ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING

PMOS 150mm PROCESS DETAILS

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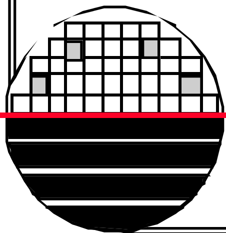

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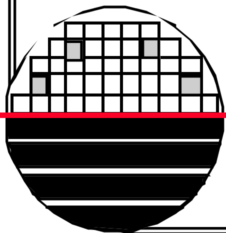
RIT METAL GATE PMOS PROCESS

- 10 Micrometer Design Rules
- 4 Design Layers
- 4 Photolithography Layers
  - 4 Levels per Plate
- Metal Gate
- Ion Implanted D/S
- Plasma Etched Aluminum
- 150mm Wafer Diameter



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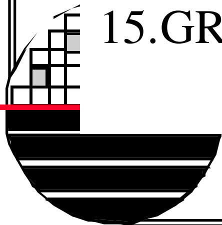
METAL GATE PMOS PROCESS

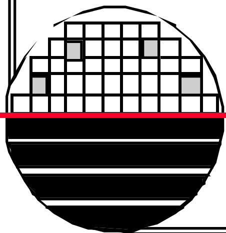
PMOS Versions 150

1. ID01 Scribe Wafers C1, C2, D1…DX
2. DE01 4 Point Probe C1, 5-15 ohm-cm
3. CL01 C1, C2, and All Device Wafers
4. OX06 6500Å, Tube 1, Recipe 406
5. PH03 – PMOS Level 1, Diffusion
6. ET06 Step Etch C1, Etch C2 Bare
7. ET06 Etch All Device Wafers
8. ET07 Ash Device Wafers
9. CL01 – RCA Clean All Wafers
10. IM01- B11, 75 KeV, All Wafers
11. OX06 – 4000Å Tube 1, Recipe 341
12. PH03 – PMOS Level 2, Oxide
13. ET06 C1, C2 and All Device Wafers
14. DE01 4 Point Probe C1
15. GRV1 Grove and Stain C1
16. ET07 Ash Device Wafers
17. CL01 C2 and All Device Wafers, 2 HF dips
18. OX05 Gate Ox, Tube 4, 700Å, Recipe 270
19. PH03 - PMOS Level 3, CC
20. ET06 C2 and All Device Wafers
21. ET07 Ash Device Wafers
22. DE01 4 pt probe C2
23. GRV1 Grove and Stain C2
24. CL01 All Device Wafers, Two HF dips
25. ME01 Sputter Metal All Device Wafers 10KÅ
26. PH03 - PMOS – Level 4, Metal
27. ET15 Etch Aluminum All Device Wafers
28. ET07 Ash Device Wafers
29. SI01 Sinter Device Wafers Tube 2, Recipe 101
30. TE01 Test Wafers



STARTING WAFER N-TYPE, 5 OHM-CM

5-15 ohm-cm, n-type, (100)



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CONTROL WAFERS

C1 (Top Half)

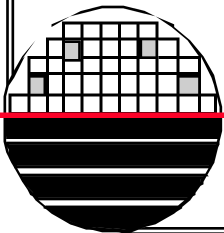
Masking oxide etch rate
Minimum masking oxide thickness

(Bottom Half)

1st Junction depth after implant & anneal
Sheet resistance after implant & anneal

C2

- 2nd Junction depth after gate oxide
- Sheet resistance after gate oxide



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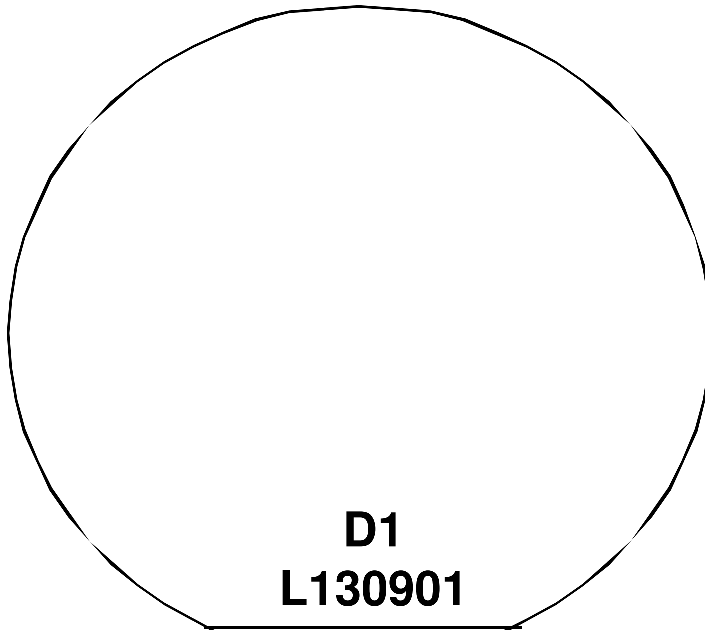
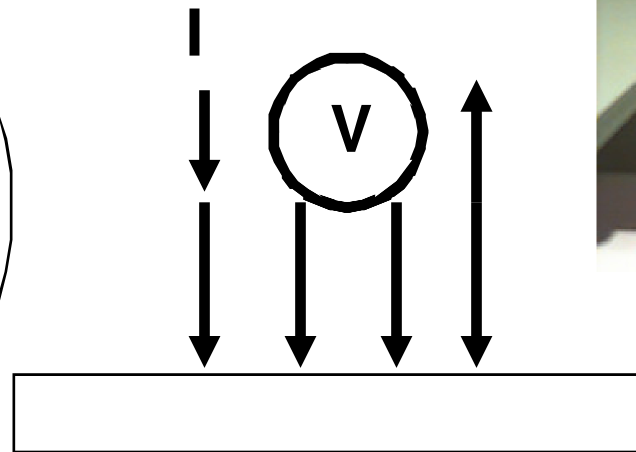
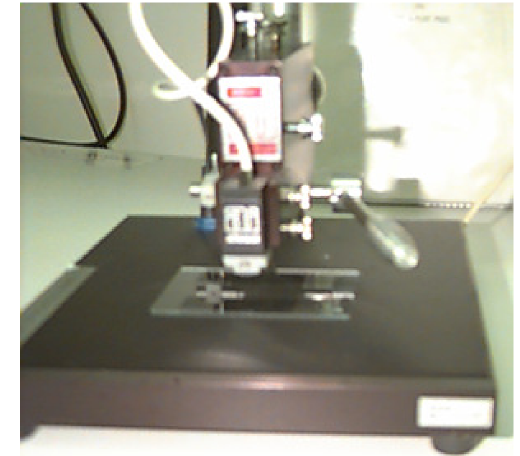
ID01 - IDENTIFY WAFER (SCRIBE WAFER)
DE01 - FOUR POINT PROBE





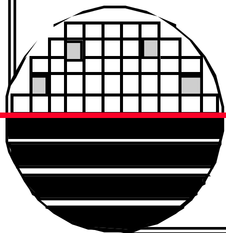


S = probe spacing

W = wafer thickness

$$\text{Rho} = \pi/\ln 2 \times W \times V / I \quad \text{ohm-cm}$$

if S<<W and S<<Wafer Diameter



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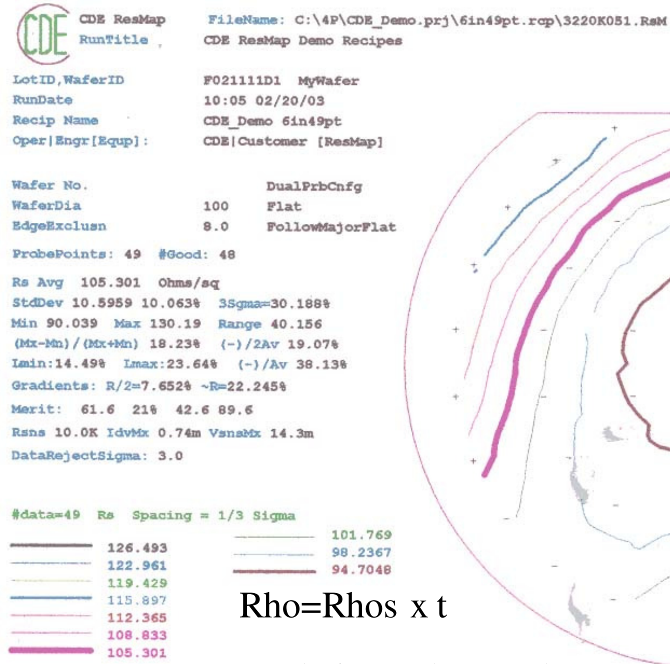
DE01 - MEASURE WAFER RESISTIVITY

CDE Resistivity Mapper



Rho=Rhos x t

Tool gives Rho or Rhos depending on recipe used, automatically adjusts correction factors for wafer thickness

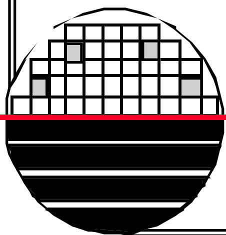
Record:

Average Resistivity on D1 only

Rho(ave) = ohm-cm

TENCORE SURF SCAN

Gives total surface particle count and count in 4 bins <0.5, 0.5 to 2.0, 2.0-10, >10. Bin boundary can be selected. Edge exclusion eliminated count from near the edge of the wafer.



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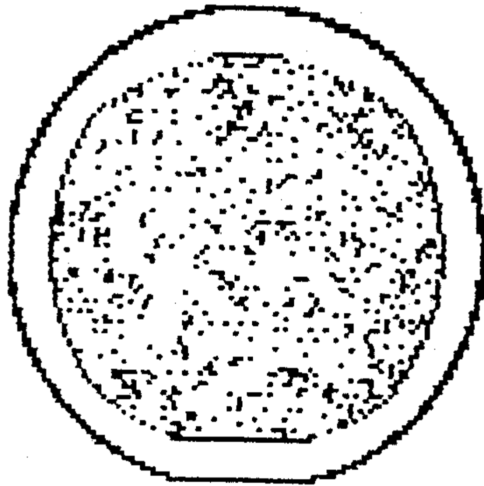
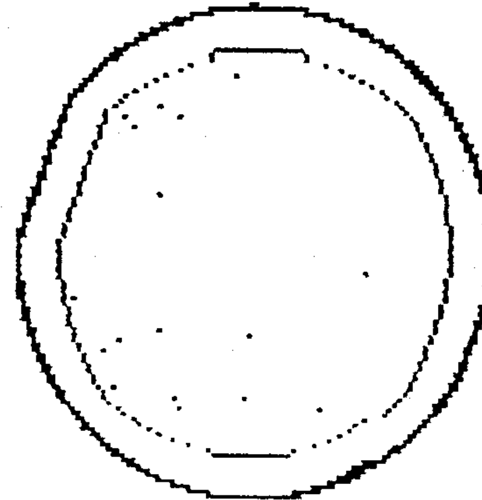
EXAMPLE SURFACE PARTICLE COUNT DATA



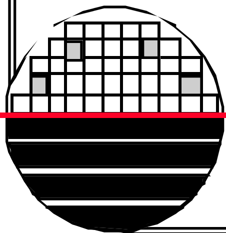


Before Cleaning (75 mm)

Size Range (µm)	Count
0.2 - 0.5	104
0.5 - 2.0	562
2.0 - 10	19
>10	2

After Cleaning (75 mm)

Size Range (µm)	Count
0.2 - 0.5	10
0.5 - 2.0	4
2.0 - 10	3
>10	0



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RCA CLEAN

APM – SC1

H_2O – 5000ml
NH_4OH–300ml
H_2O_2 – 300ml
75 °C, 10 min.

DI water
rinse, 5 min.

H_20 - 50
HF - 1
30 sec.

DI water
rinse, 5 min.

HPM – SC2

H_2O–5000ml
HCL-300ml
H_2O_2 – 300ml
75 °C, 10 min.

DI water
rinse, 5 min.

SPIN/RINSE
DRY

What does RCA stand for?

ANSWER

PLAY

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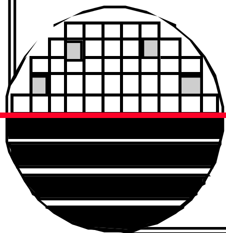
RCA CLEAN TOOLS

RCA Bench
Spin/Rinse/Dry Tool



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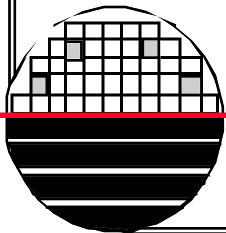
GROW 6500 Å OXIDE

6500 Å SiO2

Use Recipe 406 – Tube 1



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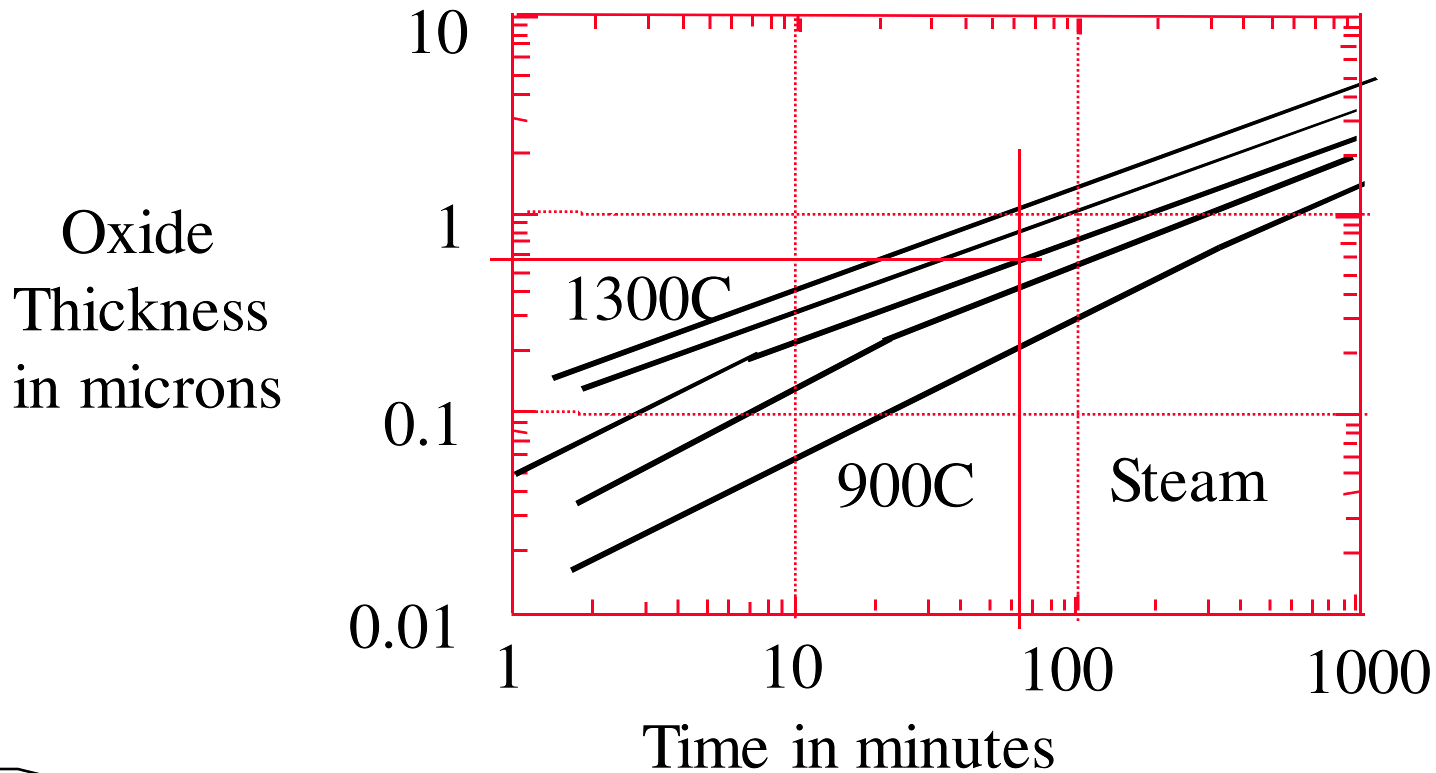
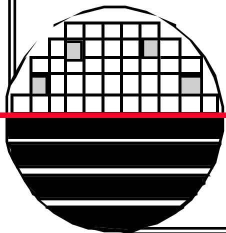
WET OXIDE GROWTH CHART





OXIDE THICKNESS CALCULATOR

ROCHESTER INSTITUTE OF TECHNOLOGY OXIDE.XLS
MICROELECTRONIC ENGINEERING 9/9/2010

CALCULATION OF OXIDE THICKNESS Dr. Lynn Fuller

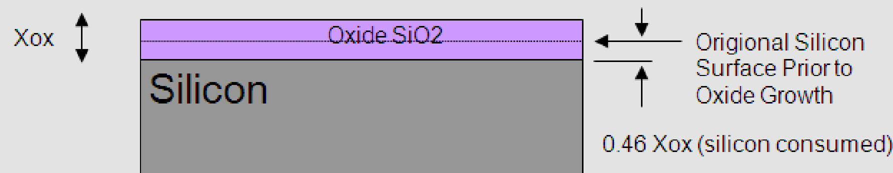
To use this spreadsheed change the values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The calculated results are shown in the purple boxes.

