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MICROELECTRONIC ENGINEERING

Two Level Metal Process Technology

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2-15-2010 Two_Level_Metal.ppt

OUTLINE

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Tools, Uniformity, Surface Roughness, Step Coverage
Metal One Sputter Etch Prior to Metal Two Deposition
Lithography for Metal One and Two
Aluminum Plasma Etch for Metal One and Two
Via Plasma Etch for Intermetal Dielectric
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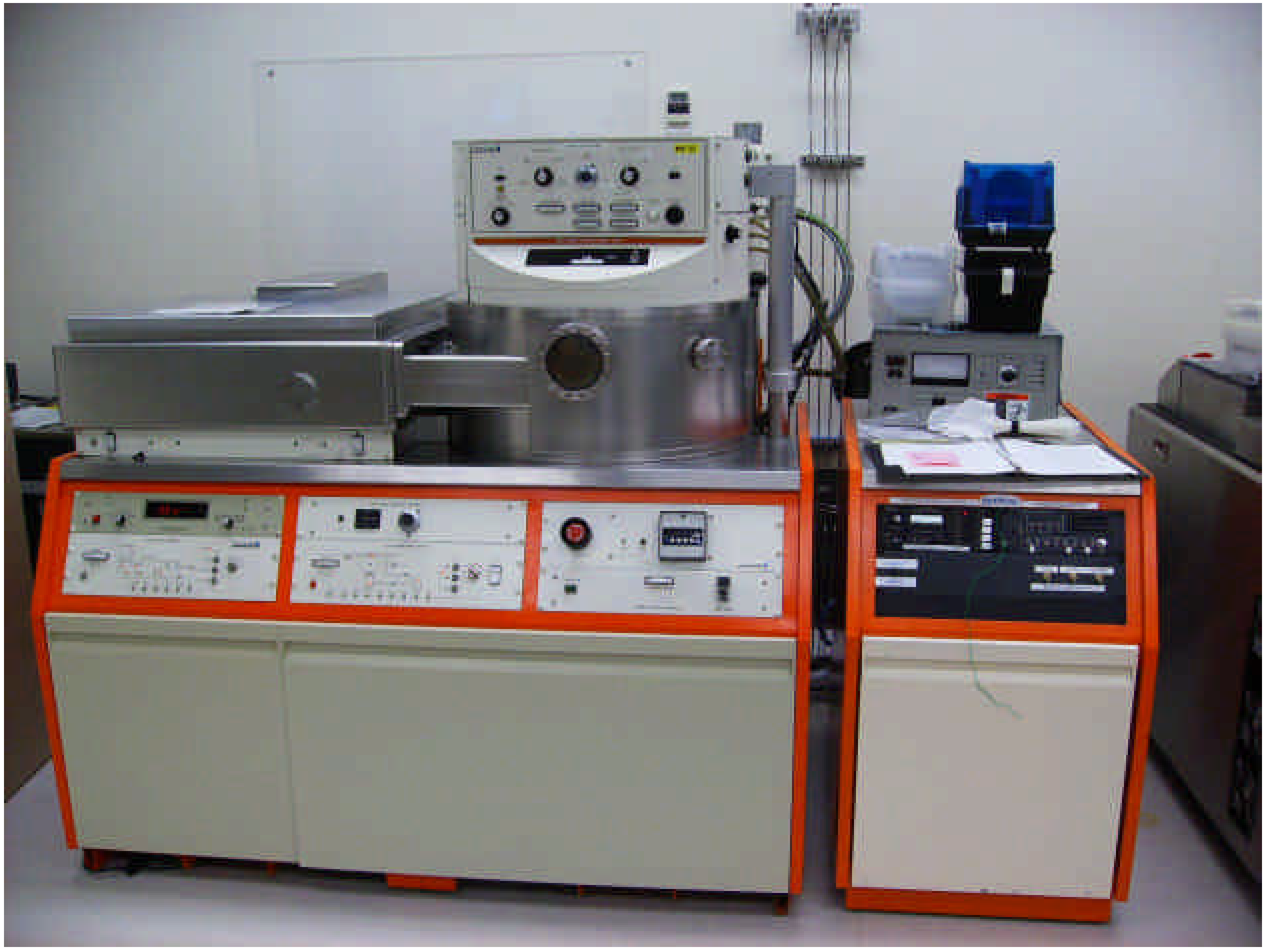
INTRODUCTION

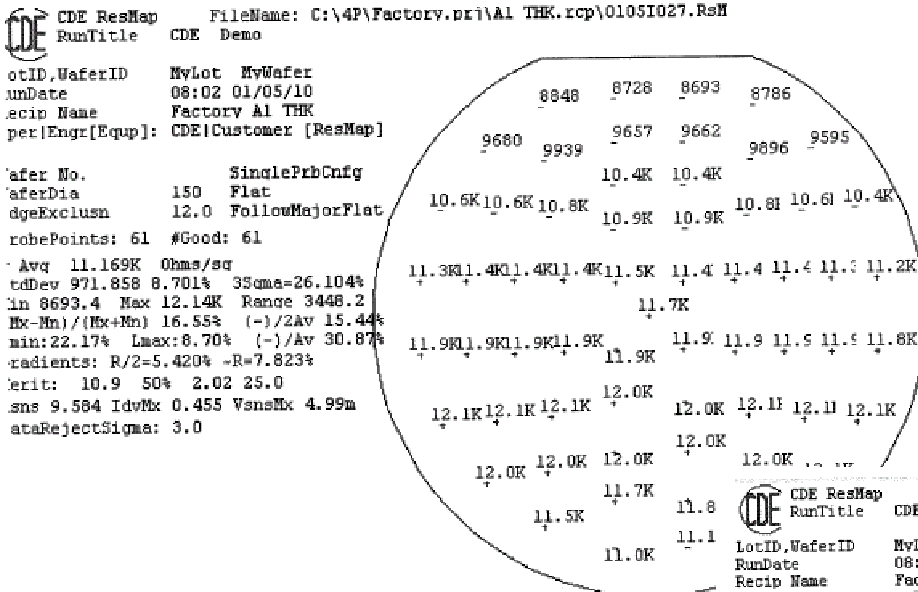
The goal of this work is to develop a useful two-layer aluminum metal interconnect technology for our submicron CMOS processes. To do this we had to improve several processes including:

