Other Processes

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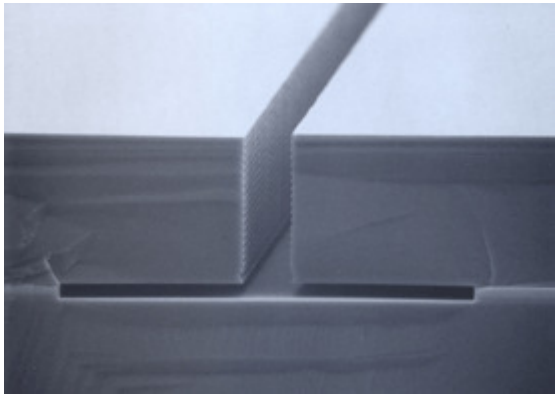
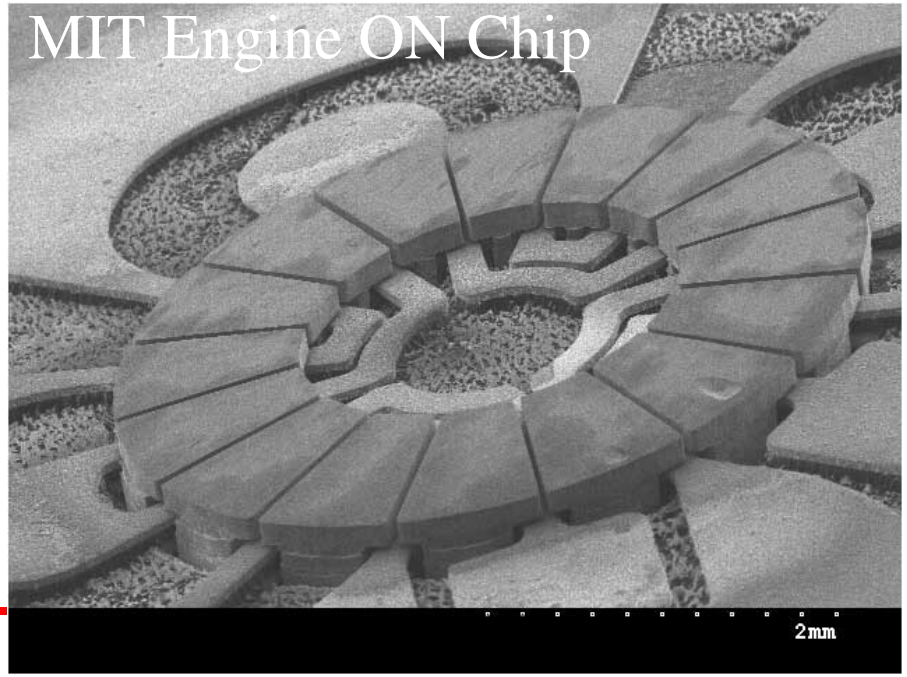
- Etching
  - Wet etching
  - Dry etching
    - Vapor phase etching
    - Plasma etching



- Treatment –
  - Doping, thermal treatment, electrical treatment, chemical treatment
- Additive process
  - Deposition, oxidation
  - CVD
  - Plating
- Mechanical methods
  - Bonding, polishing, drilling
- Others
  - Laser, 3D stereo, FIB



Several aspects of processing

- Chemistry and physics of the process
- Process variables and figure of merits
- Machine operation procedure - safety
- Principle of machine operation and machine parts
  - Vendors and pricing of machine, parts, supplies
- Electronic and mechanical subsystems of machine
- Supplies for the process
- Safety precautions and potential hazards
- Process behavior with materials and wafers
  - Rate
  - Uniformity
  - Repeatability
  - Temperature or chemical stability
  - Peculiarities (how does the process work differently after so and so worked on it before you ☺).
- Jargons

