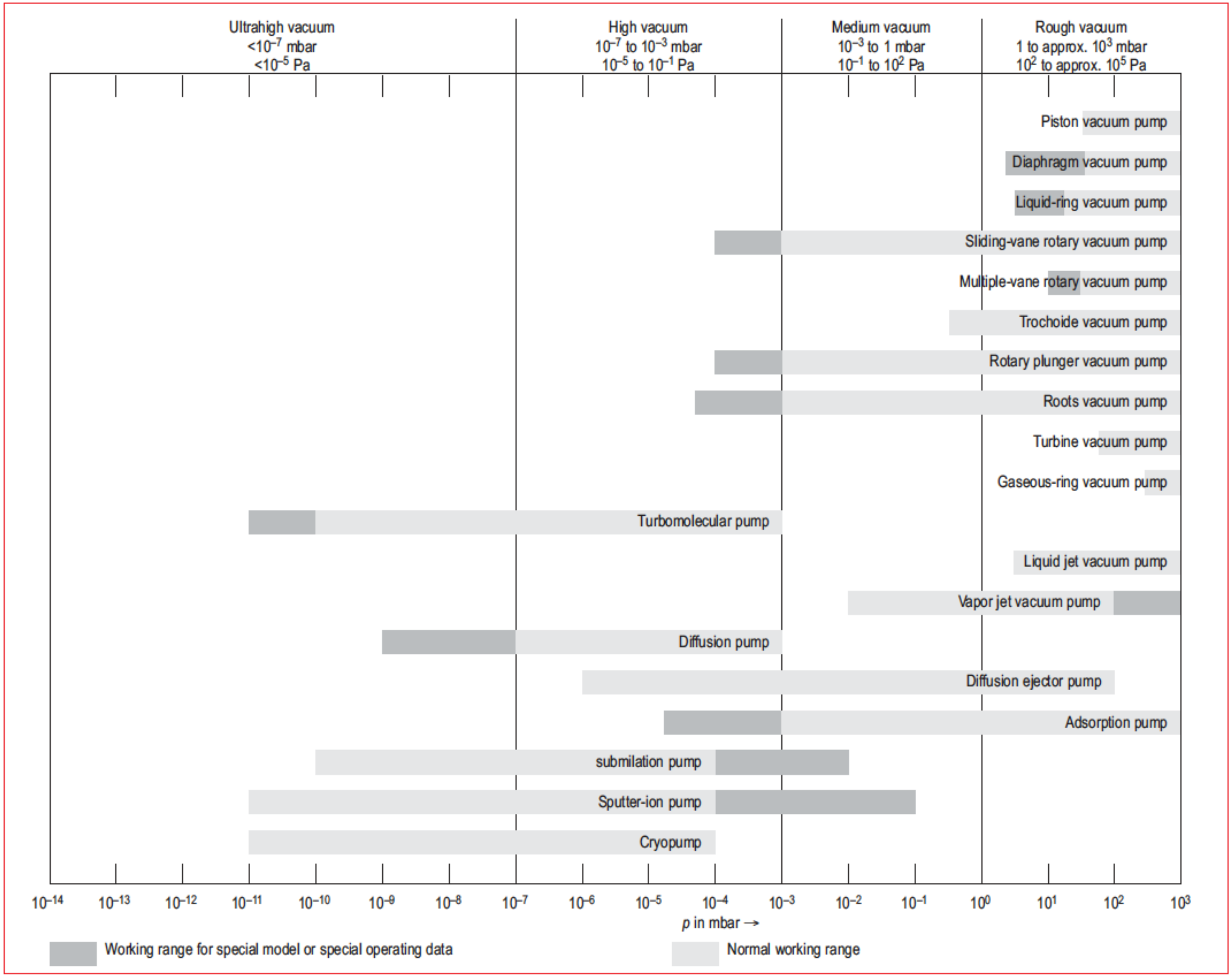
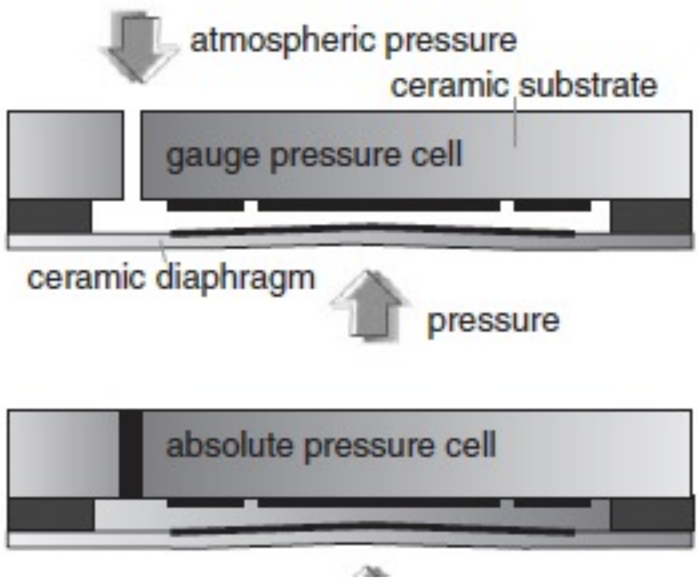


Fig. 9.16: Common working ranges of vacuum pumps

Vacuum gauges

- **Mechanical – diaphragm**
- **Electronic**
    - **Piezoresitive (strain gauge)**
    - **Capacitive**
    - **Magnetic**
    - **Piezoelectric**
    - **Optical**
    - **Potentiometric**
    - **Resonant**
- **Thermal conductivity – Pirani**
- **Ionzation gauge**
- **Hot cathode**
- **Cold cathode (Penning)**



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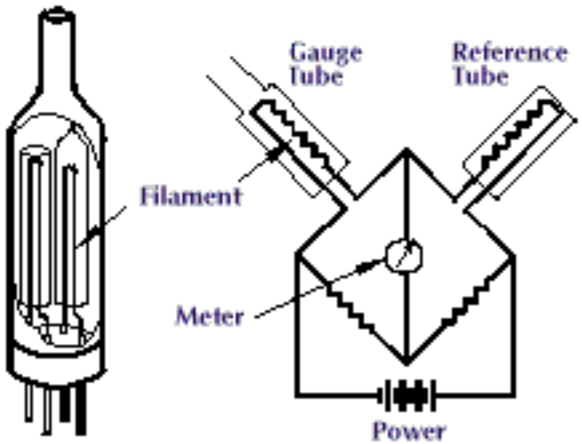
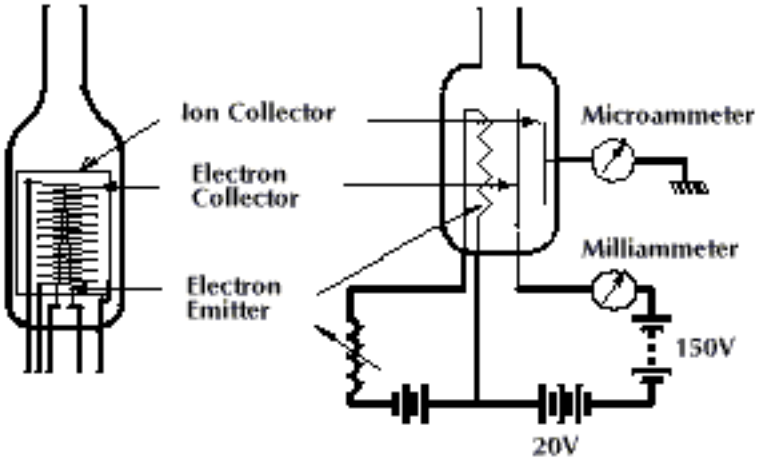
Gauges