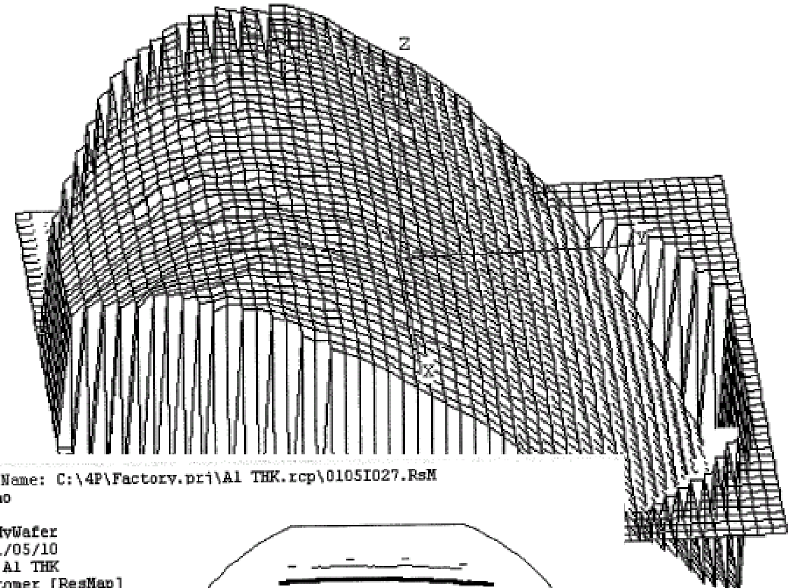
1. Metal Deposition – (For Various Tools)
   - 1.1 Uniformity
   - 1.2 Surface Roughness
   - 1.3 Step Coverage
2. Metal Sputter Etch Prior to Metal Two Deposition
3. Lithography for Metal One and Two
4. Aluminum Plasma Etch for Metal One and Two
5. Via Plasma Etch for Intermetal Dielectric

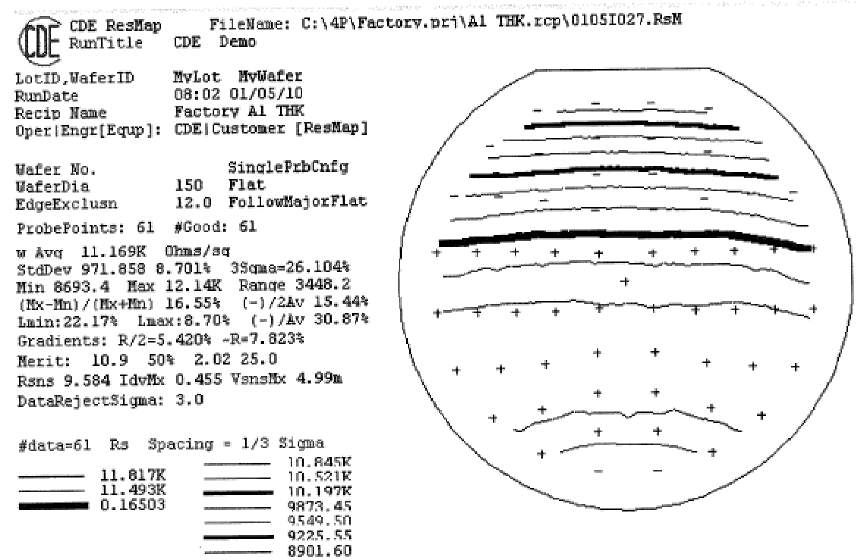
PE4400 SPUTTER / SPUTTER ETCH TOOL



PE4400 – AL THICKNESS NON UNIFORMITY







Ave = 11.17K
Min = 8.69K
Max = 12.1K
Non Uniformity = 16.55%

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PE4400 SPUTTER ETCH RATE

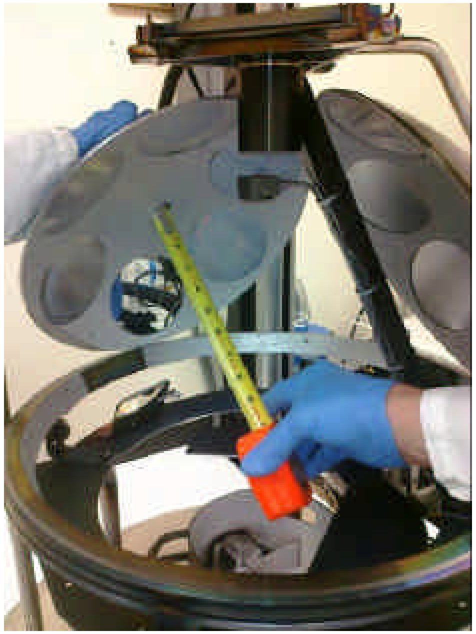
	A	B	C	D	E	F	G	H	I	J
1										
2		Original	Post Etch			Original	Post Etch		Original	Post Etch
3	1	1992	1506		Average	2241.279	1685.459		2242.28	1685.8
4	2	2046	1543		Std. Dev	115.8784	86.18035		116.699	86.524
5	3	2059	1545		Min	1981	1500		1981.3	1500
6	4	2030	1518		Max	2414	1815		2417.3	1815
7	5	1981	1500		Range	433	315		436.05	315
8	6	2111	1597							
9	7	2155	1624		Etch Rate	18.52732	Å/min		18.54933	
10	8	2168	1629							
11	9	2172	1623							
12	10	2062	1542							
13	11	2252	1696							
14	12	2273	1709							
15	13	2007	1519							
16	14	2124	1604							
17	15	2238	1689							
18	16	2327	1752							
19	17	2349	1767							
20	18	2297	1722							
21	19	2213	1661							
22	20	2117	1585							
23	21	2069	1561							
24	22	2185	1645							
25	23	2273	1714							
26	24	2344	1766							
27	25	2388	1795							
28	26	2400	1802							
29	27	2370	1780							

~18Å/min

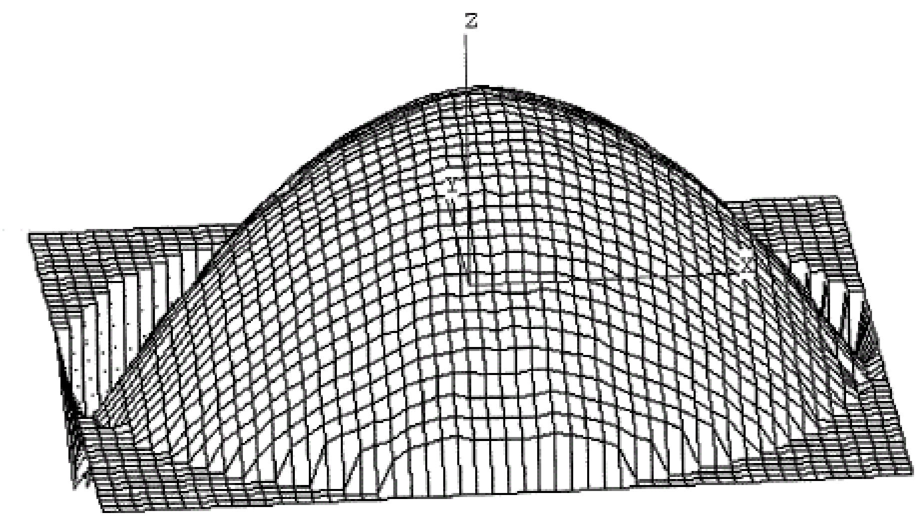
The sputter etch rate was calculated from measured aluminum thickness before and after sputter etch. Measurements were made using 4point probe thickness technique on the CDE resistivity mapper. The sputter etch rate of aluminum was 18 Å per minute.

