ROCHESTER INSTITUTE OF TEHNOLOGY
MICROELECTRONIC ENGINEERING

Microelectromechanical Systems (MEMs)
Unit Processes for MEMs
Etching

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4-4-2008 mem_etch.ppt

OUTLINE

- Basics
  - Concentration, Molarity, Normality
  - Selectivity, Anisotropy
- Subtractive Processes
  - Wet Etching
  - Plasma Etching
  - Endpoint Detection
  - CMP
- References

WET ETCH BASICS

Concentration: Often expressed as a weight percentage. That is the ratio of the weight of solute in a given weight solution. For example a solution containing 5 gms of solute in 95 grams of solvent is a 5 % solution.

Molarity: concentration expressed as moles of solute in 1 liter of solution. A solution containing one mole of solute in 1 liter of solution is termed a molar (1M) solution. A mole is the molecular weight in grams. Example: 10 gms of sulfuric acid in 500 ml of solution. H2SO4 has molecular weight of 1x2+32+16x4=98 so 10gms/98gm/M = 0.102M and 500ml is 1/2 liter, so this solution is 0.204 Molar

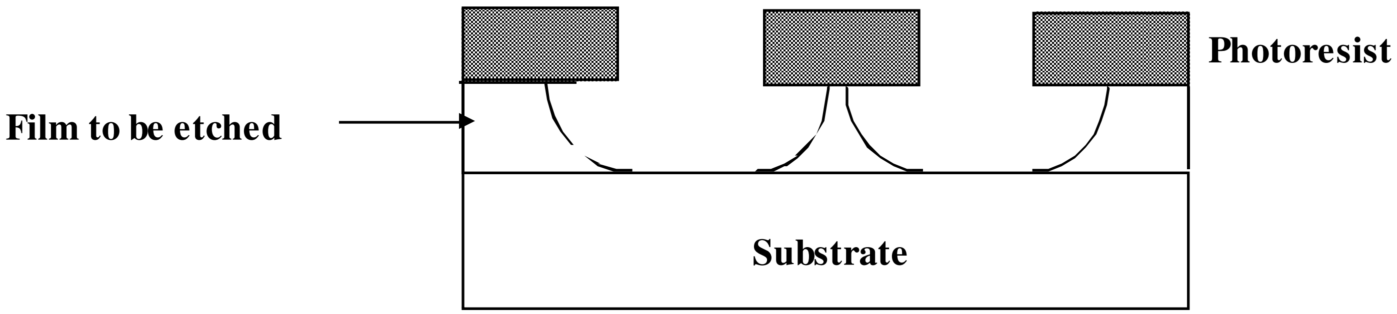
WET ETCH BASICS

Normality: concentration expressed as equivalents of solute in 1 liter of solution. One equivalent of a substance is the weight (1) which (as an acid) contains 1 gram atom of replaceable hydrogen; or (2) which (as a base) reacts with a gram atom of hydrogen; or (3) which (as a salt) is produced in a reaction involving 1 gram atom of hydrogen. Example 36.5 g of HCl contains 1 g atom of replaceable hydrogen and is an equivalent. 40 g of NaOH will react with 36.5 g of HCL which contains 1 g atom of hydrogen thus 40 g of NaOH is an equivalent. 98 grams of H2SO4 contains two gram atoms of hydrogen so 98/2 = 49 is one equivalent.

How many gams of sulfuric acid are contained in 3 liters of 0.5N solution?
(answer: 74.5g)

ISOTROPIC AND ANISOTROPIC ETCHING

Isotropic Etching - etches at equal rate in all directions



Anisotropic Etching - etches faster vertically than horizontally

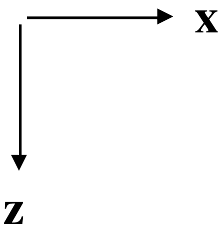
Wet Chemical Etching - is isotropic (except in crystalline materials)

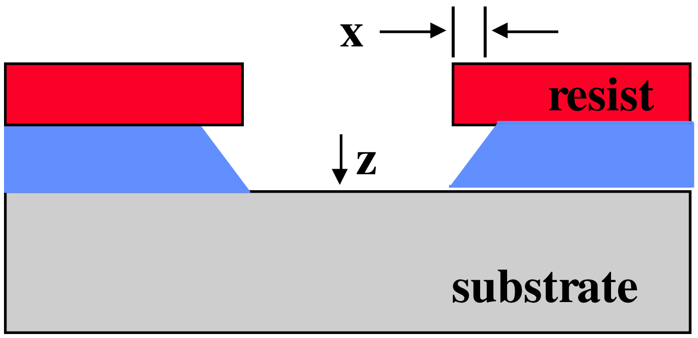
Plasma Etching (Dry Etch or Reactive Ion Etching, RIE) - is either isotropic or anisotropic depending on ion energy and chemistry of etch.

DEGREE OF ANISOTROPY

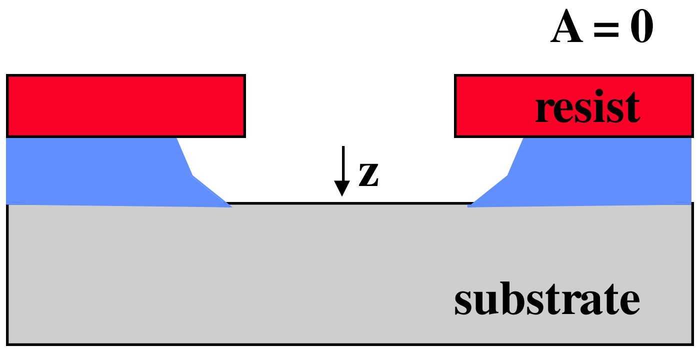
Degree of Anisotropy

A = (z-x)/z

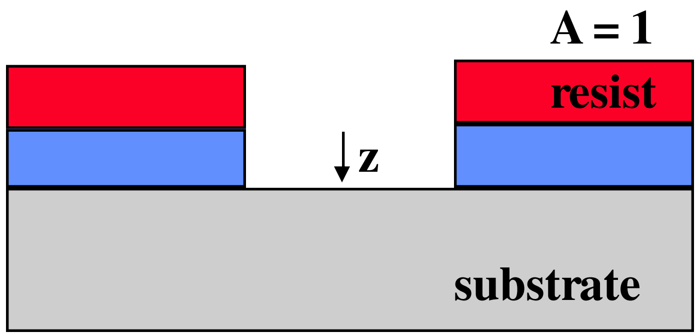




Anisotropic Etch



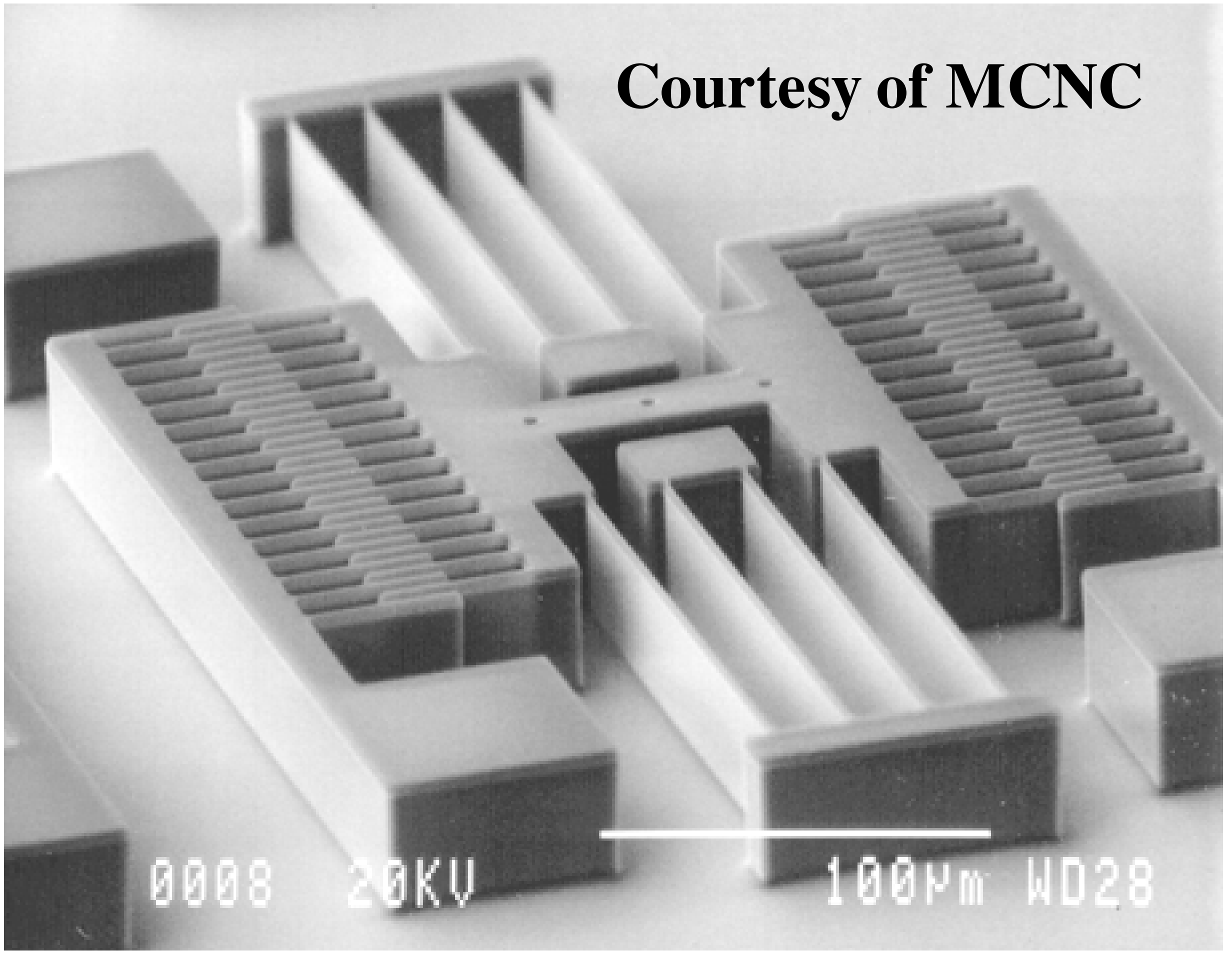
Isotropic Etch



Anisotropic Etch

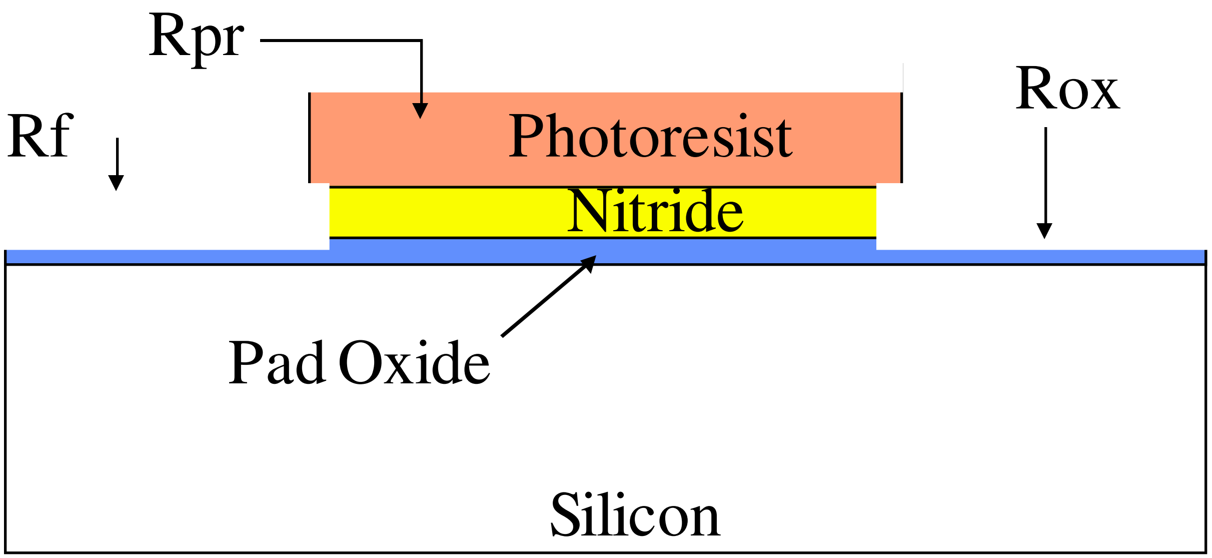
ANISOTROPIC ETCH, HIGH ASPECT RATIO

Silicon Accelerometer



Courtesy of MCNC

SELECTIVITY



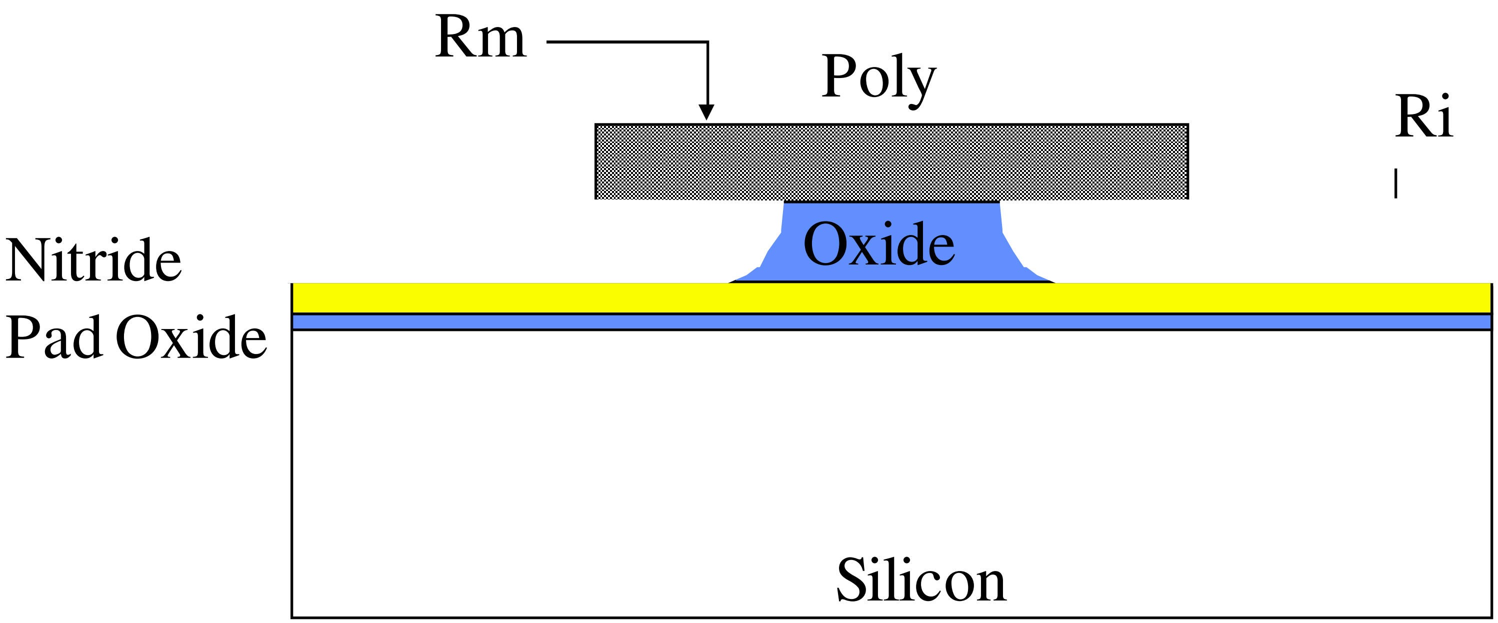
Rf = etch rate for nitride film
Rpr = etch rate for photoresist
Rox = etch rate for pad oxide

We want Rf high and Rpr, Rox low

Selectivity of film to Photoresist = Rf/Rph

Selectivity of film to pad oxide = Rf/Rox

SELECTIVITY



Rs = etch rate for spacer
Rm = etch rate for microstructure
Ri = etch rate for insulator

We want Rs high and Rm, Ri low

Selectivity of sacrificial oxide to Poly = Rs/Rm

Selectivity of sacrificial oxide to Nitride = Rs/Ri

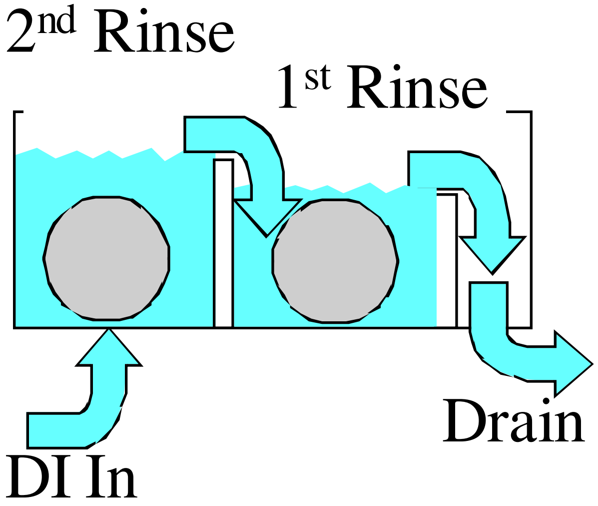
DI WATER

City Water In
Mixed Bed Filter
Water Softener
Charcoal Filter
Heat Exchanger
Reverse Osmosis Filters (6 Mohm)
Storage Tank
Recirculation Pumps
Resin Bed Filters (Rho = 18 Mohm)
Ultraviolet Light Anti Bacteria System
Final 0.2 um Particulate Filters
Special Piping