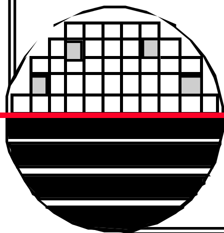
CONSTANTS			VARIABLES			CHOICES	
K	1.38E-23	J/K					1=yes, 0=no
(Bo/Ao) dry	6230000	µm/hr	Temp=	1100	°C	wet	1
Ea (dry)	2	eV	time=	70	min	dry	0
(Bo/Ao) wet	89500000	µm/hr				<100>	1
Ea (wet)	2.05	eV	Xint=	0	Å	<111>	0
Bo dry	7.72E+02	µm2/hr					
Ea (dry)	1.23	eV	Silicon VLSI Technology, Plummer, Deal, Griffin				
Bo wet	2.14E+02	µm2/hr	Prentice Hall, 2000, pg 319				
Ea (wet)	0.71	eV	(Bo/Ao)/1.68 for <100>				

CALCULATIONS:

Xox (Oxide thickness)=(A/2){[1+(t+Tau)4B/A^2]^0.5 -1} = 6435 Å

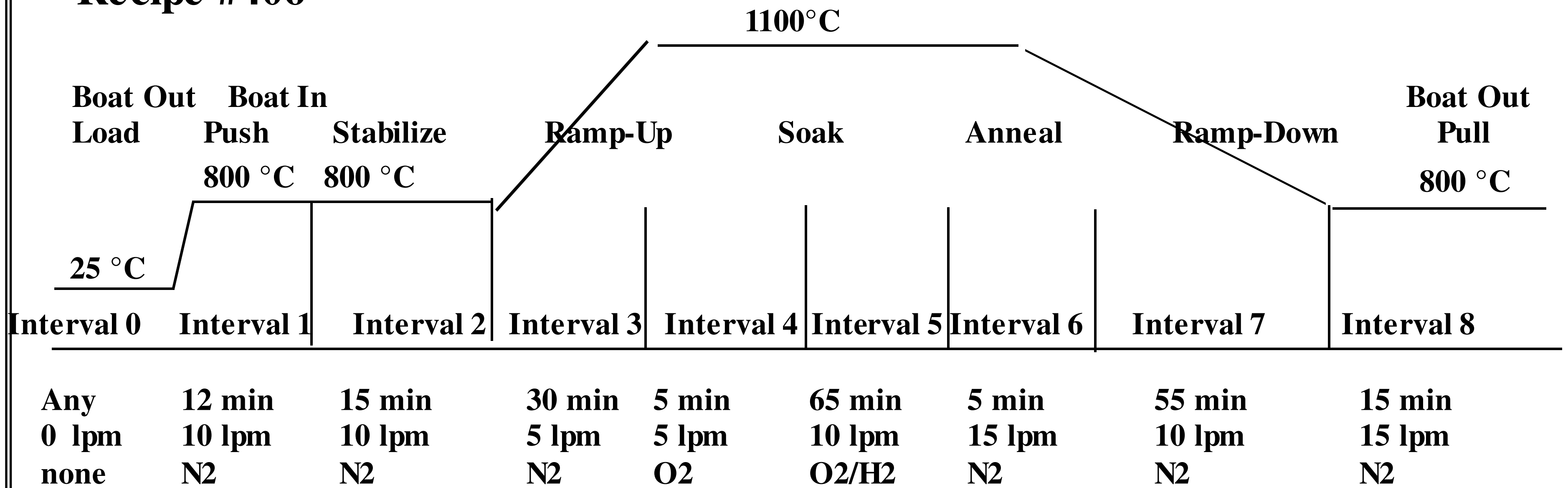
B = Bo exp (-Ea/KTemp)	0.5343504	µm2/hr
B/A = (Bo/Ao) exp (-Ea/KTemp)	1.64E+00	µm/hr
A	0.325361	µm
Tau = (Xi2+AXi)/B	0	hr





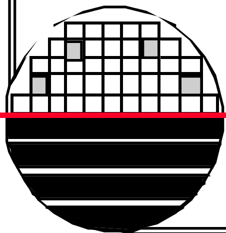
Roches
Microe

BRUCE FURNACE RECIPE 406 – WET OXIDE 6,500Å



At the end of a run the furnace returns to Interval 0 which is set for boat out, 25 °C and no gas flow. The furnace waits in that state until someone aborts the current recipe or loads a new recipe.

Wet Oxide Growth, Target 6,500 Å



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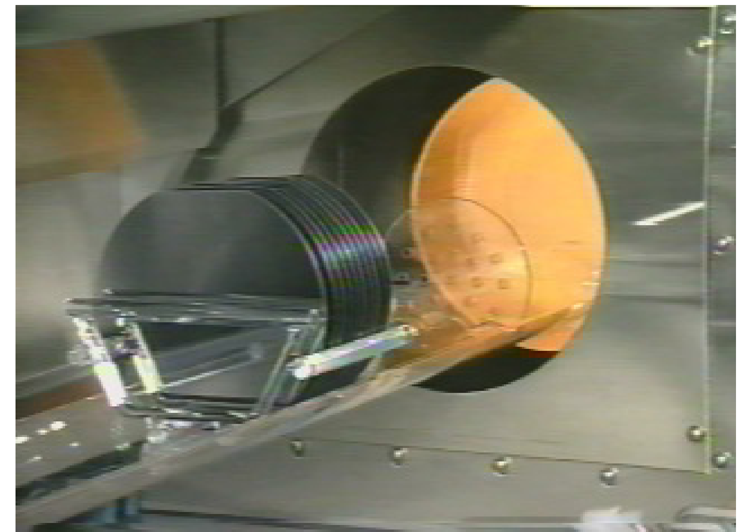
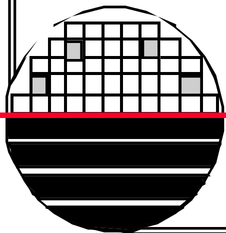
6500 Å OXIDE GROWTH

PMOSFET



n-type substrate, 5-15 ohm-cm, (100)



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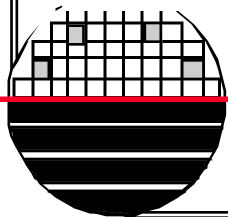
OXIDE COLOR VERSUS THICKNESS TABLE

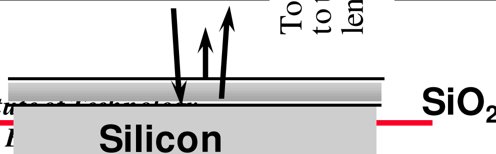
Thickness	Color
500	Tan
700	Brown
1000	Dark Violet - Red Violet
1200	Royal Blue
1500	Light Blue - Metallic Blue
1700	Metallic - very light Yellow Green
2000	LIght Gold or Yellow - Slightly Metallic
2200	Gold with slight Yellow Orange
2500	Orange - Melon
2700	Red Violet
3000	Blue - Violet Blue
3100	Blue
3200	Blue - Blue Green
3400	Light Green
3500	Green - Yellow Green
3600	Yellow Green
3700	Yellow
3900	Light Orange
4100	Carnation Pink
4200	Violet Red
4400	Red Violet
4600	Violet
4700	Blue Violet

To observe a valid color, the wafer must be observed perpendicular to the surface under white (all wavelengths) light or the optical path length will be different, hence the color will change with the angle.

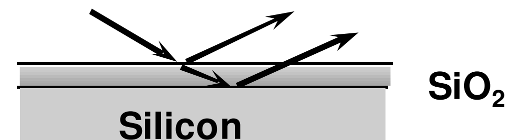
Thickness	Color
4900	Blue
5000	Blue Green
5200	Green
5400	Yellow Green
5600	GreenYellow
5700	Yellow -"Yellowish"(at times appears to be Lt gray or matellic)
5800	Light Orange or Yellow - Pink
6000	Carnation Pink
6300	Violet Red
6800	"Bluish"(appears violet red, Blue Green, looks grayish)
7200	Blue Green - Green
7700	"Yellowish"
8000	Orange
8200	Salmon
8500	Dull, LIght Red Violet
8600	Violet
8700	Blue Violet
8900	Blue
9200	Blue Green
9500	Dull Yellow Green
9700	Yellow - "Yellowish"
9900	Orange
10000	Carnation Pink



Yes!



No!



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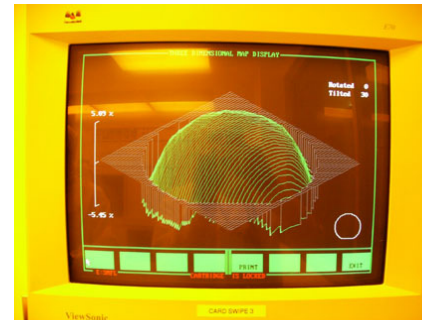
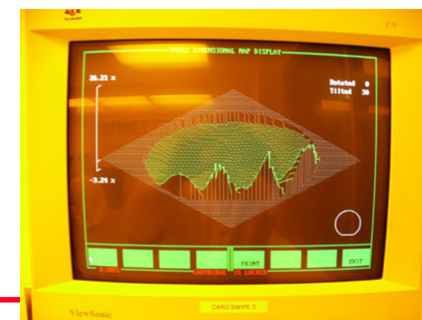
TENCORE SPECROMAP

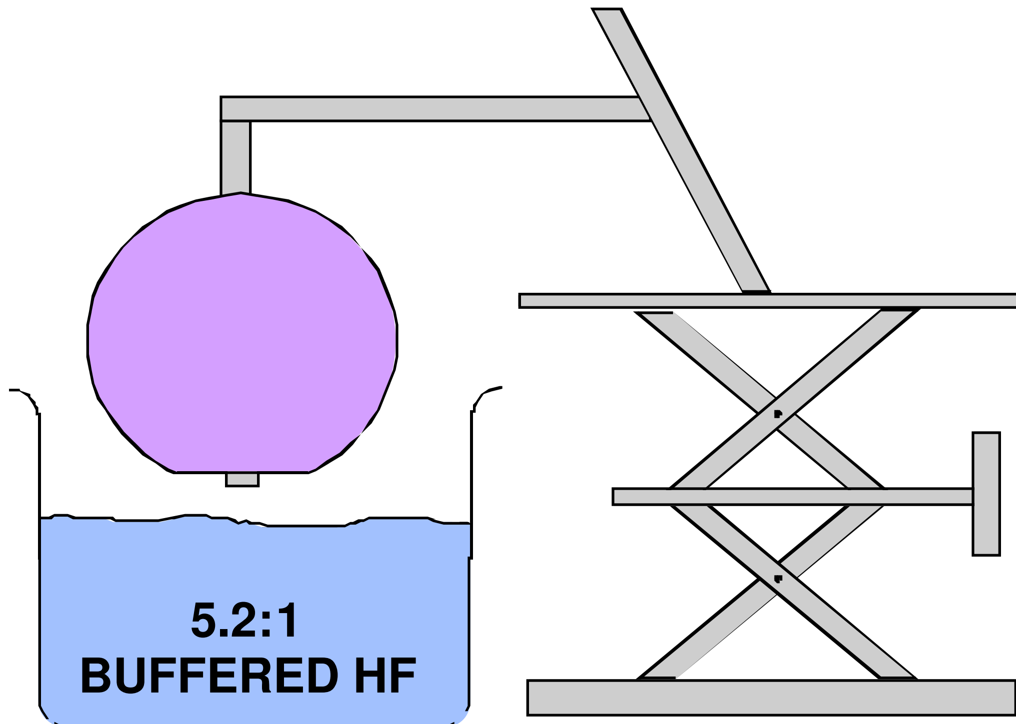




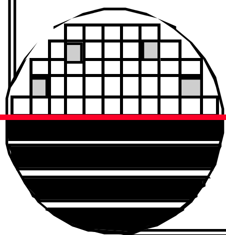
Record:

Mean
Std Deviation
Min
Max
No of Points

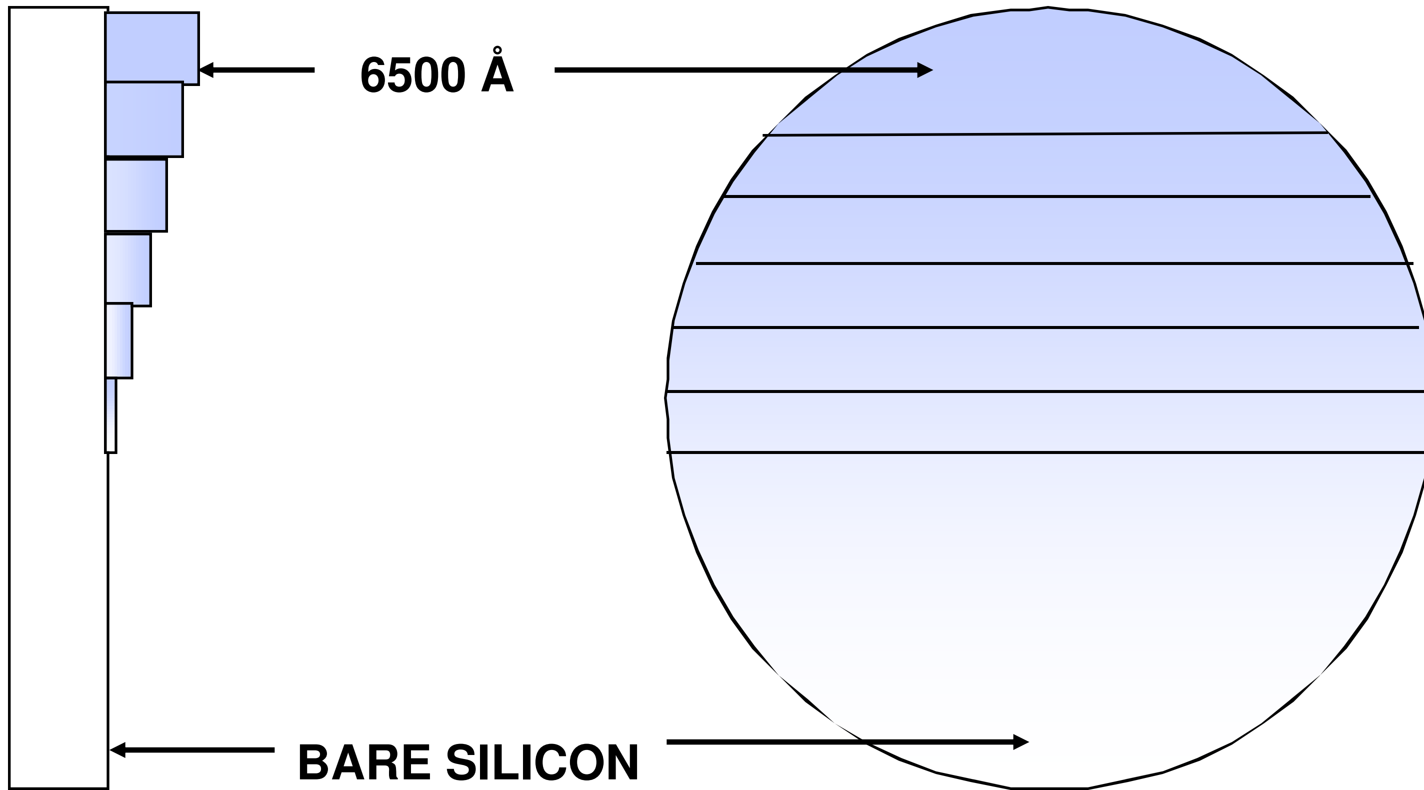
STEP ETCH APPARATUS

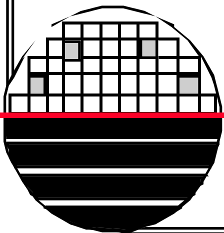


Lower 1/4 inch every 30 seconds



ETCH STEPS IN OXIDE ON C1





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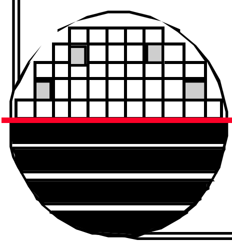
REFLECTANCE SPECTROMETER
NANOSPEC FILM THICKNESS MEASUREMENT

INCIDENT WHITE LIGHT, THE INTENSITY OF THE REFLECTED LIGHT IS MEASURED VS WAVELENGTH

Oxide on Silicon	400-30,000 Å
Nitride	400-30,000
Neg Resist	500-40,000
Poly on 300-1200 Ox	400-10,000
Neg Resist on Ox 300-350	300-3500
Nitride on Oxide 300-3500	300-3500
Thin Oxide	100-500
Thin Nitride	100-500
Polyimide	500-10,000
Positive Resist	500-40,000
Pos Resist on Ox 500-15,000	4,000-30,000



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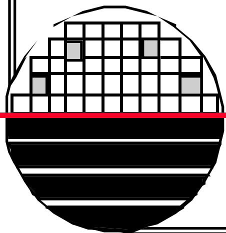
MEASURE OXIDE THICKNESS

Record:
Color =
Color Chart Thickness = Å
Nanospec Thickness = Å



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COAT WITH PHOTORESIST

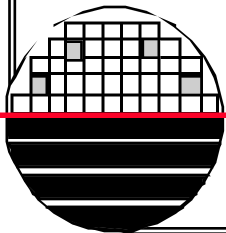
1 µm Photoresist

6500 Å SiO2

SSI Coat Recipe - COAT

SSI Develop Recipe - DEVELOP

Stepper Job Name - PMOS



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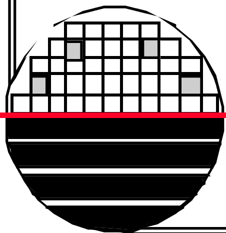
LITHOGRAPHY FOR PMOS 150 PROCESS

Lvl #	Level Name	Coat Recipe	Spin RPM	Xpr µm	Dose mj/cm^2	Dev Recipe	Dev Time	Hard Bake
1	Diff	coat	3250	1.0	250	develop	50s	140C/1min
2	ThinOx	coatmtl	2000	1.3	250	devmtl	68s	140C/2min
3	CC	coatmtl	2000	1.3	250	devCC	180s	140C/1min
4	Metal	coatmtl	2000	1.3	250	devmtl	68s	140C/2min