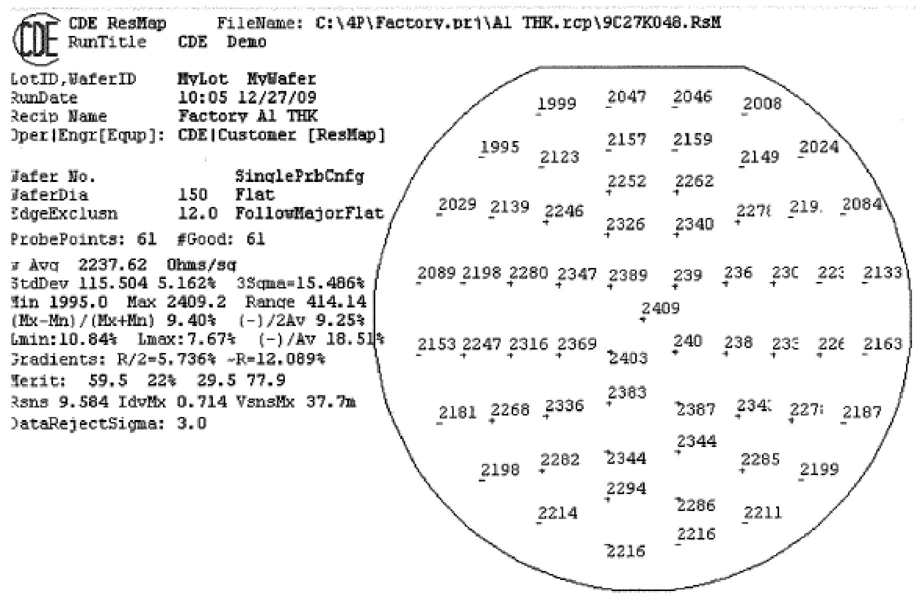
Power = 500 watts
Pressure = 5 mTorr
Flow = 20 sccm
Table Rotation = Yes

CHA FLASH EVAPORATOR

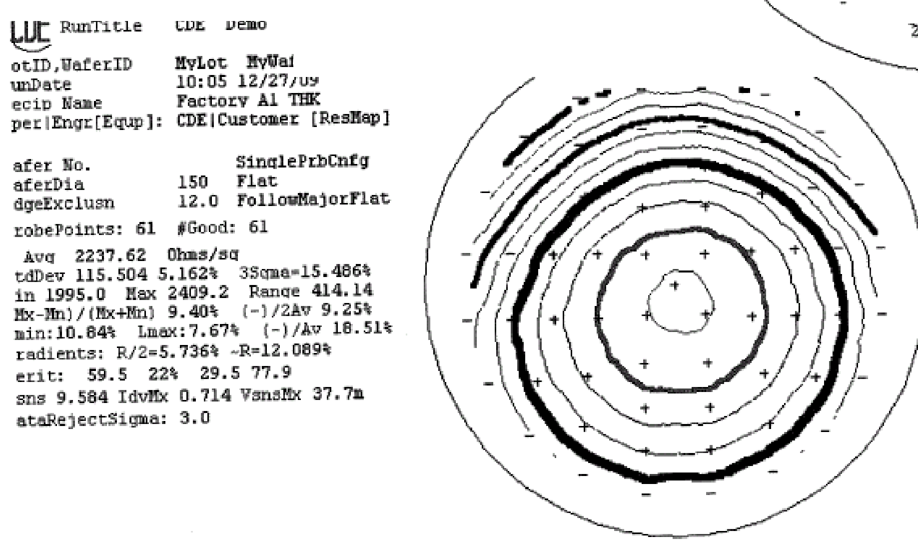


FLASH EVAPORATOR THICKNESS UNIFORMITY



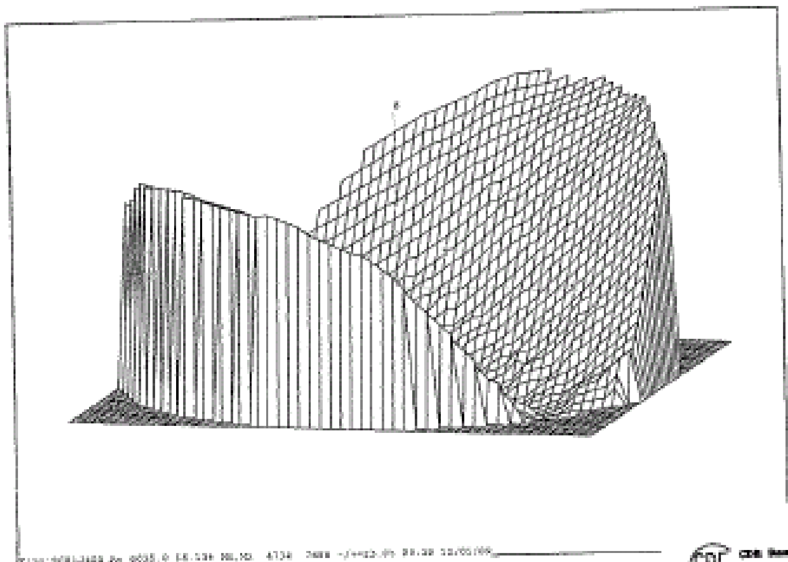


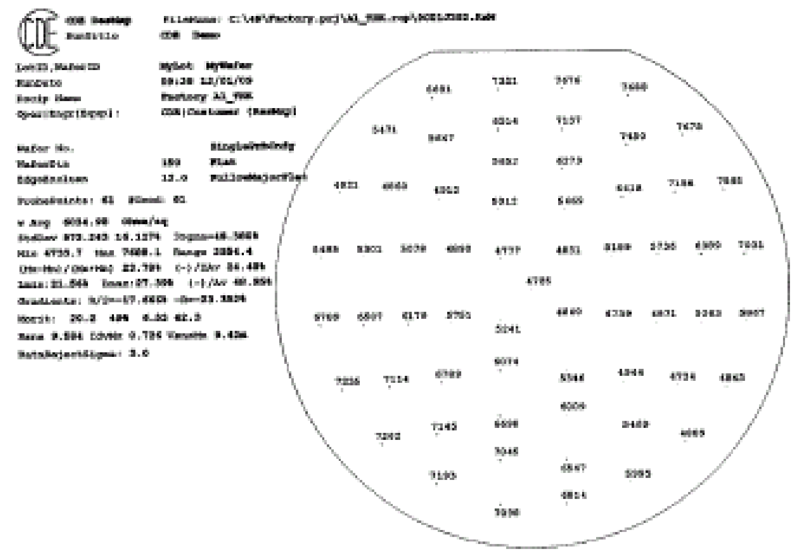
Ave = 2.03K
Min = 1.90K
Max = 2.18K
Non Uniformity = 6.95%