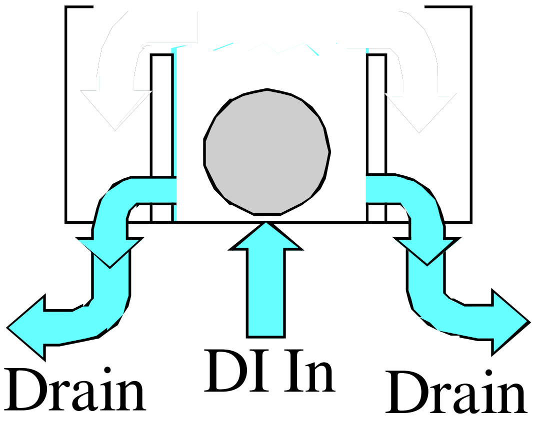
DI Water Plant at RIT

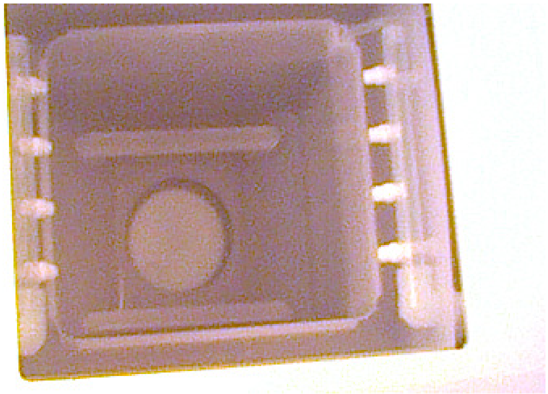
RINSE TANKS

Cascade Rinser



Dump Rinser





Spin Rinse Dry (SRD)

WET ETCHING OF SILICON DIOXIDE

HF with or without the addition of ammonium flouride (NH_4F). The addition of ammonium flouride creates a buffered HF solution (BHF) also called buffered oxide etch (BOE). The addition of NH_4F to HF controls the pH value and replenishes the depletion of the fluoride ions, thus maintaining stable etch rate.

$$SiO_2 + 6HF = H_2SiF_6 + 2H_2O$$

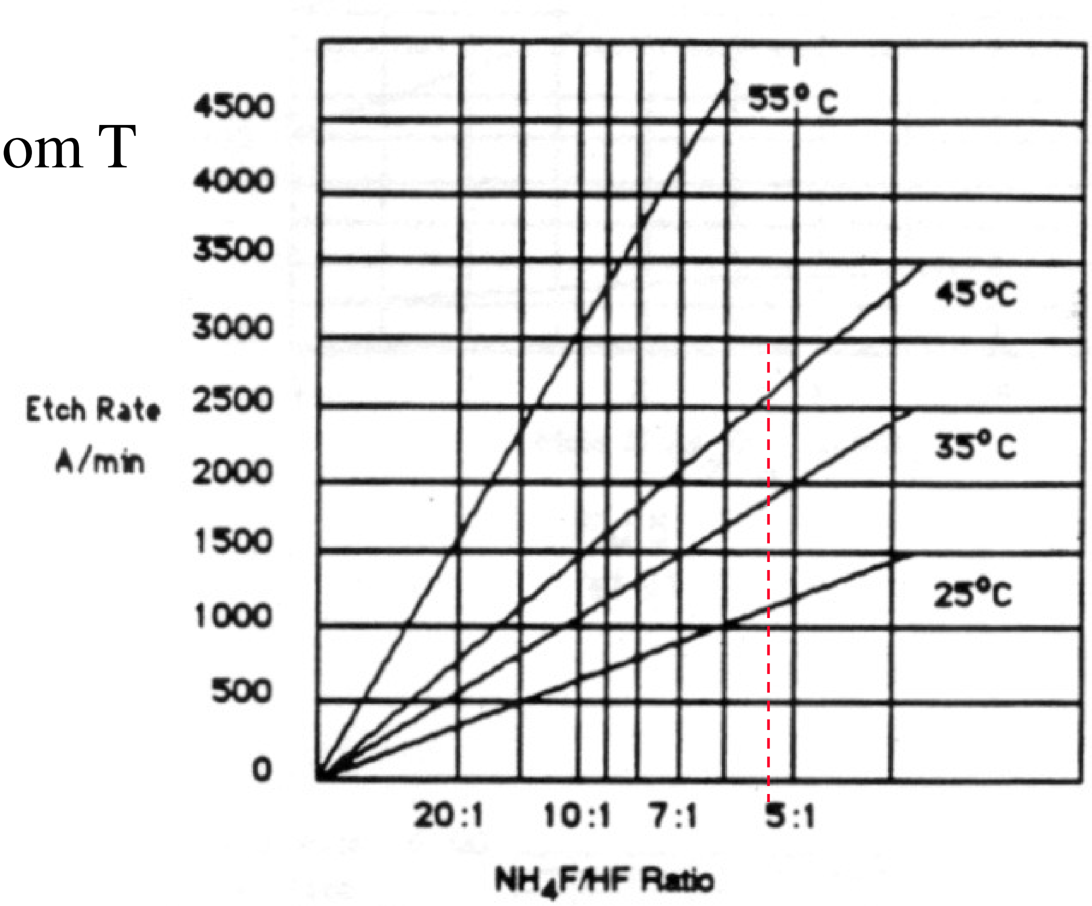
Types of silicon dioxide etchants:

49% HF - fast removal of oxide, poor photoresist adhesion
BHF - medium removal of oxide, with photoresist mask
Dilute HF - removal of native oxide, cleans, surface treatments
HF/HCl or HF/Glycerin mixtures – special applications

TYPES OF BHF

7:1 NH_4F/HF gives about
1000 Å/min etch rate at room T

7 Parts 40% NH4F
and 1 part 48% HF



Oxide Etch Rates in Buffered Hydrfluoric Acid

ETCH RATES FOR VARIOUS TYPES OF SiO2

Thermal SiO2	BOE (7:1)	1,000 Å/min *
	1:1 HF:HCl	23,000 Å/min**
* RIT data, Dr. Fuller, et.al.	49% HF	18,000 Å/min #
# from Madou Text	KOH@ 72 °C	900 Å/min*
** from Journal of MEMs, Dec.’96, Muller, et.al.	KOH @ 90 °C	2500 Å/min*
CVD SiO2 (LTO)	BOE (7:1)	3,300 Å/min #
	1:1 HF:HCl	6,170 Å/min #
	49% HF	
P doped SiO2	BOE (7:1)	2000 Å/min
(spin-on dopant)	1:1 HF:HCl	25,000 Å/min
(Photoresist adhesion problems)	49% HF	
Boron doped SiO2	BOE (7:1)	200 Å/min*
(spin-on dopant)	1:1 HF:HCl	
	49% HF	
Phosphosilicate Glass (PSG)	BOE (7:1)	10,000 Å/min #
	1:1 HF:HCl	11,330 Å/min #
* RIT data, Dr. Fuller, et.al.	49% HF	28,000 Å/min

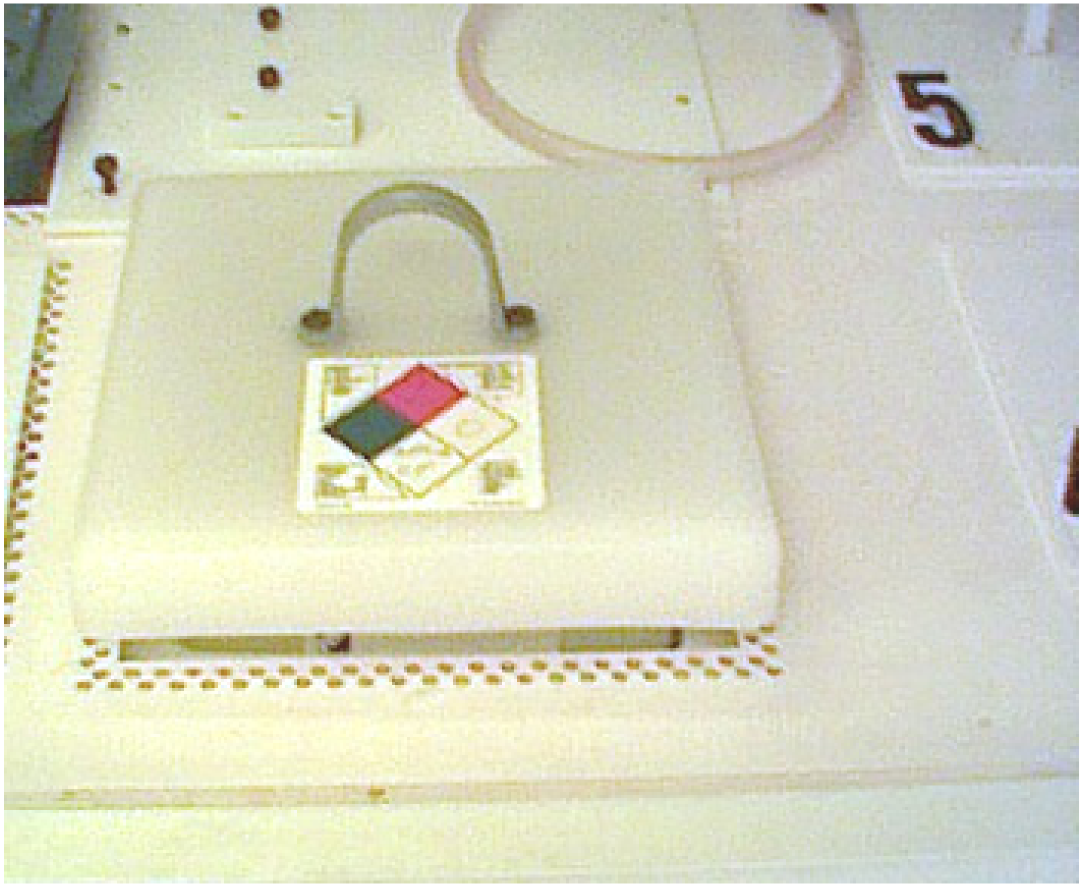
from Madou Text

** from Journal of MEMs, Dec.’96, Muller, et.al.

MORE ETCH RATES

Rochester Institute of Technology	Dr. Lynn Fuller			Revised: 2/24/2008
Microelectronic Engineering				
Summary of Etch Rates and Deposition Rates for RIT Processes				
Wet Etch Process Description	**Date**	**Rate**	**Units**	**Comment**
5.2:1 Buffered Oxide Etch (Transene) of Thermal Oxide, 300°K	2/12/2008	1200	Å/min	EMCR650
5.2:1 BOE (Transene) Etch of PECVD TEOS Oxide, no anneal, 300°K	2/12/2008	3840	Å/min	EMCR650
5.2:1 BOE (Transene) Etch of PECVD TEOS Oxide, anneal 1000C - 60 min, 300°K	1/22/2008	2029	Å/min	EMCR650
5.2:1 BOE (Transene) Etch of PECVD TEOS Oxide, anneal 1100C - 6 hr, 300°K	2/18/2008	1212	Å/min	EMCR731
10:1 Buffered Oxide Etch of Thermal Oxide, 300°K	10/15/2005	586	Å/min	Mike Aquilino
10:1 BOE Etch of PECVD TEOS Oxide, no anneal, 300°K	10/15/2005	2062	Å/min	Mike Aquilino
10:1 BOE Etch of PECVD TEOS Oxide, anneal 1000C - 60 min, 300°K	10/15/2005	814	Å/min	Mike Aquilino
10:1 BOE Etch of PECVD TEOS Oxide, anneal 1100C - 6 hr, 300°K	10/15/2005	562	Å/min	Mike Aquilino
Pad Etch on Thermal Oxide, 300 °K	12/1/2004	629	Å/min	EMCR650
Pad Etch of PECVD TEOS Oxide, 300°k	6/8/2006	1290	Å/min	Dale Ewbank
Hot Phosphoric Acid Etch of Thermal Oxide at 175 °C	10/15/2005	<1	Å/min	Mike Aquilino
Hot Phosphoric Acid Etch of TEOS Oxide, no anneal, at 175 °C	10/15/2005	17	Å/min	Mike Aquilino
Hot Phosphoric Acid Etch of TEOS Oxide, 1000 C 60 min Anneal, at 175 °C	10/15/2005	3.3	Å/min	Mike Aquilino
Hot Phosphoric Acid Etch of TEOS Oxide, 1100 C 6 Hr Anneal, at 175 °C	10/15/2005	3.8	Å/min	Mike Aquilino
Hot Phosphoric Acid Etch of Si3N4 at 175 °C	11/15/2004	82	Å/min	EMCR650
50:1 Water:HF(49%) on Thermal Oxide at room T	10/15/2005	187	Å/min	Mike Aquilino
50:1 Water:HF(49%) on PECVD TEOS Oxide, no anneal, at room T	10/15/2005	611	Å/min	Mike Aquilino
50:1 Water:HF(49%) on PECVD TEOS Oxide, anneal 1000 C -30 min, at room T	10/15/2005	115	Å/min	Mike Aquilino
50:1 Water:HF(49%) of PECVD TEOS Oxide, anneal 1100C - 6 hr, 300°K	10/15/2005	107	Å/min	Mike Aquilino
KOH 20 wt%, 85 °C, Etch of Si (crystaline)	2/4/2005	30	µm/hr	EMCR870
KOH etch rate of PECVD Nitride (Low σ)	2/4/2005	10	Å/min	EMCR870

BUFFERED OXIDE ETCH TANK



ETCHING GLASS OVER ALUMINUM WITH BOE AND GLYCERIN MIXTURE

In multilevel metal processes it is often necessary to etch vias through an insulating interlevel dielectric. Also if chips are given a protective overcoat it is necessary to etch vias through the insulating overcoat to the bonding pads. When the underlying layer is aluminum and the insulating layer is glass the etchant needs to etch glass but not etch aluminum. Straight Buffered HF acid will etch Aluminum.

A mixture of 5 parts BOE and 3 parts Glycerin works well. Etch rate is unaffected by the Glycerin. Original work was published by J.J. Gajda at IBM System Products Division, East Fishkill Facility, Hopewell Junction, NY 12533

BOND PAD ETCHES FROM TRANSENE

Silox Vapox III – TRANSENE CO. (www.Transene.com)

This etchant is designed to etch deposited oxides on silicon surfaces. These oxides are commonly grown in vapox silox or other LPCVD devices and differ radically from their thermally grown cousins in many important ways. One way is their etch rate another is their process utility. The deposited oxide is many times used as a passivation layer over a metallized silicon substrate. Silox Vapox Etchant III has been designed to optimize etching of a deposited oxide used as a passivation layer over an aluminum metallized silicon substrate. This etchant has been saturated with aluminum to minimize its attack on the metallized substrate.