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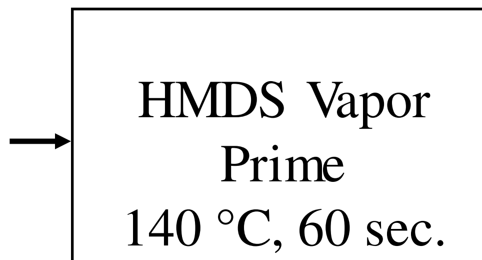
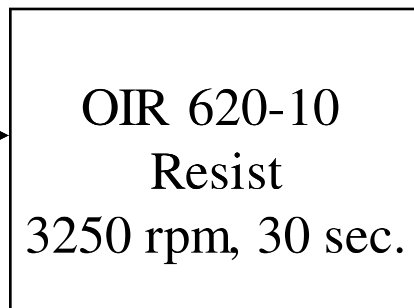
COAT.RCP

DEHYDRATE BAKE/ HMDS PRIMING

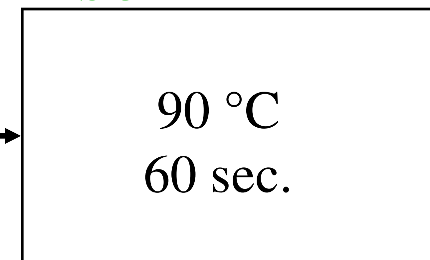


COAT.RCP

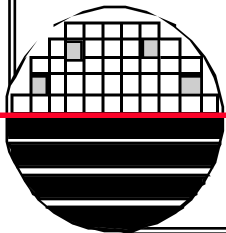
SPIN COAT



SOFT BAKE



Thickness of 10,000 Å



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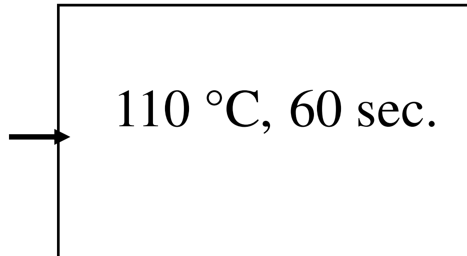
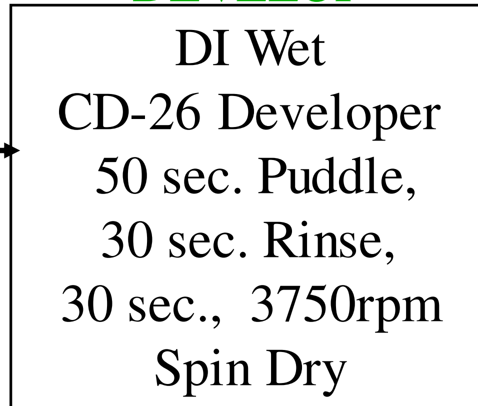
DEVELOP.RCP

DEVELOP.RCP

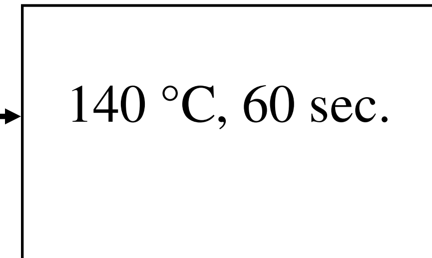
POST EXPOSURE BAKE

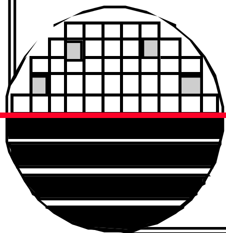


DEVELOP



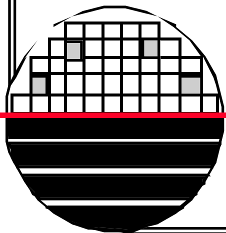
HARD BAKE





SSI COAT AND DEVELOP TRACK FOR 6" WAFERS

Use Recipe: Coat.rcp and Develop.rcp



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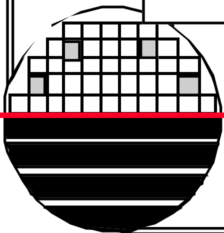
EXPOSE WITH LEVEL ONE DIFFUSION

6500 Å SiO2



Stepper Job Name = PMOS

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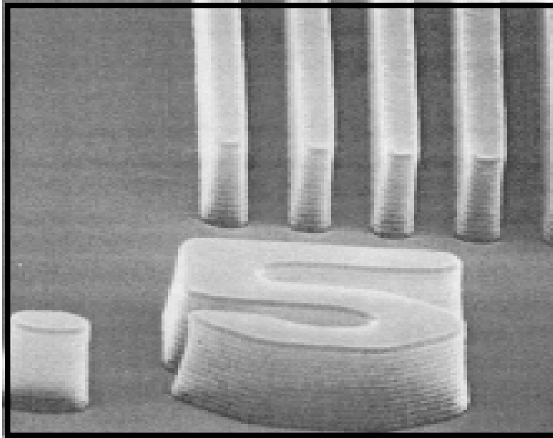
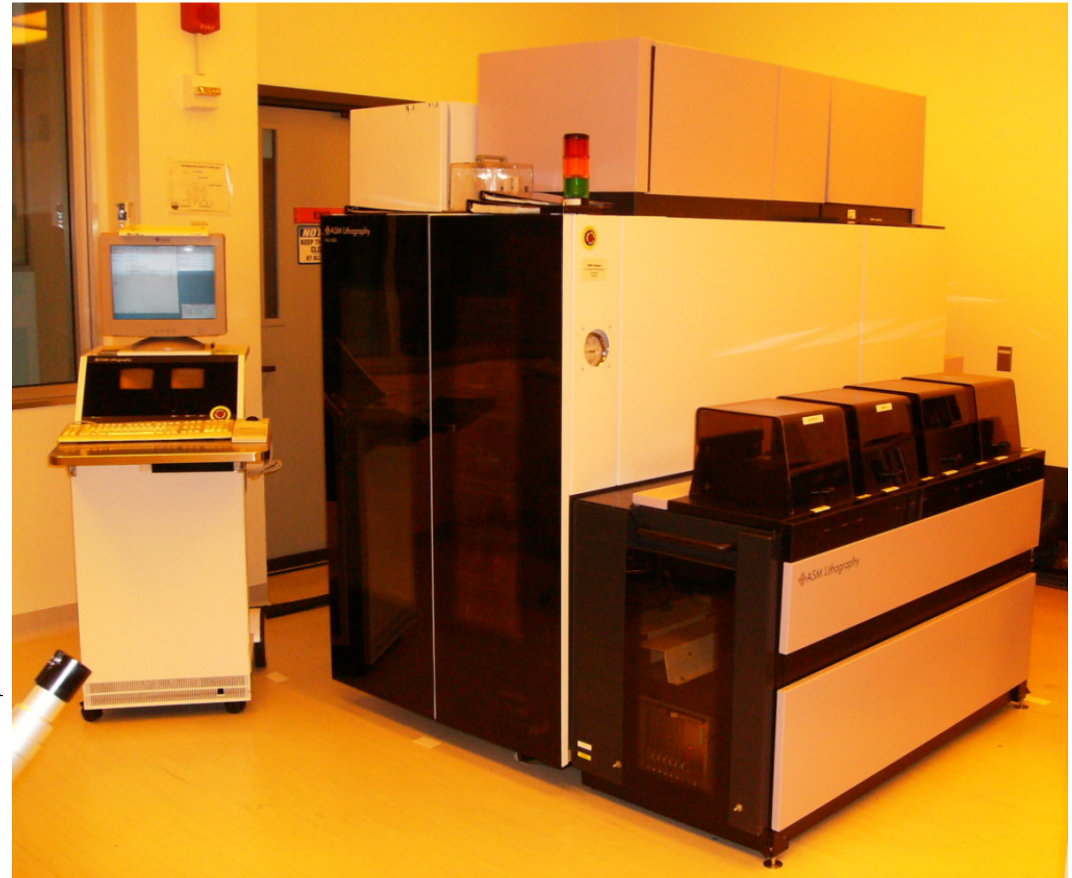
ASML 5500/200 STEPPER



NA = 0.48 to 0.60 variable
σ= 0.35 to 0.85 variable
With Variable Kohler, or
Variable Annular illumination
Resolution = K1 λ/NA
= ~ 0.35µm
for NA=0.6, σ =0.85
Depth of Focus = k_2 $\lambda/(NA)^2$
= > 1.0 µm for NA = 0.6



i-Line Stepper λ = 365 nm
22 x 27 mm Field Size

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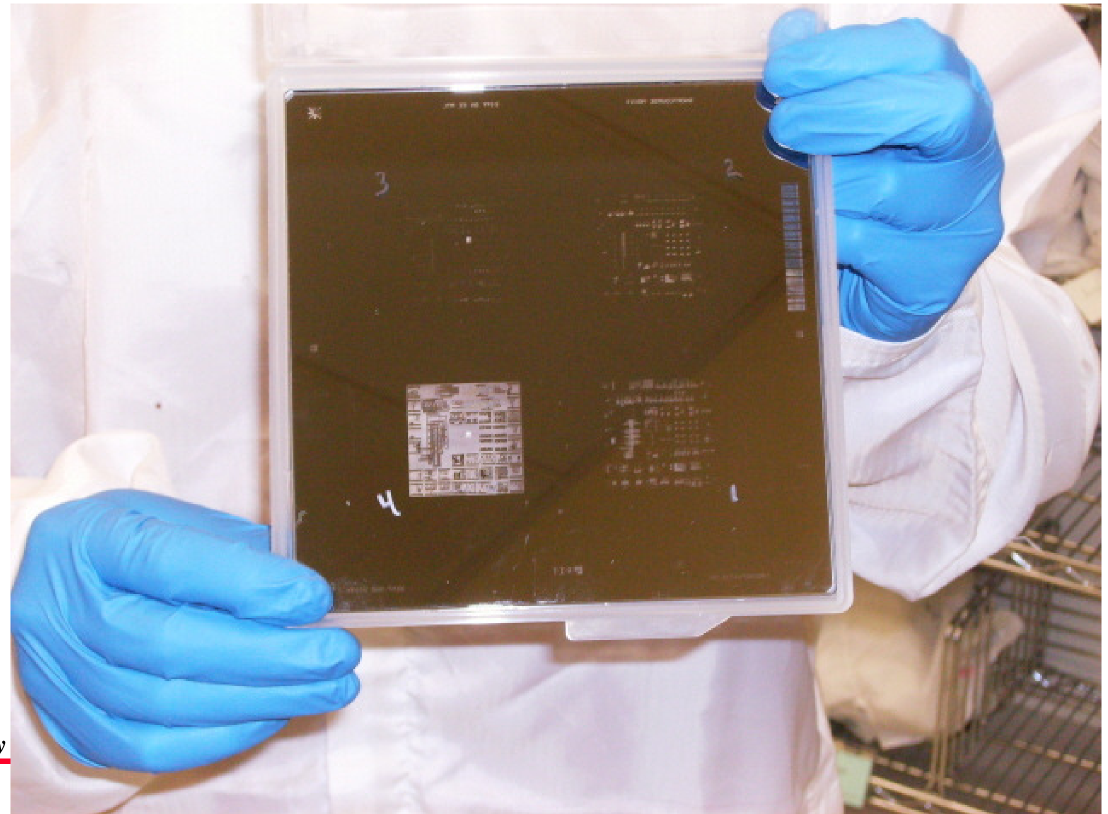
MASKS AND STEPPER JOBS

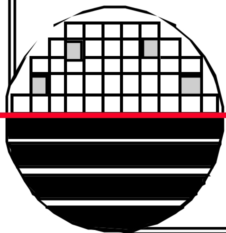
Masks with 4 levels

Saves money, time, inventory

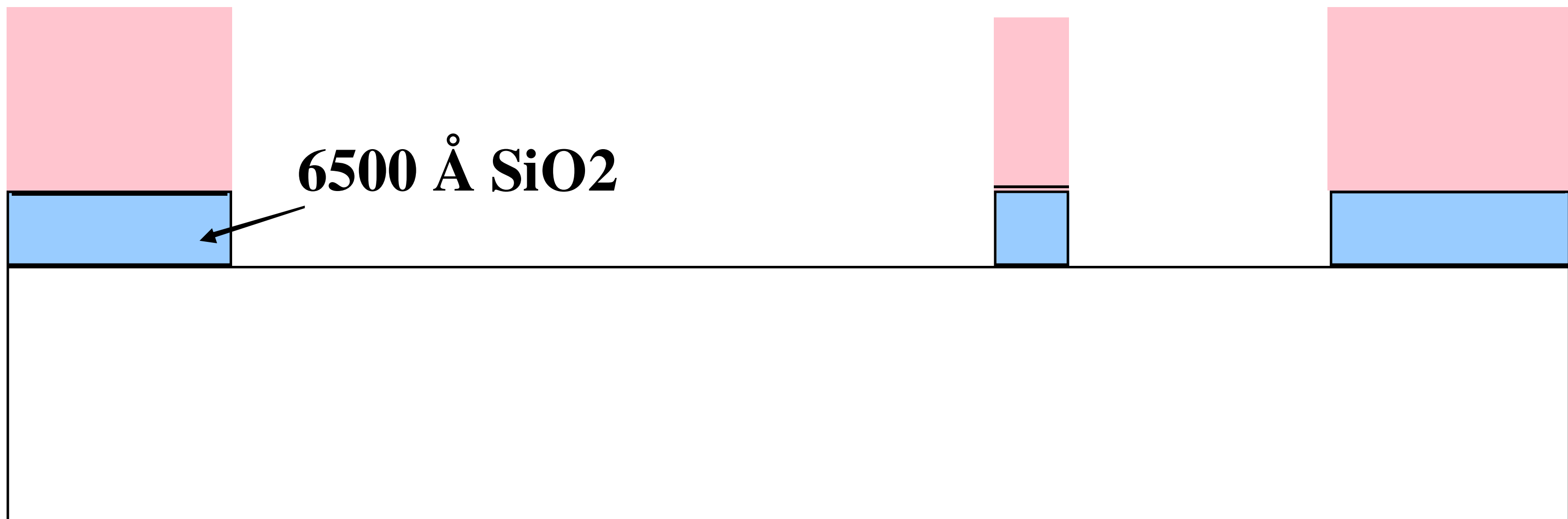
Chip size 10mm by 10mm

Stepper Job Name = PMOS





ETCH OXIDE

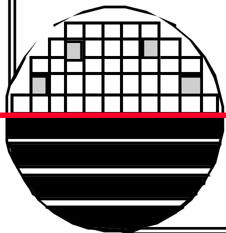


Buffered HF

If 5.2:1 BOE time = 8 min

If 10:1 BOE time= 15 min

Rinse/Spin Dry



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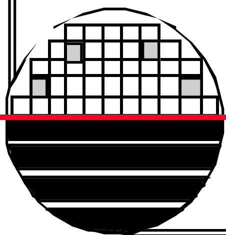
ASHER, RCA CLEAN & SRD

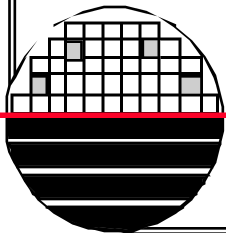
O_2 + Energy = 2 O
O is reactive and will combine with plastics, wood, carbon, photoresist, etc.