Heat transfer ⇝ pressure

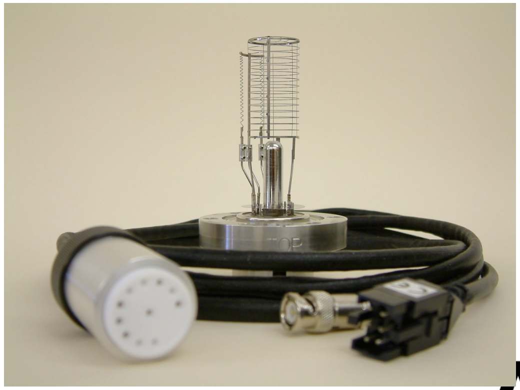


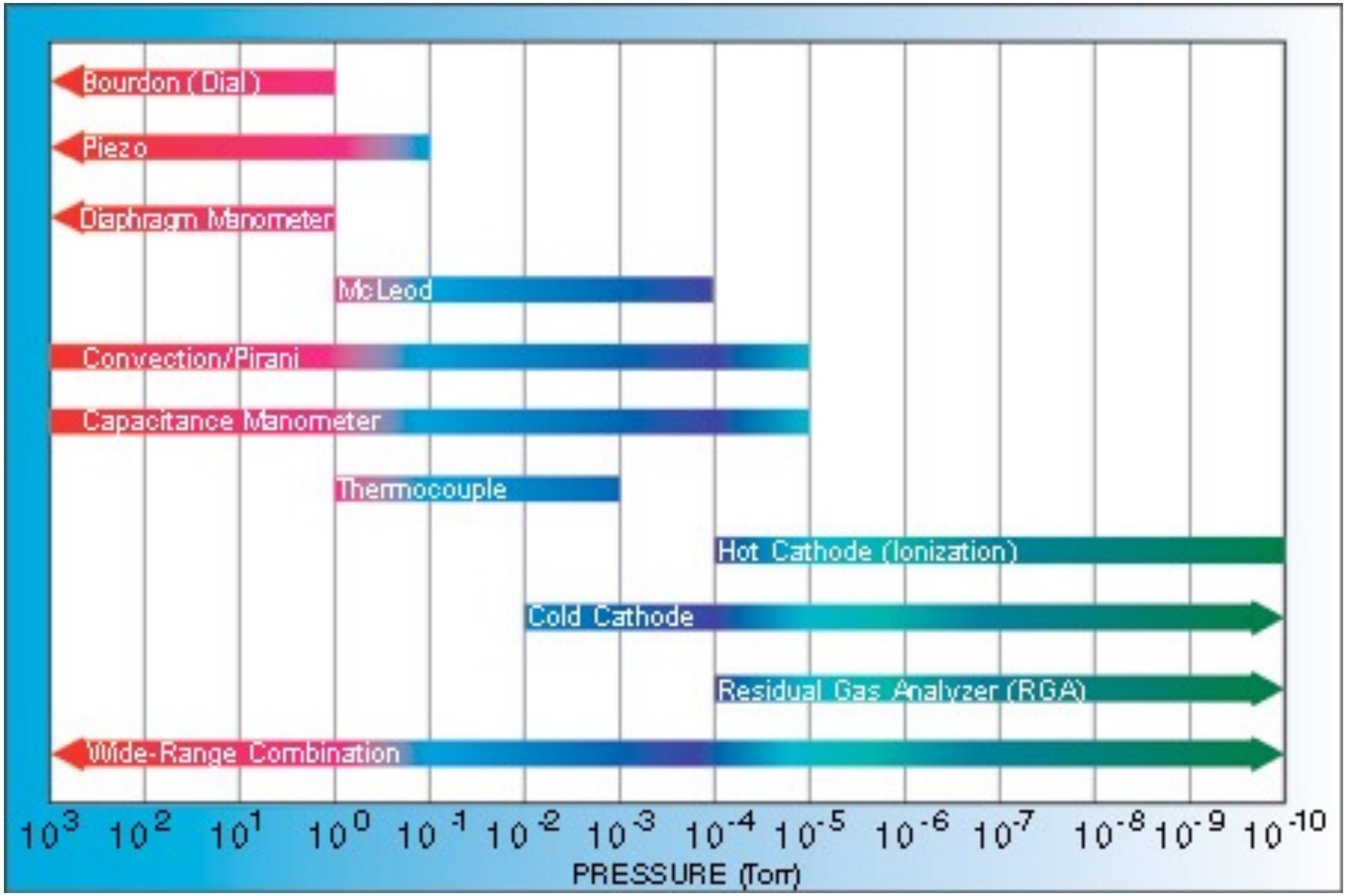
Pirani

Ionization rate ⇝ pressure



ionization gauge hot filament





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Residual gas analyser

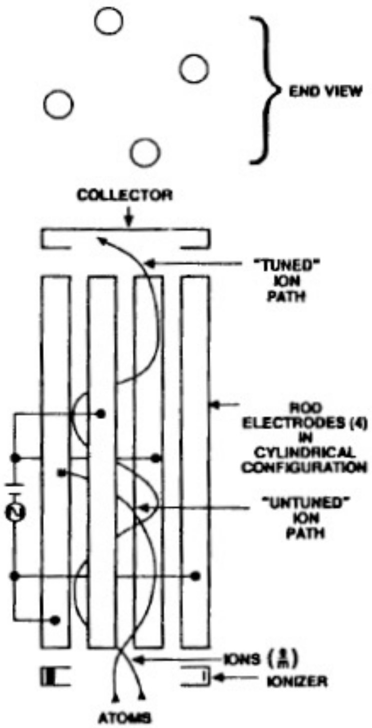
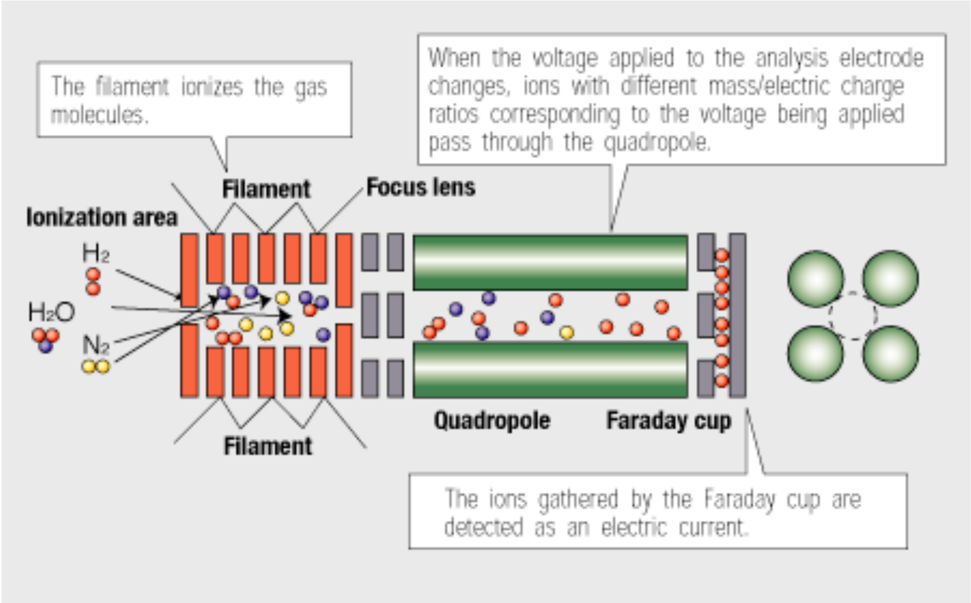


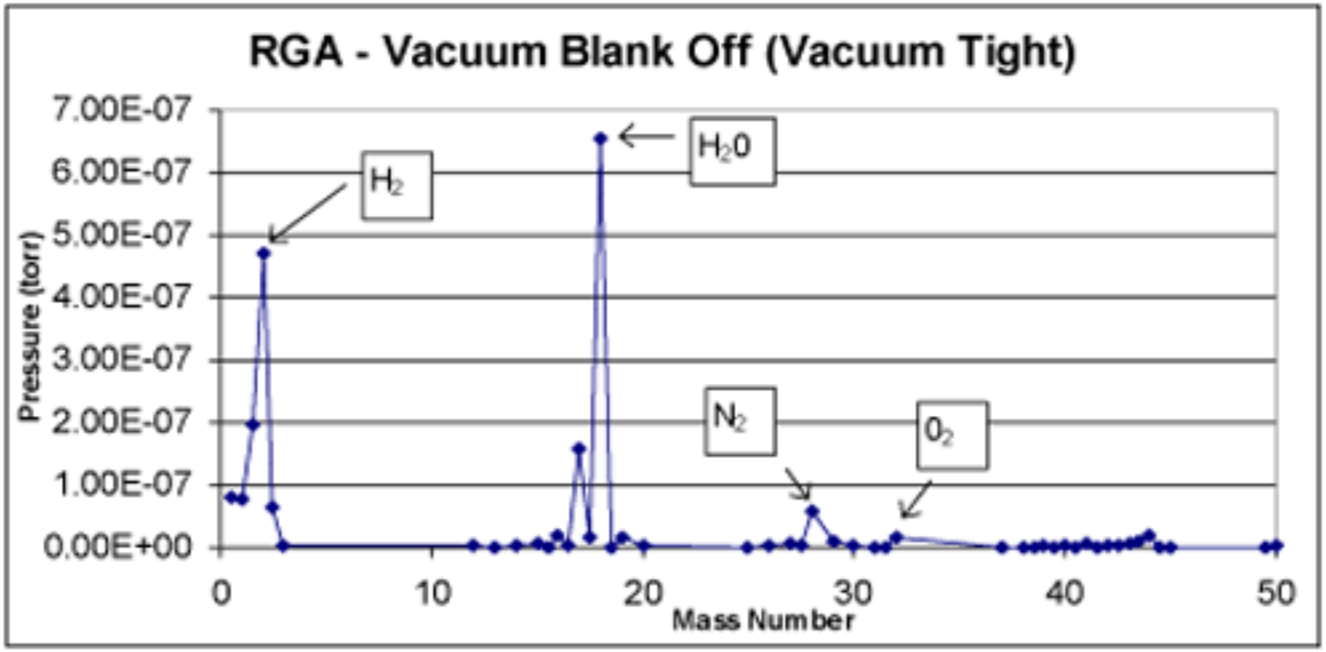
Figure 3-1 cont. A quadrapole mass spectrometer.