Deposited Oxide (Vapox/Silox) Etch Rate: 4000 Å / minute @ 22 °C

This product contains:

- Ammonium Fluoride
- Glacial Acetic Acid
- Aluminum corrosion inhibitor
- Surfactant
- DI Water

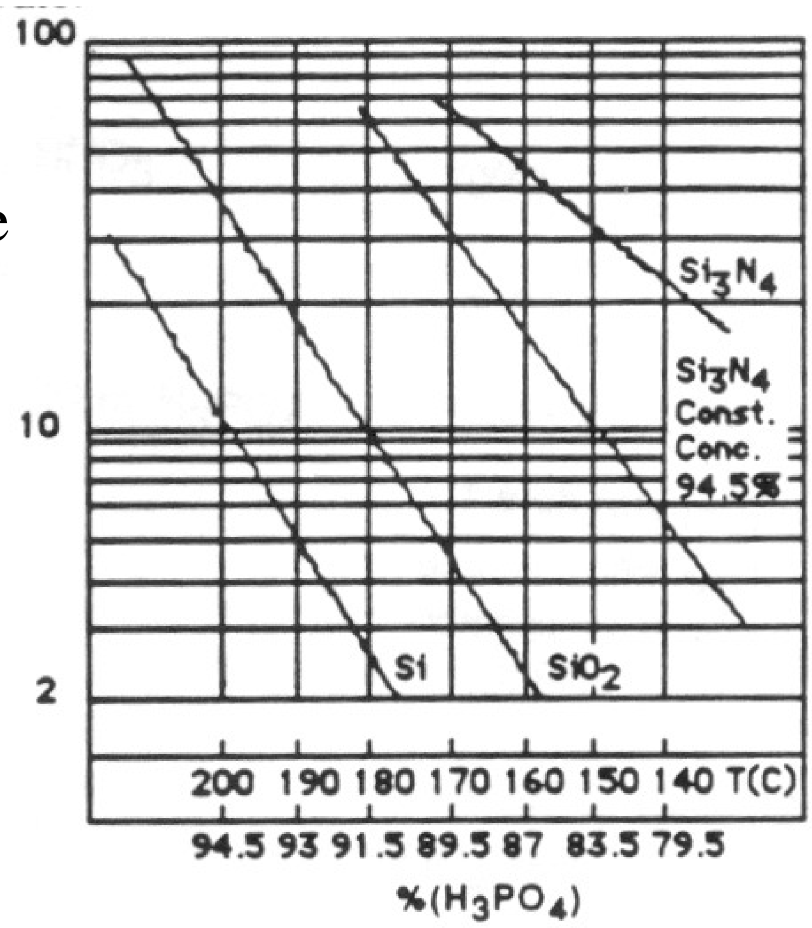
WET ETCHING OF SILICON NITRIDE

Silicon Nitride - BOE (7:1) 20A/min,
1:1 HF:HCL 120A/min,
49% HF 140 A/min
165°C Phosphoric Acid 55A/min (BOE dip first to remove oxynitride layer), etches silicon dioxide at 10 Å/min and silicon

Hot phosphoric acid etch of nitride can not use photoresist as an etch mask. One can use a thin patterned oxide (or oxynitride) to act as the etch mask. Etch rate for silicon is even lower than the etch rate of oxide.

HOT PHOSPHORIC ACID ETCH OF SI3N4

The boiling point of phosphoric acid depends on the concentration of H_3PO_4 in water. So if you heat the solution until it boils you can find the corresponding concentration. If you operate at the boiling temperature (temperature is controlled without a closed loop control system) and the water boils off, the concentration increases making the boiling point hotter. Thus reflux condensers and drip systems replace the water to control the concentration and boiling temperature.



Silicon Nitride Etch Rate in Boiling Phosphoric Ac

HOT PHOSPHORIC ACID NITRIDE ETCH BENCH

- Warm up Hot Phos pot to 175º
- Dip in BHF to remove oxynitride
- Use Teflon boat to place wafers in acid bath
    - 3500Å +/-500 → 50 minutes
    - 1500Å +/- 500 → 25minutes
    - Etch rate of ~80 Å/min
- Rinse for 5 min. in Cascade Rinse
- SRD wafers

WET ETCHING

Aluminum - "Aluminum Etchant Type A" from Transene Co., Inc. Route 1, Rowley MA, Tel (617)948-2501 and is a mixture of phosphoric acid, acetic acid and nitric acid. Al/1%Si leaves behind a silicon residue unless the aluminum etch is heated to 50C.

WET ETCHING

Poly - KOH

Nickel - Use “Aluminum Etch Type A” at 50C, rate ~2000A/min

Chromium - CR-9 Etch, Cyantek Corp., 3055 Osgood Court, Fremont, CA 94539-5652, (510)651-3341

Gold - Gold Etch, J.E.Halma Co., 91 Dell Glen Ave, Lodi, NJ 07644

Copper - Ferric Chloride or mix Etchant from 533 ml water, add 80 ml $Na_2S_2O_3$, Sodium Persulfate, (white powder, Oxidizer), prepare in glass pan, place pan on hot plate and heat to 50 C (plate Temp set at 100 C)

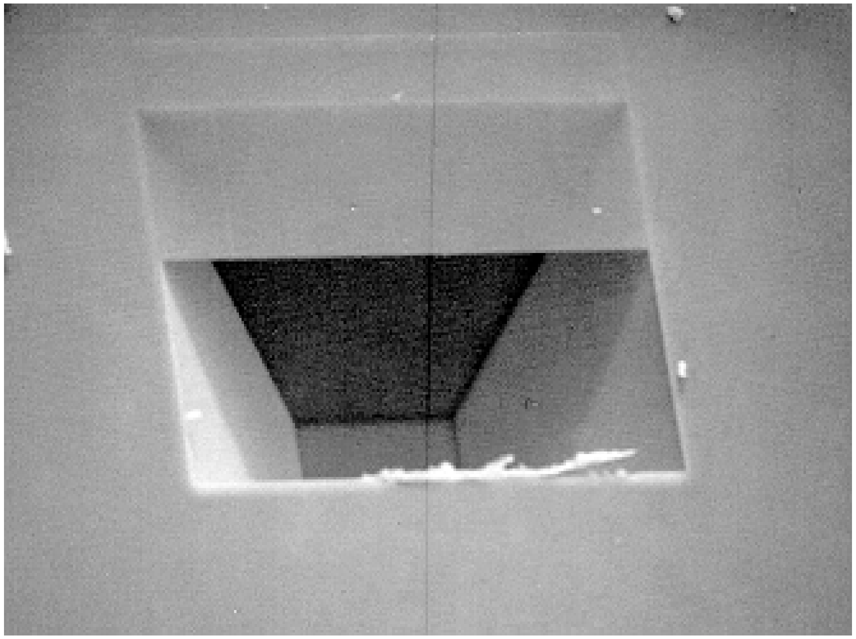
ETCHING OF Poly and Nitride in BOE, HF 49%, HF:HCl

Nitride	BOE (7:1) 1:1 HF:HCl 49%HF	20 Å/min # 120 Å/min #
Nitride (Silicon Rich)	BOE (7:1) 1:1 HF:HCl 49%HF	5Å/min 10Å/min
Polysilicon	BOE (7:1) 1:1 HF:HCl 49%HF	0Å/min
N+ Poly (Phosphorous)	BOE (7:1) 1:1 HF:HCl 49%HF	0Å/min

* RIT data, Dr. Fuller, et.al.
\# from Madou Text
** from Journal of MEMs, Dec.'96, Muller, et.al.

KOH ETCHING OF SINGLE CRYSTAL SILICON

KOH etches silicon along the (111) crystal plane giving a 53° angle.



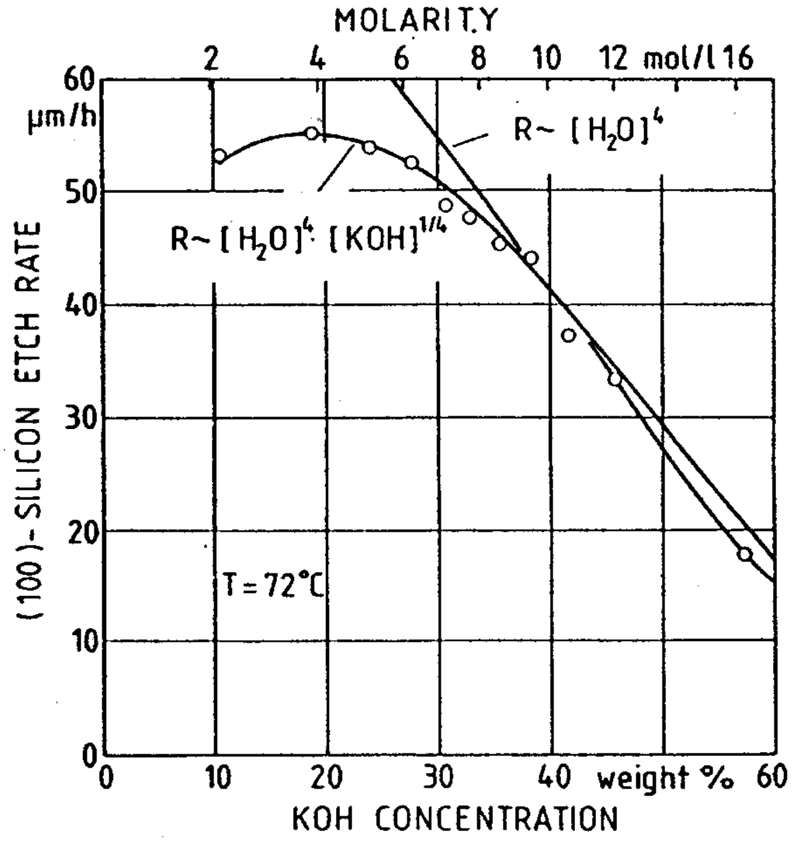
KOH ETCHING OF SINGLE CRYSTAL SILICON

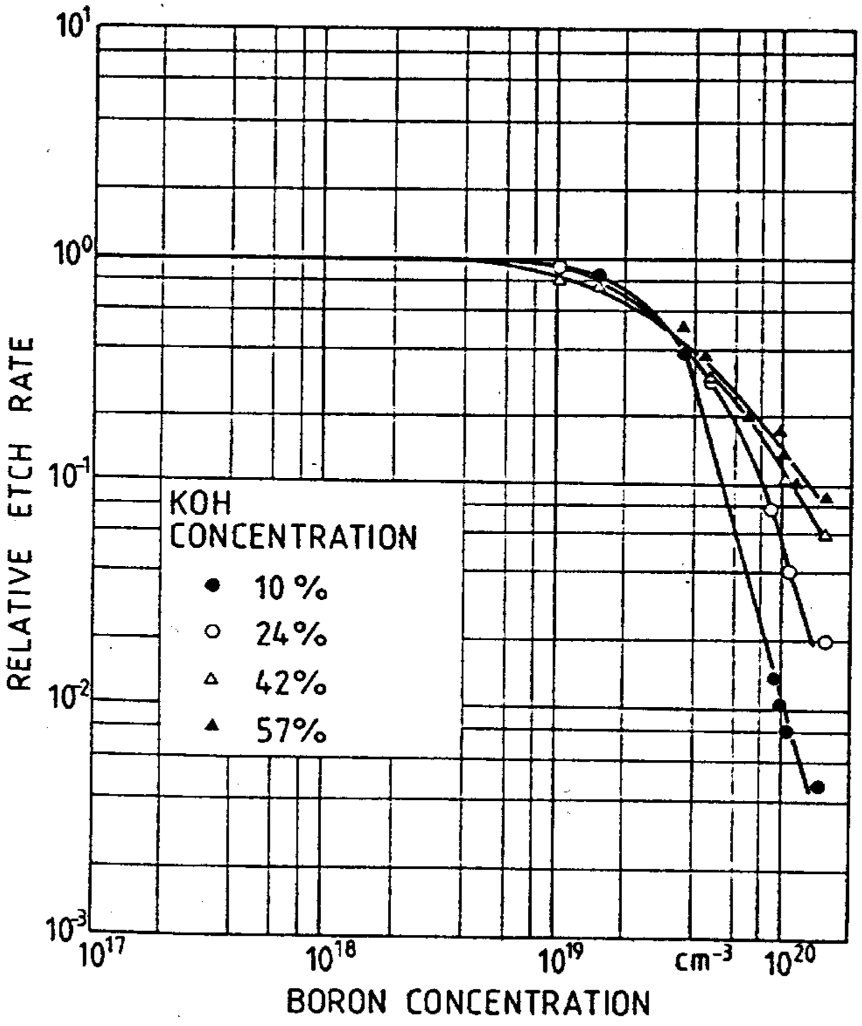
Si_3N_4 is the perfect masking material for KOH etch solution. The etch rate for Silicon Nitride appears to be zero.

When SiO_2 is used as a masking with a KOH solution both temperature and concentration should be chosen as low as possible. LTO is not the same as thermal oxide and can be attacked by KOH at a much higher rate. KOH etch rate is about 50 to 55 µm/min at 72 °C and KOH concentrations between 10 and 30 weight %. The Si/SiO etch ratio is 1000:1 for 10% KOH at 60 °C, at 30% it drops to 200:1. The relative etch rate of doped silicon to lightly doped silicon decreases for doping concentrations above 1E19 and at 1E20 the relative etch rate is 1/100 for 10% concentration. (on (100) wafer the angle is 50.6°)

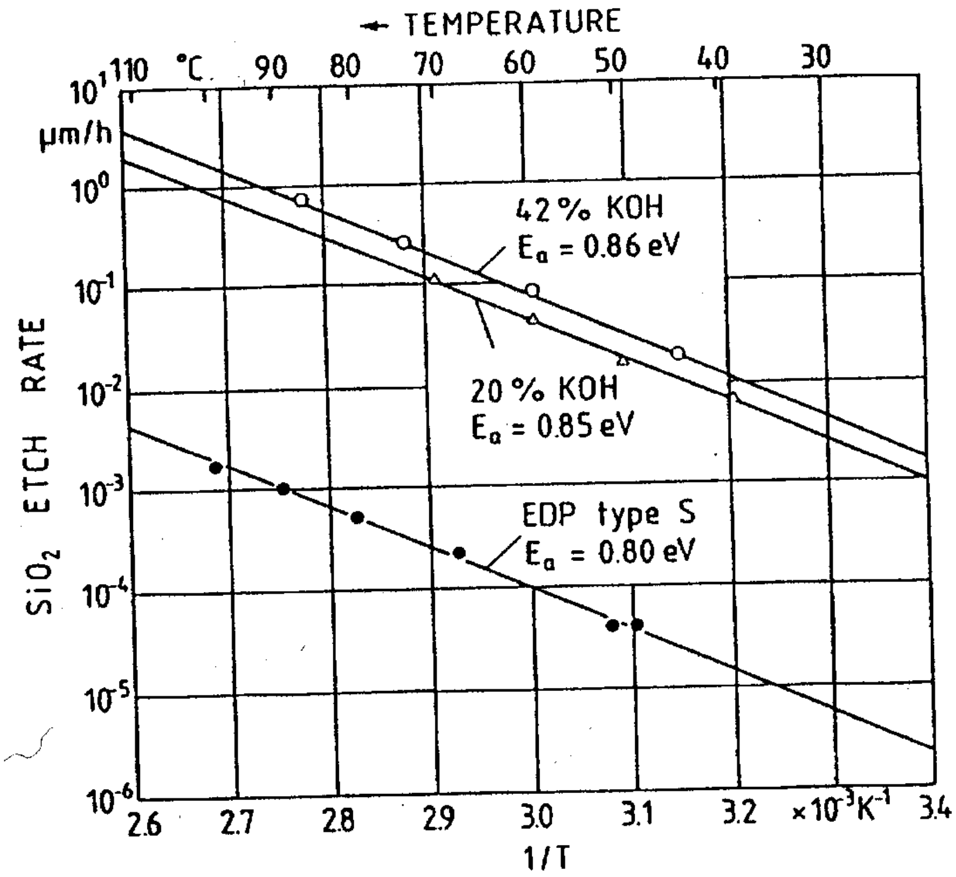
C. Strandman, L. Rosengren, H. Elderstig, and Y Backlun uses Isopropyl Alcohol (IPA) added to the KOH mixture at 30 wt% before IPA was added. 250 ml of IPA per liter of KOH was added giving an excess of IPA on the surface of etchant during etching.