Gassonics Asher

RCA Clean Bench



AFTER ASH RESIST AND CLEAN



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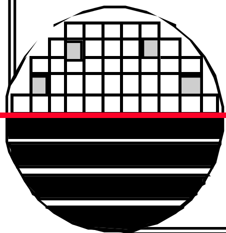
VARIAN 350 D ION IMPLANTER (4" AND 6" WAFERS)



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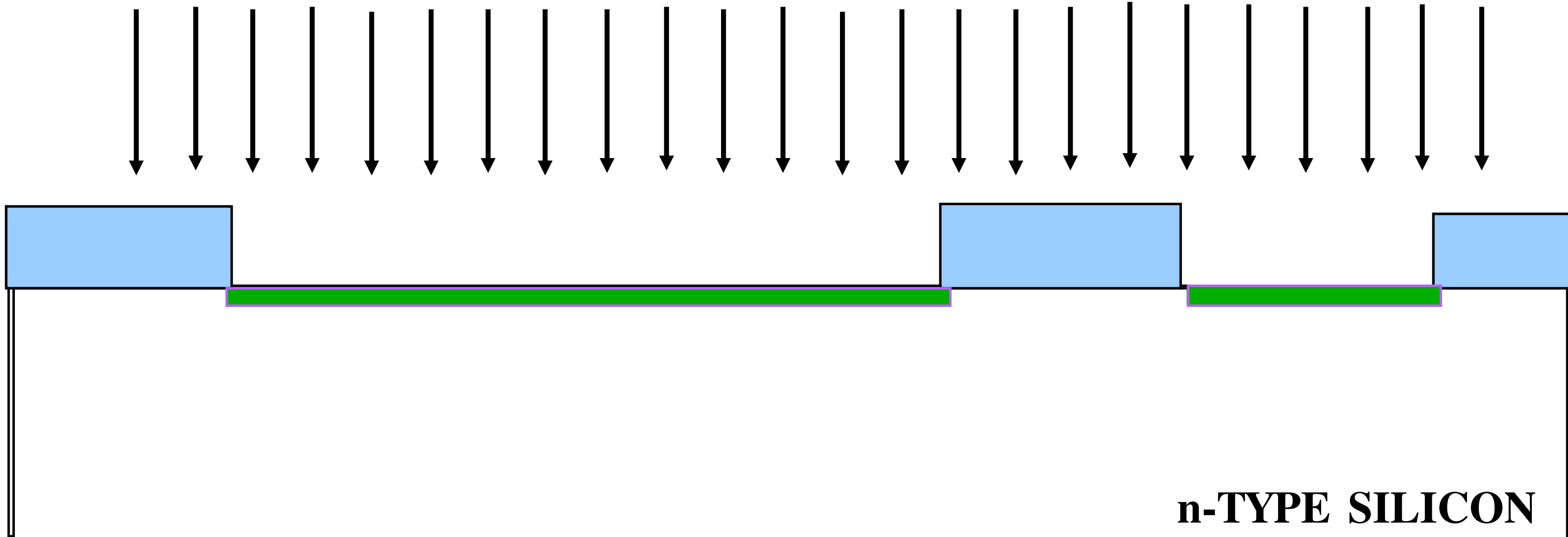
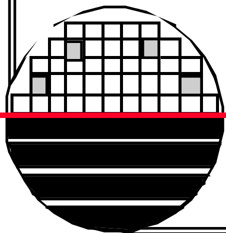
ION IMPLANT P-TYPE DOPANT



All device wafers
All control wafers

Boron
Species: B_{11}
Gas: BF3
Dose: $2x10^{15}$ ions/cm^2
Energy: 75 KeV
Implant Time: ~ 5 minutes per wafer
@225µA



Rochester Institute of Technology
Microelectronic Engineering

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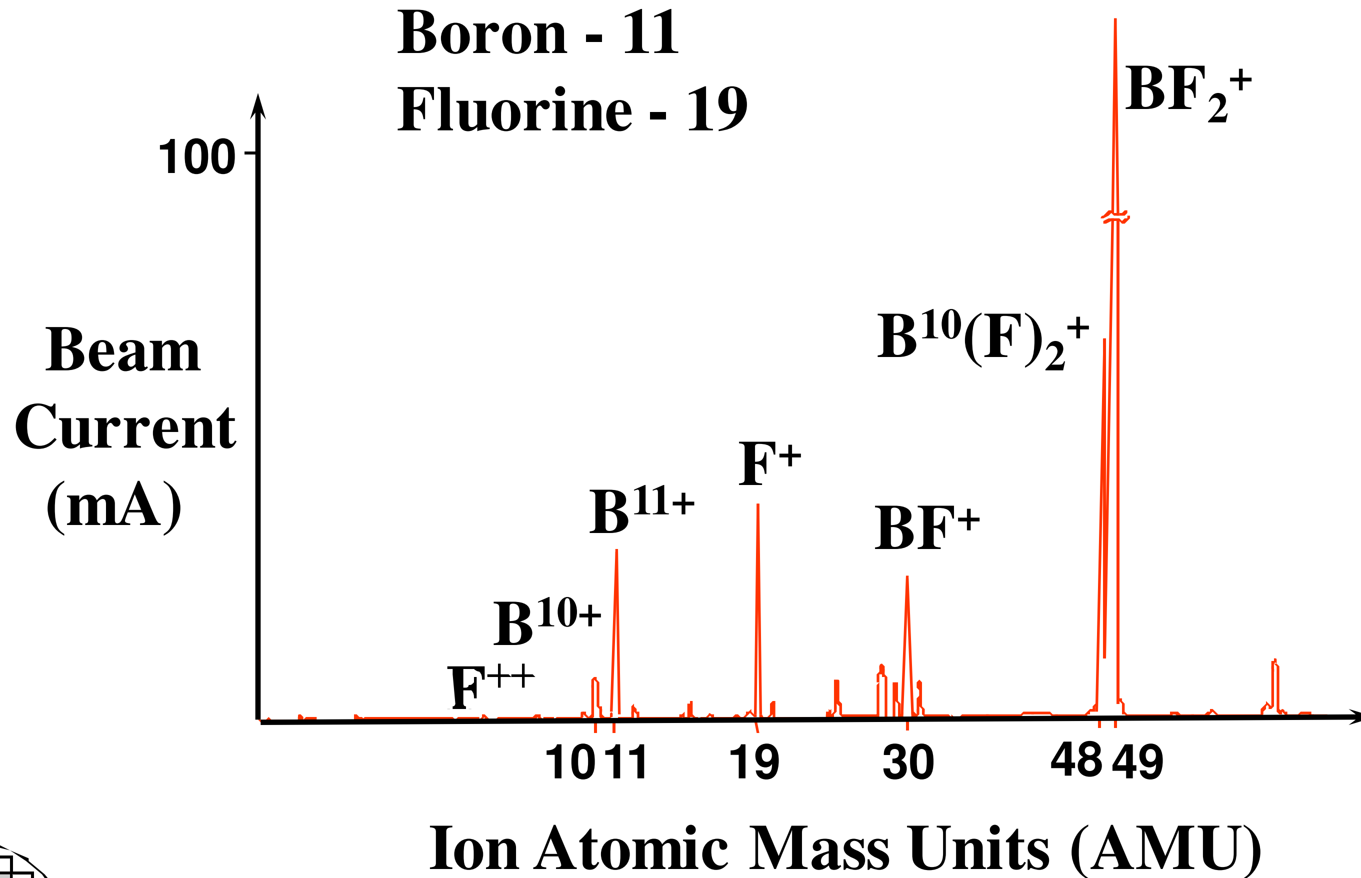
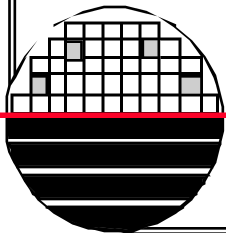
BF_3 GAS SPECTRUM





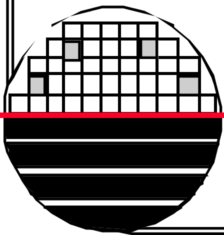
IMPLANT MASKING THICKNESS CALCULATOR

Rochester Institute of Technology			Lance Barron	
Microelectronic Engineering			Dr. Lynn Fuller	
11/20/2004				

IMPLANT MASK CALCULATOR — **Enter 1 - Yes 0 - No in white boxes**

DOPANT SPECIES		MASK TYPE		ENERGY	
B11	1	Resist	0	75	KeV
BF2	0	Poly	0		
P31	0	Oxide	1		
		Nitride	0		

Thickness to Mask >1E15/cm3 Surface Concentration 3971.104 Angstroms



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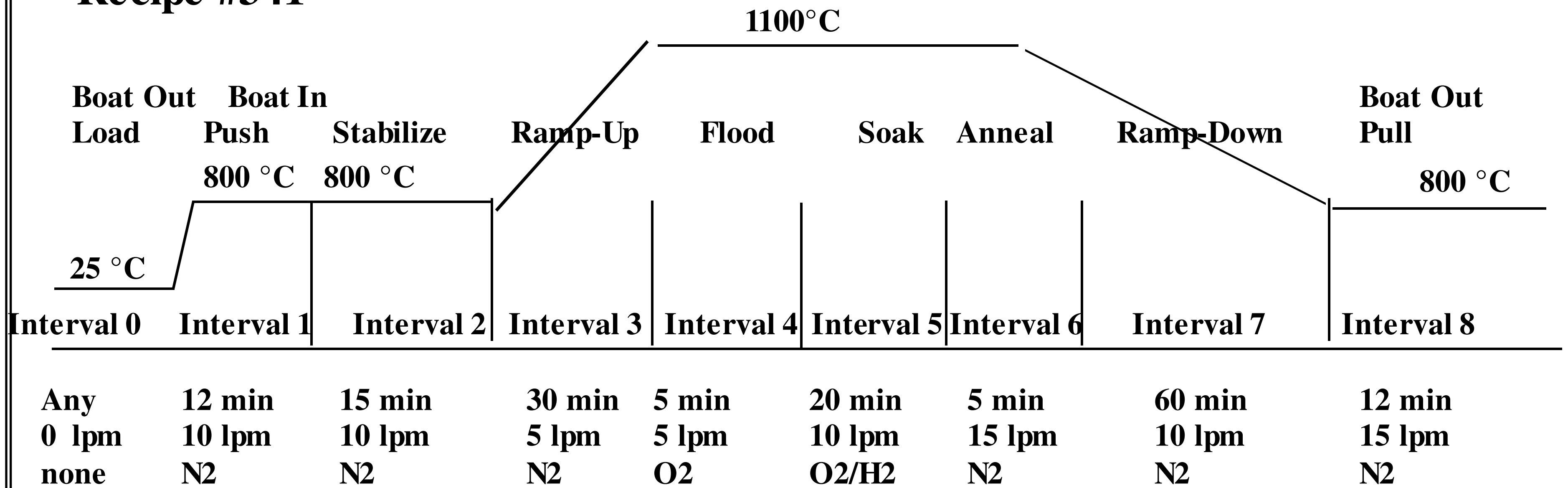
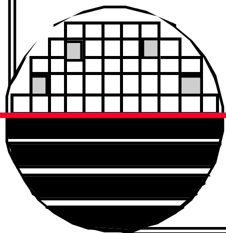
BRUCE FURNACE RECIPE 341 – WET OXIDE 4,000Å



At the end of a run the furnace returns to Interval 0 which is set for boat out, 25 °C and no gas flow. The furnace waits in that state until someone aborts the current recipe or loads a new recipe.

Wet Oxide Growth, Target 4000 Å



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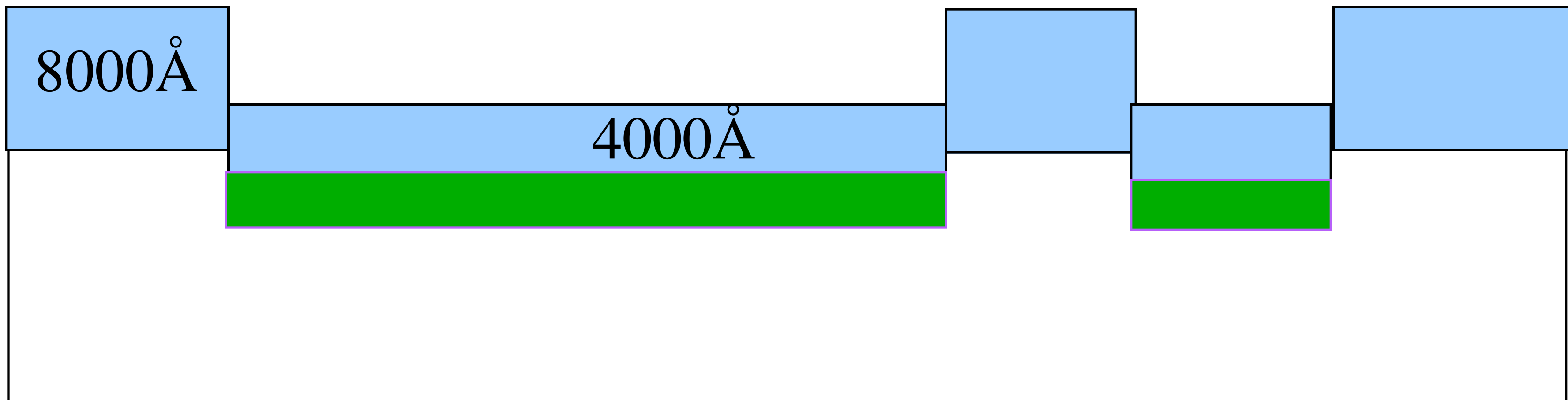
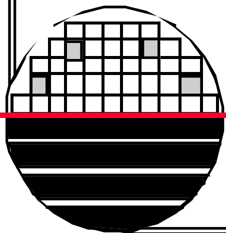
AFTER ANNEAL AND OXIDE GROWTH





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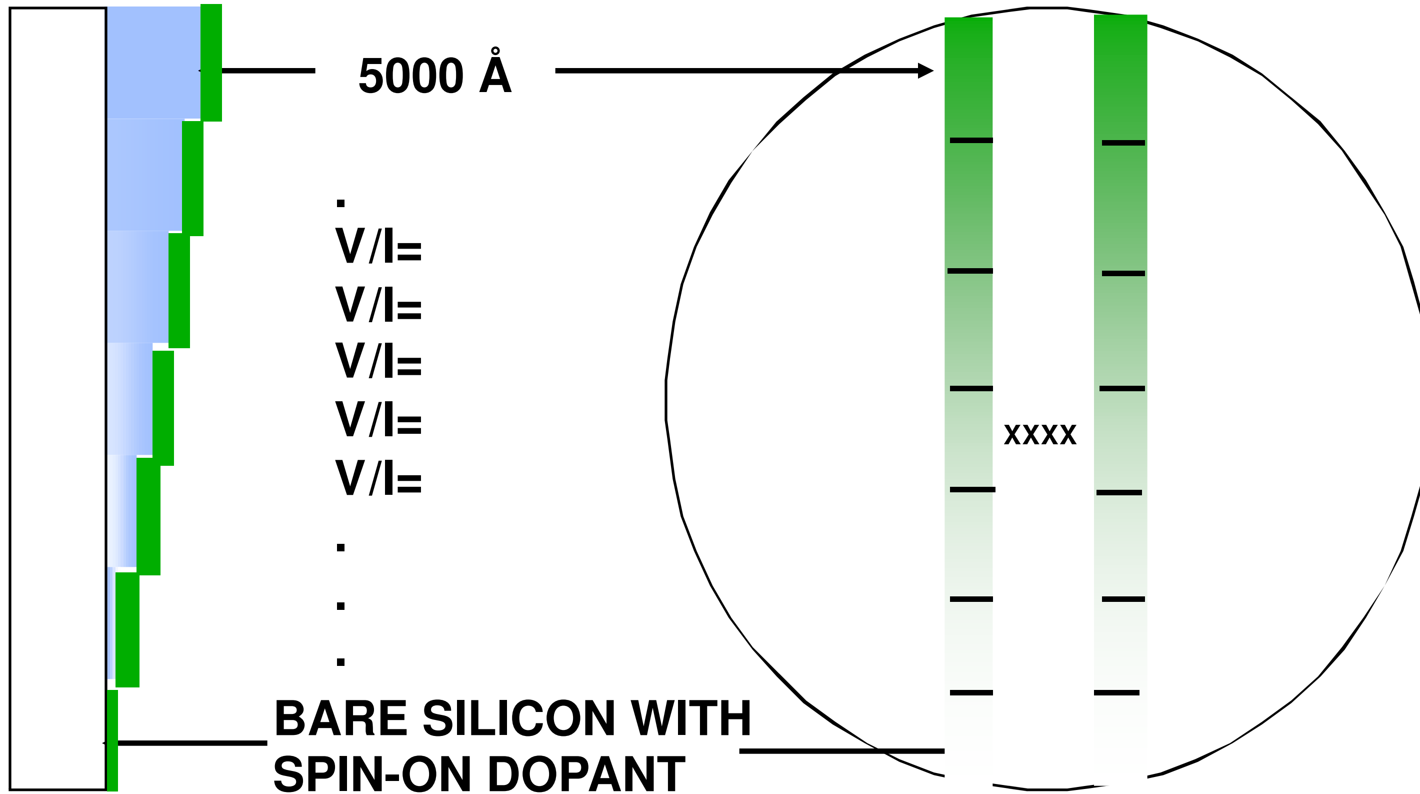
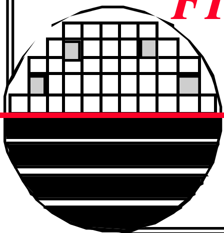
PAINT RESIST STRIP ETCH C1 BARE



FIND MINIMUM OXIDE THICKNESS TO MASK BORON IMPLANT



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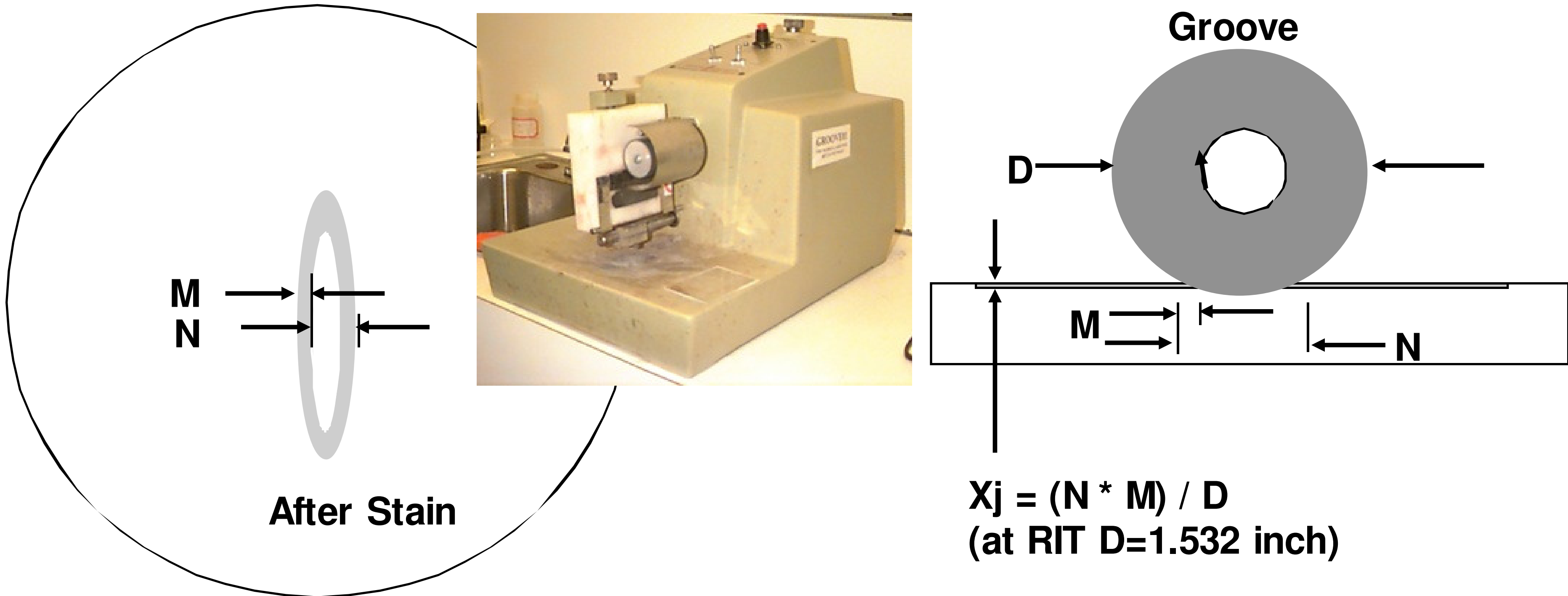
GROOVE and STAIN C1
FIND Xj AFTER PRE DEPOSIT



$X_j = (N * M) / D$
(at RIT D=1.532 inch)

Staining Solution - 1 Vol part HF, 2 Vol part Nitric Acid, 12 Vol part Acetic Acid After mixing drop a penny in solution for about 10 sec. result in a light blue color. Safety Stain - (does not have HF) is available from Philtec Instrument Co. Philadelphia, PA 19129-1651, (215) 848-4500, Signatone makes groove tool and wheels, (408)732-3280

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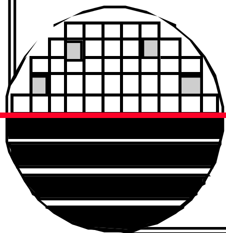
TRAVELING STAGE MICROSCOPE

Example: If M=.003 inches and N=0.025 inches, find xj.