SRS RGA100 Residual Gas Analyzer

https://vacaero.com/information-resources/vac-aero-training

Residual gas analyser



Mass Number (Major Peak)	Constituent
43	Acetone
28	Air
45	Alcohol, isopropyl
31	Alcohol, methyl
17	Ammonia
40	Argon
44	Carbon Dioxide
28	Carbon Monoxide
35, 37	Chlorine
36, 37	Hydrogen chloride
2	Hydrogen
4	Helium
39 - 43	Hydrocarbons
16.0	Methane
14, 28	Nitrogen
32	Oxygen
29	Propane
17, 18	Water

https://vacaero.com/information-resources/vac-aero-training/6884-residual-gas-analyzers.html

Vacuum systems

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Vacuum systems

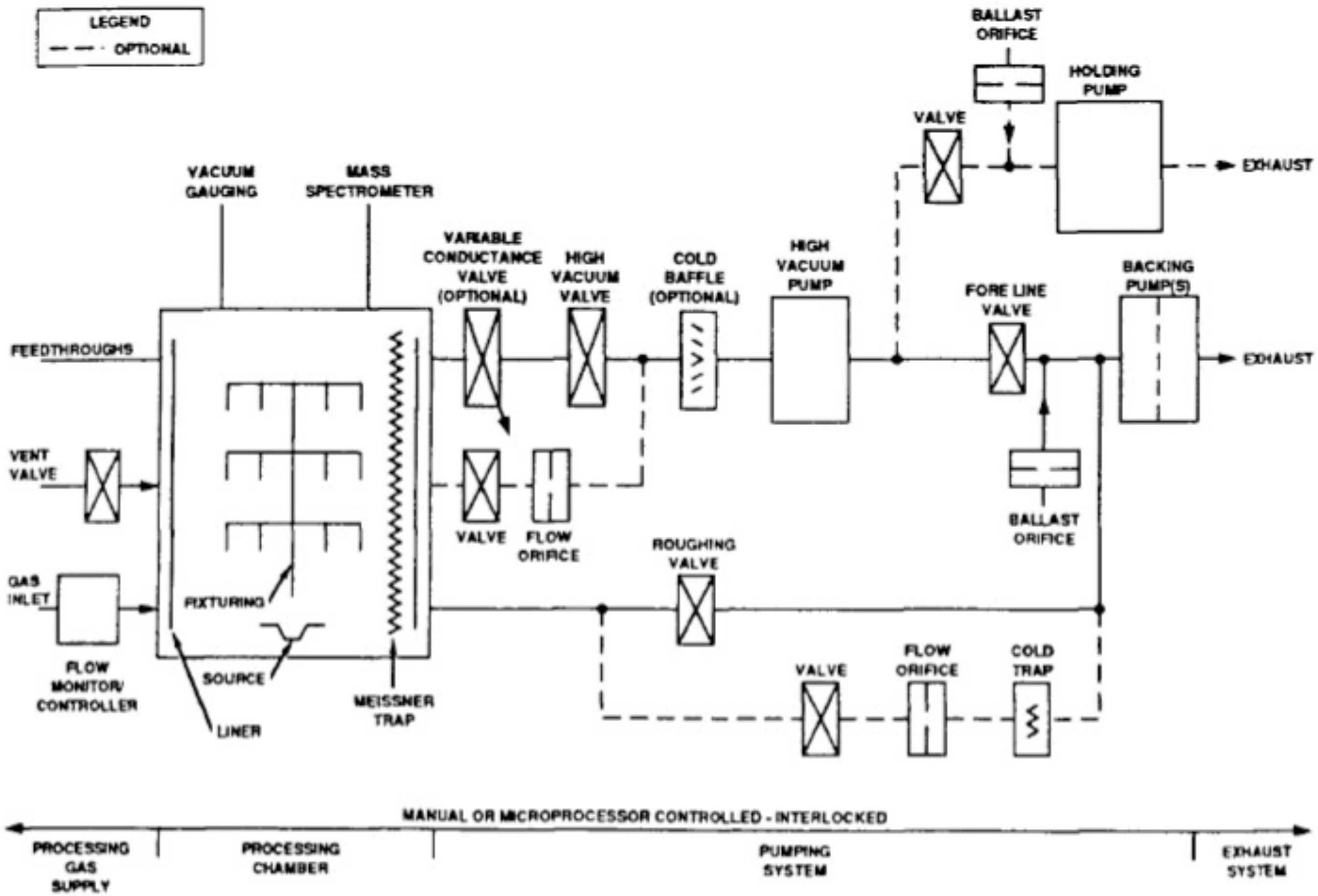

Figure 3-8. Vacuum/plasma processing system.

Handbook of Physical Vapor Deposition (PVD) Processing

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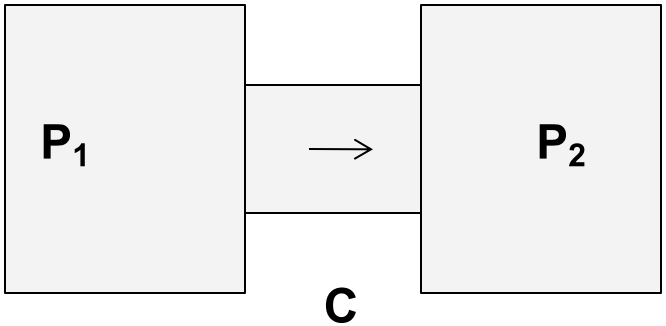
Gas flow in vacuum systems

$Q = C(P_1 - P_2)$

Q gas troughput [pressure*volume/s]



Conductance [l/s]

in series:

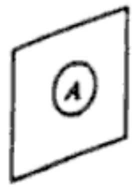
$$\frac{1}{C_{sys}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots .$$

in parallel:

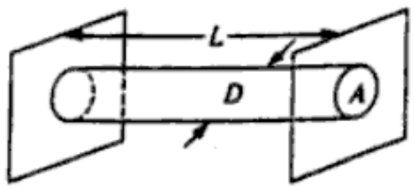
$$C_{sys} = C_1 + C_2 + C_3 + \cdots .$$

Conductance of various geometries

M. Ohring



$$C = 3.64A\left(\frac{T}{M}\right)^{1/2} \qquad = 11.7A$$



$$C = 6.18\frac{A^2}{DL}\left(\frac{T}{M}\right)^{1/2} \qquad = 12.2\frac{D^3}{L}$$

Out gassing

At room temperature									
Standard values1 (mbar · l · s^{-1} · cm^{-2})			Metals 10^{-9} ... · 10^{-7}				Nonmetals 10^{-7} ... · 10^{-5}		
Outgassing rates (standard values) as a function of time									
Examples:	1/2 hr.	1 hr.	3 hr.	5 hr.	Examples:	1/2 hr.	1 hr.	3 hr.	5 hr.
Ag	$1.5 \cdot 10^{-8}$	$1.1 \cdot 10^{-8}$	$2 \cdot 10^{-9}$		Silicone	$1.5 \cdot 10^{-5}$	$8 \cdot 10^{-6}$	$3.5 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$
Al	$2 \cdot 10^{-8}$	$6 \cdot 10^{-9}$			NBR	$4 \cdot 10^{-6}$	$3 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$	$1 \cdot 10^{-6}$
Cu	$4 \cdot 10^{-8}$	$2 \cdot 10^{-8}$	$6 \cdot 10^{-9}$	$3.5 \cdot 10^{-9}$	Acrylic glass	$1.5 \cdot 10^{-6}$	$1.2 \cdot 10^{-6}$	$8 \cdot 10^{-7}$	$5 \cdot 10^{-7}$
Stainless steel		$9 \cdot 10^{-8}$	$3.5 \cdot 10^{-8}$	$2.5 \cdot 10^{-8}$	FPM, FKM	$7 \cdot 10^{-7}$	$4 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$1.5 \cdot 10^{-7}$

[1] All values depend largely on pretreatment!

Table X: Outgassing rate of materials in mbar · l · s^{-1} · cm^{-2}

Monolayer formation times

Table 3.2. Pressure (in Pascal and Torr), impingement rate, and monolayer formation time for selected vacuum and process conditions

p (Pa)	p (Torr)	J_g ($m^{-2} s^{-1}$)	τ (s)
		Nitrogen	
1	7.5×10^{-3}	2.9×10^{22}	3.5×10^{-4}
10^{-1}	7.5×10^{-4}	2.9×10^{21}	3.5×10^{-3}
10^{-2}	7.5×10^{-5}	2.9×10^{20}	3.5×10^{-2}
		water vapor	
10^{-3}	7.5×10^{-6}	3.6×10^{19}	0.28
10^{-4}	7.5×10^{-7}	3.6×10^{18}	2.8
10^{-5}	7.5×10^{-8}	3.6×10^{17}	28

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Vacuum Baking

- In order to obtain UHV
- heated to high temperatures (100 - 300 ° C or so)
- mostly water is adsorbed to the chamber walls
- very long time at room temperature.

- Electrical heating tapes (shown in the picture below).
- Then everything is covered with aluminium foil for insulation and heat distribution.

http://philiphofmann.net/ultrahighvacuum/ind_bakeout.html

Out gassing - 1

Basics 5:Outgassing Resources

The outgassing table below is a bit dated but still useful as an introduction. Check the N.A.S.A. link below for a really large data base on the subject.