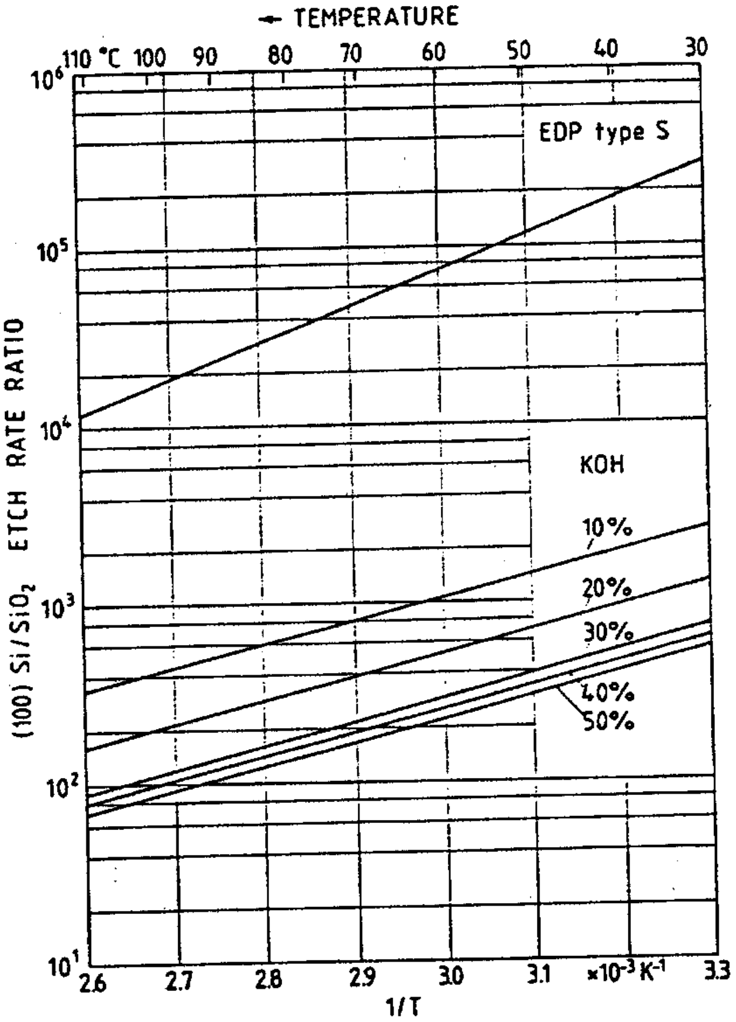
KOH ETCHING OF SILICON



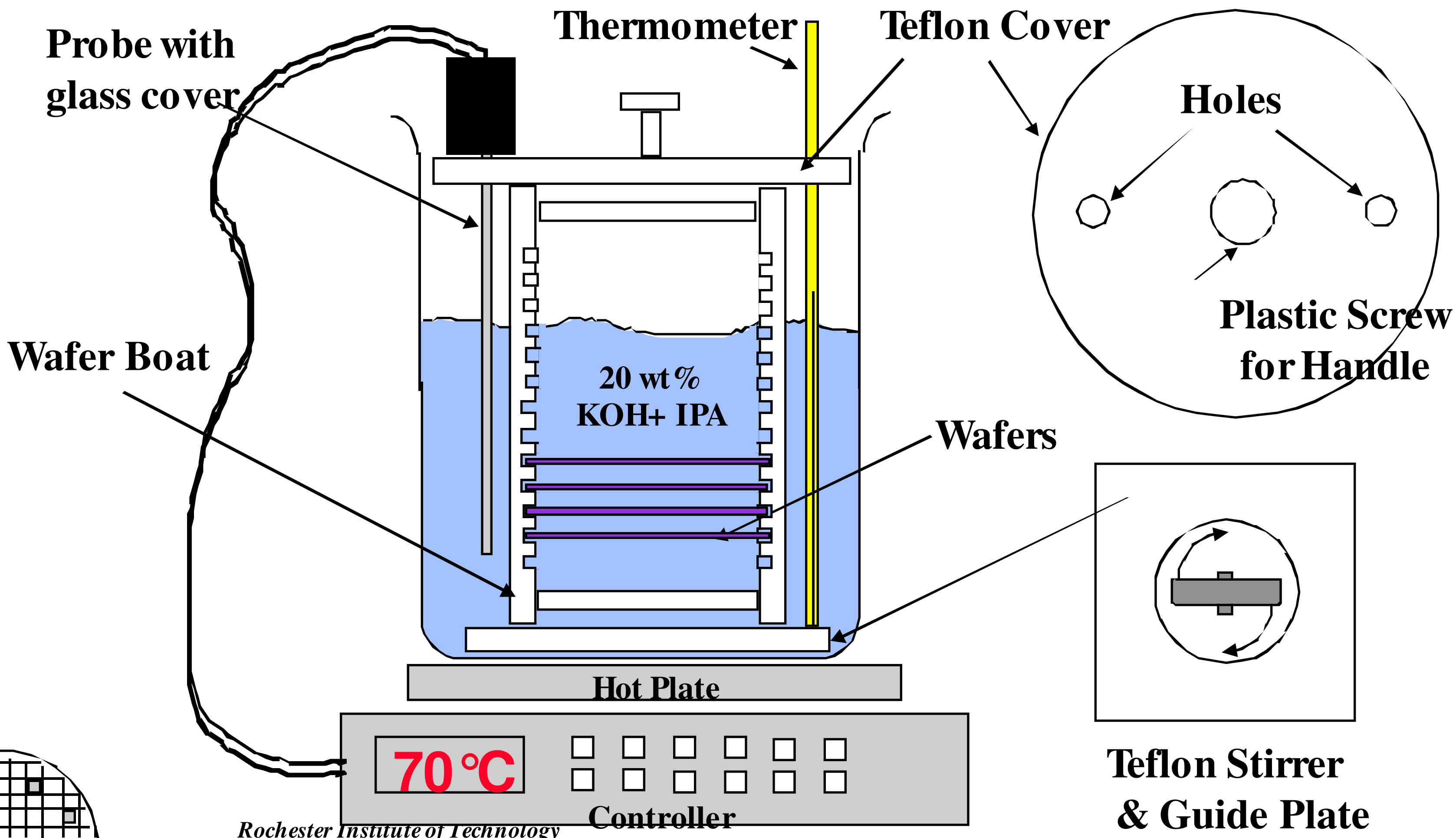


KOH ETCHING OF SILICON OXIDE





KOH ETCH APPARATUS



SINGLE SIDED KOH ETCH APPARATUS

Dual 4 inch wafer holder with “O” ring seal to protect outer ½ “ edge of the wafer. Integral heater and temperature probe for feedback control system. Stainless steel metal parts do not etch in KOH.

KOH ETCHING OF SINGLE CRYSTAL SILICON

This is a summary of some of the results made in the RIT laboratory.

Date	Etchant	Temp	Material	Etch Rate	Comments
8-23-96	10 wt% KOH no IPA	50°C	Si	16µm/hr	Fuller, did not see 51° angle
			Si3N4	0.0 Å/hr	
5-23-96	20 wt% KOH no IPA	72°C	Si	50µm/hr	Stropko, set hotplate to 110°C to get 72°C, etched holes thru wafer
			SiO2	900Å/hr	
		90°C	SiO2	2500Å/hr	
8-26-96	10 wt% KOH + IPA	70°C	Si	17.5µm/hr	Fuller/Babbitt, 10 um undercut
8-27-96	20 wt% KOH + IPA	75 C	Si	30um/hr	Fuller/Babbitt,

KOH ETCHING (continued)

Date	Etchant	Temp	Material	Etch Rate	Comments
4-8-98	10% KOH	50 C	Si	25 µm/hr	Lundeen/Akpan
	20%	75		62	
	10% + IPA	70		12	
	20% + IPA	75		20	
	10%	50	SiO2	900 Å/min	
	20%	75		1680	
	10% + IPA	50		480	
	20% + IPA	75		1500	
	10%	50	LTO	4200 Å/min	
	20%	75		5400	
	10% + IPA	50		2400	
	20% + IPA	75		5100	
	10%	50	Si3N4	0 Å/min	
	20%	75		0	
1-6-99	20% KOH	75	Si	60 µm/hr	Pushkar
			Si3N4	50 Å/hr	
3-29-02	20% KOH	72	Si	53Å/hr	EMCR890 Class

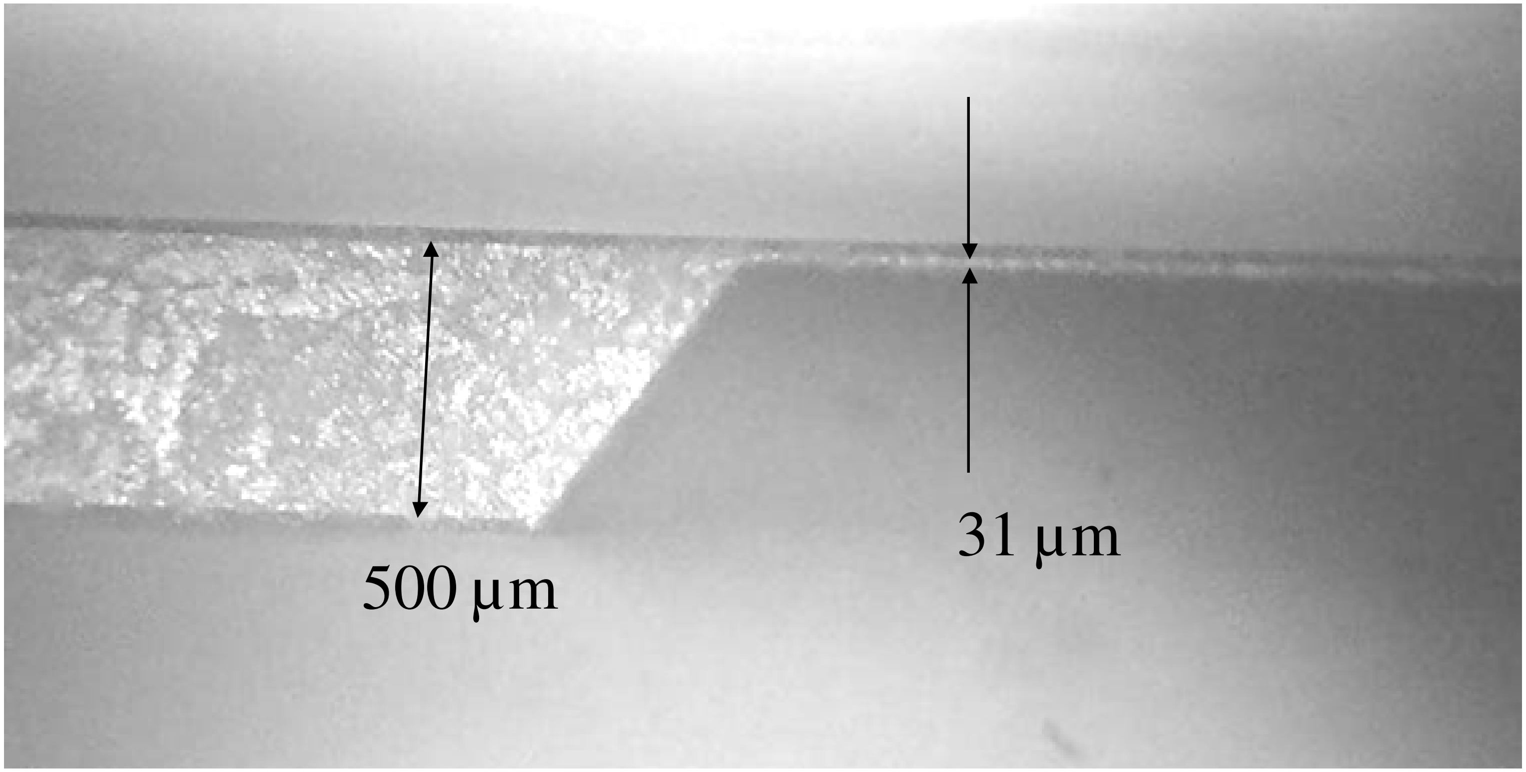
THIN DIAPHRAGM FORMATION

Heavily doped p-type silicon etches 100 times slower than lighter doped p-type silicon

$$N(x,t) = N_o \text{ erfc } [x / ((4Dt)\char`^0.5)]$$

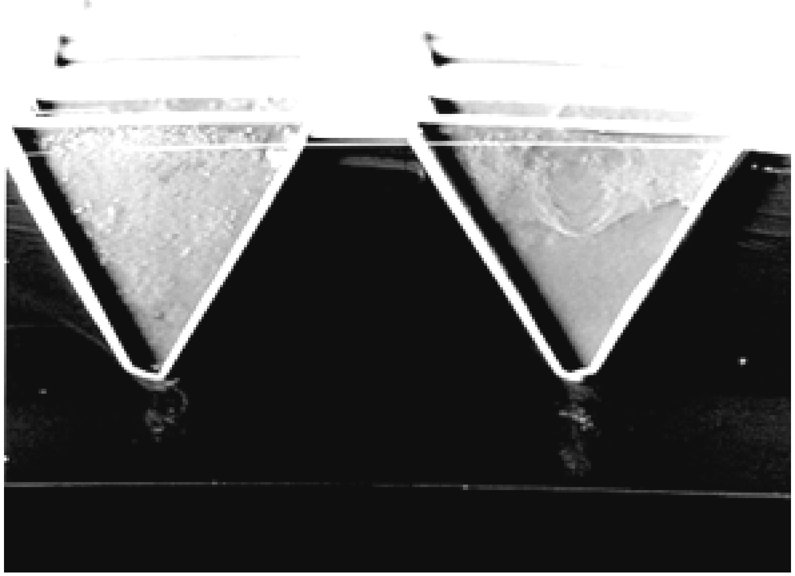
Diaphragm Design: Select a 2 µm diaphragm thickness and a 500 µm by 500 µm size. Select boron diffusion at 1100 °C and calculate the diffusion time. What is the size of the etch opening if the wafer is 500 µm thick?

SEM PICTURES OF DIAPHRAGM ETCH

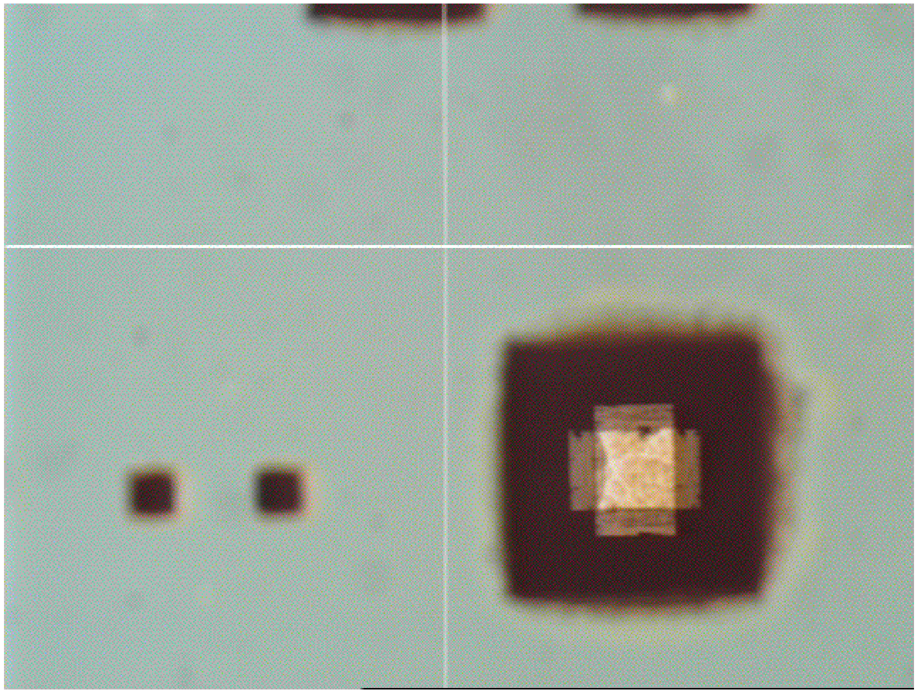


20% KOH Etch, @ 72 C, 10 Hrs.

PICTURES OF KOH ETCH PITS



SEM

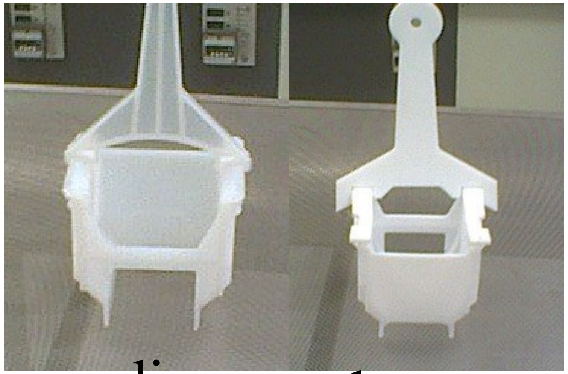


Optical

20% KOH <100> Si Etch - 8 Hrs. @ 72C

TYPES OF CASSETTS AND CARRIERS

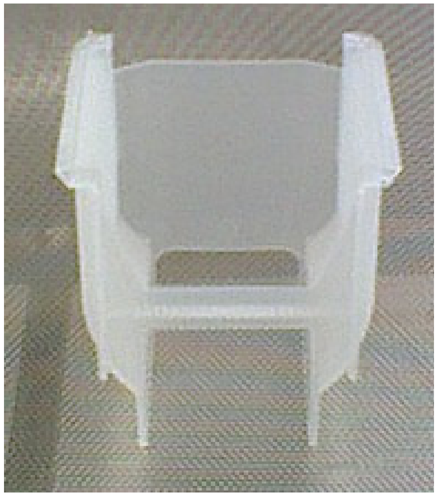
Black, Blue, Red wafer cassetts:
- Fluoroware PA182-60MB, PA72-40MB
- STAT-PRO© 100 (polypropylene)
- 6” wafers (SSI track, Canon stepper)
- 4” wafers (SVG track, GCA stepper)
- DO NOT USE IN WET CHEMISTRY



medium heavy

Teflon Chemical Process Wafer Cassett:
- Fluoroware A182-60MB
- PerFluoroAlkoxy (Teflon®) – heavy, medium
- High resistance to chemicals and temperature
- Can be used in wet chemistry processes (RCA clean, BOE etch, wet nitride etch, wet aluminum etch)

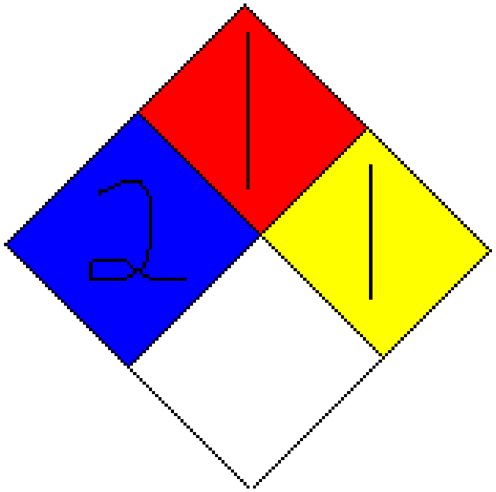
TYPES OF CASSETTS AND CARRIERS



Shipping Cassette:
- Empak PX9150-04
- Thin high purity polypropylene
- Available in 6” and 4” wafer sizes
- Not for use in processing
- DO NOT USE IN WET CHEMISTRY

Metal Cassetts:
- Stainless steel
- Available for 6” and 4” wafers
- Use on Branson Asher only
- DO NOT USE IN WET CHEMISTRY

WET RESIST STRIP WITH BAKER PRS-1000



What steps will use wet strip?