Xj = (N * M) / D

= (0.025 * 0.003)/1.588 inch)
= 0.0000472 inch
= 1.20 µm



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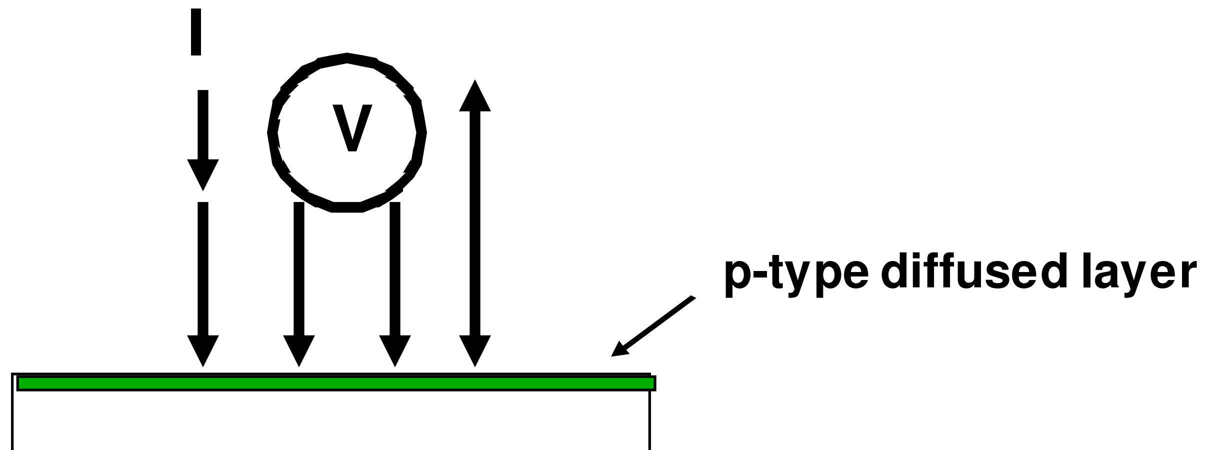
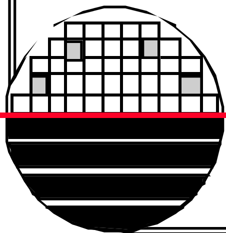
DE01 - FOUR POINT PROBE BOTTOM OF C1

FIND SHEET RESISTANCE OF IMPLANT P+



Rhos = V / I * Pi / ln 2 ohms/square = 4.53 V/ I ohms/sq



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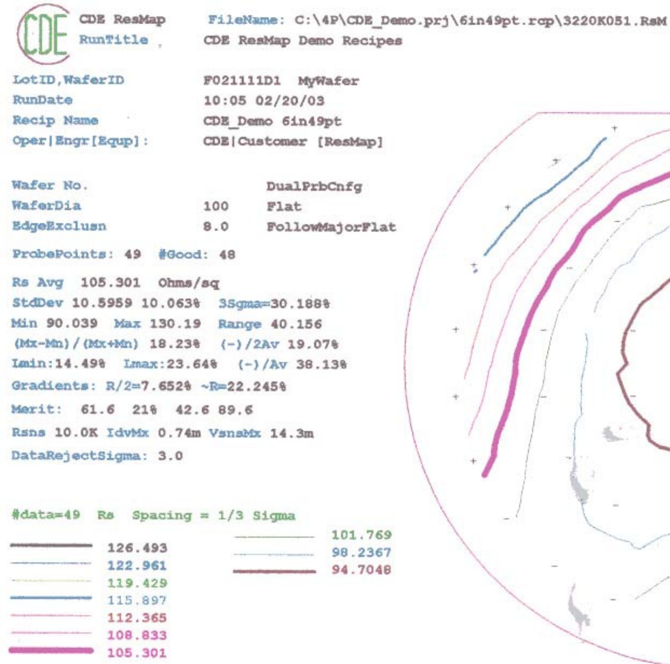
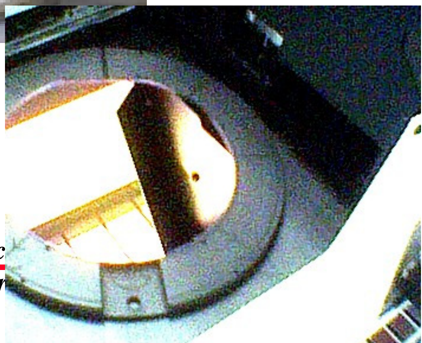
MEASURE SHEET RESISTANCE

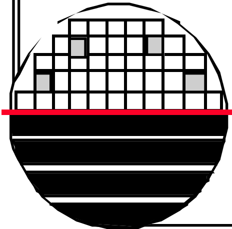
CDE Resistivity Mapper



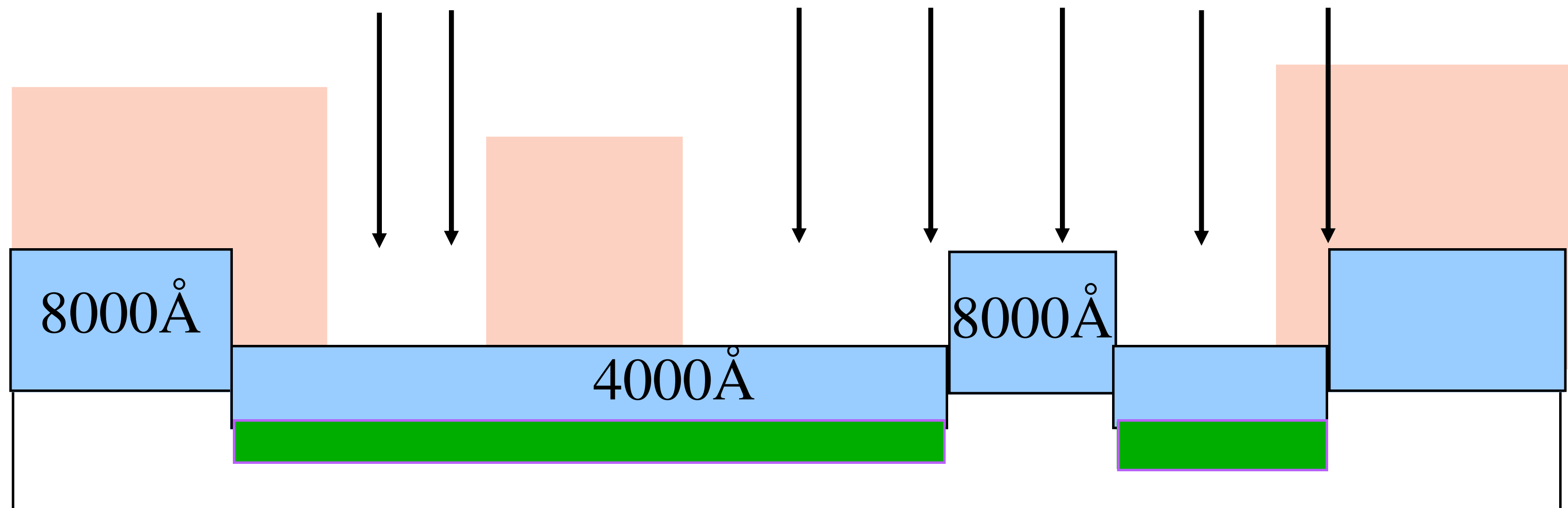


Rho=Rhos x t

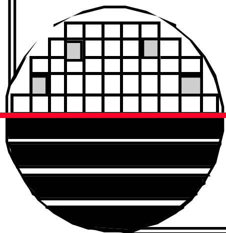
Tool gives Rho or Rhos depending on recipe used, automatically adjusts correction factors for wafer thickness



PHOTOLITHOGRAPHY LEVEL TWO THIN OXIDE



- Coat (Recipe: COATMTL.RCP)
  - 2000RPM for 30 seconds
  - Thickness of 13127A
- Exposure
  - Energy: 250mJ/cm2
  - Focus: 0.0 um
- Develop (Recipe: DEVMTL.RCP)
  - Wait 68 seconds
  - Hard Bake 2 min.



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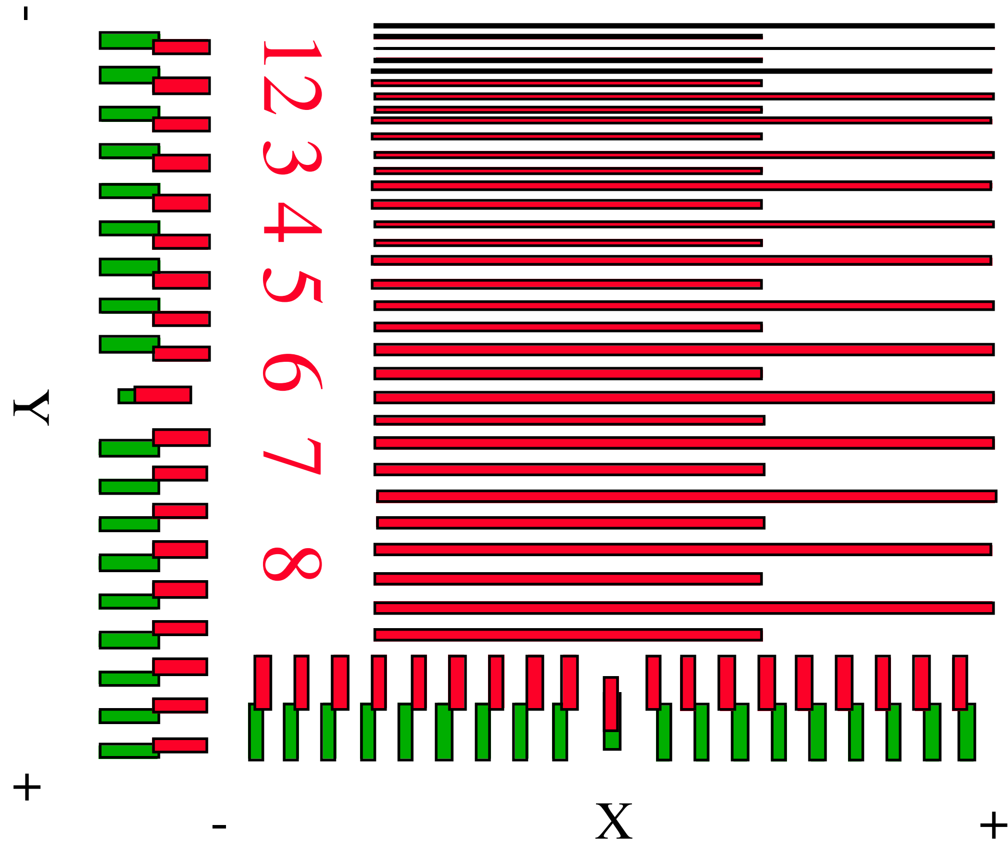
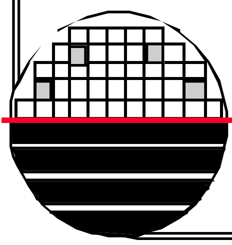
2ND PHOTOLITHOGRAPHY

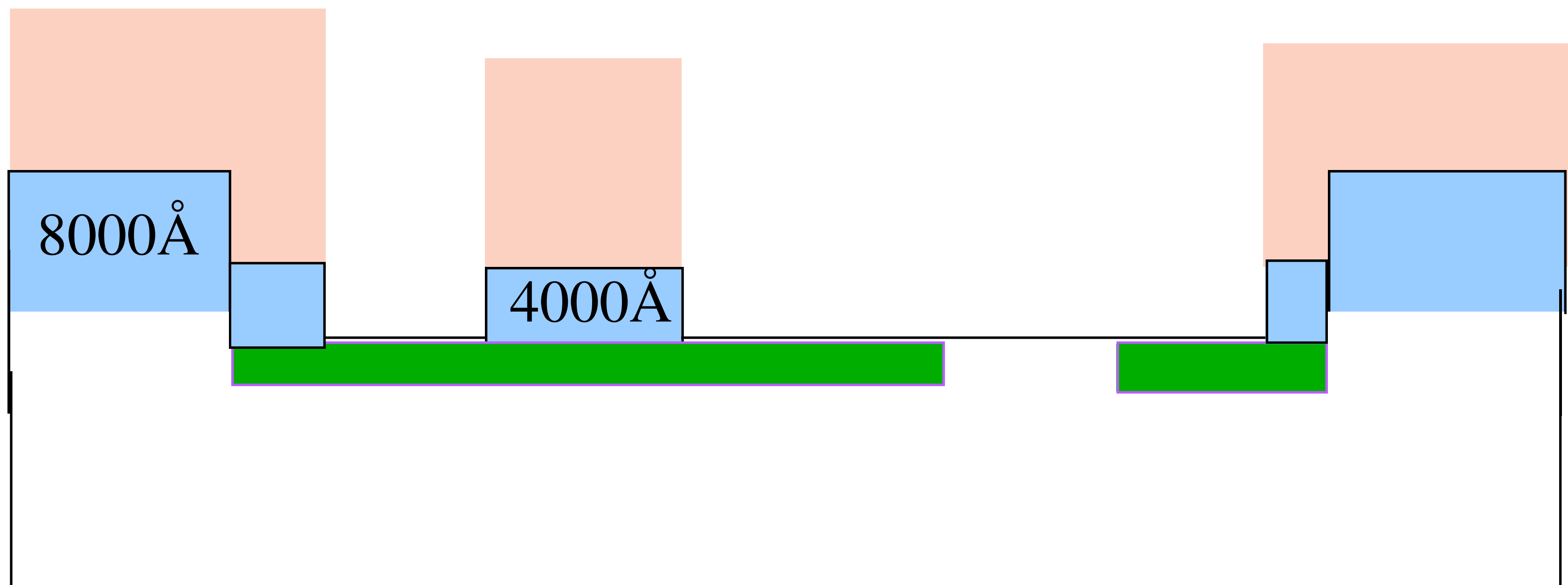


ALIGNMENT VERNIERS

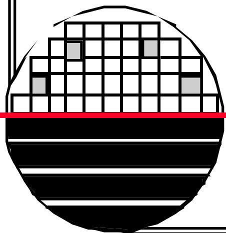
CRITICAL DIMENSION (CD) STRUCTURES



ETCH THIN OXIDE AREAS



Include C2
10 min. in 5.2:1 BOE
20 min. in 10:1 BOE
Rinse/Spin Dry



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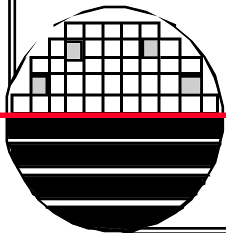
OXIDE ETCH C2 BARE



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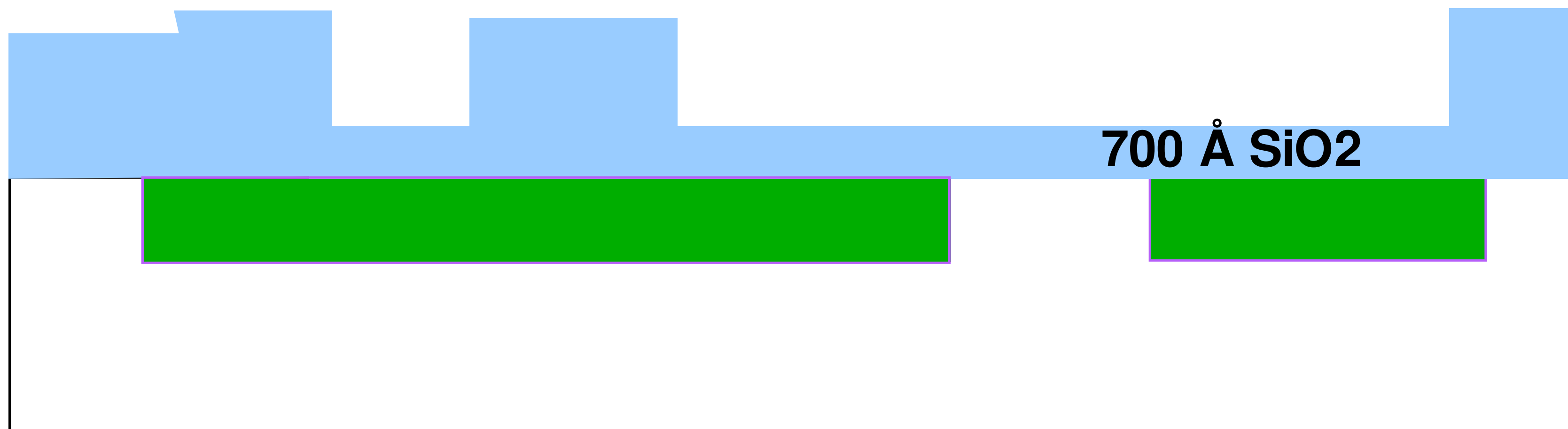
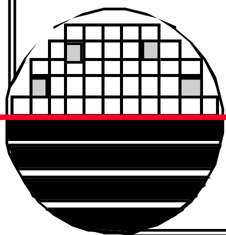
ASH RESIST, RCA CLEAN
GATE OXIDE GROWTH OF 700 A