Outgassing Data Table

		Outgassing Rate in Torr Liters Per Square Cm. Per Second			
Material	Condition	1 Hour	10 Hours	100 Hours	Source
Aluminum	Cleaned	_	8X10e-09	_	1
Aluminum	Anodized	_	1X10e-07	_	1
Aluminum	Anodized	_	1X10e-07	_	3
Aluminum	degassed	1.7X10e-07	2.7X10e-08	4.6X10e-09	4
Aluminum	none	1.3X10e-06	_	_	4
Aluminum 6061-T6	none	_	2.5X10e-09	_	5
Aluminum 6061-T6 @ 200 deg. C	hot	_	4.5X10e-09	_	5
Aluminum 6061-T6	Bake 13.5 hr. @ 200 deg. C	_	3.7X10e-10	_	5
Aluminum 6061-T6 @ 300 deg. C	hot	_	1.4X10e-08	_	5
Aluminum 6061-T6	Bake 15 hr. @ 300 deg. C	_	1.6X10e-10	_	5
Brass	Cast, cleaned	_	3X10e-07	_	1
Copper	_	2.3X10e-06	_	_	3
Copper, 450 Deg.C	None	1.6X10e-06	_	_	4
Copper, 450 Deg.C	degreased, pickled	2.6X10e-07	_	_	4
Copper, 450 Deg.C	degreased	1.4X10e-06	_	_	4
Molybdenum	_	7X10e-07	_	_	3
Nickel	_	6X10e-07	_	_	3
Silver	_	6X10e-07	_	_	3
Silver	_	6X10e-07	_	_	3

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Out gassing - 2

Basics 5:Outgassing Resources

The outgassing table below is a bit dated but still useful as an introduction. Check the N.A.S.A. link below for a really large data base on the subject.

Outgassing Data Table

Material	Condition	Outgassing Rate in Torr Liters Per Square Cm. Per Second 1 Hour	10 Hours	100 Hours	Source
Steel, Mild	Shot-blasted	_	6X10e-08	_	1
Steel, mild	_	5X10e-07	5X10e-08	_	3
Steel, mild	degassed	5.3X10e-08	1X10e-08	1.9X10e-09	4
Steel, mild	none	_	1.9X10e-9	4X10e-10	5
Steel, mild @ 200 deg. C	hot	_	8.6X10e-9	_	5
Steel, mild	baked 15 hrs. @ 200 deg. C	_	_	4.3X10e-11	5
Steel, mild @ 400 deg. C	hot	_	8.4X10e-9	_	5
Steel, mild	Baked 15 hrs. @ 400 deg. C	_	1.2X10e-11	_	5
Steel, mild	none	4.2X10e-07	_	_	4
Steel, mild	none	4.2X10e-07	_	_	4
Steel, chrome plated	Polished & vapour degreased	1X10e-08	9X10e-10	_	3
Steel, nickel plated	Polished & vapour degreased	5X10e-07	1X10e-09	_	3
Steel, stainless	_	2X10e-07	2X10e-08	_	1
Steel, stainless	Polished & vapour degreased	_	1.4X10e-09	_	3
Steel, stainless	none	6.4X10e-07	_	_	4
Steel, stainless	degreased	4X10e-07	_	_	4
Steel, stainless	annealed	5.3X10e-08	_	_	4
Steel, stainless	none	7.6X10e-10	_	1.1X10e-10	5
Steel, stainless	none	_	1.2X10e-08	_	5
Steel, stainless	bake 24 hr, 200 deg. C	_	1.5X10e-10	_	5
Steel, stainless	bake 12 hr., 400 deg. C	_	9.3X10e-13	_	5
Steel, stainless @ 400 deg. C	hot	_	1.4X10e-09	_	5
Tantalum	_	9X10e-07	_	_	3
Tungsten	_	2X10e-07	_	_	3

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Out gassing - 3

Basics 5:Outgassing Resources

The outgassing table below is a bit dated but still useful as an introduction. Check the N.A.S.A. link below for a really large data base on the subject.

Outgassing Data Table

		Outgassing Rate in Torr Liters Per Square Cm. Per Second			
Material	**Condition**	**1 Hour**	**10 Hours**	**100 Hours**	**Source**
"Araldite D"	_	_	1X10e-06	3X10e-07	1
Neoprene	_	3X10e-05	1.5X10e-05	_	1
PVC	_	_	8X10e-07	1.3X10e-07	1
Mylar	outgassed	2X10e-07	_	_	2
Neoprene	As received	2X10e-04	_	_	2
Silicone rubber	As received	3X10e-05	_	_	2
Teflon	As received	5X10e-06	_	_	2
PVC	As received	9X10e-07	_	_	2
Textolite	As received	7X10e-06	_	_	2
Mylar	As received	3X10e-06	_	_	2
Zirconium	_	1.3X10e-06	_	_	3
Butyl rubber	_	1.5X10e-06	_	_	3
Kel F	_	4X10e-08	_	_	3
Plexiglass	Outgassed	1X10e-06	_	_	3
Polyethylene	_	2.6X10e-07	_	_	3
Nylon	_	1.2X10e-05	_	_	3
Porcelain	Glazed	6.5X10e-07	_	_	3
Steatite	_	9eX10e-08	_	_	3
Epon 828	degassed	6.7X10e-07	5.9X10e-08	9.4X10-09	4
Teflon	degassed	4.6eX10e-07	2.1X10e-07	9X10e-09	4

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Oxygen contamination

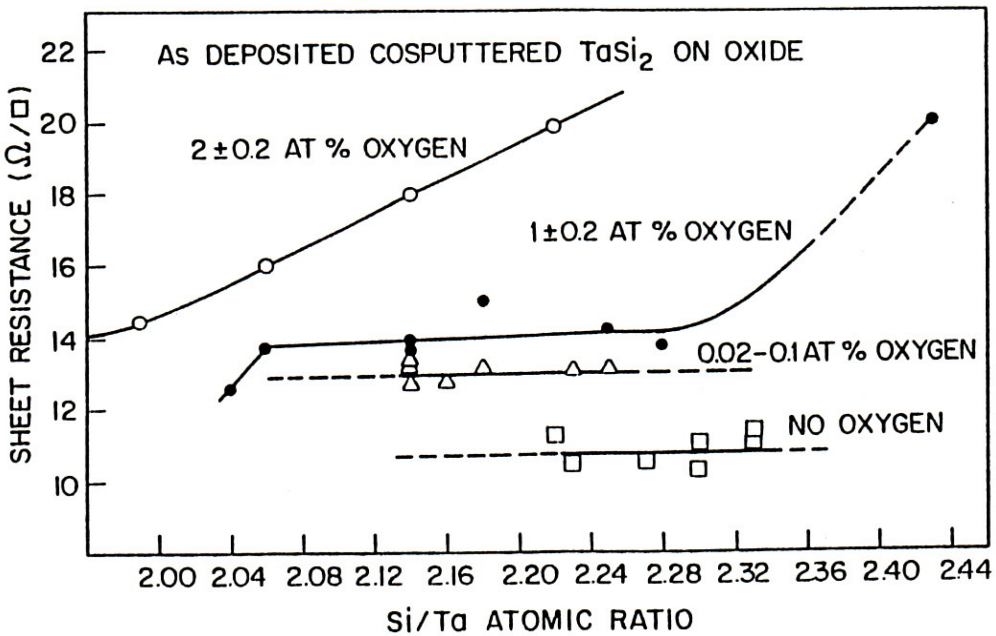
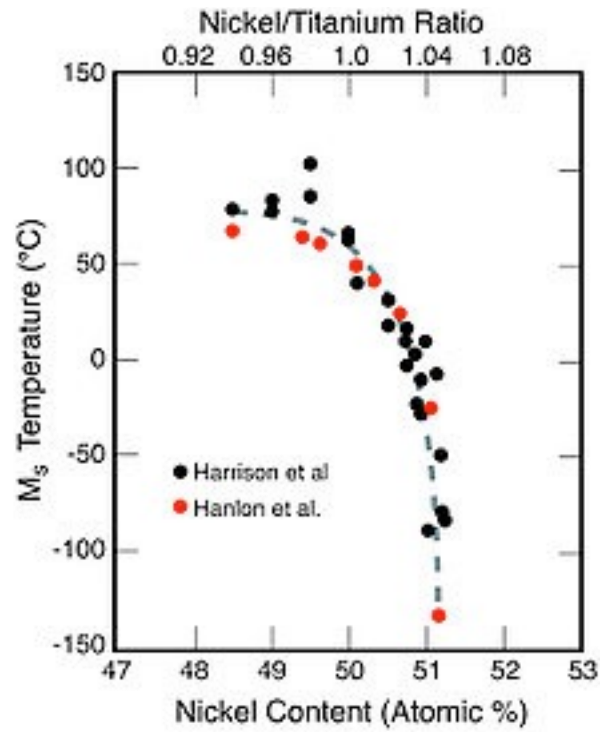


Figure 4.3. Variation in the as-deposited sheet resistance of cosputtered Ta-Si deposits (on SiO_2) as a function of Si:Ta atomic ratio for several oxygen concentration ranges. Oxygen was incorporated as a contaminant during sputtering.