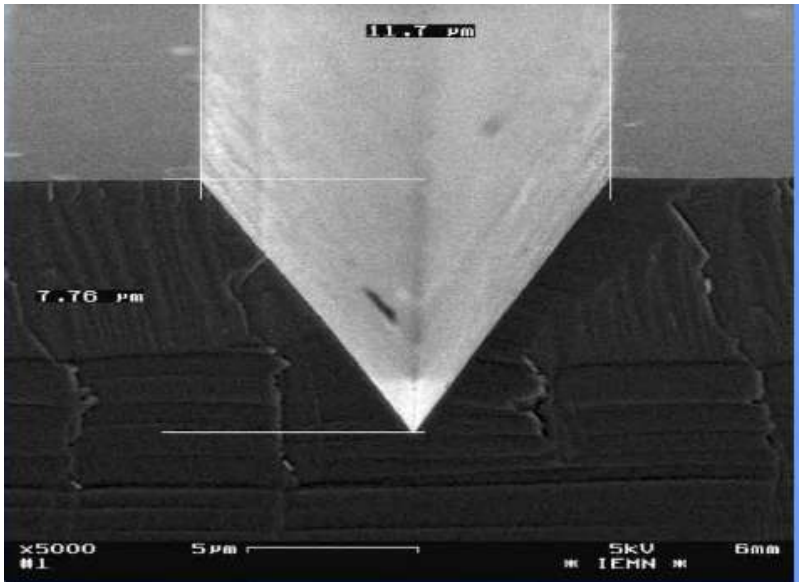
Process Resume

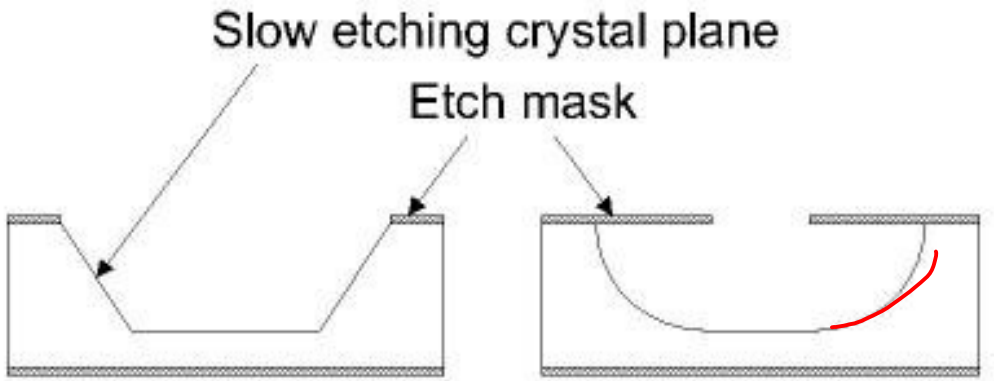
Resume:

- Chemistry and physics
- Process variables
- Jargons
- Common process

Wet Etching Types

- Isotropic etching
  - Substrate: silicon, glass, thin films (oxide, nitride)
- Anisotropic etching
  - Substrate: silicon, III-V compound





Anisotropic Isotropic

Etch Rates for Micromachining Processing—Part II

Kirt R. Williams, *Senior Member, IEEE*, Kishan Gupta, *Student Member, IEEE*, and Matthew Wasilik