Include C2

Recipe 270



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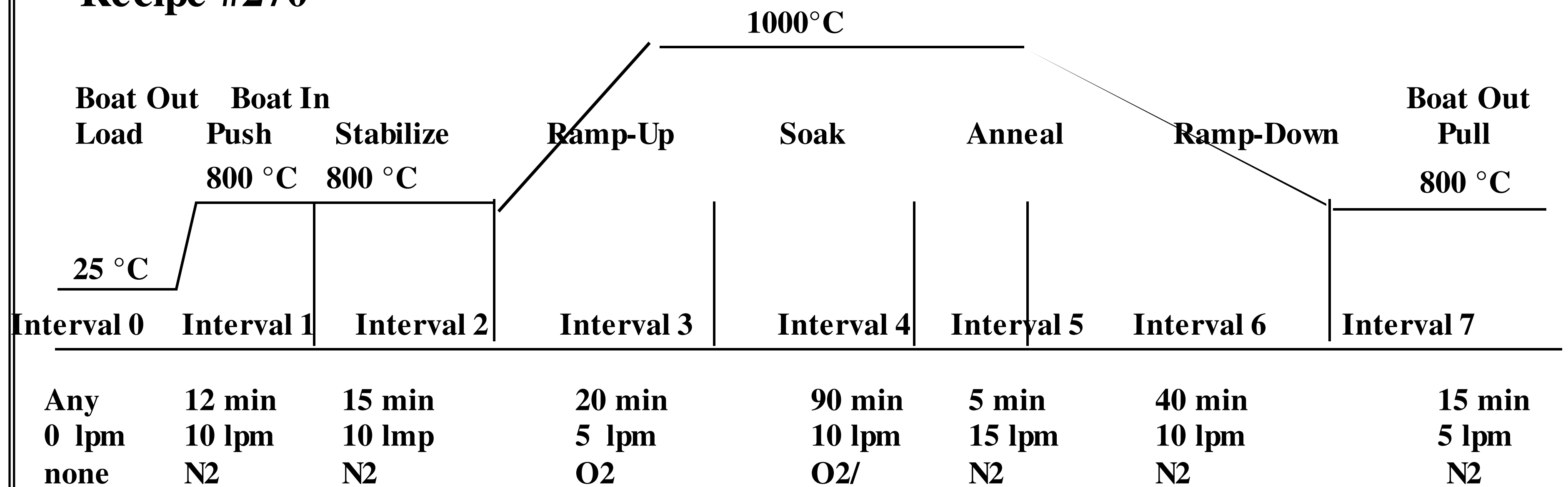
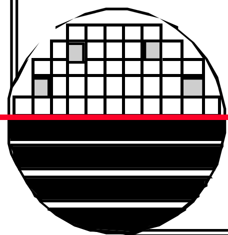
BRUCE FURNACE RECIPE 270 – 700Å DRY OXIDE

Verified: 3-1-04



At the end of a run the furnace returns to Interval 0 which is set for boat out, 25 °C and no gas flow. The furnace waits in that state until someone aborts the current recipe or loads a new recipe.

Dry Oxide Growth, Target 700 Å



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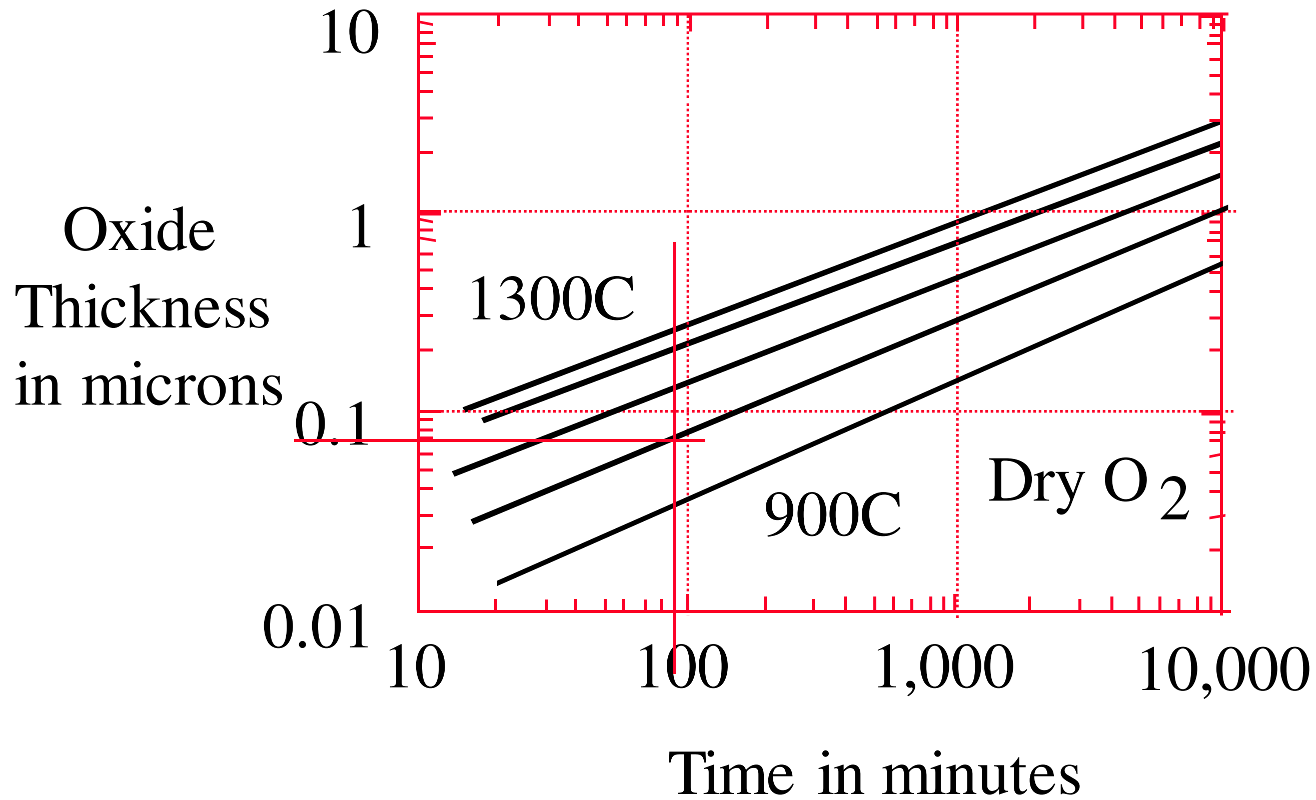
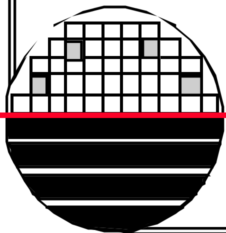
DRY OXIDE GROWTH CHART





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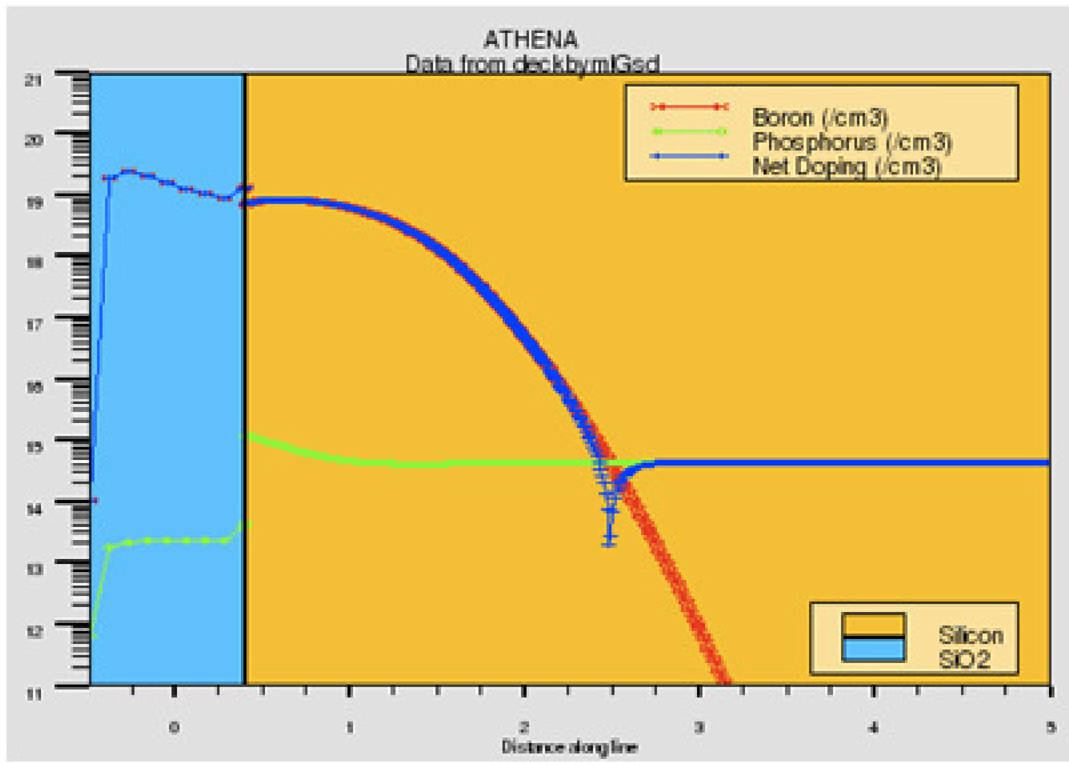
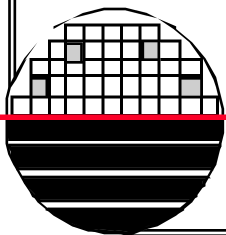
SIMULATION AFTER ALL HIGH TEMP STEPS



Boron
Dose: 2×10^{15} ions/cm^2
Energy: 75 KeV
X_j = ~2.0 µm



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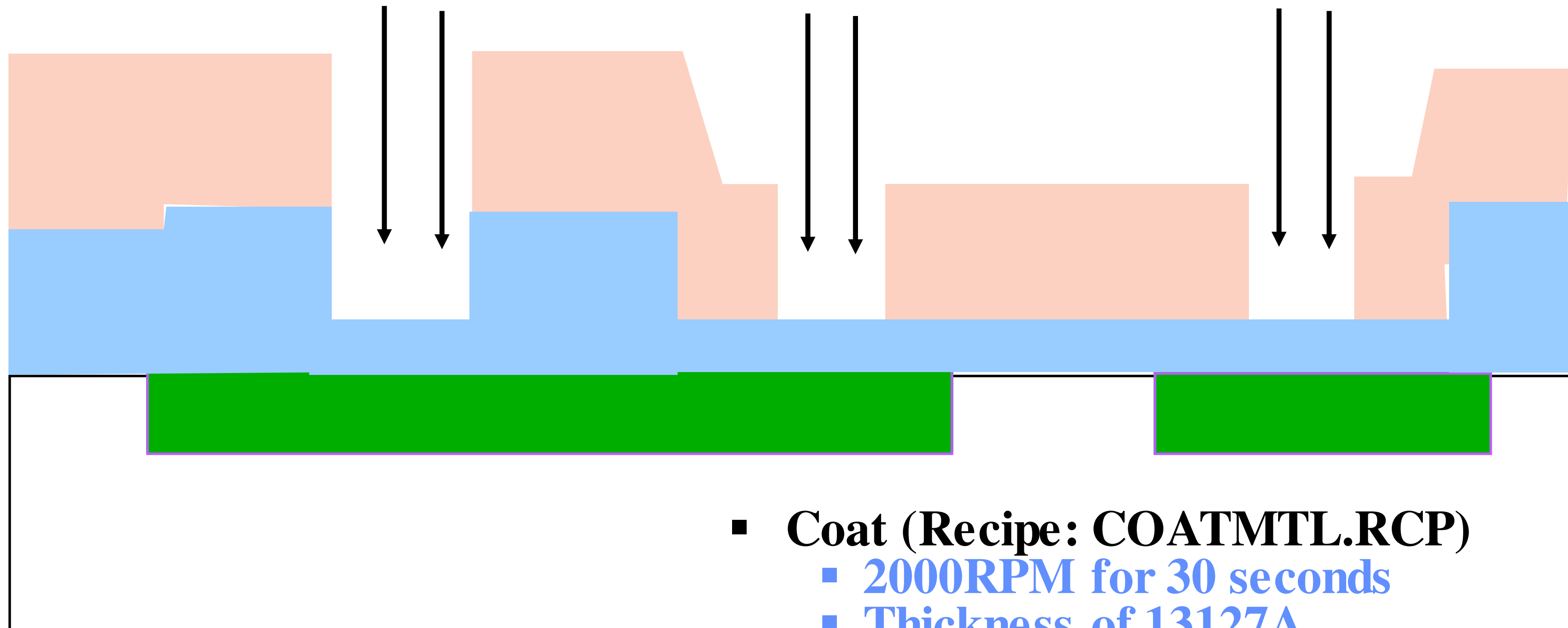
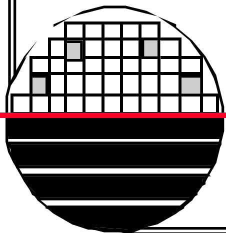
PHOTOLITHOGRAPHY CONTACT CUT



- Coat (Recipe: COATMTL.RCP)
  - 2000RPM for 30 seconds
  - Thickness of 13127A
- Exposure
  - Energy: 250mJ/cm2
  - Focus: 0.0um
- Develop (Recipe: DEVCC.RCP)
  - Wait 68 seconds
  - Hard Bake 2 min.



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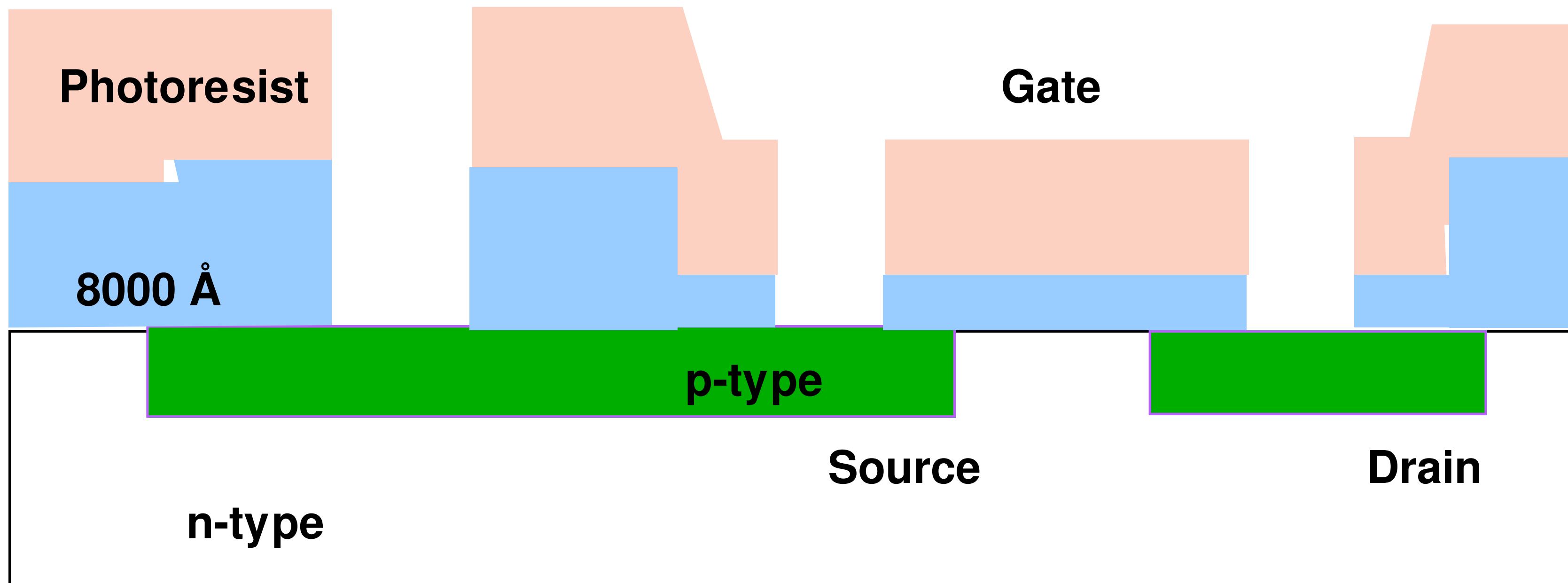
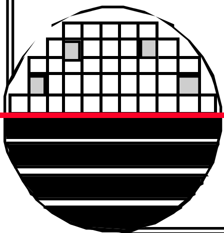
CONTACT CUT ETCH