Case NiTi

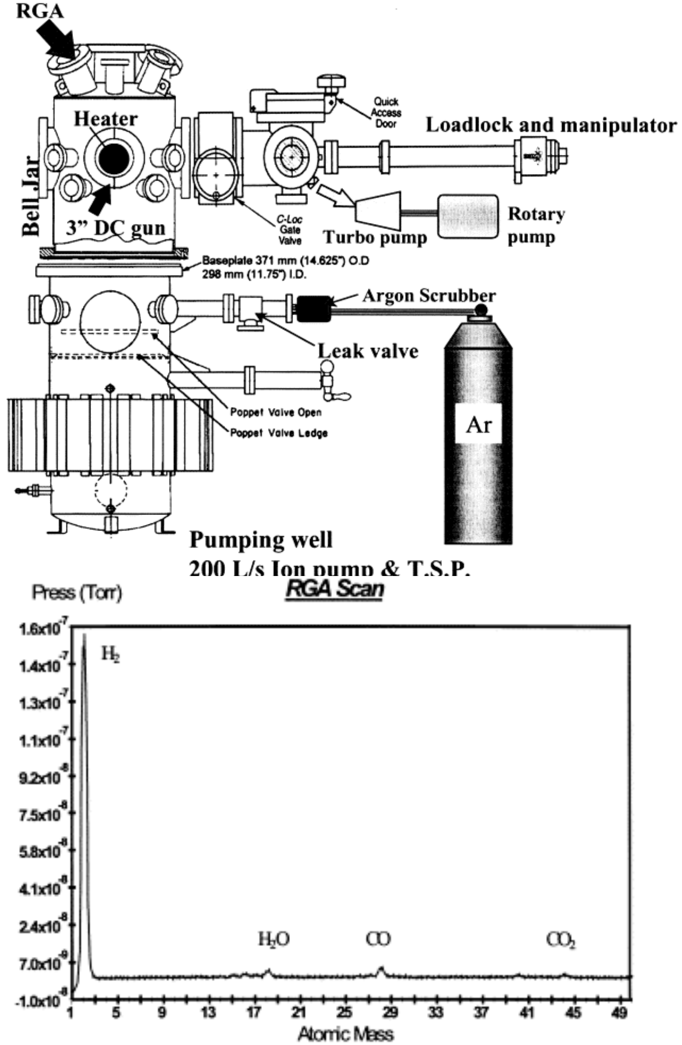
- Nickel Titanium shape memory alloy
- MEMS devises
- Based on reversible austenite-martensite transformation, which is temperature driven
- Transformation temperature depends on stoichimetry
- oxygen reacts with Ti forming TiO_x, which changes Ni/Ti ratio in alloy



Thin Solid Films 370 (2000) 18-29

Case NiTi

- RGA control in UHV vacuum
- Before baking H_2, H_2O, CO_2 and CO
- By baking H_2O, CO_2 and CO gases were kept below 10^{-8} Torr
- Sputtering with Ar partial pressure of 2 mtorr during film growth
- Stoichimetry and transition temperature as in bulk NiTi
- without careful ambient control transition temperature changes radically. (Oxygen detection al low contents difficult in metallic thin films)



Vacuum systems and sample loading

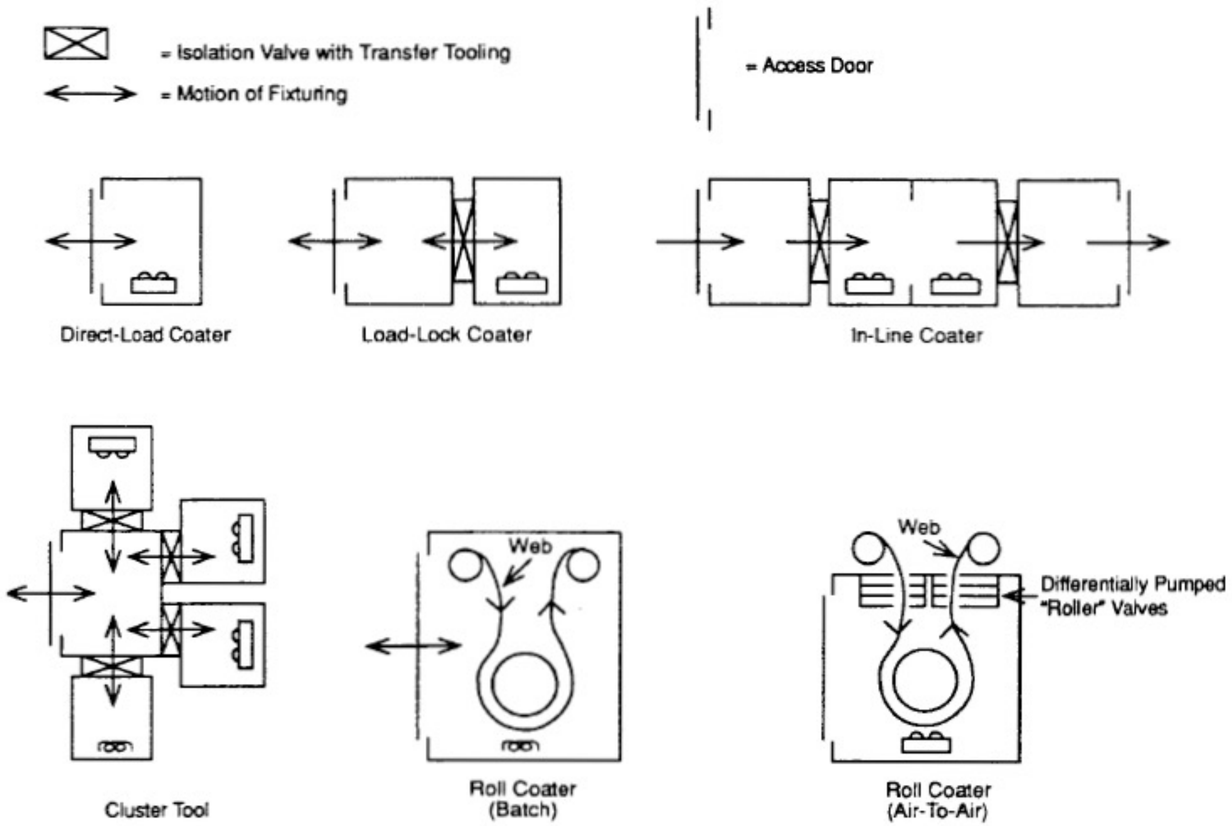


Figure 3-9. Deposition chamber configurations.