Etchant	Etchant Abbrev.	Target Material
Isotropic Silicon Etchant "Trilogy Etch" (126 HNO_3 : 60 H_2O : 5 NH_4F), ~20°C	Si Iso Etch	Silicon
KOH (30% by weight), 80°C	KOH	Silicon GDE
10:1 HF (10 H_2O : 1 49% HF), ~20°C	10:1 HF	Silicon Dioxide
5:1 BHF (5 40% NH_4F : 1 49% HF), ~20°C	5:1 BHF	Silicon Dioxide
Pad Etch 4 from Ashland (13% NH_4F + 32% HAc + 49% H_2O + 6% propylene glycol + surfactant), ~20°C	Pad Etch 4	SiO_2, not Al
Phosphoric Acid (85% by weight), 160°C	Phosphoric	Silicon nitride
Al Etchant Type A from Transene (80% H_3PO_4 + 5% HNO_3 + 5% HAc +10%H_2O), 50°C	Al Etch A	Aluminum
Titanium wet etchant (20 H_2O : 1 H_2O_2 : 1 HF), ~20°C	Ti Etch	Titanium
Chromium etchant CR-7 from Cyantek (9% $(NH_4)_2Ce(NO_3)_6$ + 6% $HClO_4$ + H_2O), ~20°C	CR-7	Chromium
Chromium etchant CR-14 from Cyantek (23% $(NH_4)_2Ce(NO_3)_6$ ± 8% HAc± H_2O), ~30°C	CR-14	Chromium
Molybdenum etchant (180 H_3PO_4 : 11 HAc : 11 HNO_3 : 150 H_2O), ~20°C	Moly Etch	Molybdenum
Hydrogen peroxide (30wt% H_2O_2, 70wt% H_2O), 50°C	H_2O_2 50°C	Tungsten
Copper etchant type CE-200 from Transene (30% $FeCl_3$ + 3-4% HCl + H_2O), ~20°C	Cu $FeCl_3$ 200	Copper
Copper etchant APS 100 from Transene (15-20% $(NH_4)_2S_2O_8$ + H_2O), 30°C	Cu APS 100	Copper
Dilute aqua regia (3 HCl : 1 HNO_3 : 2 H_2O), ~30°C	Dil. Aqua regia	Noble metals
Gold etchant AU-5 from Cyantek (5% I_2 +10% KI + 85% H_2O), ~20°C	AU-5	Gold
Nichrome etchant TFN from Transene (10-20% $(NH_4)_2Ce(NO_3)_6$ + 5-6% HNO_3 + H_2O), ~20°C	NiCr TFN	NiCr
1 H_2SO_4 : 1 H_3PO_4, 160°C	Phos+Sulf	Sapphire
Piranha (~50 H_2SO4 : 1 H_2O_2), 120°C	Piranha	Cleaning
Microstrip 2001 photoresist stripper, 85°C	Microstrip	Photoresist
Acetone, ~35°C	Acetone	Photoresist
Methanol, ~20°C	Methanol	Cleaning
Isopropanol, ~20°C	IPA	Cleaning
XeF_2, 2.6 mTorr, homemade chamber	XeF_2	Silicon
HF + H_2O vapor, 1 cm over dish with 49% HF	HF vapor	Silicon dioxide
Technics plasma, O_2, 400 W @ 30 kHz, 300 mTorr	Technics O_2	Photoresist
STS ASE DRIE, mechanical chuck, high frequency, typical recipe	DRIE HF mech.	Silicon
STS ASE DRIE, electrostatic chuck, high frequency, typical recipe	DRIE HF ES	Silicon
STS ASE DRIE, mechanical chuck, stop-on-oxide (low-frequency platen), typical recipe	DRIE LF mech.	Silicon
STS ASE DRIE, electrostatic chuck, stop-on-oxide (low-frequency platen), typical recipe	DRIE LF ES	Silicon
STS 320 RIE, SF_6, 100 W @13.56 MHz, 20 mTorr	STS 320 SF_6	Si, SiN, metals
STS 320 RIE, SF_6 + O_2, 100 W @13.56 MHz, 20 mTorr	STS SF_6+O_2	Si, SiN, metals
STS 320 RIE, CF_4, 100 W @13.56 MHz, 60 mTorr	STS 320 CF_4	Si, SiO, SiN
STS 320 RIE, CF_4 + O_2, 100 W @13.56 MHz, 60 mTorr	STS CF_4+O_2	Si, SiO, SiN
Ion milling with argon ions at 500 V, ~1 mA/cm^2, normal incidence (Commonwealth Scientific)	Ion Mill	Everything

Notation:
BHF = buffered hydrofluoric acid
DRIE = deep reactive ion etch
RIE = reactive ion etch
STS ASE = Surface Technology Systems Advanced Silicon Etch