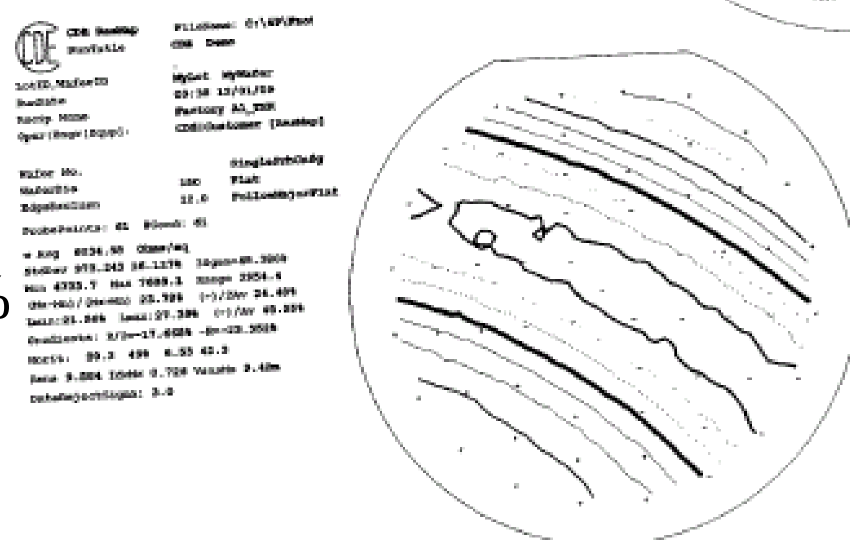
CVC601

CVC601 THICKNESS UNIFORMITY





Ave = 6.03K
Min = 4.73K
Max = 7.68K
Non Uniformity = 23.78%



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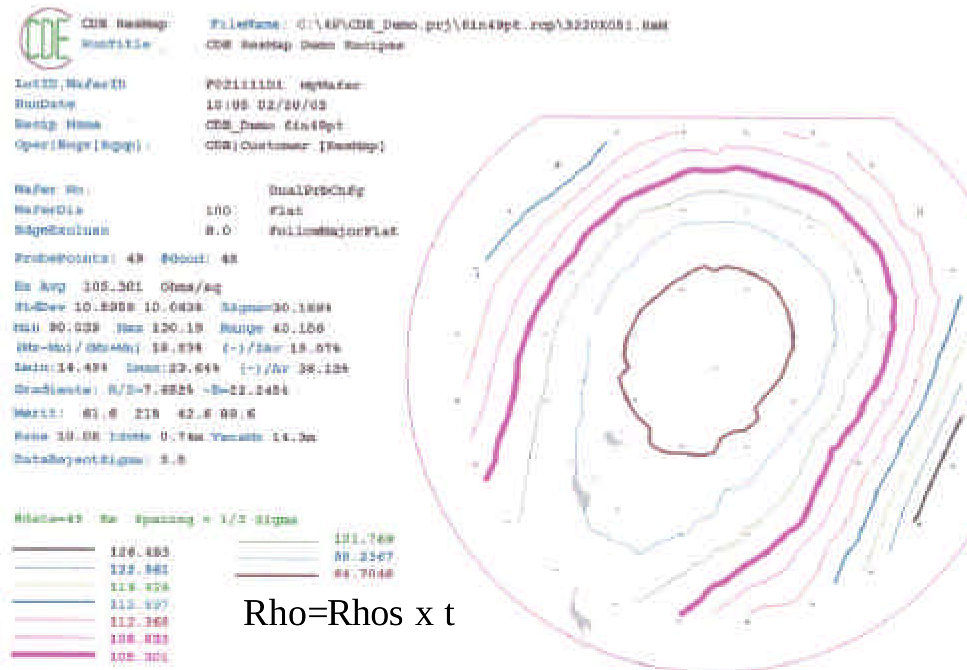
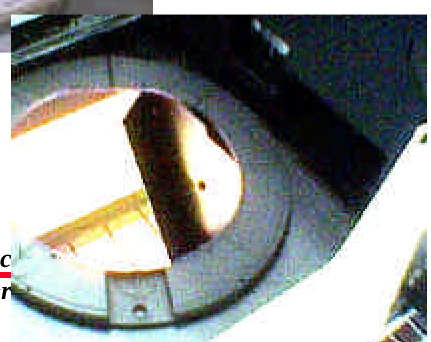
4 PT PROBE WAFER THICKNESS MEASUREMENTS

CDE Resistivity Mapper





Rho=Rhos x t

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

t = Rho/Rhos

EQUATIONS USE BY CDE RESISTIVITY MAPPER

$$\text{Thickness} = \frac{\text{Known Bulk Resistivity}}{\text{Measured Sheet Resistance}}$$

Bulk Resistivity is assumed to be known

$$\text{Measured Sheet Resistance} = (\pi/\ln 2)(V/I)$$

The CDE Resistivity Mapper can be programmed to automatically convert measured V/I to thickness

$$\text{Uniformity} = (\text{Max}-\text{Min})/(\text{Max}+\text{Min})$$

MODELING OF BULK RESISTIVITY

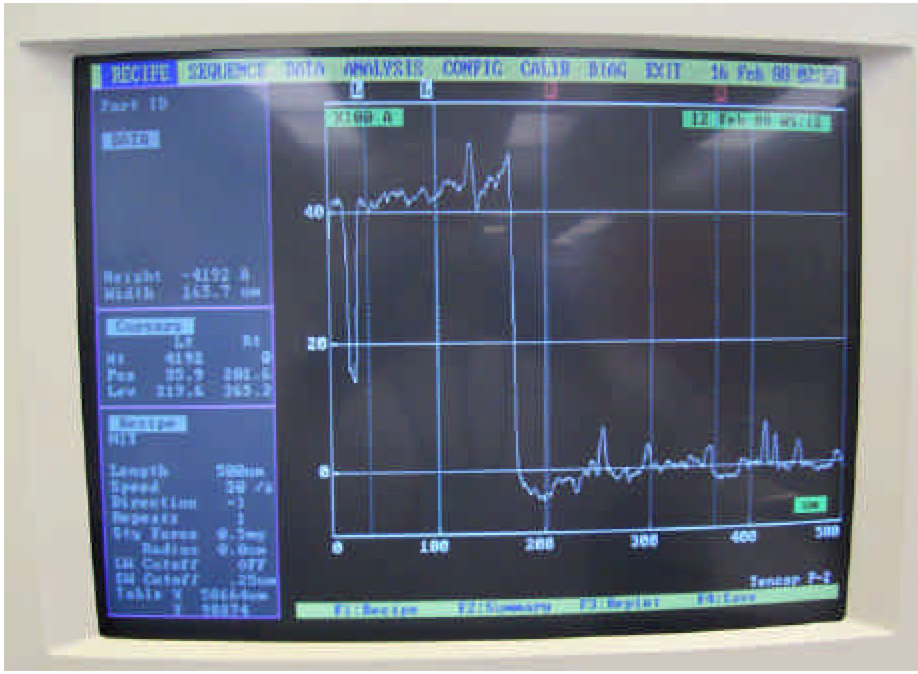
Bulk Resistivity is assumed to have a value = x $Exp^{(y)}$