Eventually all steps after Gate Oxide Growth

Why use wet strip?

Lower temperatures

No electric field from plasma

Gate oxide reliability increases

Harmful if swallowed or inhaled. Causes irritation to skin, eyes and respiratory tract.

Flashpoint 96C

Explosive vapors can be formed above this temperature (sealed container)

BAKER PRS-1000 PHOTORESIST STRIP

Processing temperature is 95C

Etch rate calculated to be 760A/min

Process designed for 1000A/min

Inhibition layer could slow etch at start

10 minutes fully stripped most wafers

PHOTORESIST DEVELOPERS

CD-26 DI water

RCA CLEAN WAFERS

APM

H_2O – 4500ml
NH_4OH–300ml
H_2O_2 – 900ml
75 °C, 10 min.

DI water
rinse, 5 min.

H_20 - 50
HF - 1
60 sec.

DI water
rinse, 5 min.

HPM

H_2O–4500ml
HCL-300ml
H_2O_2 – 900ml
75 °C, 10 min.

DI water
rinse, 5 min.

SPIN/RINSE
DRY

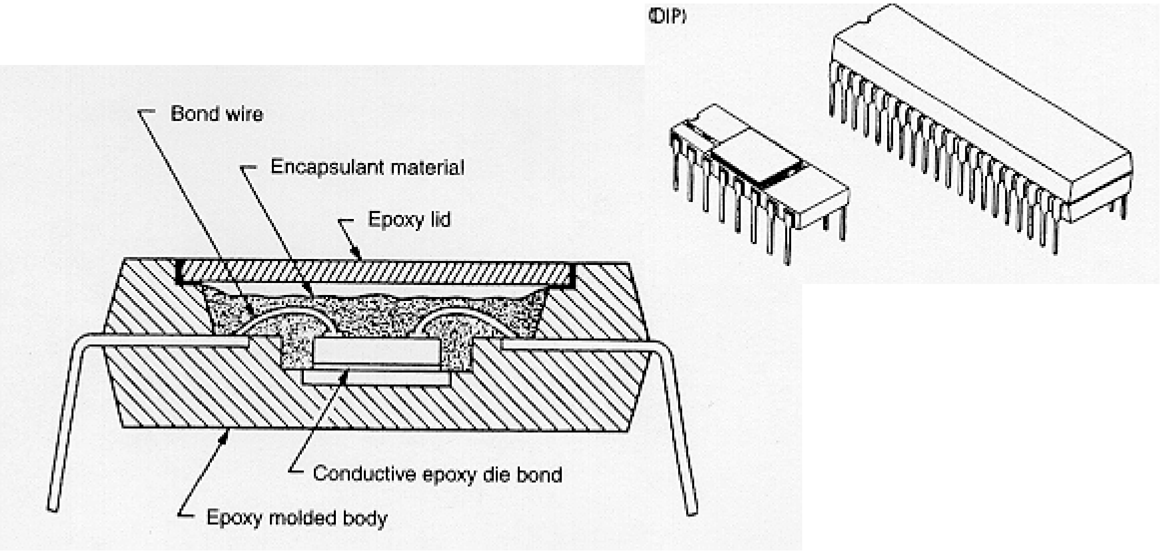
What does RCA
stand for?

ANSWER

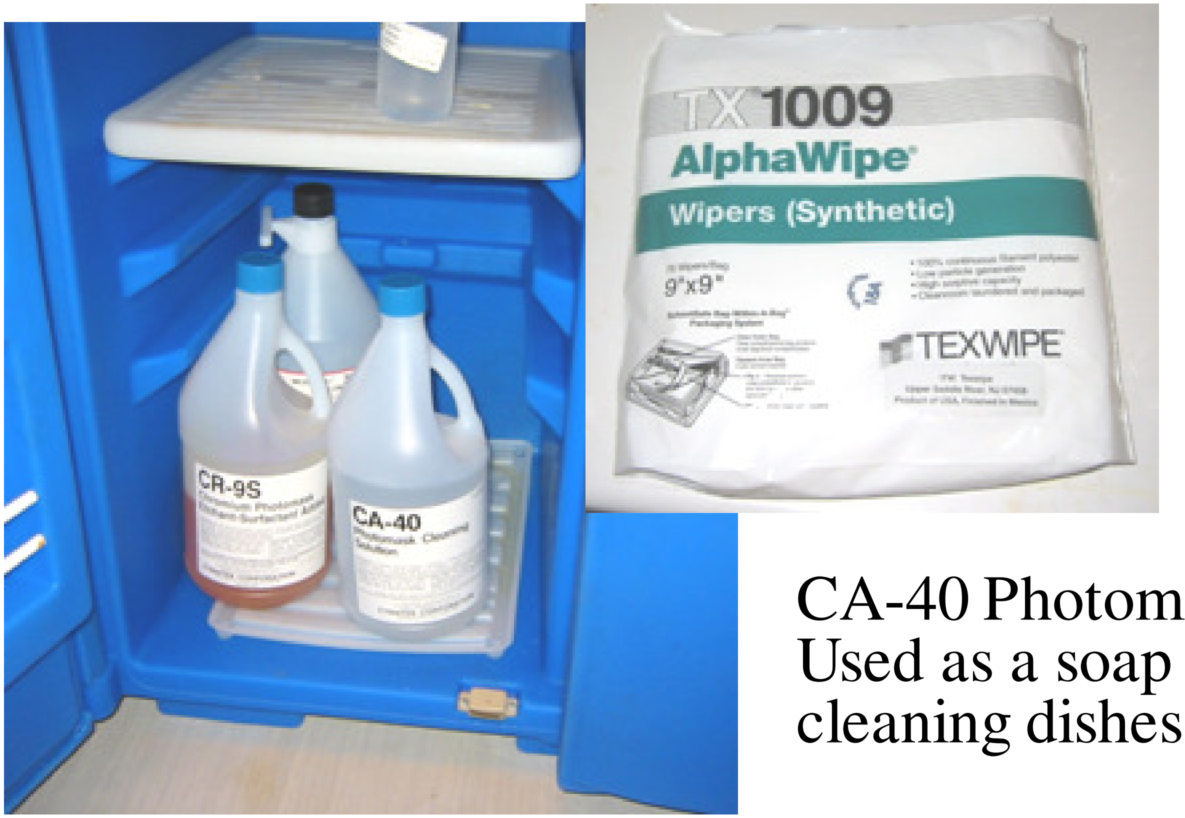
PLAY

ETCHING THE DUAL-IN-LINE PLASTIC PACKAGE OFF OF PACKAGED CHIPS (DECAPSULATING)

Hot H_2SO_4 will etch the plastic package and not etch the metal wire bonds or other metal parts as long as no water is present. Straight H_2SO_4 heated to 100 C for 3 hours to remove all water. Allow to cool to 80C. This etch will remove a plastic package in 30 minutes. Immerse briefly in room temperature H_2SO_4 to cool the part, then rinse in DI water.



MASK CLEANING SOLUTION



CA-40 Photomask Cleaning Solution
Used as a soap with texwipe similar to cleaning dishes.

CLEANING SOLUTIONS

PLASMA ETCHING

Etch Chemistry
SF6
CF4
CHF3

Added Gases
O2
H2
He
C4F8

Added gases affect anisotropy, selectivity and etch rate

RIT PLASMA ETCH TOOL

Lam 490 Etch Tool
Plasma Etch Nitride (~ 1500 Å/min)
SF6 flow = 200 sccm
Pressure= 260 mTorr
Power = 125 watts
Time=thickness/rate

Use end point detection capability This system has filters at 520 nm and 470 nm. In any case the color of the plasma goes from pink/blue to white/blue once the nitride is removed.

LAM 490 PLASMA ETCH

RIT RIE ETCH TOOLS

RIE – Reactive Ion Etching

DRYTECH QUAD RIE

LAM 4900 ETCH TOOL

LAM 4900 Aluminum Etch Tool

RF Top (W)	0	0	0	0	0
RF Bottom (W)	0	350	275	275	0
Gap (cm)	3	3	3	3	5.3
N2	25	25	40	50	50
BCl3	100	100	50	50	0
Cl2	10	10	60	45	0
Ar	0	0	0	0	0
CFORM	15	15	15	15	15
Complete	Stabl	Time	endpoint	Overetch	time
time (s)	15	8	120	25%	15

BASICS OF PLASMA ETCHING

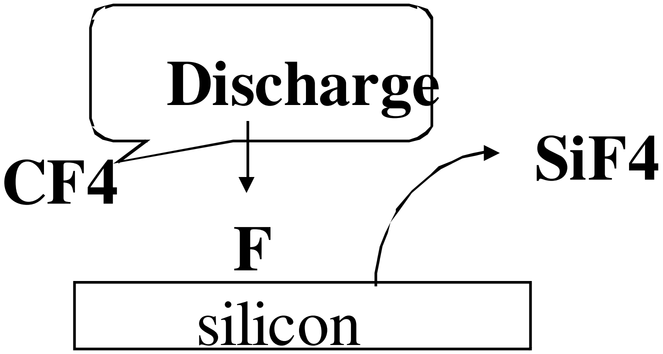
CF4 is inert gas
add electron impact:

$CF_4 + e \Rightarrow CF_3^+ + F + e$ (Dissociative Ionization)

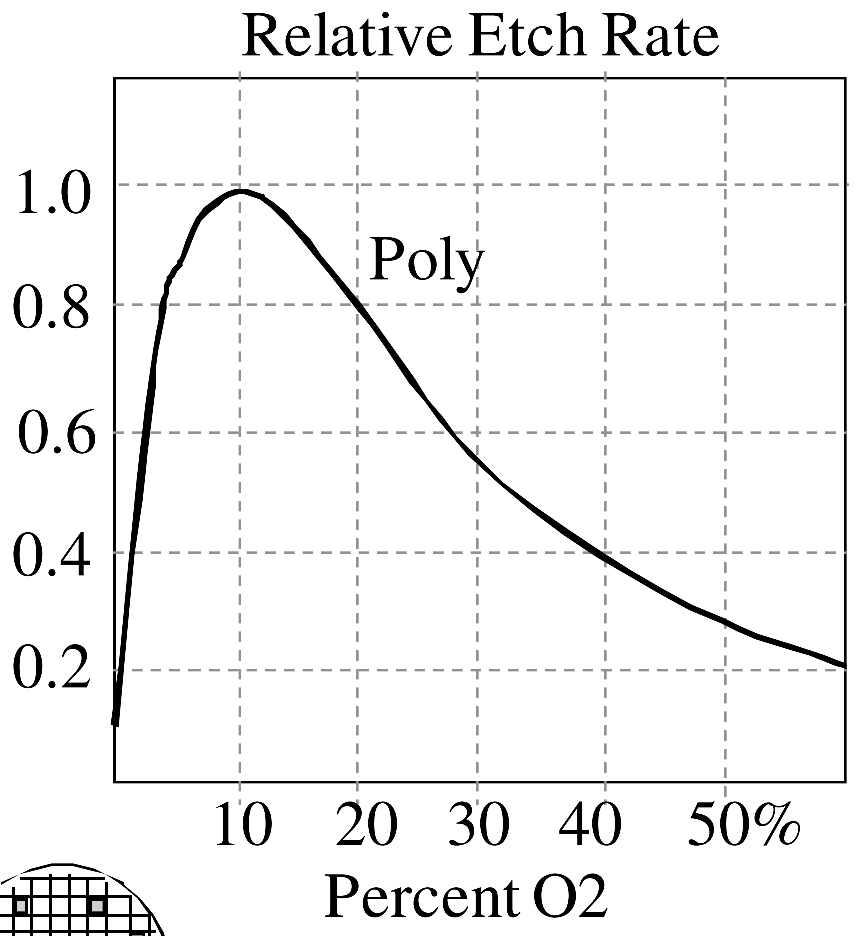
$CF_4 + e \Rightarrow CF_3 + F + e$ (impact dissociation)

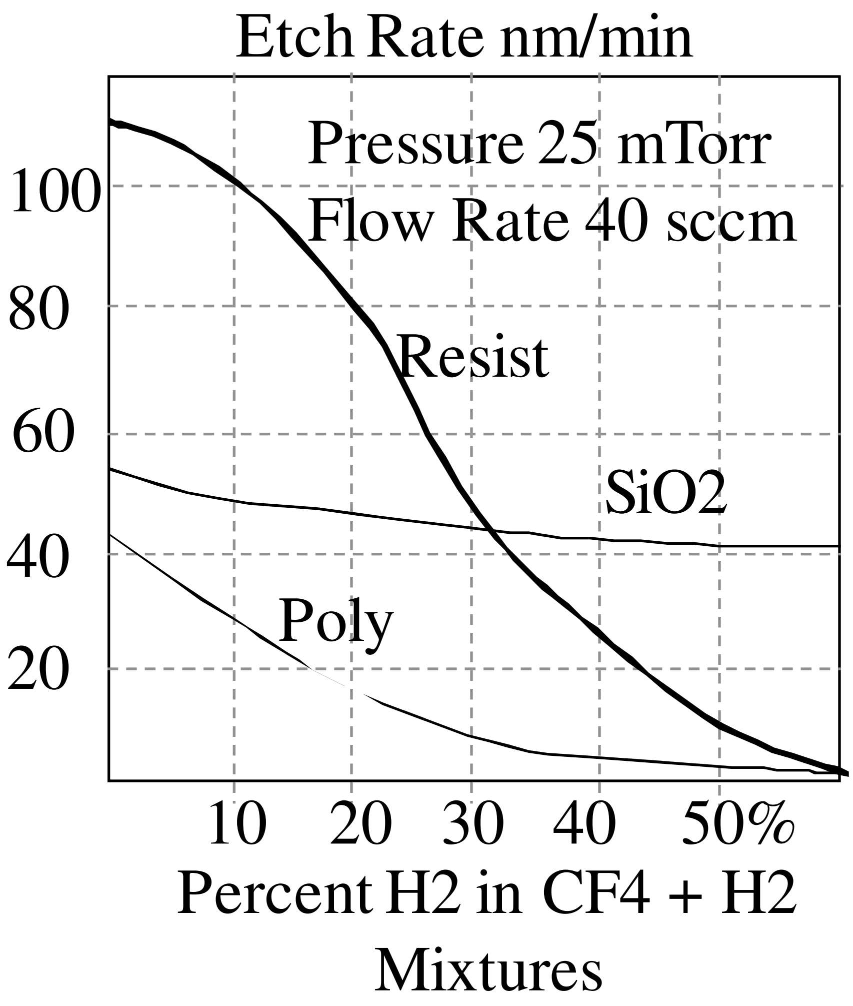
To produce fluorine radicals. Then:

$Si + 4F \Rightarrow SiF_4$ (gas)



ADDED GASES AFFECT ETCH RATE





ADDED GASES AFFECT SELECTIVITY

Hydrogen - reduces fluorine concentration by combination to form HF

Oxygen - Increases fluorine concentration by combining with carbon which would otherwise require fluorine or reacting with CF3 to liberate F

Gas	C:F Ratio	SiO2:Si Selectivity
CF_4	1:4	1:1
C_2F_6	1:3	3:1
C_3F_8	1:2.7	5:1
CHF_3	1:2	10:1

ANISOTROPIC PLASMA ETCHING OF SILICON

SF6 plus CHF3, 50:50, 25 mTorr, 150 nm/min, 98% Anisotropy

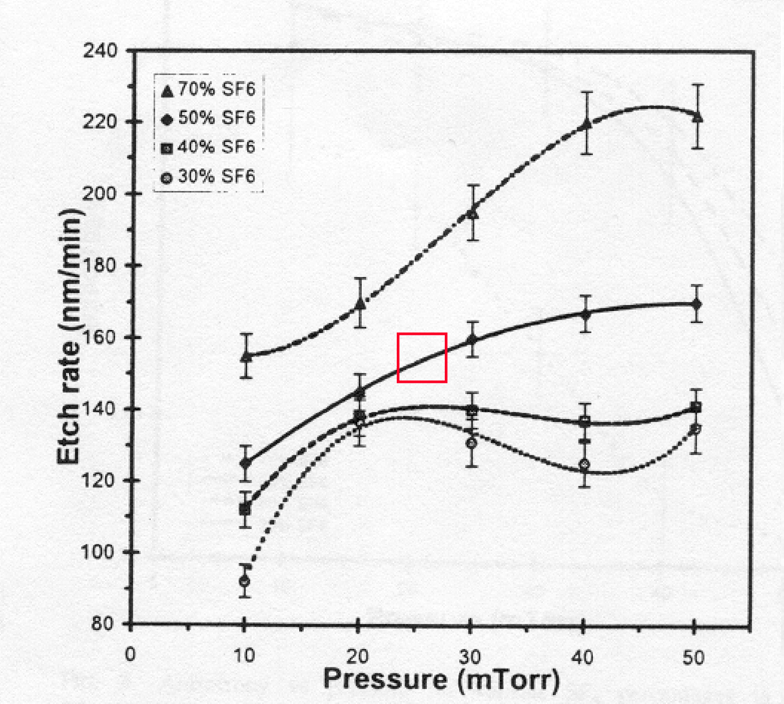


FIG. 1. Silicon etch rate vs pressure for various SF$_6$ percentages in SF$_6$/CHF$_3$ mixture.