Etch	Si (100) Wafer	Float-Zone Si Wafer	Poly Si LPCVD Undoped	Poly Si LPCVD In situ n+	Poly Ge LPCVD Undoped	Poly SiGe LPCVD P+ type	Graphite Ion-Milled
Si Iso Etch	150	W	100	310	890	550	60
KOH	1100	F	670	>1000	-	-	-
10:1 HF	S	S	0	0.7	0	0.42	-
5:1 BHF	0	S	0.2	0.9	R 1.8	0.45	R 17
Pad Etch 4	S	S	S	S	-	-	-
Phosphoric	0.17	S	S	0.7	0.13	0.40	-
Al Etch A	S	S	<0.9	<1	13	0.11	-
Ti Etch	S	S	S	1.2	-	-	-
CR-7	0	S	0	S	260	-	-
CR-14	S	S	0	S	-	-	-
Moly Etch	-	-	-	-	-	-	-
H_2O_2 50°C	S	S	S	S	460	-	-
Cu $FeCl_3$ 200	-	-	-	-	-	-	-
Cu APS 100	-	-	-	-	-	-	-
Dil. Aqua regia	0	0	0	0	-	-	-
AU-5	S	S	0	S	-	-	-
NiCr TFN	0	S	S	S	-	-	-
Phos+Sulf	0.86	S	S	S	-	-	-
Piranha	0	S	0	0	soft	-	-
Microstrip	S	S	S	S	-	-	-
Acetone	S	S	0	0	-	-	-
Methanol	S	S	0	S	-	-	-
IPA	S	S	S	S	-	-	-
XeF_2	400	W	160	100	-	-	-
HF vapor	S	S	0	0	-	-	-
Technics O_2	S	S	0	0	-	-	-
DRIE HF mech.	1500	1600	W	W	-	-	-
DRIE HF ES	2400	W	W	W	400	-	-
DRIE LF mech.	2400	W	W	W	-	-	-
DRIE LF ES	2000	W	W	W	170	-	-
STS 320 SF_6	W	W	W	W	-	-	-
STS SF_6+O_2	1500	W	W	W	-	-	-
STS 320 CF_4	W	W	W	W	-	-	-
STS CF_4+O_2	95	-	-	-	-	-	-
Ion Mill	38	38	38	38	-	-	4.4

Etch	Fused Quartz Wafer	Pyrex 7740 Wafer	Thermal Oxide Wet-Gen	Ann. LTO LPCVD Calogic	Unan. LTO LPCVD Tylan	Ann. LTO LPCVD Tylan	Unan. PSG LPCVD Tylan	Ann. PSG LPCVD Tylan	Oxide PECVD Unannealed	Oxide PECVD Annealed	Oxide Ion-Mill
Si Iso Etch	12	R 140	8.7	15	-	11	400	170	100	25	43
KOH	8.7	11	7.7	8.1	-	9.4	-	38	15	7.8	8.0
10:1 HF	26	W	23	W	W	34	1500	470	W	W	W
5:1 BHF	130	43	100	150	W	120	680	440	490	240	82
Pad Etch 4	29	17	31	W	30	W	200	W	100	W	W
Phosphoric	0.23	3.7	0.18	S	0.21	0.21	2.7	1.8	-	-	S
Al Etch A	S	-	0	S	S	0	S	<1	0	S	S
Ti Etch	-	-	12	W	W	W	W	210	W	W	-
CR-7	R <0.4	R 0	0.02	0	S	S	S	S	0	0	0
CR-14	S	-	0.01	S	S	S	S	S	S	S	S
Moly Etch	-	-	-	-	-	-	-	-	-	-	-
H_2O_2 50°C	S	S	0	S	S	S	S	S	S	S	S
Cu $FeCl_3$ 200	-	-	-	-	-	-	-	-	-	-	-
Cu APS 100	-	-	-	-	-	-	-	-	-	-	-
Dil. Aqua regia	0	-	0	0	0	0	0	0	0.7	S	S
AU-5	S	-	S	S	S	S	S	S	0	S	S
NiCr TFN	S	-	S	S	S	S	S	S	S	S	S
Phos+Sulf	S	-	0.057	S	S	S	S	S	S	S	S
Piranha	R 0	R 0	0	0	S	0	S	0	0	0	0
Microstrip	S	S	S	S	S	S	S	S	S	S	S
Acetone	S	S	0	0	0	0	S	0	3	3	3
Methanol	S	S	S	S	S	S	S	S	S	S	S
IPA	S	S	S	S	S	S	S	S	S	S	S
XeF_2	S	-	0	S	S	0	0	0	S	S	S
HF vapor	W	W	66	W	W	78	210	150	W	W	W
Technics O_2	S	S	0	S	S	0	0	0	S	S	S
DRIE HF mech.	S	-	S	7.5	6.2	6.9	9.5	11	9.5	S	S
DRIE HF ES	S	-	24	W	W	W	W	W	W	W	W
DRIE LF mech.	0	-	0	0.0	8.0	9.4	13	13	4.0	3	3
DRIE LF ES	S	-	24	W	W	W	W	W	W	W	W
STS 320 SF_6	W	-	W	W	W	W	W	W	W	W	W
STS SF_6+O_2	35	10	29	38	55	48	73	60	55	32	30
STS 320 CF_4	Yt	Yt	W	22	W	W	W	W	W	W	W
STS CF_4+O_2	41	31	44	42	51	46	69	62	51	43	21
Ion Mill	W	W	39	W	W	W	W	W	W	W	W