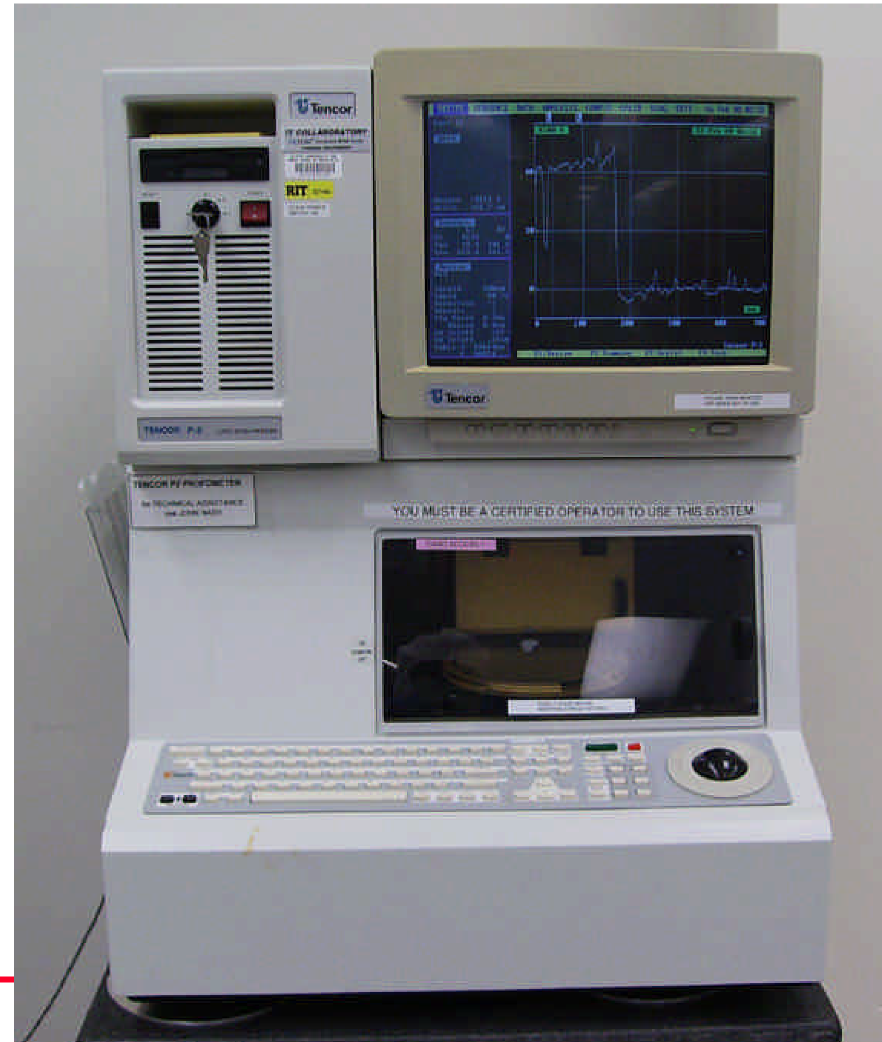
Where the pre exponential value may be different for different film deposition techniques (i.e. evaporation, RF sputtering, DC sputtering, etc.)

	x	y	Rho ohm-Å
CDE Manual	337.17	-0.92401	133.8
PE4400 (300watts)	412	-0.92401	163.5
CVC601			
Flash Evaporator			

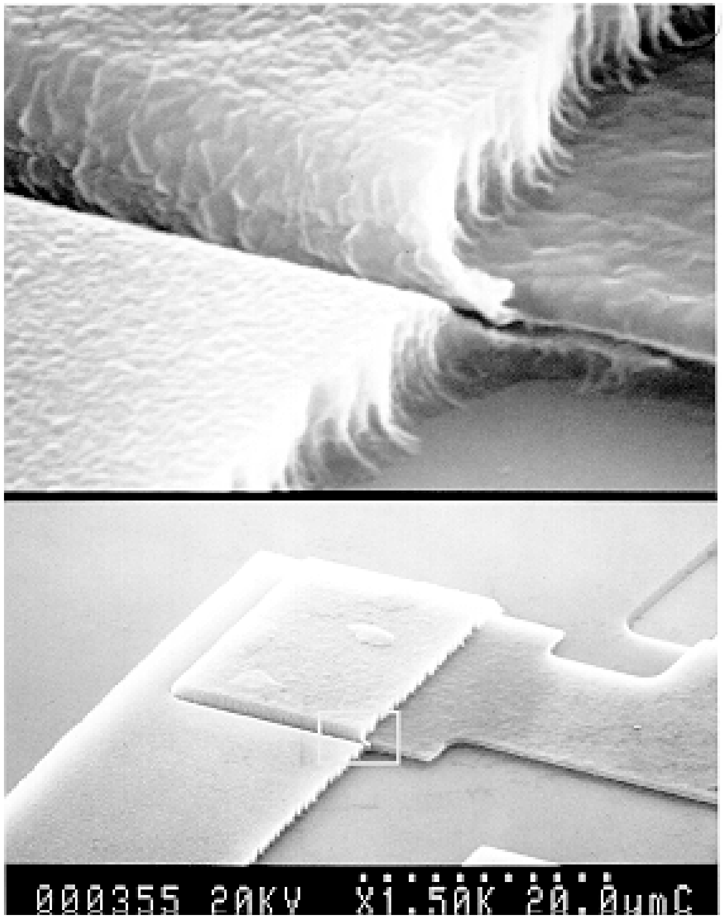
Note: bulk Aluminum Rho = 270 ohm-Å

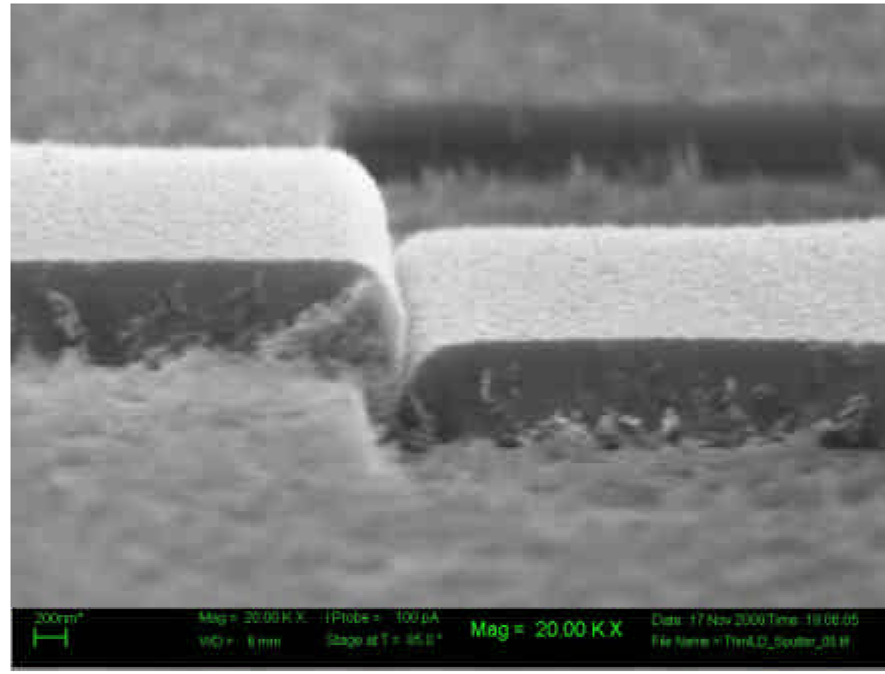
VERIFICATION USING THE TENCORE P2





STEP COVERAGE





These SEM pictures show typical profiles of aluminum over steps from the CVC601.