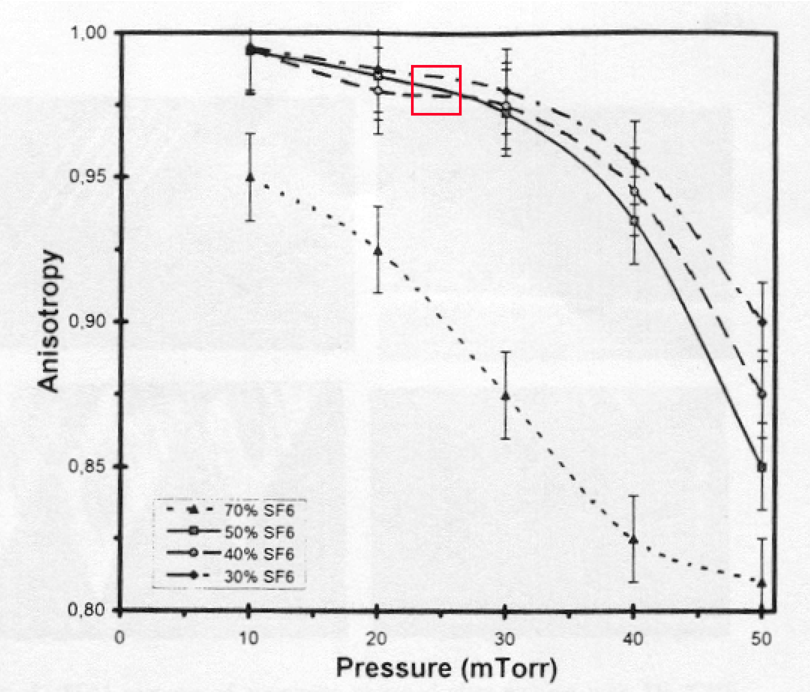
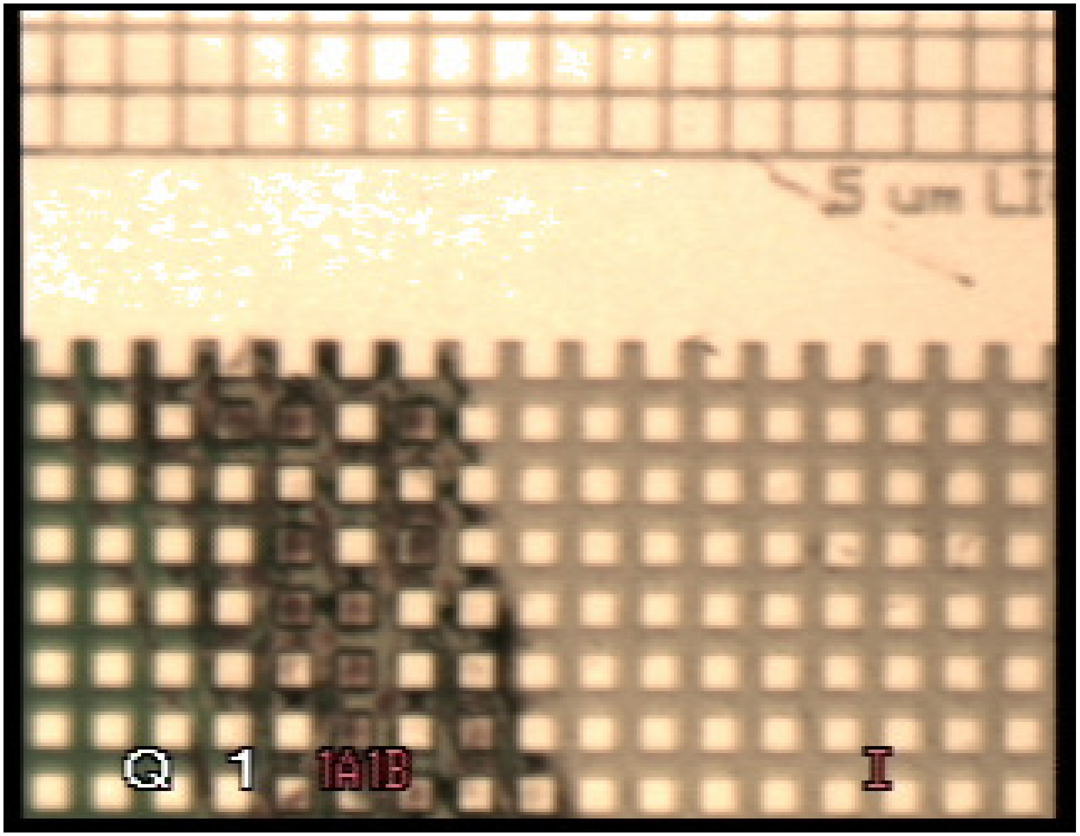


FIG. 3. Anisotropy vs pressure for various SF$_6$ percentages in the SF$_6$/CHF$_3$ mixture. For 100% SF$_6$, anisotropy is 0.6.

Highly Anisotropic Silicon Reactive Ion Etching for Nano Fabrication Using Mixtures of SF6/CHF3 Gases, S. Grigoropoulos, et.al., J.Vac Sci. Technol. May/Jun 1997

SF6 and CHF3 PLASMA ETCHING

1.8 µm of poly etched in GEC tool with SF6 +CHF3 at 50 mTorr flow of 3 sccm and 3 sccm, power of 40 watts, time of 50 minutes. Results: etch rate for poly and photoresist is about the same, no undercutting, picture shows checkerboard with resist on the left and with no resist on the right. The top shows 5 µm lines. Poly etch rate of about 300 Å/min.



Plasma ignition made possible by closing throttle valve and letting the pressure rise to ~125 mTorr, then return valve to auto.

SILICON ETCHING MECHANISM

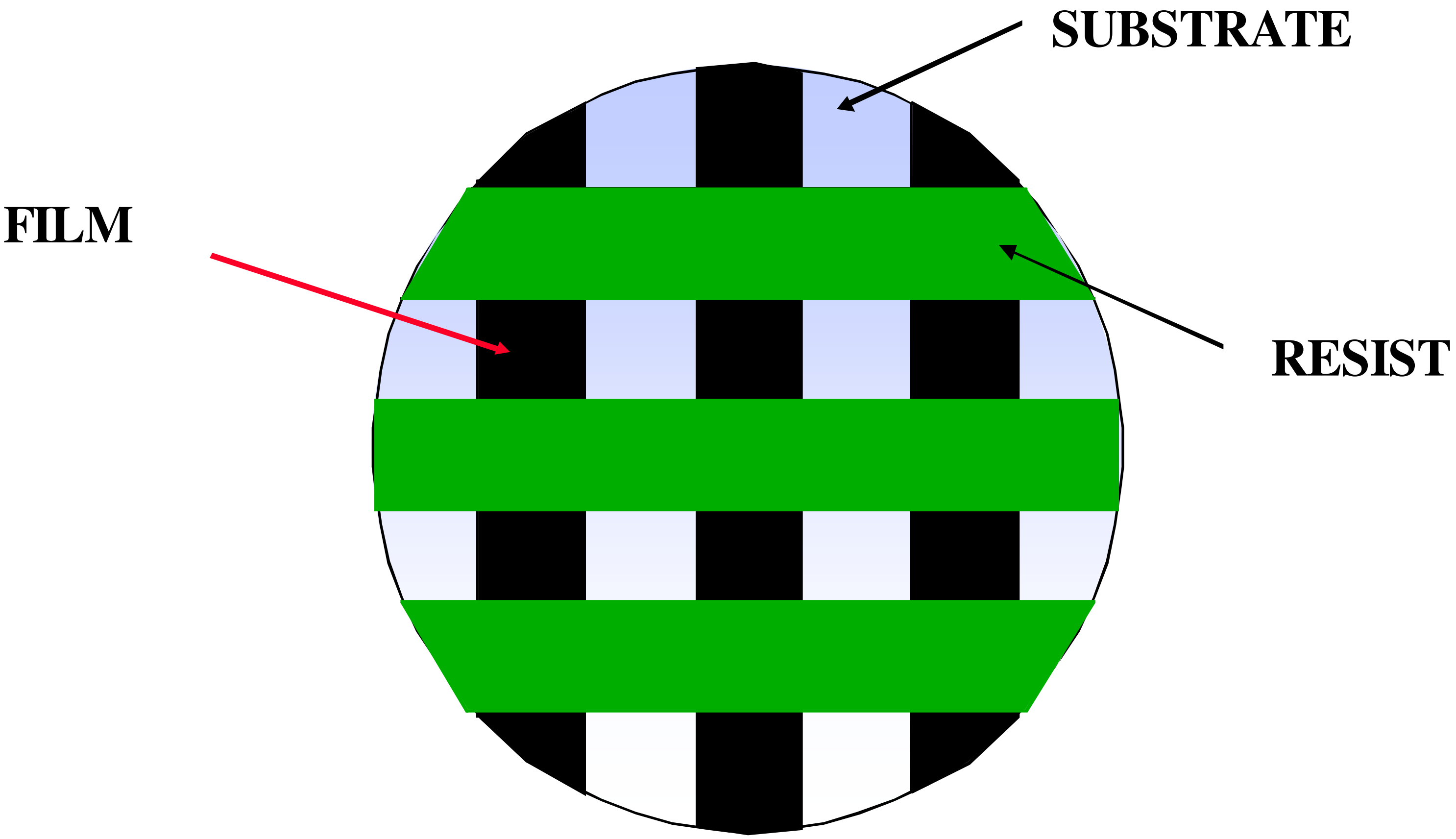
CF4 is Freon 14 F/C ratio is 4

CF4 + e- --> CF3 + F e-

F radicals adsorb on silicon surface; SiF4 desorbs
CF3 radicals also adsorb
CF3 + F --> C4 desorbs

The presence of carbon on the surface reduces the amount of fluorine available to etch silicon. Carbon will leave the surface by combining with F reducing fluorine, carbon can remain on the surface forming C-F polymers which in turn inhibits etching. High F/C ratio favors etching. Adding O2 can increase etch rate and increases selectivity over oxide.

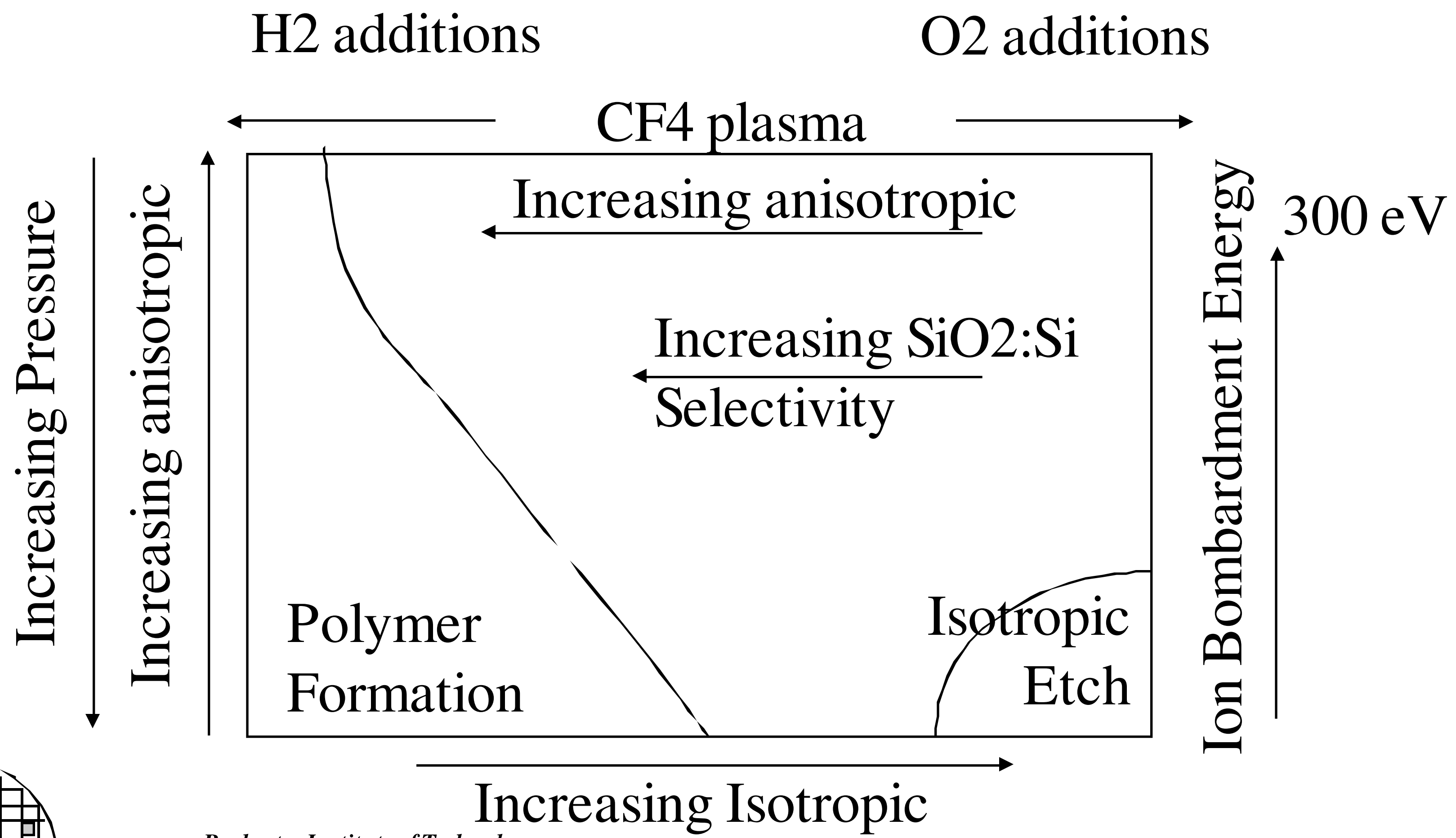
DRY ETCH SELECTIVITY AND ETCH RATE



SILICON DIOXIDE ETCHING MECHANISM

C3 and F radicals adsorb. C bonds with oxygen at the surface F bonds with Si. By-products are CO, CO2, COF2, SiF4. The addition of H2 removes F from the system by forming stable HF gas. Addition of H2 therefore decreases the effective F/C ratio and increases selectivity of SiO2 with respect to silicon. As H2 is increased, it begins to consume fluorine H + F = HF This slows the formation of SiF4 and slows the removal of Silicon. Polymerization will be promoted on all surfaces, which tends to inhibit etching. On horizontal surfaces however, ionic bombardment provides enough energy cause the carbon/hydrogen to combine with surface oxygen. Released CO and H2O expose the surface silicon which is removed by combining with released fluorine radicals. Silicon will not be etched because of the absence of oxygen at the surface.