Notation:
W = Etch known to work, but etch rate not measured
F = Etch known to be fast, but etch rate not measured
S = Etch rate known to be slow or zero, but etch rate not measured
R = Film was visibly roughened or attacked
T = Thicker after etch (due to swelling or compound formation)
P = Some of film peeled during etch or when rinsed
I = Incubation time before etching fully starts
C = Film congealed
soft = a soft material remained after etching

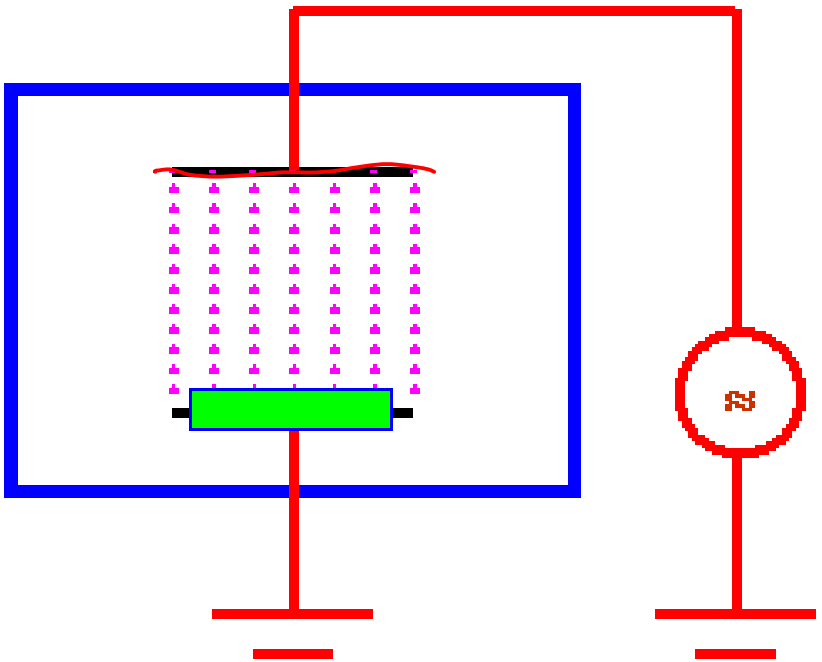
Ion-Milled = Ion-mill deposited
LPCVD = low-pressure chemical-vapor deposition
poly Ge = polycrystalline germanium
poly SiGe = polycrystalline SiGe
poly Si = polycrystalline silicon