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SUMMARY FOR DEPOSITION, UNIFORMITY and STEP COVERAGE

1. None of the deposition tools are that great from a thickness uniformity point of view. The best tool we investigated is the Cha Flash Evaporator.
2. The PE 4400 is the only tool that can do sputter etch prior to metal deposition. So we need to use this tool for the 2^{nd} layer of aluminum.
3. The four point probe technique for measuring thickness is a good way to measure uniformity.
4. Step coverage can be a problem so we choose to deposit metal thickness larger than the step height. Our metal thicknesses are 0.75µm for metal one and two.

SURFACE ROUGHNESS

The PE4400 RF sputtering tool has sputter etch capability. There is a lot of heat produced during sputtering in this tool which causes large grain size in the sputtered aluminum. The metal sputtered in this tool can have a white look due to the large grain size. The large grain size and the 1.3 microns of photoresist on top of the aluminum makes it difficult to see alignment marks for the metal two lithography step.

Large grain size aluminum contributes to photoresist adhesion problems and the plasma etch seems to be more isotropic.

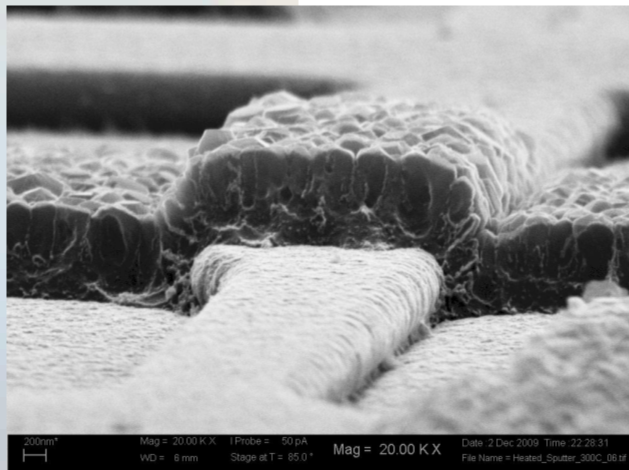
IMAGE OF WAFER SHOWING EFFECT OF SURFACE ROUGHNESS

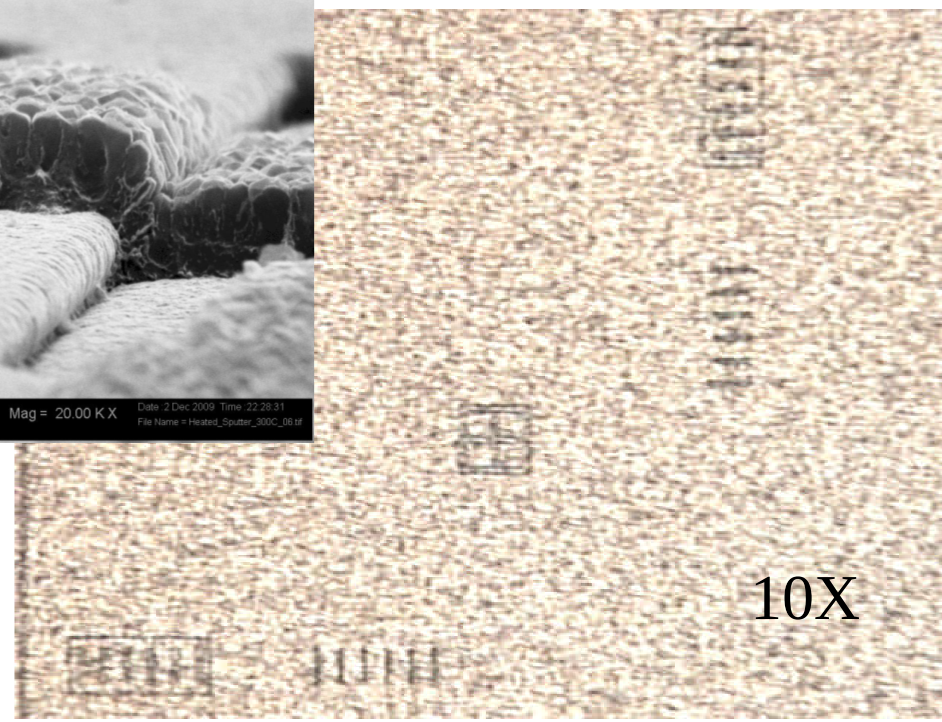
Al Thickness = 7225Å

Sputtered at 900 watts

Veeco Wyco

RMS Surface Roughness = 37 nm





Metal two looks white instead of shiny silver due to large grain size

Photograph of alignment keys with no photoresist

PE4400 SETTINGS AND SOME RESULTS

Power Watts	**Space**	**Pressure mT**	**Flow sccm**	**Time min**	**Deposition Rate Å/min**	**Total Thickness Å**	**Surface Rough nm RMS**
Bare Wafer		-	-	-	None	Zero	4.6
CVC601						6800	11
900	A	5	20	90	80.3	7225	37
600	A	5	20	60	54	3265	17
500	A	5	40	120	44	5300	20.5
500	A	5	40	90+90	44	~7500	21
500	A	5	40	90	44	~3750	6
400	A	5	40	240	37	9000	7
400	B	5	40	120			11
400	C	5	40	180	62	11169	~20
300	C	5	45	150	38.7	5800	~11