POLYMER FORMATION



H2 additions

O2 additions

CF4 plasma

Increasing anisotropic

Increasing SiO2:Si Selectivity

Polymer Formation

Isotropic Etch

Increasing Pressure

Increasing anisotropic

Ion Bombardment Energy

300 eV

Increasing Isotropic

BOSCH ICP (PLASMA THERM)

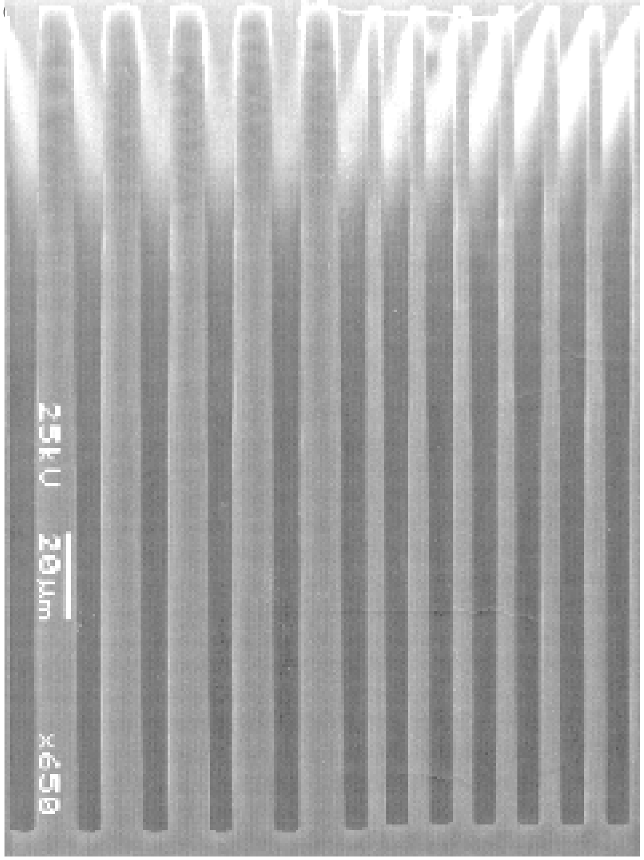
Deep Reactive Ion Etch (DRIE) The Bosch process uses two chemistries, one to generate polymers and the other to etch silicon. The etch machine switches between the two every few seconds to ensure that the sidewalls are covered with p

deep trench etching. (the substrate is on a chuck that is cooled by liquid nitrogen.

STS

SURFACE TECHNOLOGY SYSTEMS

- **5µm spaces**
- **200µm etch depth**
- **40:1 aspect ratio**
- **2µm/min Si etch rate**
- **>75:1 selectivity to photoresist**



STS ETCH SYSTEM AT RIT

Deep Reactive Ion Etch (DRIE)

SF6 and C4F8
1 to 10 um/min,
Oxide, Nitride or Photoresist masks.

STS ETCH SYSTEM AT RIT

Deep Reactive Ion Etch (DRIE)

13 sec etch in SF_6 at 130 sccm plus O_2 at 13 sccm
7 sec polymer deposition in C_4F_8 at 80 sccm

600 watts RF power
45 mTorr Pressure during etch
100 V wafer bias during etch

3 um/min etch rate

PLASMA ETCHING OF VARIOUS MATERIALS

Material	Kind of Gas Plasma	Remark
Si	CF_4, $CF_4 + O_2$, CCl_2F_2	
poly-Si	CF_4, $CF_4 + O_2$, $CF_4 + N_2$	doped or undoped
SiO_2	CF_4, $CF_4 + O_2$, HF*	*selective
	CCl_2F_2, C_3F_8**, $C_2F_6 + H_2$**	**diode system
Si_3N_4	CF_4, $CF_4 + O_2$	
Mo	CF_4, $CF_4 + O_2$	
W	CF_4, $CF_4 + O_2$	
Au	$C_2Cl_2F_4$	
Pt	$CF_4 + O_2$, $C_2Cl_2F_4 + O_2$, $C_2Cl_3F_3 + O_2$	
Ti	CF_4	
Ta	CF_4	
Cr	Cl_2, CCl_4, CCl_4 + Air	evaporate or sputter
Cr_2O_3	Cl_2 + Ar, CCl_4 + Ar	oxidation method
Al	CCl_4, CCl_4 + Ar, BCl_3	
Al_2O_3	CCl_4, CCl_4 + Ar, BCl_3	
GaAs	CCl_2F_2	

PLASMA ETCHING OF VARIOUS MATERIALS

This is a summary of some of the results made in the RIT laboratory.

Date	Etchant	Material	Etch Rate	Comments
4-8-98	SF6 (10sccm) +	LTO	800 Å/min	Josh Roberrge
	CHF3 (15sccm)			Rick Anundson
	50 watts, 270 mT	Thick Resist (no hard bake)	1875 Å/min.	Should Hardbake
3-1-98	SF6 (10sccm) +	LTO	1250 Å/min	Thresa Evans
	CHF3 (15sccm)	Thermal SiO2	800 Å/min	
	50 watts, 270 mT	Thick Resist	2100 Å/min	
		Poly	???	
		Nitride	1648 Å/min	
	CHF3 only	LTO	105 Å/min	
	SF6 off	Thick Resist	5 Å/min	

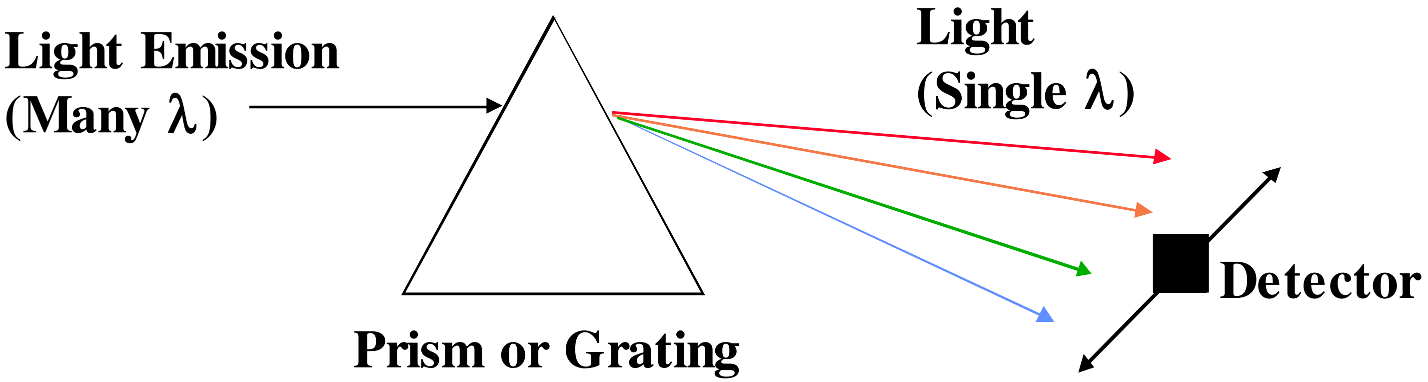
END POINT DETECTION

Time
Plasma Brightness
Changes in Emission Spectrum

EMISSION SPECTRUM

The emission of light occurs when electrons, ions or molecules in a high energy state relax to a lower energy state. In a plasma, gas molecules are broken into fragments and excited to high energy states by the applied radio frequency power. These fragments recombine giving off photons equal in energy to the difference between the excited state and the relaxed state called an emission spectrum. In general plasmas are quite complex and the emission spectrum has many spikes and peaks at different wavelengths. Some of these spikes and peaks change as the chemistry of the plasma changes. For example in etching silicon nitride once the etching is complete the amount of nitrogen in the plasma goes to zero and peaks associated with nitrogen disappear. If the nitride is over oxide than once the nitride is gone the amount of oxygen in the plasma will increase and peaks associated with oxygen will appear. Usually several signals are watched at the same time to determine end point in plasma etching.

EMISSION SPECTROSCOPY

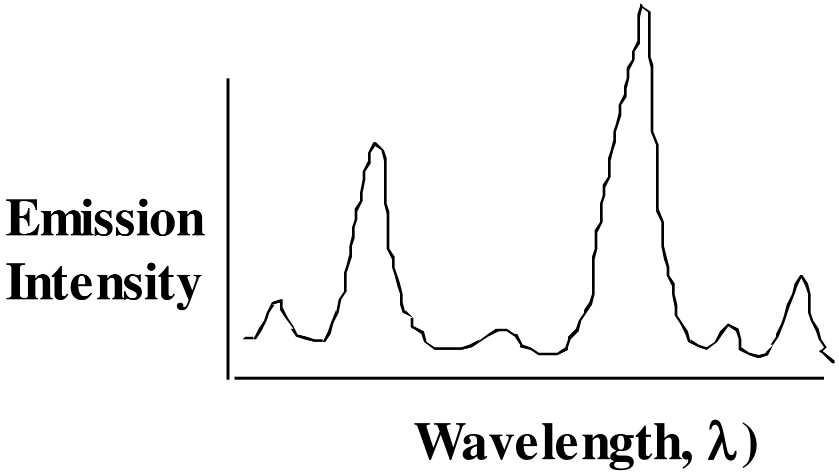


Light Emission (Many λ)

Light (Single λ)

Detector

Prism or Grating

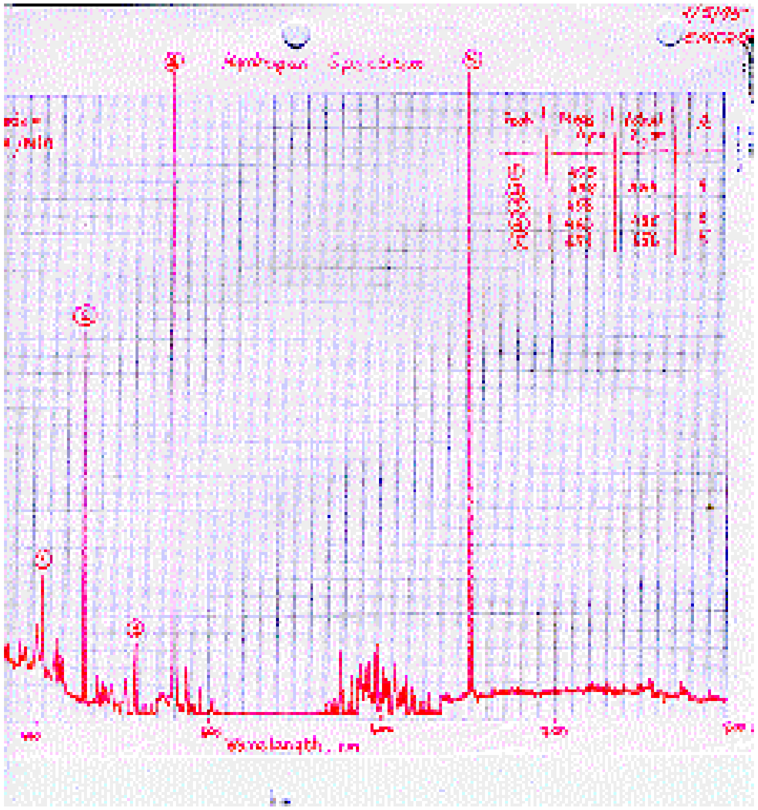


Emission Intensity

Wavelength, λ)

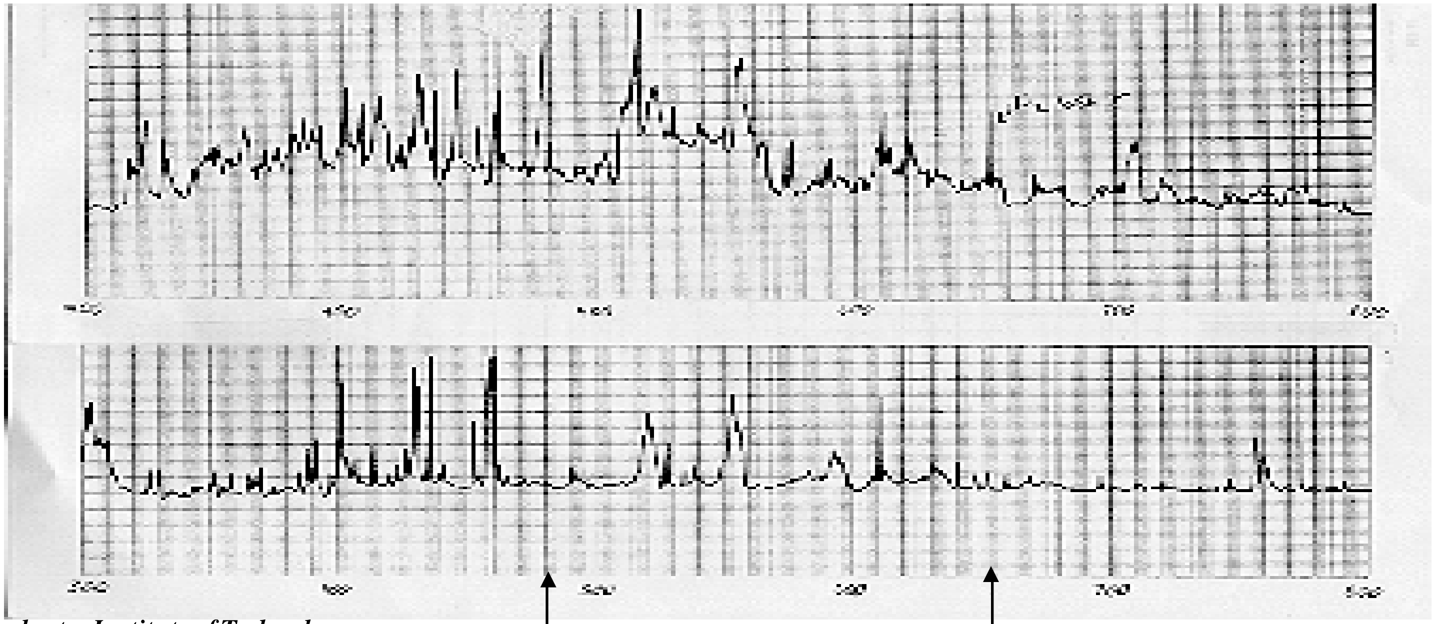
CALIBRATION

Your emission spectrometer can be calibrated by looking at well known emission spectra such as Hydrogen, which has peaks at 405, 438, 458, 486, and 656 nm.



EXAMPLES OF EMISSION SPECTRA MEASURED AT RIT

Compare the emission spectra with no wafer to the spectra with a film being etched. Find a peak that represents a byproduct of the etch. Set the spectrometer on one or more of these characteristic peaks and monitor etch completion as these peaks change. For example in O2 plasma etch of photoresist there is a peak at 483.5 nm associated with CO which disappears at the end of the etch.



O2 Plasma Wafer with Photoresist

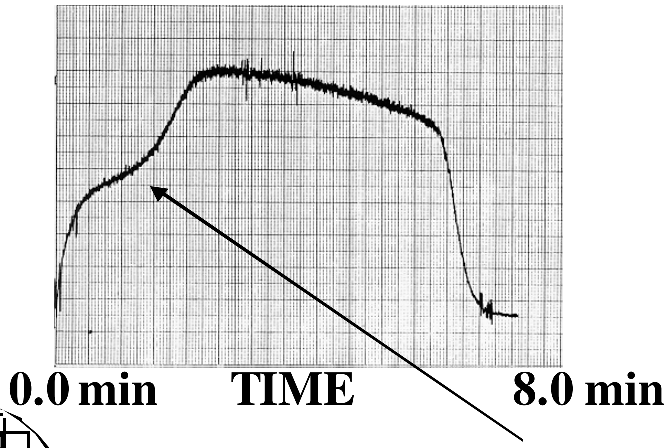
O2 Plasma No Wafer in the System

CO peak at 483.5 nm

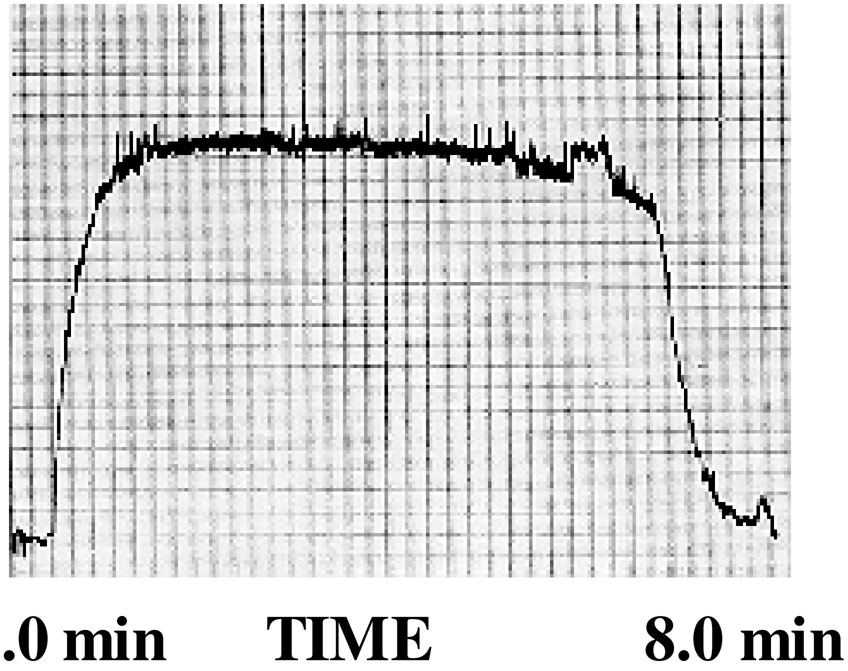
H2 peak at 656.5 nm

O2 PLASMA STRIP END POINT DETECTION

Monitor the CO peak at 483.5 nm. During photoresist stripping there are large numbers of CO molecules. At end of Photoresist stripping the number of CO molecules is reduced.