Process Resume

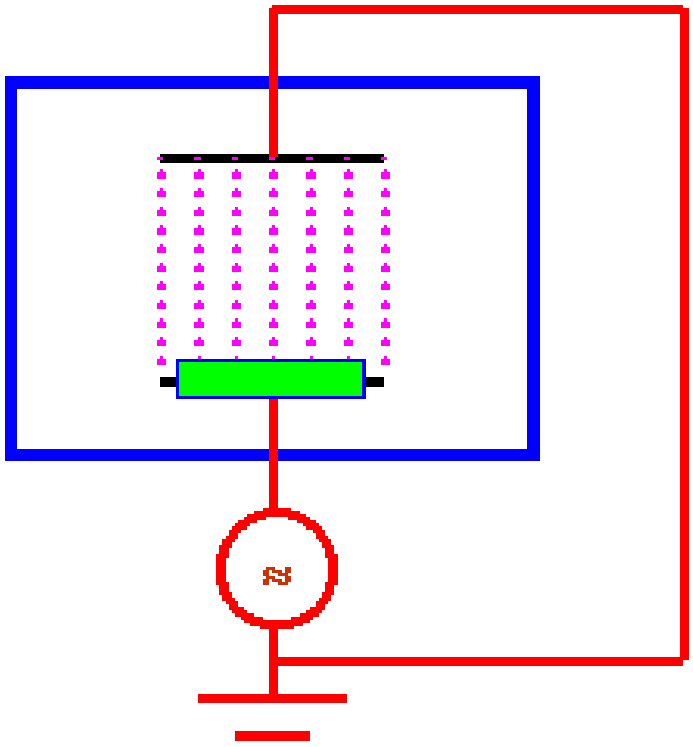
Resume: Wet Etch

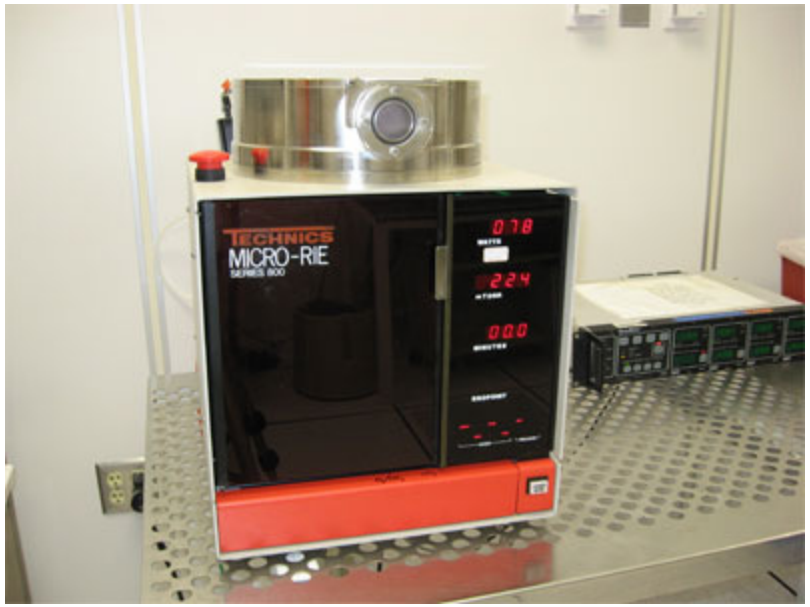
- Chemistry and physics
  - Solution phase chemical reaction and etching
  - Substrates, thin films
- Process variables
  - Temperature
  - Concentration
  - Mixture cocktail percentages
- Jargons
  - Under cut
  - <111>
  - <100>
  - <110>
  - Aspect ratio
- Common process
  - HF etch oxide
  - EDP or KOH etch silicon
  - HNA etch silicon
  - Metal etchants etch metal