Include C2
Be Sure to Etch for 20 min. or 10 min.
If BOE is 10:1 then 20 min.
If BOE is 5.2:1 then 10 min.
SRD



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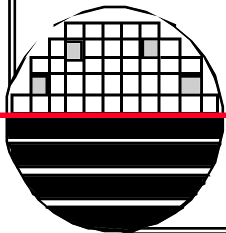
OXIDE ETCH C2 BARE



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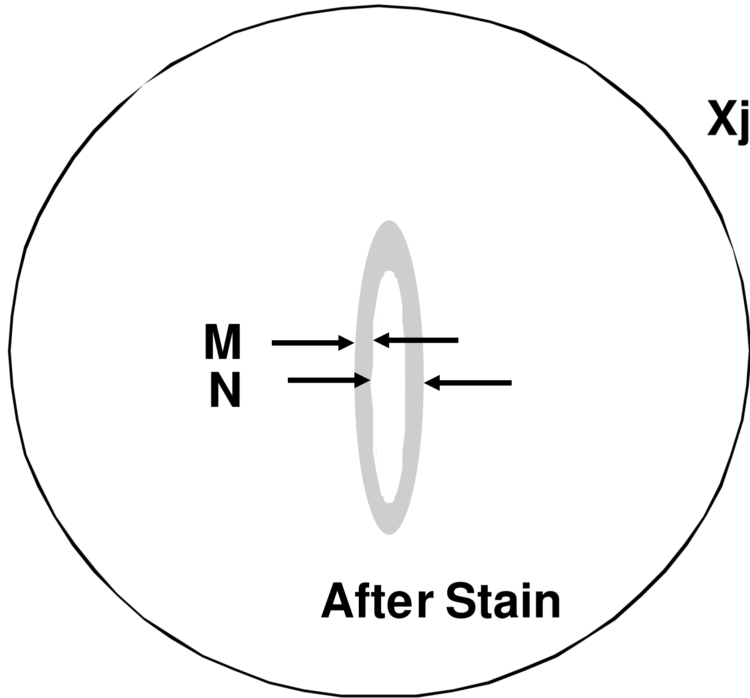
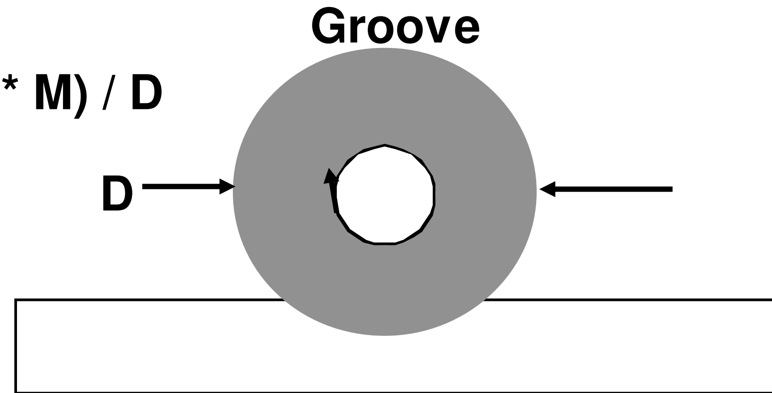
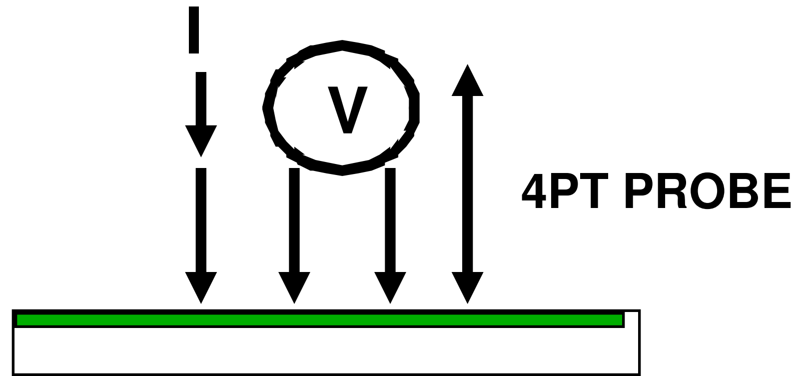
GROOVE and STAIN and 4PT PROBE C2



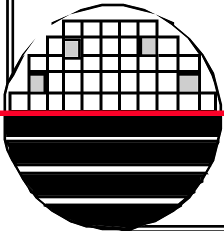
$$X_j = (N * M) / D$$





p-type diffused layer

Rhos = V / I * Pi / ln 2 ohms/square = 4.53 V/ I ohms/sq



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RCA CLEAN WAFERS PRIOR TO METAL

APM
H_2O – 5000ml
NH_4OH–300ml
H_2O_2 – 300ml
75 °C, 10 min.

→ DI water rinse, 5 min.

→ H_20 - 50
HF - 1
20 sec.

→ DI water rinse, 5 min.

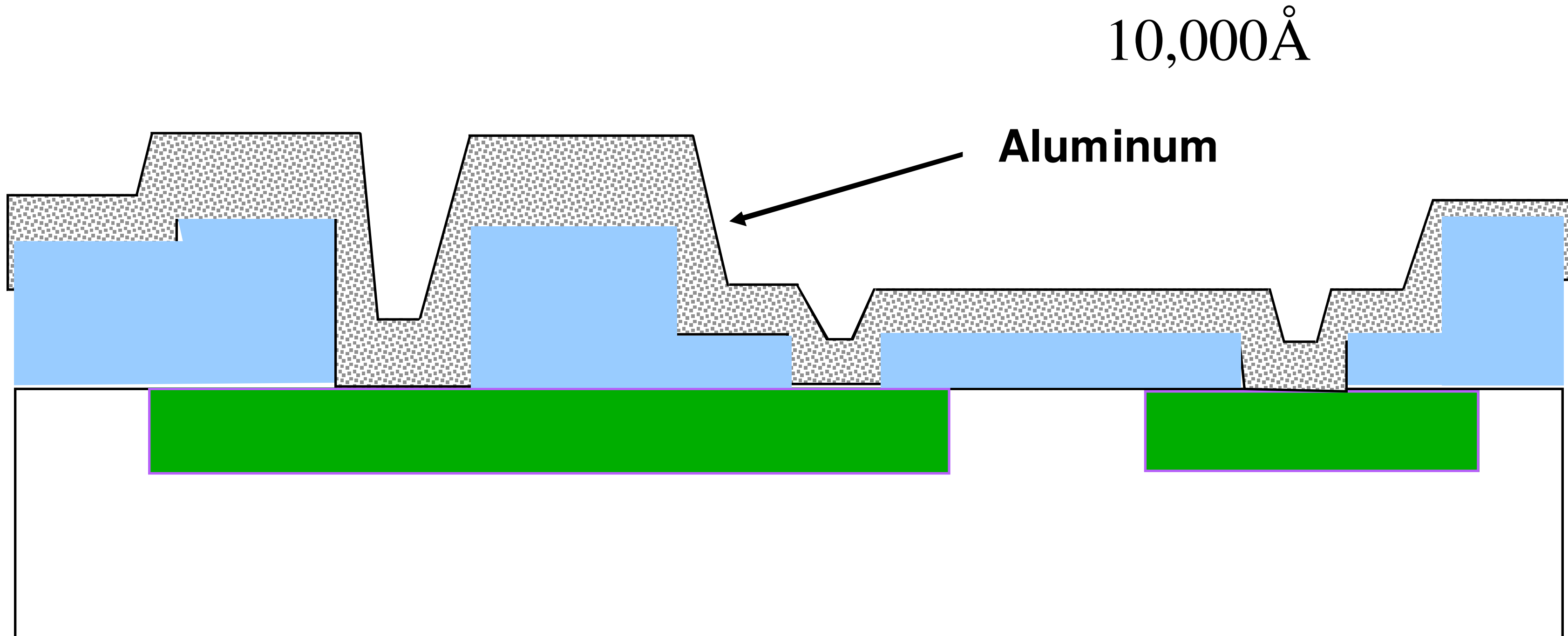
→ HPM
H_2O–5000ml
HCL-300ml
H_2O_2 – 300ml
75 °C, 10 min.

→ DI water rinse, 5 min.

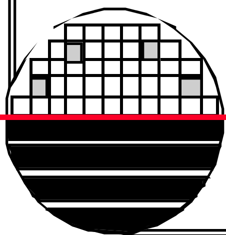
→ **H_20 - 50**
HF - 1
20 sec.

→ SPIN/RINSE DRY

ASH RESIST, RCA CLEAN and SPUTTER ALUMINUM



Be sure to do additional dilute HF dip 10 sec at the end of the RCA clean.



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METAL DEPOSITION

CVC 601

Thickness 10,000Å

Dep Rate ~300 A/min

Pressure 5 mT

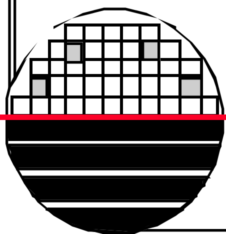
Ar Flow 28 sccm

Time ~ 20 min

~2000 sec

Power 2000 watts

Pre Sputter 300 sec



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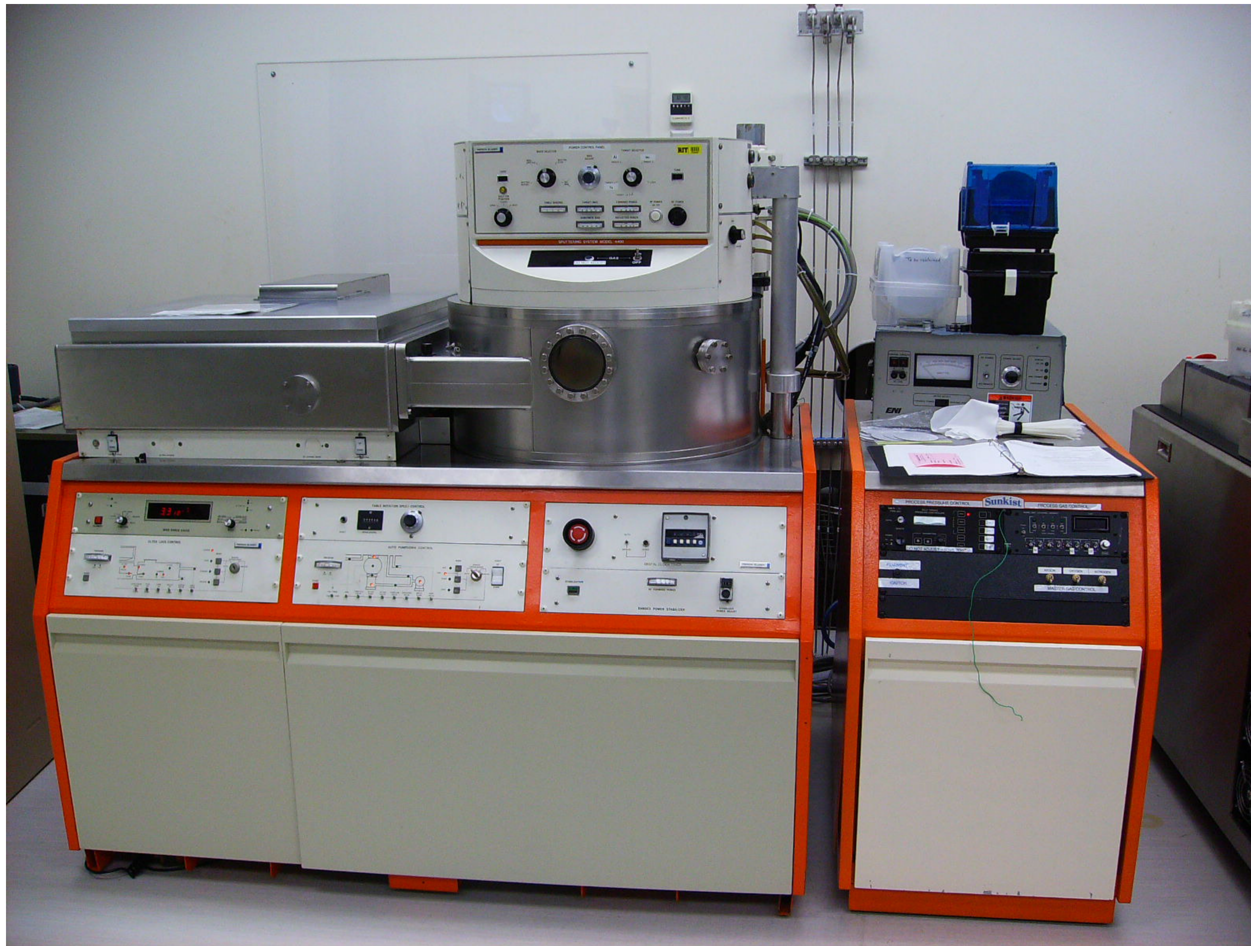
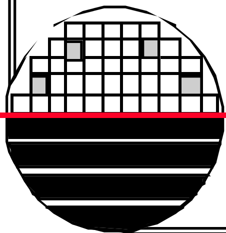
PE4400 SPUTTER / SPUTTER ETCH TOOL





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PE4400 – ALUMINUM DEPOSITION

Tool Parameters

Power = 400 watts

Pressure 5 mTorr

Chiller 20 °C

Argon flow 40 sccm

Dep Rate ~64Å/min?

Time = 135 min (2hr 15min)

Blank Wafers

Table rotation speed 200 =~6rpm

Magnet array @1° angle

Table space as close as possible

Results

Wafer ID: 10/4

Ave thickness =

From P2 8665 Å

Min =

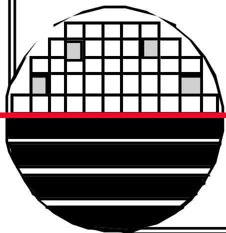
Max =

Non Uniformity = %

Surface Roughness 10nm great

Name:

Date:



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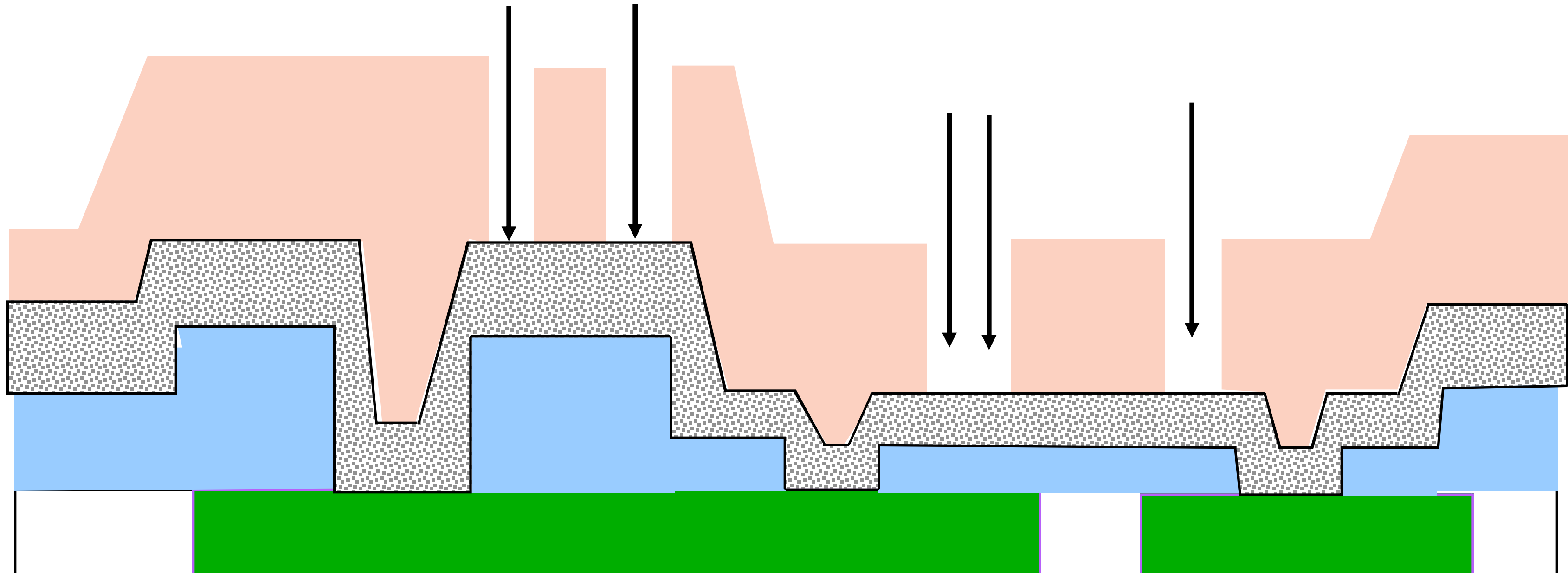
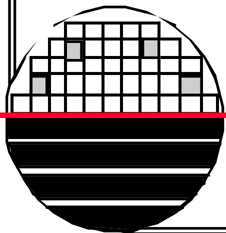
PHOTOLITHOGRAPHY METAL



- Coat (Recipe: COATMTL.RCP)
  - 2000RPM for 30 seconds
  - Thickness of 13127A
- Exposure
  - Energy: 250mJ/cm2
  - Focus: 0.0 um
- Develop (Recipe: DEVMTL.RCP)
  - Wait 68 seconds
  - Hard Bake 2 min.