BF2 heavy dose implant causes the surface to strip more slowly than bulk, thus initial CO emission is lower

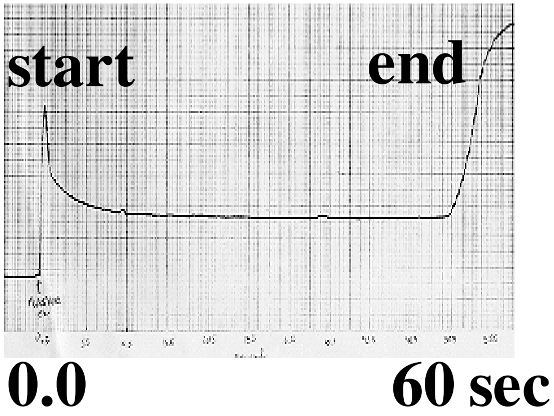

O2, 30 sccm, 50 watts, 300 mTorr

POLY ETCH END POINT EXAMPLE

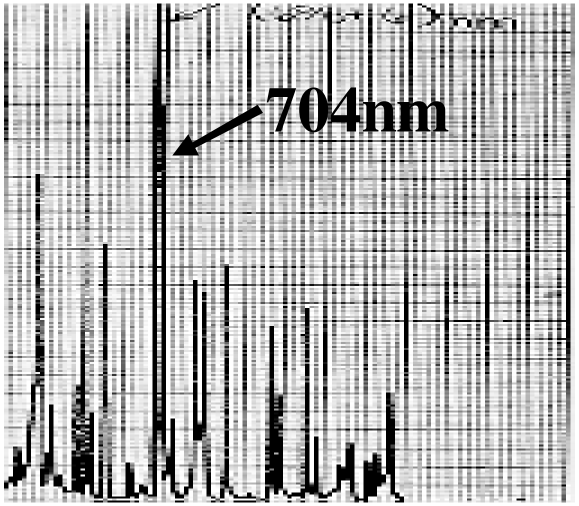
End Point

SF6 + O2

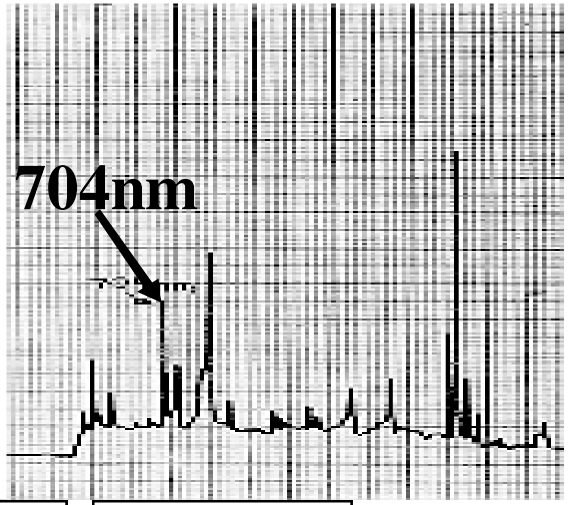
704nm Line



Emission Spectra
in SF6 + O2 Plasma
No Silicon Wafer
in System



Emission Spectra
During Etching
of Poly
in SF6 + O2 Plasma

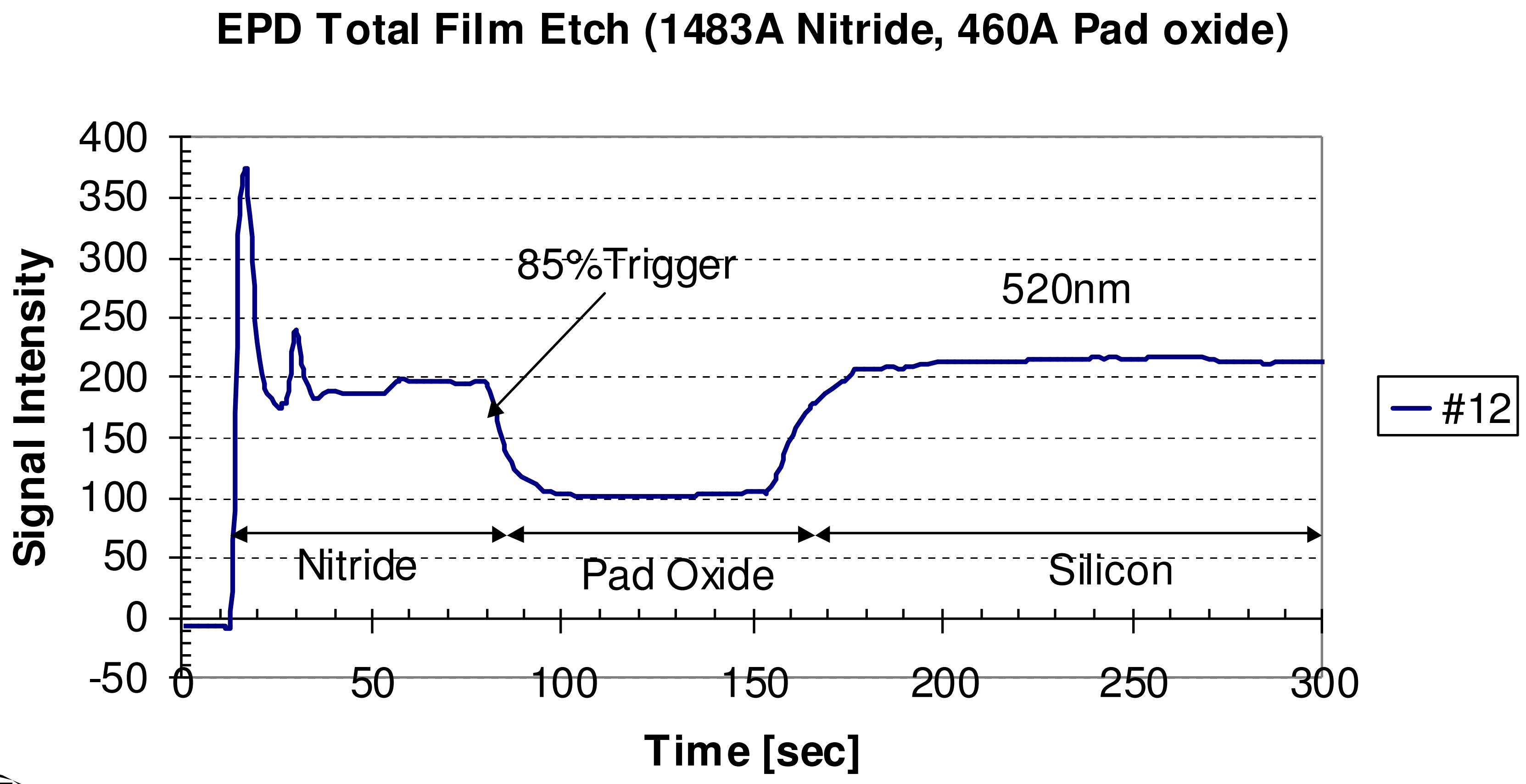


PLASMA ETCH TOOL

Lam 490 Etch Tool
Plasma Etch Nitride (~ 1500 Å/min)
SF6 flow = 200 sccm
Pressure= 260 mTorr
Power = 125 watts
Time=thickness/rate

Use end point detection capability This system has filters at 520 nm and 470 nm. In any case the color of the plasma goes from pink/blue to white/blue once the nitride is removed.

LAM 490 END POINT



LAM 490 PLASMA ETCH FOR 1500Å NITRIDE

- Follow LAM490 SMFL operations manual for start up
- Send FNIT1500.RCP
- Press ‘Recipe’ button on LAM to verify the Recipe
- Press ‘Parameters’ button and **modify** Endpoint 1 to match
- Proceed with Etch

Parameters
Endpoint 1
Press field select to change to endpoint setup screen and edit the following
Sampling A only [520nm ch 12]
Active during step 02
Delay 50 sec before normalizing
Normalize for 10 sec
Trigger @ 85% of normalized value

	Step 1	Step 2	Step3
Pressure	260 mT	260 mT	260 mT
RF Top	0	125	125
Gap	1.65	1.65	1.65
CF4	0	0	0
Oxygen	0	0	0
Helium	0	0	0
SF6	200	200	200
Compl	Time Only	Time & Endpoint	Overetch
Max	2 min	2 min 20s	40%

Robert Saxer, Dan Brown, Dr. Fuller

LAM 490 PLASMA ETCH FOR 6000Å POLY

- Follow LAM490 SMFL operations manual for start up
- Send FACPOLY.RCP
- Press ‘Recipe’ button on LAM to verify the Recipe
- Press ‘Parameters’ button and **modify** Endpoint 1 to match
- Proceed with Etch

Parameters
Endpoint 1
Press field select to change to endpoint setup screen and edit the following
Sampling A only [520 nm ch 12]
Active during step 02
Delay 15 sec before normalizing
Normalize for 10 sec
Trigger @ 90% of normalized value

	Step 1	Step 2	Step3
Pressure	325 mT	325 mT	325 mT
RF Top	0	140	140
Gap	1.65	1.65	1.65
CF4	0	0	0
Oxygen	0	15	15
Helium	0	0	0
SF6	140	140	140
Compl	Time Only	Time & Endpoint	Overetch
Max	2 min	1 min 15s	10%

Robert Saxer, Dan Brown, Dr. Fuller

LAM 490 ETCHING OF PARYLENE, CARBON FILM (DIAMOND LIKE FILM) AND PHOTORESIST STRIPPING

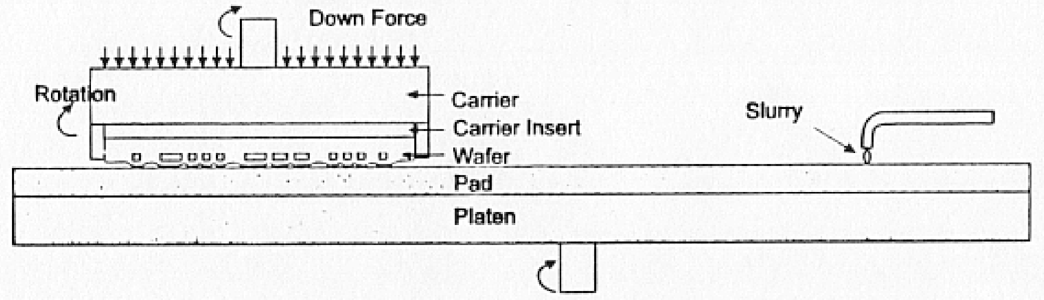
Etch Rate (for Resist) = 3500 Å/min
Etch Rate (for Parylene) = 3000 Å/min
Etch Rate (for Carbon) = 2500 Å/min

Step 01
Pressure = 225 mTorr
Power = 0 watts
Gap = 1.5 cm
O2 Flow = 100 sccm
He Flow = 50 sccm
Time = 60 sec

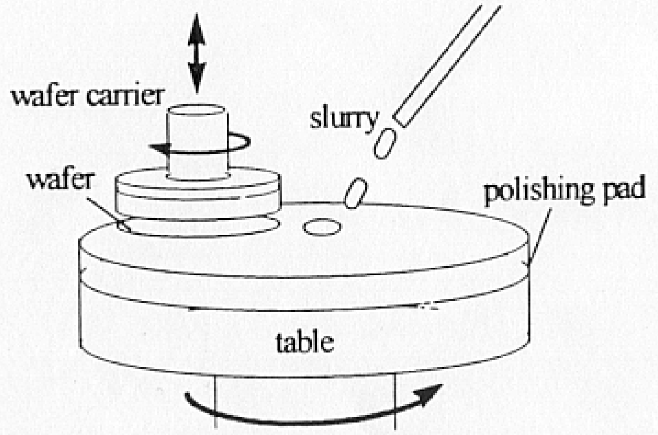
Step 02
Pressure = 225 mTorr
Power = 225 watts
Gap = 1.5 cm
O2 Flow = 100 sccm
He Flow = 50 sccm
Time = thickness/rate

Chamber clean is same etch recipe with step 02 time of 10-20 min. using bare 150 mm silicon wafer

CMP EQUIPMENT SCHEMATIC CONVENTIONAL ORBITAL

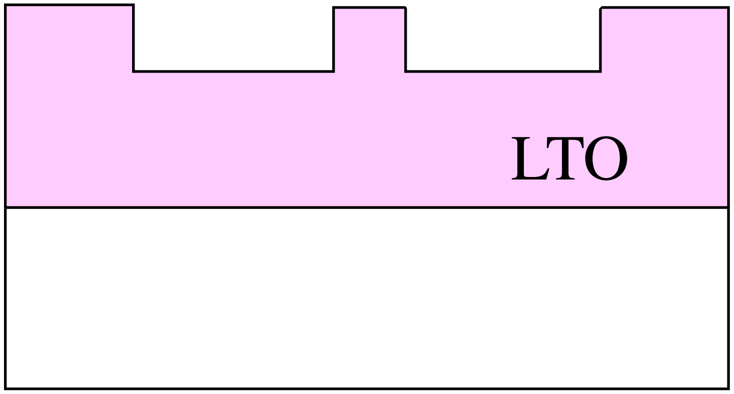


IBM Patent: 4,944,836, Jul. 31, 1990

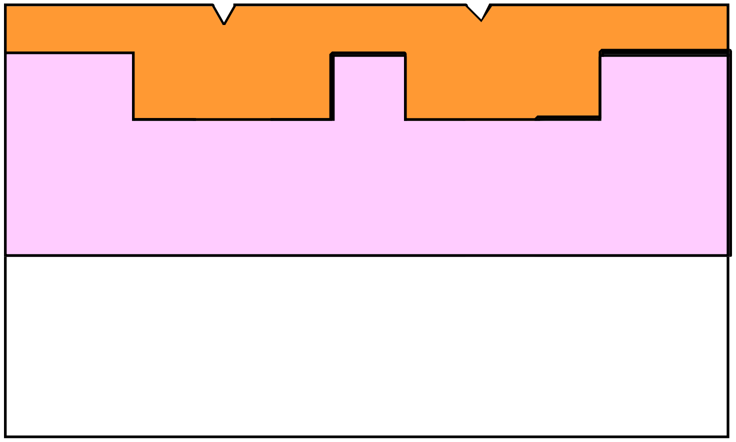


SILICON WAFER CMP

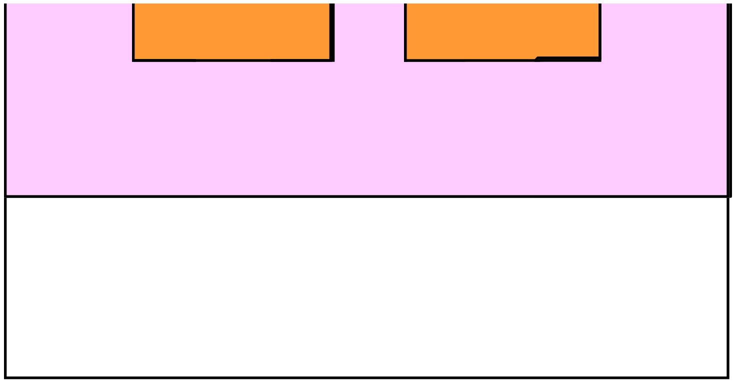
DAMASCENE PROCESS



Pattern Trenches in Oxide



Fill with Copper Metal



CMP Excess Metal Off

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MORE
MORE
MORE
MORE
MORE

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10. Andy McQuarrie, STS Company, Surface Technology Systems,

11. Highly Anisotropic Silicon Reactive Ion Etching for Nano Fabrication Using Mixtures of SF6/CHF3 Gases, S. Grigoropoulos, et.al., J.Vac Sci. Technol. May/Jun 1997

HOMEWORK – MEMS ETCHING

1. Design a process to make a 1.5 um diaphragm in single crystal silicon wafer of 500 µm thickness. Recommend photoresist opening size on the back of the wafer to give a 750 µm square diaphragm.
2. Look up the etch rate for poly, oxide and silicon nitride in HF/HCl.
3. If you are etching oxide off of silicon nitride in HF/HCL and you have to over etch to undercut some cantilever structures how far can you etch laterally before the underlying nitride is gone. Make reasonable assumptions.