Plasma Etching



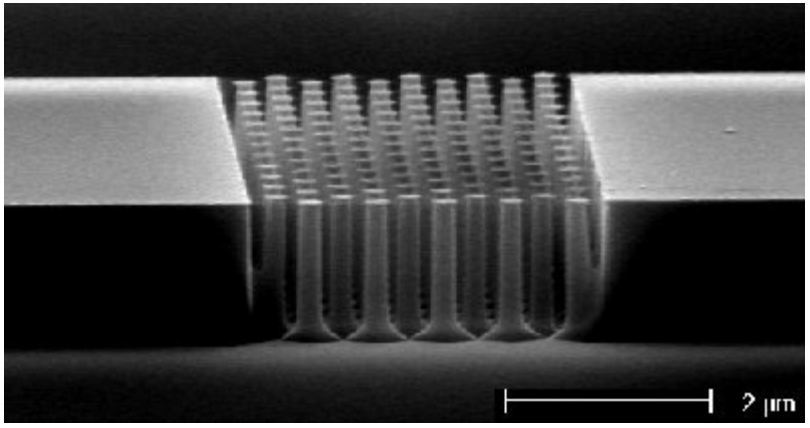
Reactive Ion Etching





Variants

- High aspect ratio, deep reactive ion etching
  - Cryogenic
  - Bosch process



Process Resume

Resume: Dry Etch

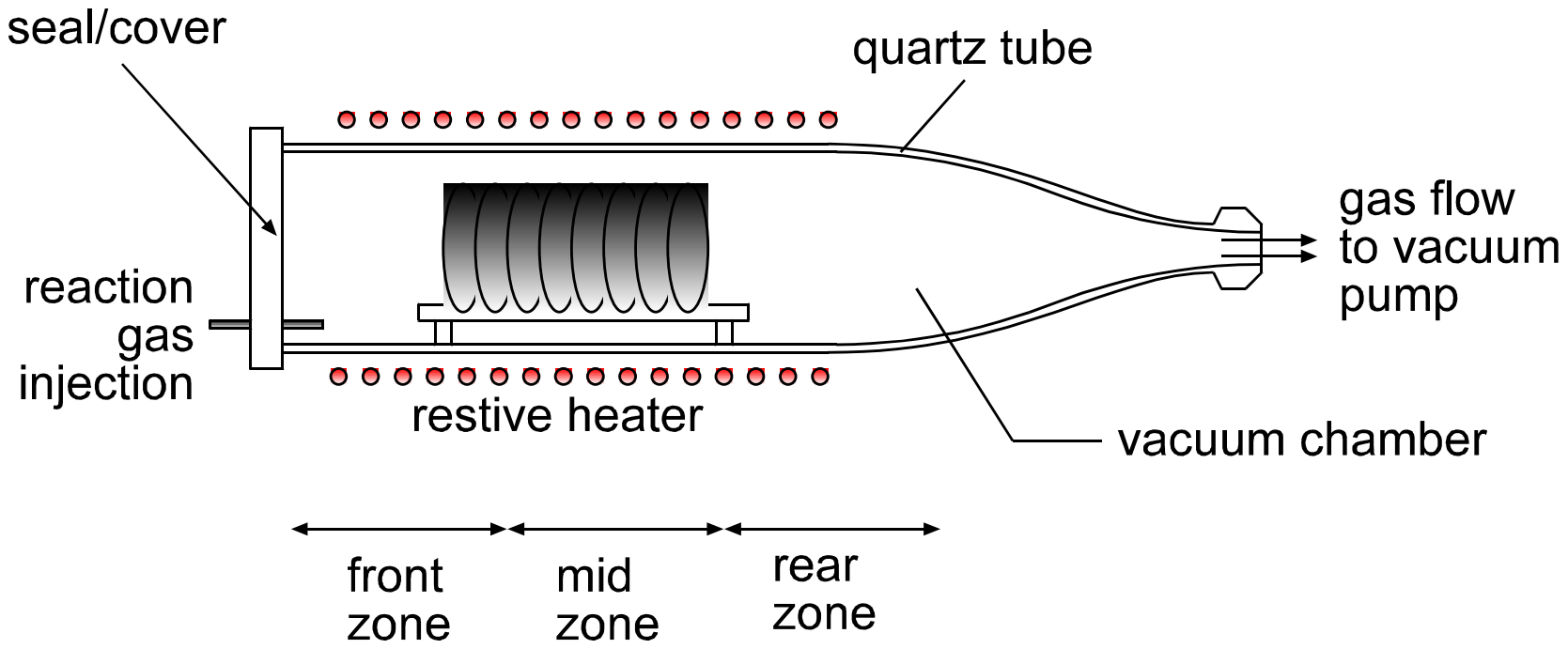
- Chemistry and physics
  - High voltage induces ionization of gas, which then accelerates to wafer surfaces
  - Both chemical and physical reactions occur
- Jargons
  - Passivation
- Process variables
  - Power input
  - DC/AC ratio
  - Temperature of substrate
  - Gas mixture
- Common process
  - CF4 plasma etch nitride
  - SF6 plasma etch of silicon
  - Bosch DRIE of silicon
  - Oxygen plasma ashing