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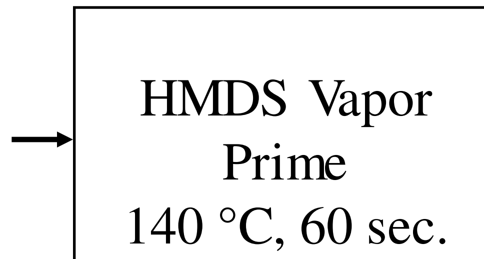
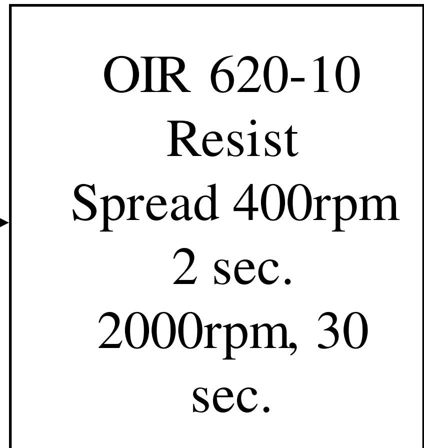
COATMTL.RCP

COATMTL.RCP

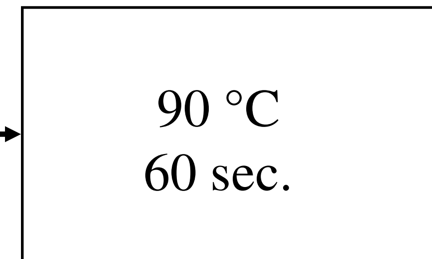
DEHYDRATE BAKE/ HMDS PRIMING



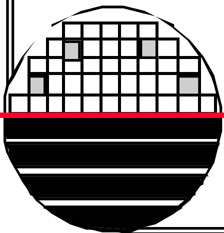
SPIN COAT



SOFT BAKE



Thickness of 13,127 Å



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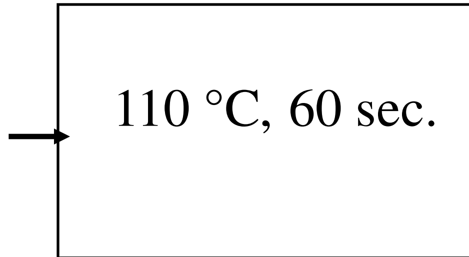
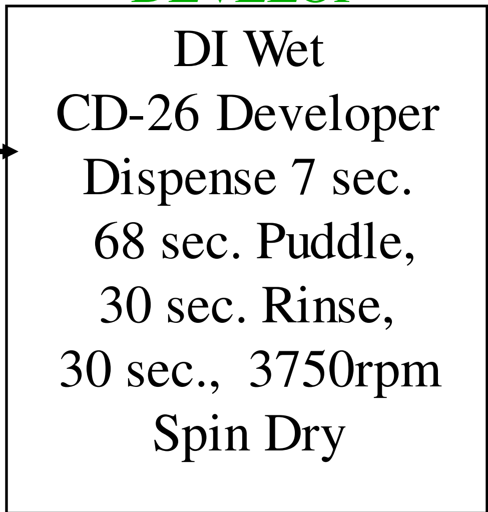
DEVMTL.RCP

DEVMTL.RCP

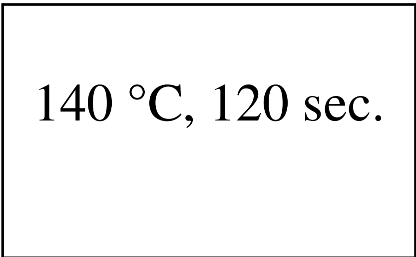
POST EXPOSURE BAKE

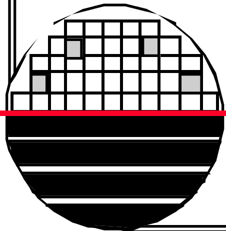


DEVELOP



HARD BAKE





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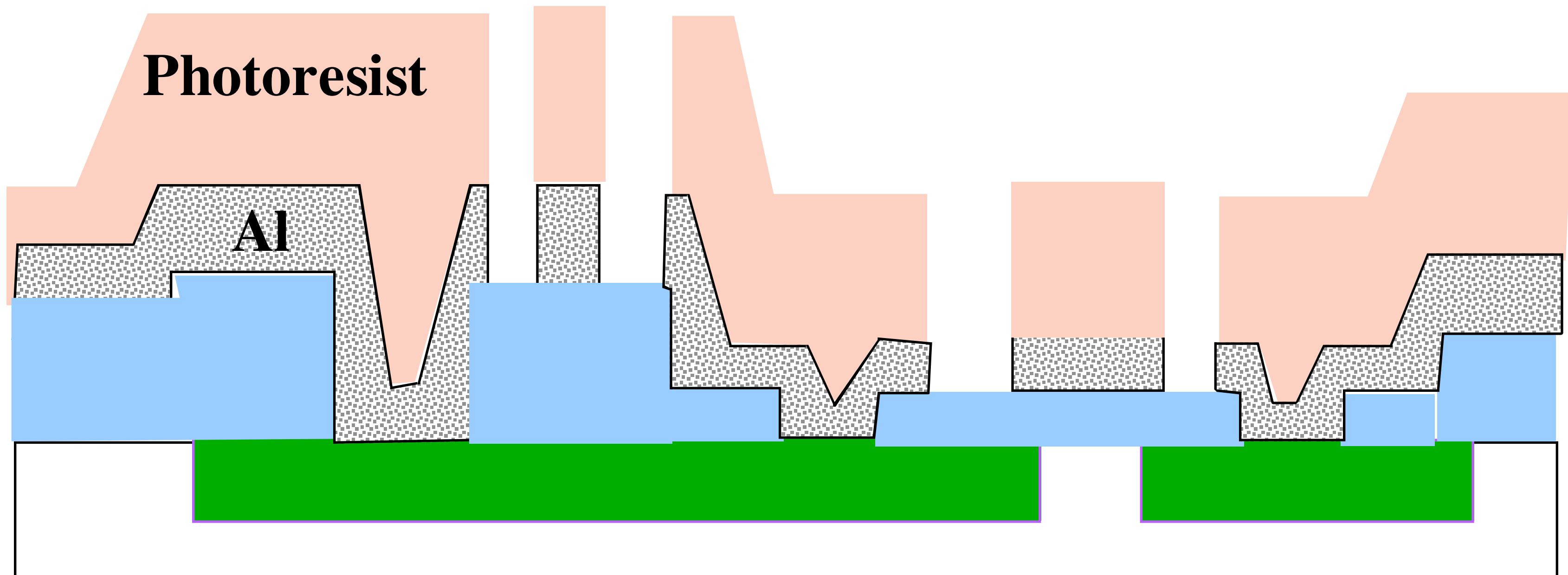
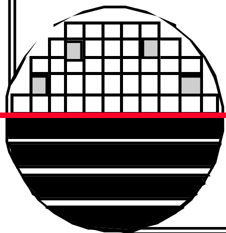
ETCH ALUMINUM



If wet etch:
Aluminum Etch 50 °C, 3-5 min.
DI Rinse 5 min
Freckle Etch 2min
DI Rinse 5 min.
SRD Spin Dry



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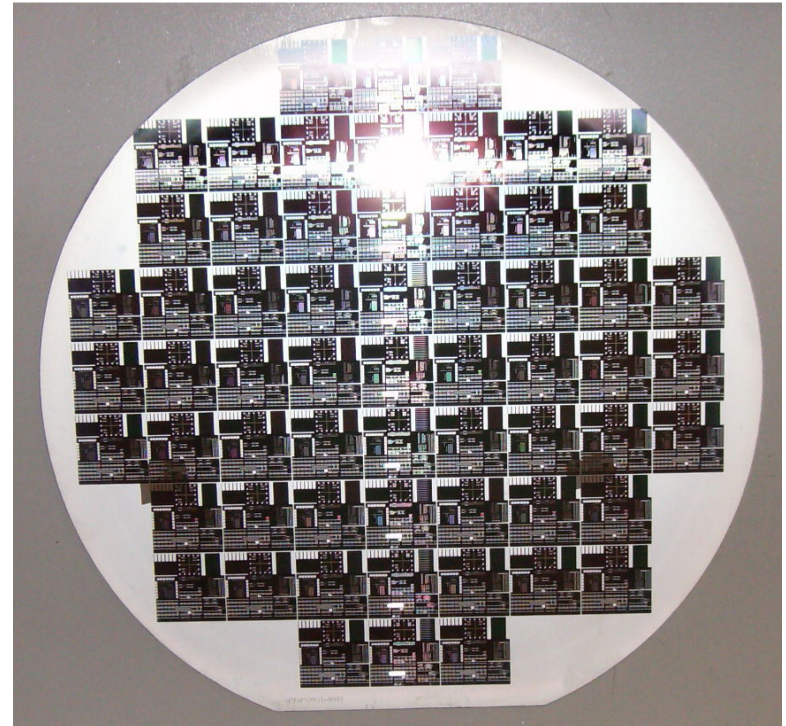
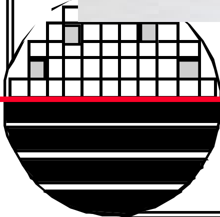
ALUMINUM ETCH USING LAM4600

LAM4600





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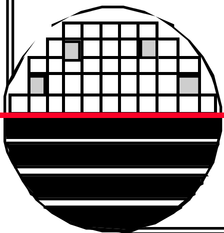
LAM4600 ANISOTROPIC ALUMINUM ETCH

Step	1	2	3	4	5
Pressure	100	100	100	100	0
RF Top (W)	0	0	0	0	0
RF Bottom	0	250	125	125	0
Gap (cm)	3	3	3	3	5.3
O2 111	0	0	0	0	0
N2 222	13	13	20	25	25
BCl 333	50	50	25	25	0
Cl2 444	10	10	30	23	0
Ar 555	0	0	0	0	0
CFORM 666	8	8	8	8	8
Complete	Stabl	Time	Time	Oetch	Time
Time (s)	15	8	230	10%	15

Channel	B
Delay	130
Normalize	10 s
Norm Val	5670
Trigger	105%
Slope	+

Fuller, May 2010



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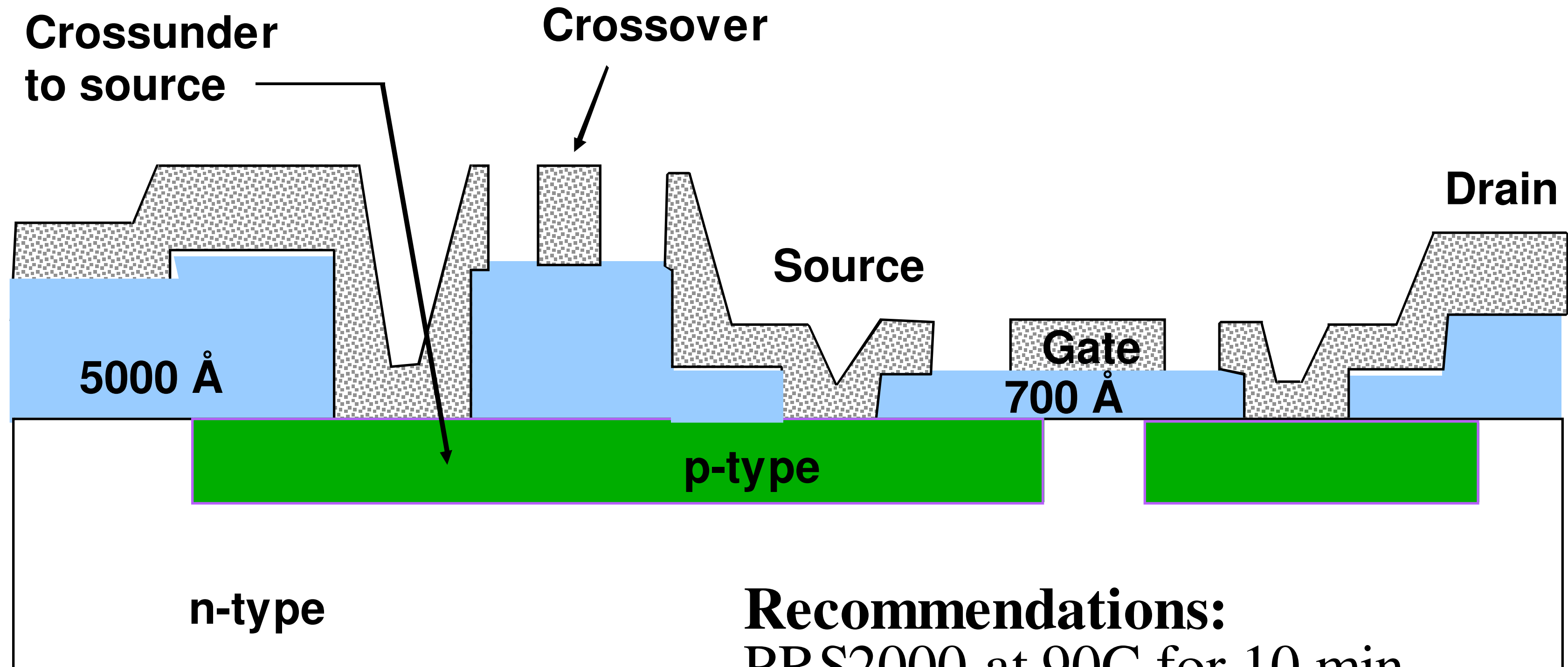
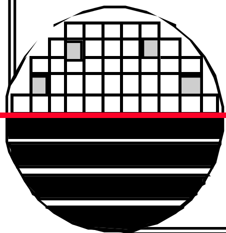
ASH RESIST



Recommendations:
PRS2000 at 90C for 10 min
Rinse 5 min. / SRD
Follow up with 6” FF on the Gas Sonics Asher



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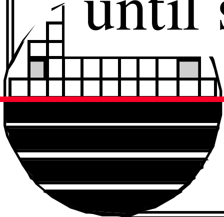
BRUCE FURNACE RECIPE 101 SINTER

SINTER Recipe #101

	Warm	Push	Stabilize	Soak	Anneal	Pull	
25 °C			400°C			25 °C	
Interval 0	**1**	**2**	**3**	**4**	**5**	**6**	
Any`	5	20	15	15	5	15	min
0 lmp	10	10	10	5	10	5	lpm
None	N2	N2/H2	N2/H2	N2/H2	N2	N2	

At the end of a run the furnace returns to Interval 0 which is set for boat out, 25 °C and no gas flow. The furnace waits in that state until someone aborts the current recipe or loads a new recipe.



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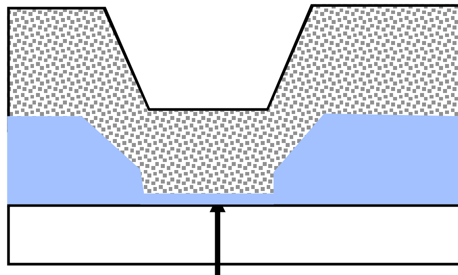
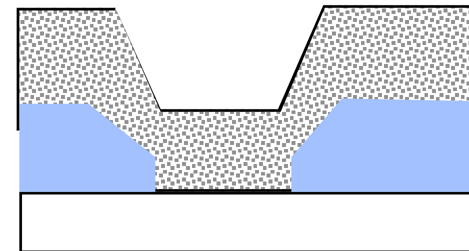
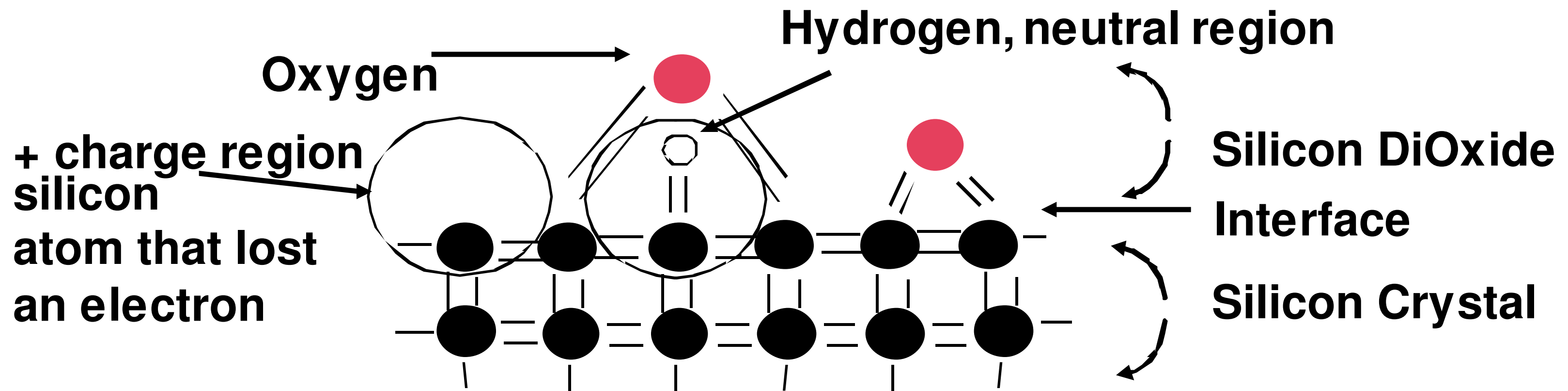
SINTER

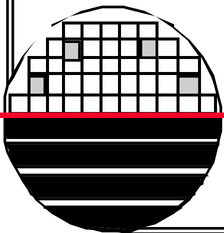


Reduce Contact Resistance





Reduce Surface States



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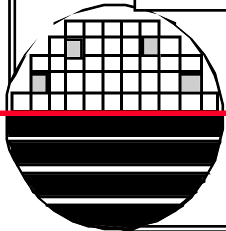
TEST



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TEST RESULTS