Goal is 7500 Å Al thickness and surface roughness <10nm RMS

10nm RMS = 283Å peak-to-peak

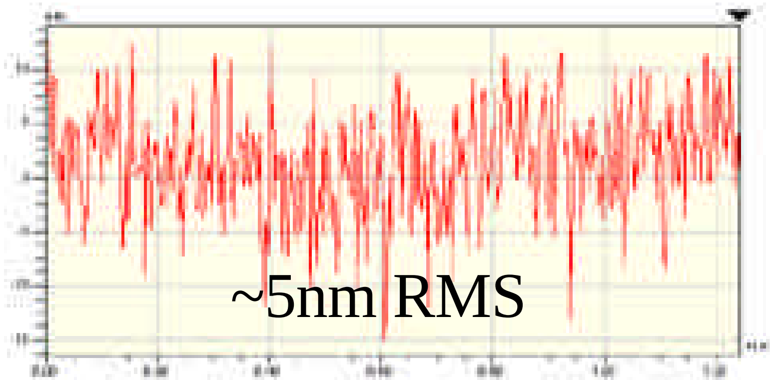
VEECO WYCO NT1100 OPTICAL PROFILOMETER

Used to measure RMS surface roughness

SURFACE ROUGHNESS DATA

X Profile

Bare Silicon Wafer



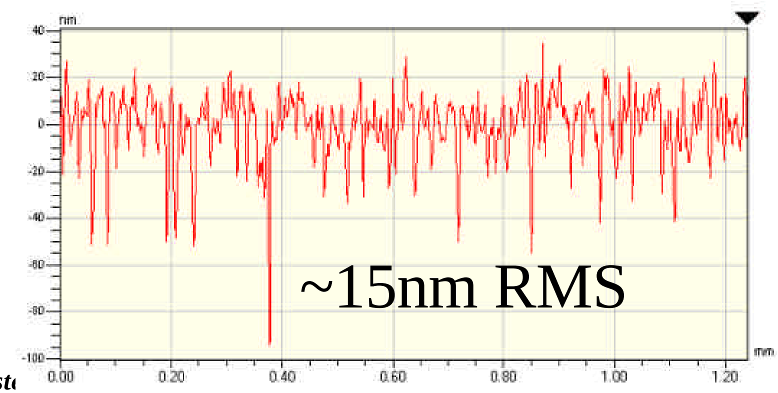
~5nm RMS

Rq	[illegible]	nm
Ra	[illegible]	nm
Rt	[illegible]	nm
Rp	[illegible]	nm
Rv	[illegible]	nm

Angle	[illegible]	[illegible]
Curve	[illegible]	[illegible]
Terms	[illegible]	
Avg Ht	[illegible]	[illegible]
Area	[illegible]	[illegible]