Handbook of Physical Vapor Deposition (PVD) Processing

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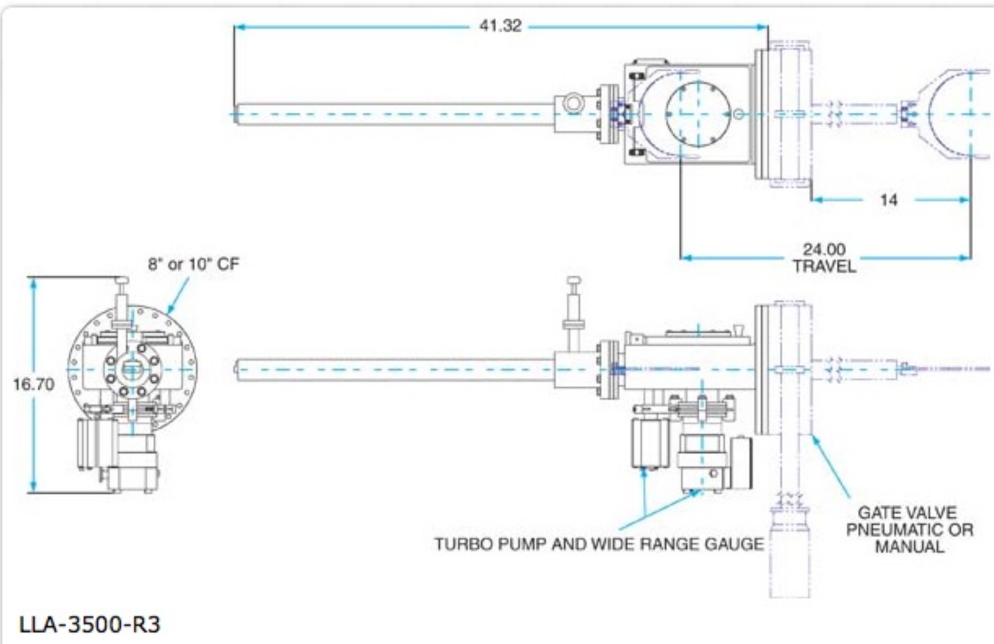
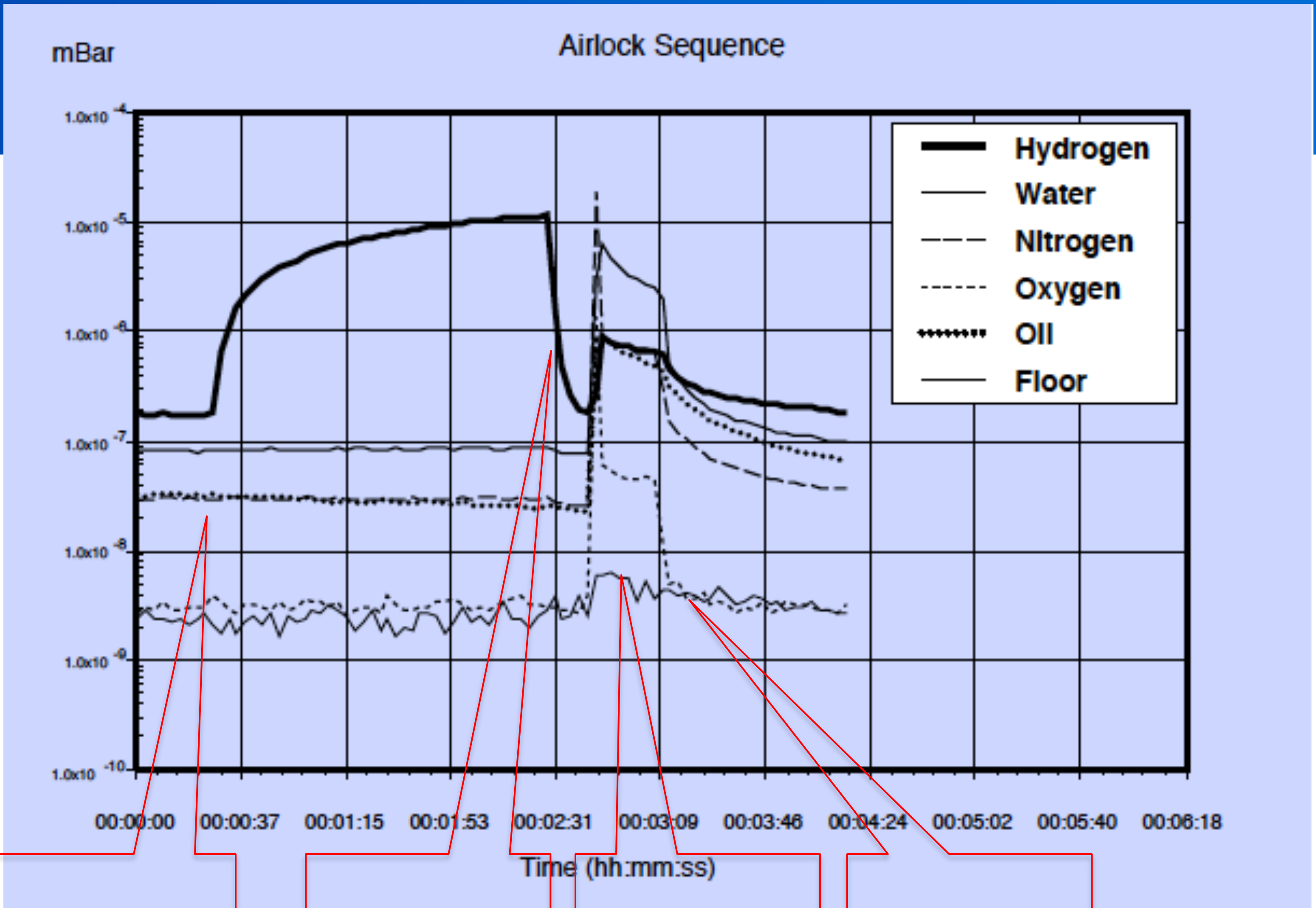
Planar Load Lock Assemblies

ENLARGE



- Connected to main chamber via gate valve
- transferring samples
- its volume can be pumped and vented without disturbing the main chamber pressure
- chamber clean from water vapor or other contaminant’s
- increased sample throughput.
- Components
- viewport
- o-ringed door
- ports for pumping and gauging



Turbo closed pumping of load lock

Turbo opened

gate valve opened

gate valve closed

Sputter cleaning effect

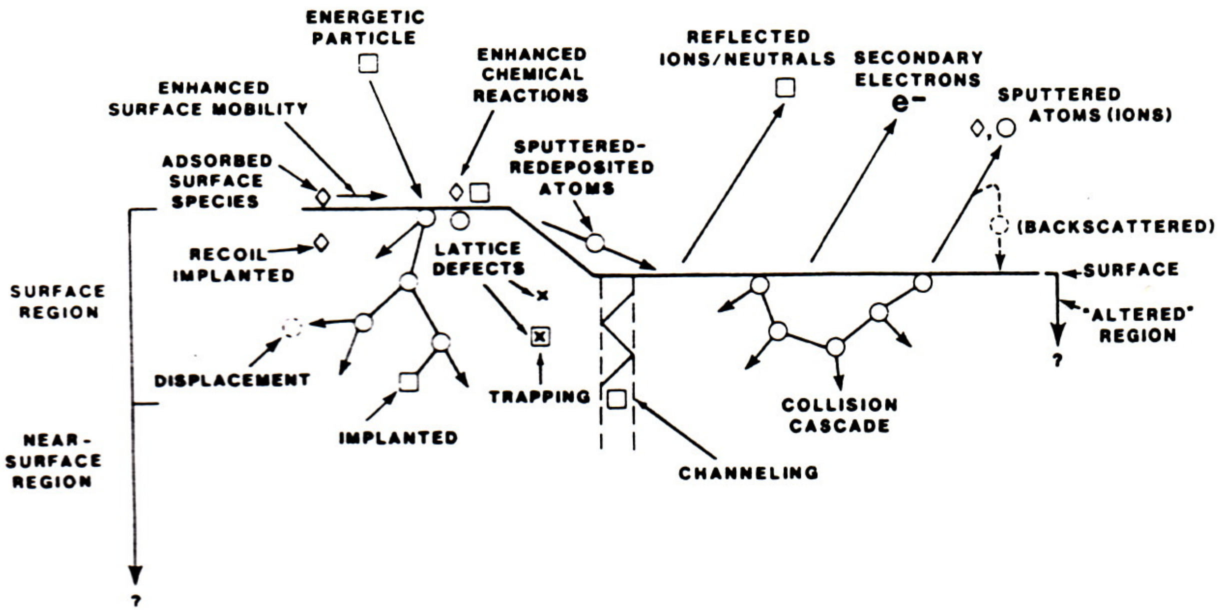
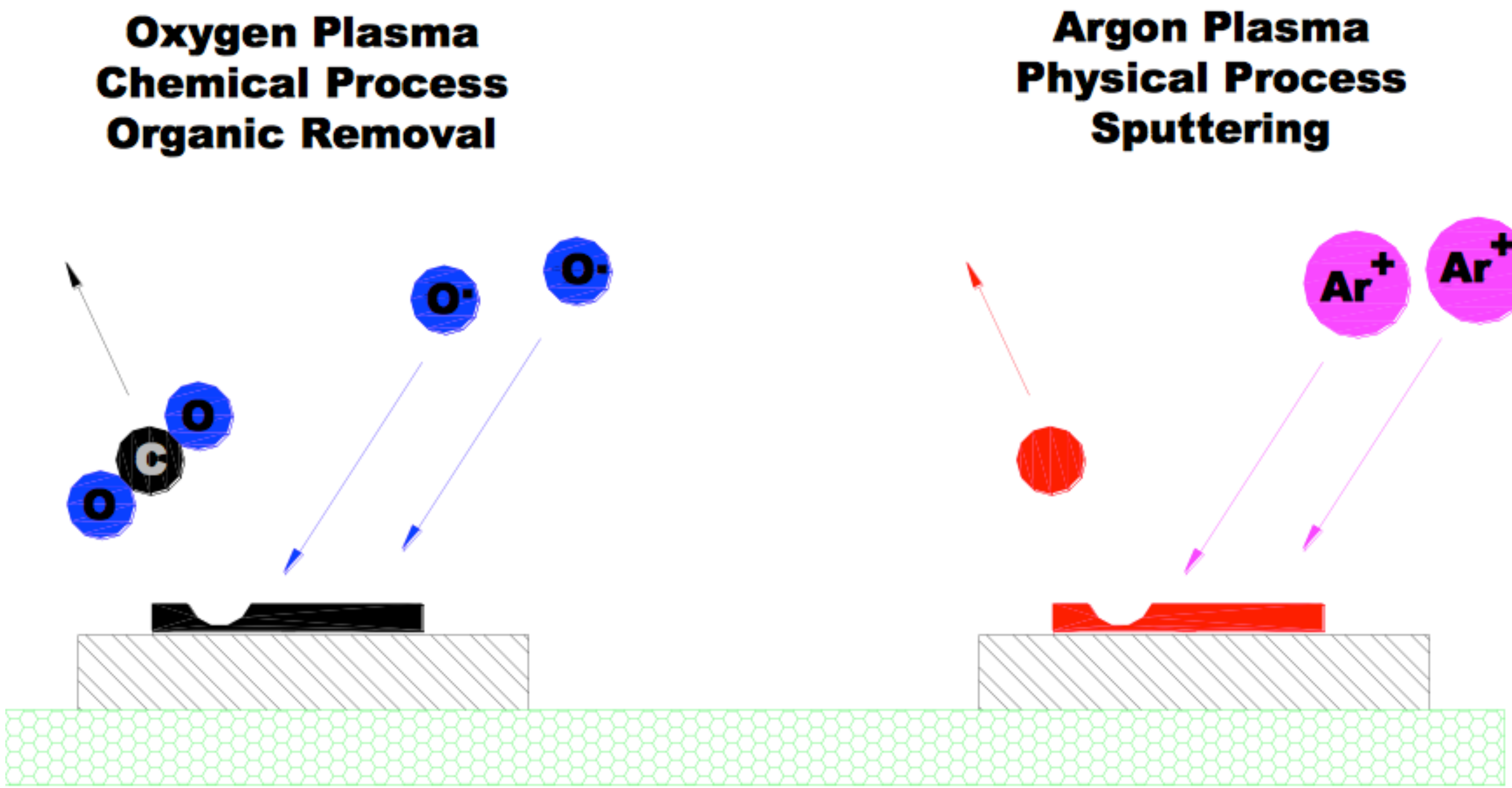


Figure 3.5. Schematic depiction of the energetic particle bombardment effects on surfaces and growing films.