Chemical Vapor Deposition

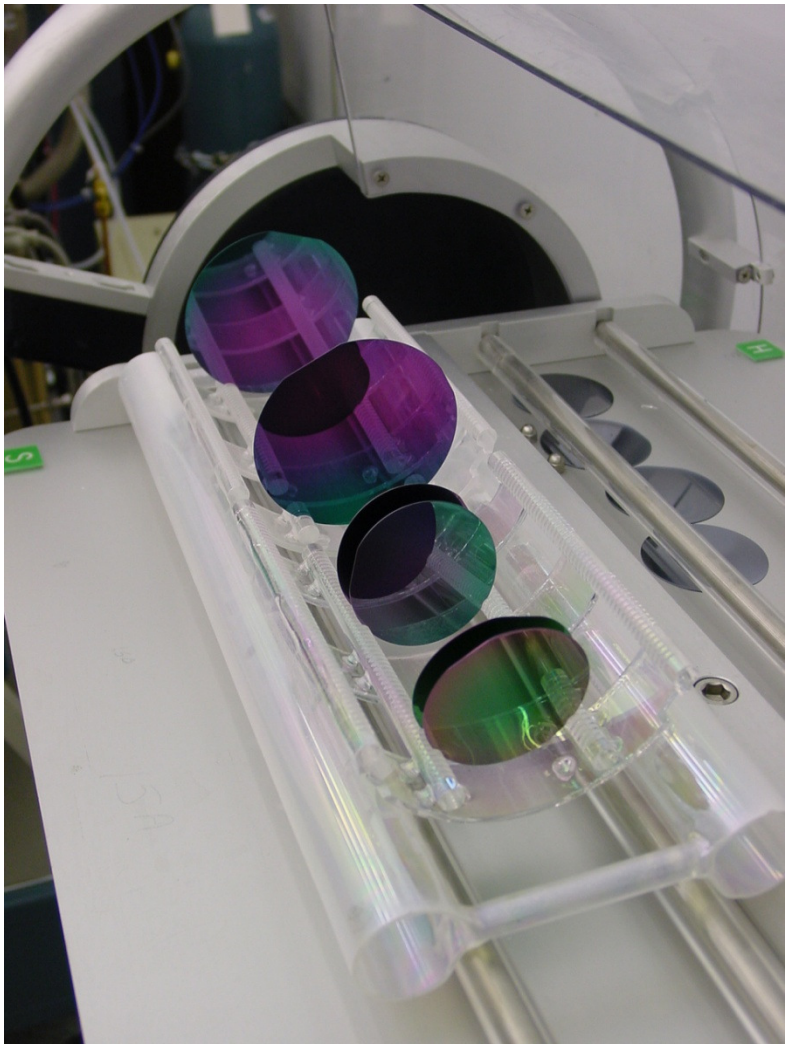
- Low Pressure chemical vapor deposition
- Plasma enhanced chemical vapor deposition
- Polymer deposition

LPCVD Process

- Temperature range 500-800 degrees
- Pressure range 200 - 400 mtorr (1 torr = 1/760 ATM)
- Gas mixture: typically 2-3 gas mixture
- Particle free environment to prevent defects on surface (pin holes)



A Laboratory LPCVD Machine



LPCVD Recipes for Silicon Nitride, Polysilicon, and Oxide

- Polycrystalline silicon
  - Polysilicon is deposited at around 580-620 ^{o}C and can withstand more than 1000 ^{o}C temperature. The deposition is conducted by decomposing silane (SiH4) under high temperature and vacuum (SiH_4> $Si+2H_2$).
  - Polysilicon is used extensively in IC - transistor gate
- Silicon nitride
  - Silicon nitride is nonconducting and has tensile intrinsic stress on top of silicon substrates. It is deposited at around 800 ^{o}C by reacting silane (SiH_4) or dichlorosilane ($SiCl_2H_2$) with ammonia (NH_3) - SiH_4+NH_3 -> Si_xN_y+ H.
- Silicon oxide
  - The PSG is knows to reflow under high temperature (e.g. above 900 ^{o}C); it is deposited under relatively low temperature, e.g. 500 ^{o}C by reacting silane with oxygen (SiH_4+O_2-> $SiO_2+2H_{2)}$. PSG can be deposited on top of Al metallization.
  - Silicon oxide is used for sealing IC circuits after processing.
  - The etch rate of HF on oxide is a function of doping concentration.

A PECVD Machine

Processing gases

Reaction chamber

RF plasma generator

Resume: Chemical Vapor Deposition

Process Resume

- Chemistry and physics
  - Chemical reaction of two gases deposit solid particles on sufaces
  - Energy is provided by either temperature or plasma power.
- Jargons
  - LPCVD
  - PECVD
  -
- Process variables
  - Temperature
  - Pressure
  - Gas mixture
- Common process
  - LPCVD of oxide
  - LPCVD of nitride
  - LPCVD of polysilicon
  - PECVD of oxide
  - PECVD of nitride
  - PECVD of amorphous silicon