Sputter cleaning using oxgen plasma or Ar-plasma



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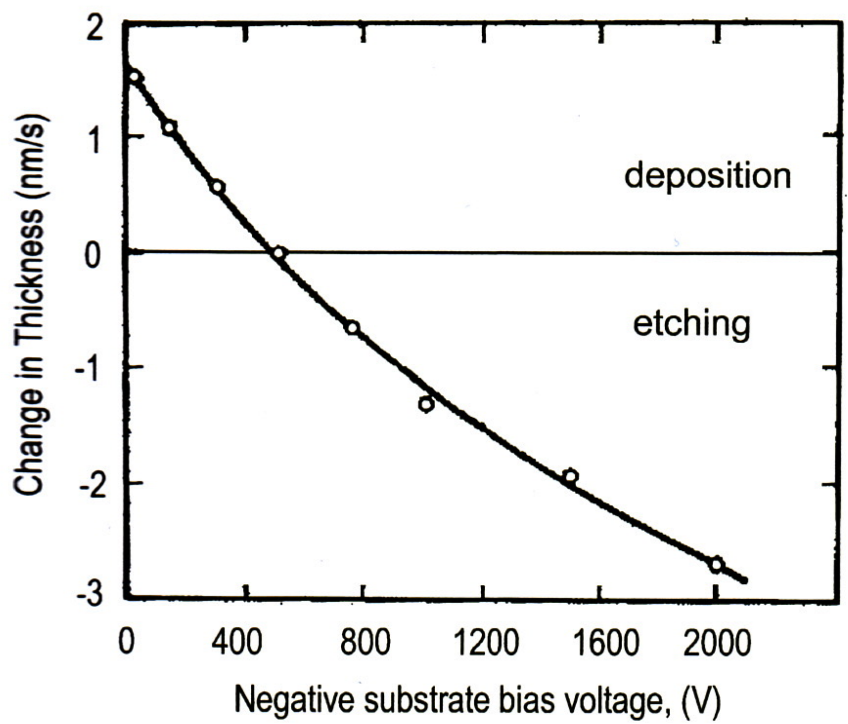
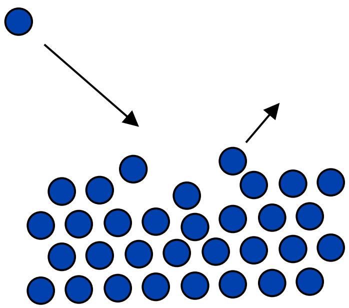
Self-sputtering of Ni ions



7. Rate of deposition or etching as a function of bias voltage for aluminum arc . (Adapted from [67])



Self sputtering of selected metals
Yield of self-sputtering

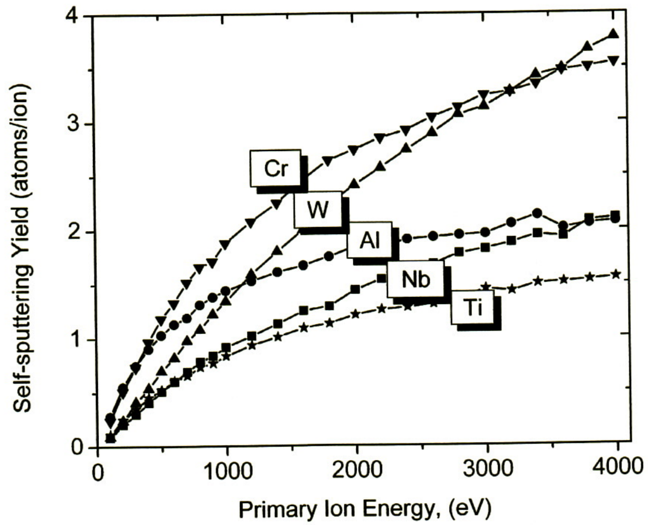


Fig. 8.16. Self-sputtering yield for selected metals as a function of ion energy (calculated by T-DYN Monte Carlo code; the apparent scatter is due to the statistics). The energy scale of up to 4 keV is quite appropriate considering the typical bias of 1 kV and the presence of multiply charged ions

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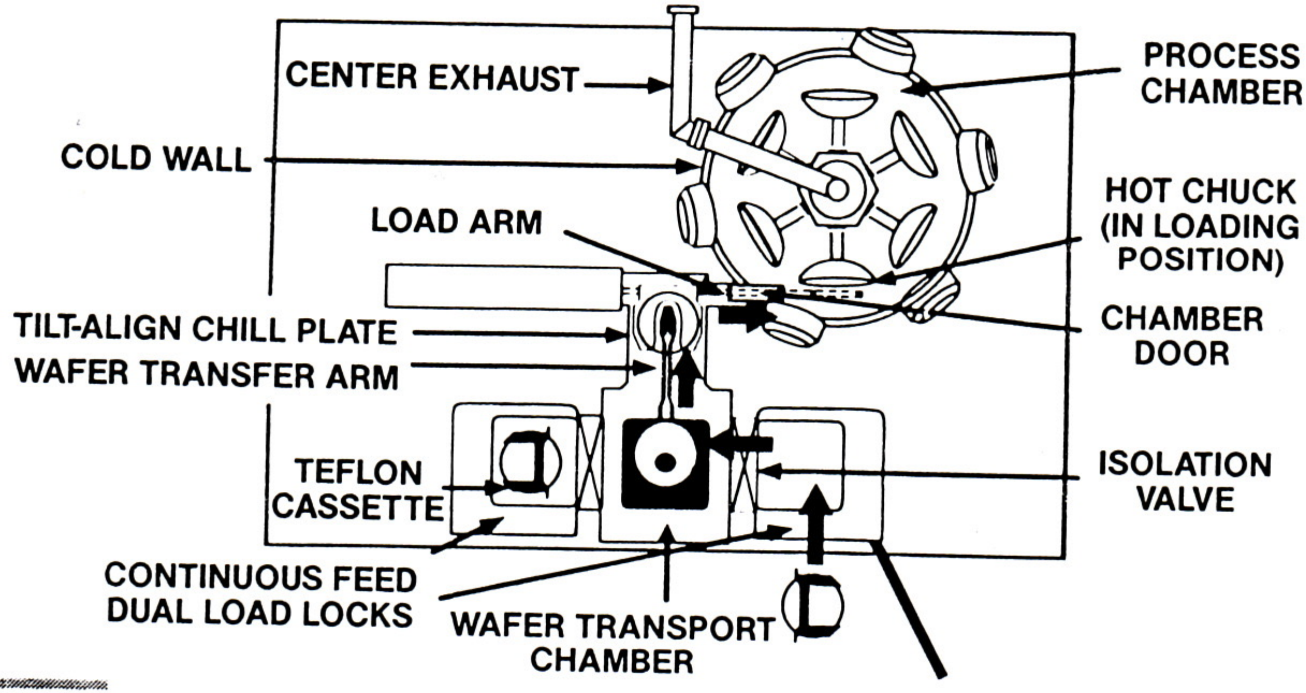
8700 CONTINUOUS FEED LOAD LOCK

Isolated Chamber Layout and Backside/Edge Wafer Transfer System



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In-situ fabrication and characterization

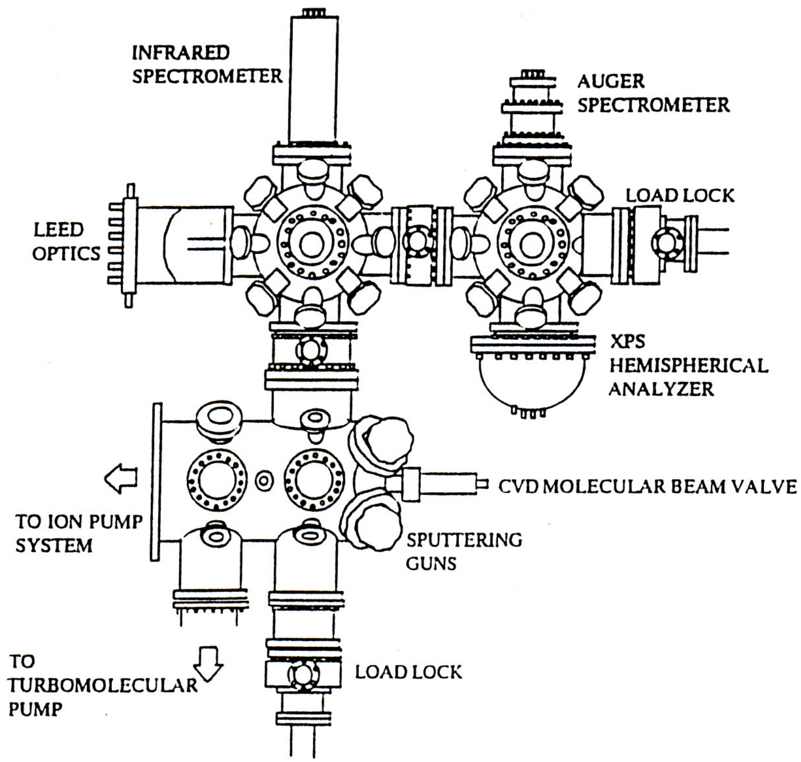

Figure 8.11. Top view of special dual-chamber system for in-situ fabrication and characterization. Courtesy of A. Kaloyeros, SUNY, Albany, NY.

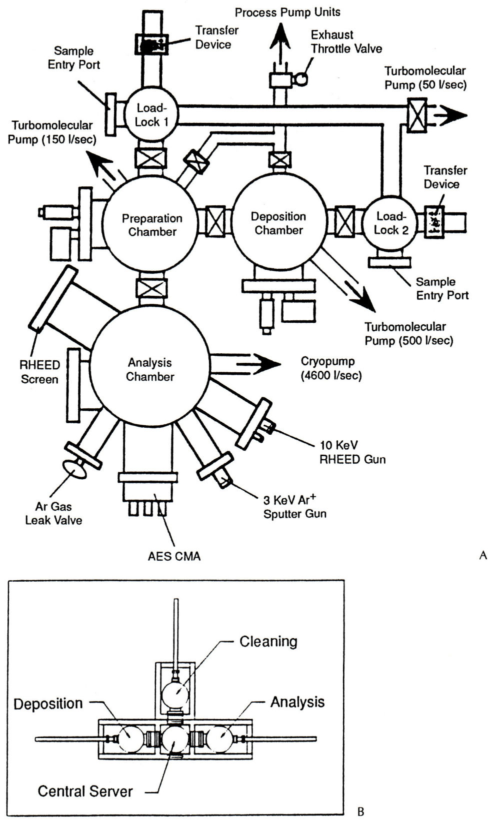

Figure 8.12. Schematic representations of multichamber integrated processing with chambers for substrate cleaning, remote PECVD deposition, and analysis (AES and RHEED or LEED). Both systems provide for substrate introduction into load-lock chambers. From Lucovsky et al [21].

Schematic of in-situ UHV processing system

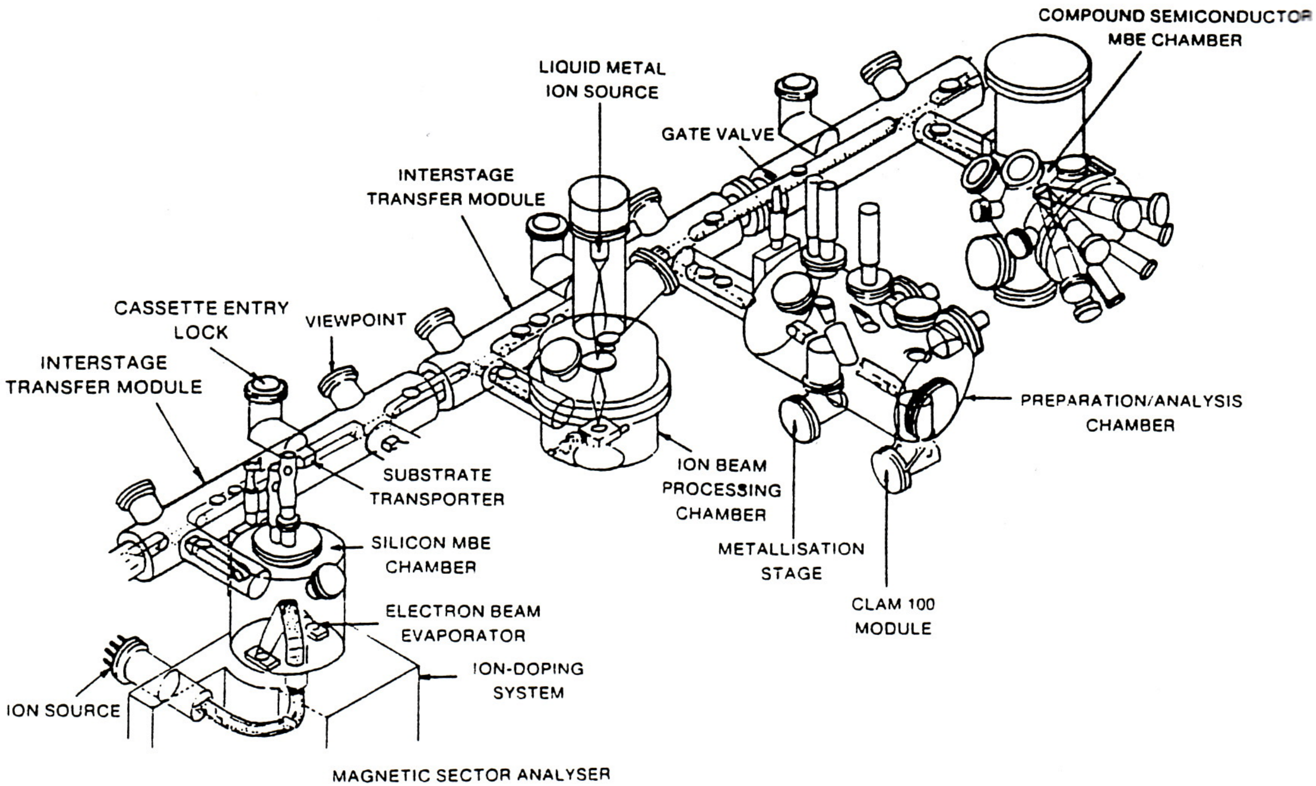

Figure 8.13. A schematic drawing of possible all-UHV in-situ processing system.

MBE system

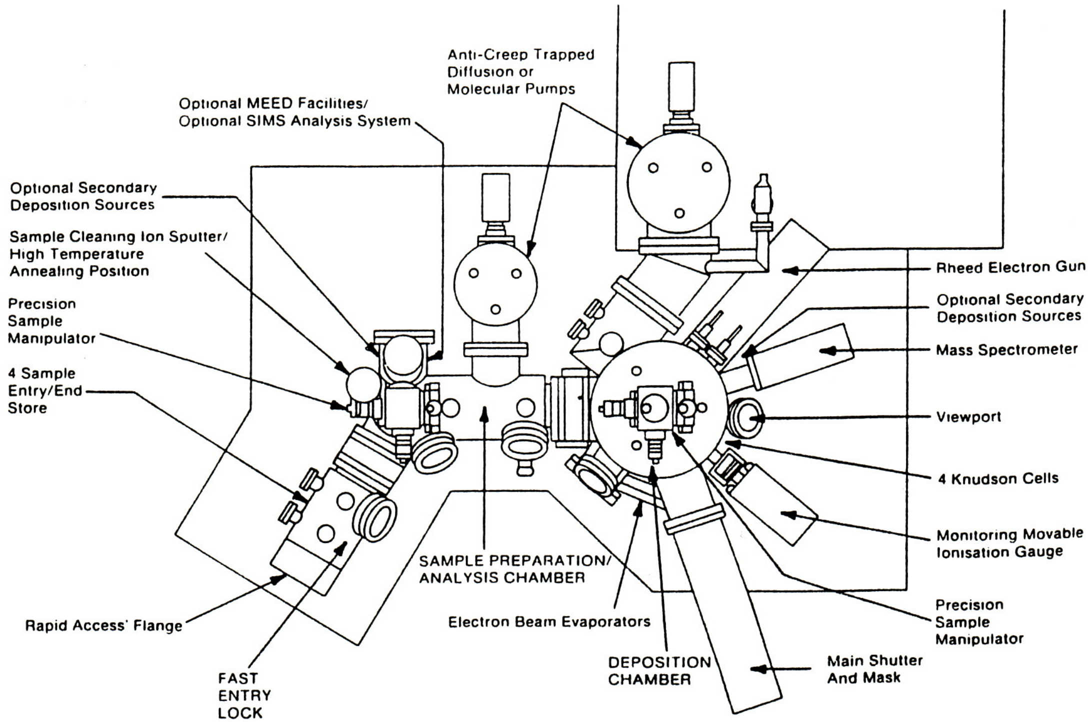

Figure 8.14. A typical sophisticated MBE system.

Vacuum system design

- Access—how large and heavy are the parts and fixturing?
- Do the parts need to have *in-situ* processing? e.g. outgassing, heating, plasma treatments, etc.
- System cleaning—is there a lot of debris generated in the process? Does the debris fall into critical areas such as valve sealing surfaces? How often will system cleaning be necessary?
- Cycle time for the system—production rate.
- How often do fixtures and tooling need to be changed?
- Is the processing sensitive to the processing environment?
- Sophistication of the operators—operator training.
- Maintenance.
- Safety aspects—high voltage, interlocks.
- Fail safe design—short or long power outages, water failure.
- Environmental concerns—exhaust to the atmosphere, traps.