X Profile

Aluminum CVC 601 – 6800Å



~15nm RMS

Rq	14.59	nm
Ra	10.58	nm
Rt	128.34	nm
Rp	34.18	nm
Rv	-94.15	nm

Angle	-9.13	urad
Curve	97.02	m
Terms	None	
Avg Ht	-0.79	nm
Area	-0.97	um2

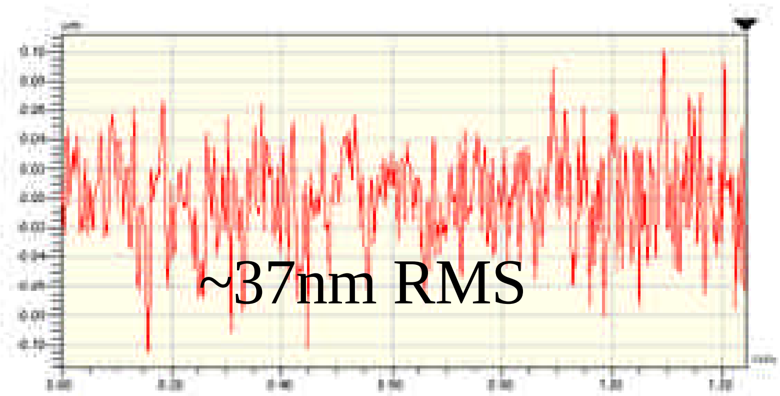
Y Profile

Rochest
Microele

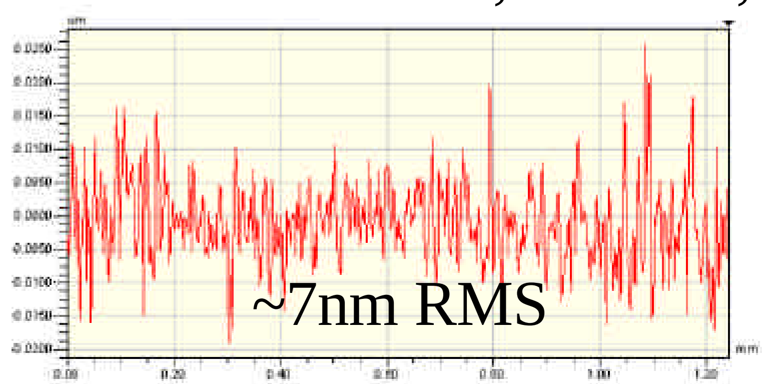
ALUMINUM SURFACE ROUGHNESS DATA

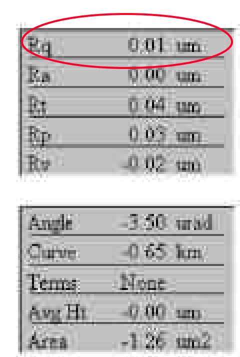
X Profile

900W, 20 sccm, 5mT, 90 min, 7225Å



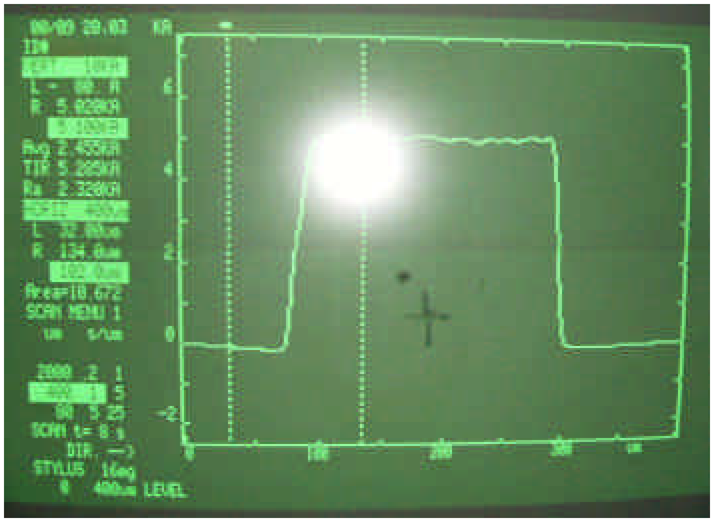
400W, 40 sccm, 5mT, 240 min, 9000Å





AL DEPOSITED AT 600 WATTS TO THICKNESS OF 3265Å

600 Watts, Ar Flow 20sccm, 2mT, Table Rotation 100, 60 min
Dep Rate = 3265Å/60min = 54Å/min



10X

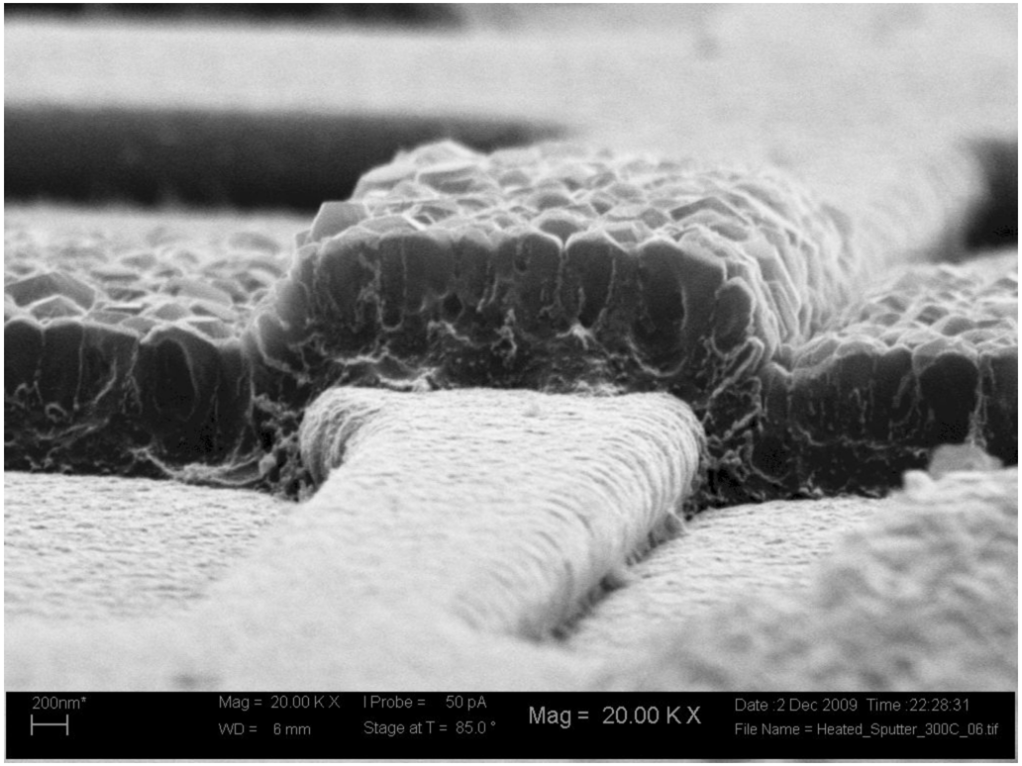
Veeco Wyco
RMS Surface Roughness = 17 nm

SUMMARY - FOR SPUTTERING IN PE4400

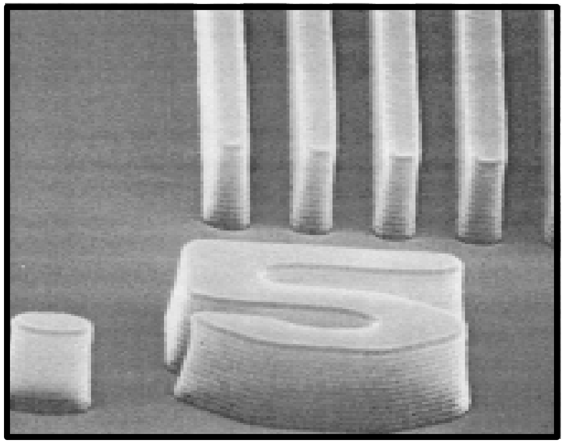
1. Smoother films can be deposited at lower powers.
2. Thinner films are smoother.
3. To quantify the roughness/smoothness the Veeco Wyco Optical Surface Profilometer is useful.
4. The deposition rate is lower at lower powers.
5. Deposition times become many hours for low power and film thickness approaching 1 micron.
6. Moving the wafers closer to the target increases sputter rate and surface roughness. (The height is as close as possible now "C")
7. Rough films give problems for lithography and etching.
8. Surface roughness needs to be less than 10nm RMS for successful lithography and plasma etching.
9. Best conditions observed so far are, 300 watts, 5 mT, 40 sccm, to give a deposition rate of 37Å/min and surface roughness of ~11nm RMS for a film thickness of ~7500 Å. after 180 min sputter time.
10. Non uniformity is 22%. Wafers are thinner toward the flat.

LITHOGRAPHY PROBLEMS ON ROUGH ALUMINUM

Rough aluminum makes it hard to see the alignment marks from previous layers. Photoresist adhesion is not as good on rough films. The plasma etch seems to be more isotropic.



CANON FPA-2000 i1 STEPPER



i-Line Stepper λ = 365 nm

NA = 0.52, σ = 0.6

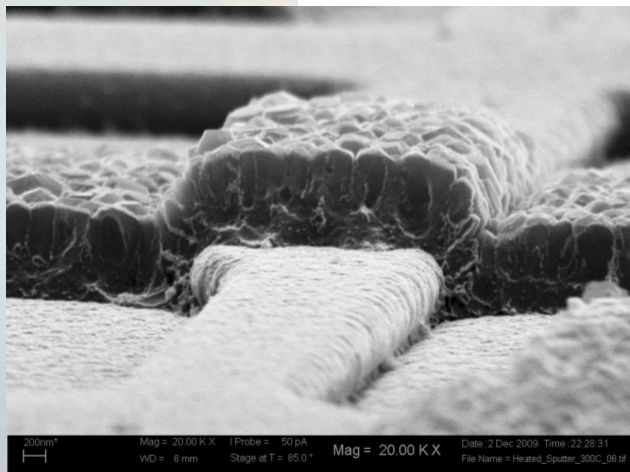
Resolution = 0.7 λ / NA = ~0.5 µm

20 x 20 mm Field Size

Depth of focus = $k_2\ \lambda/(NA)^2$ = 0.8 µm

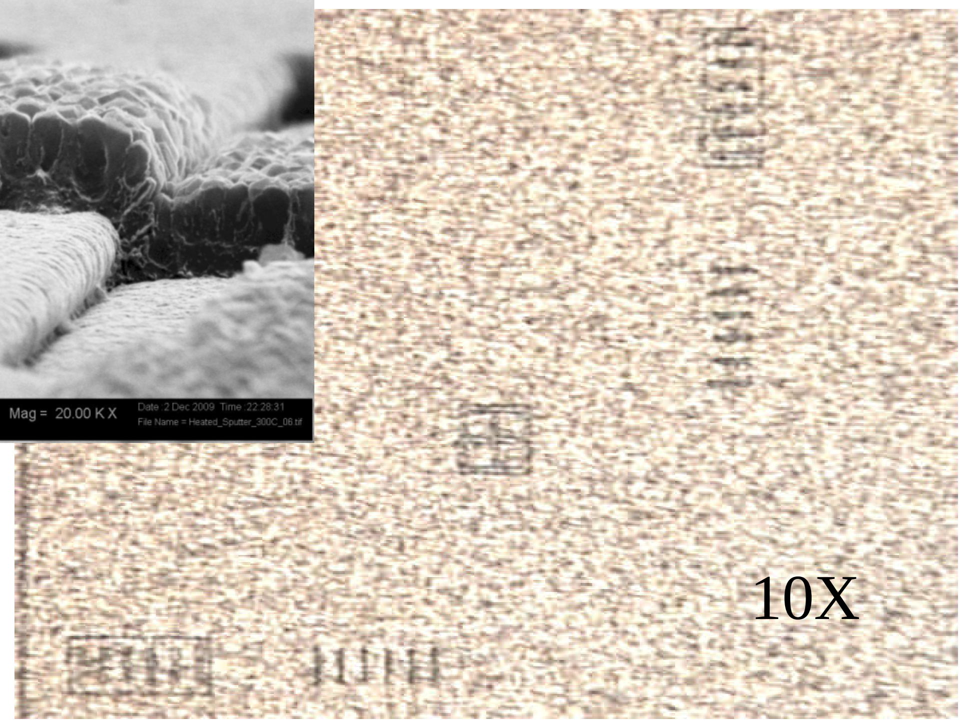
Overlay ~0.1µm

IMAGE OF WAFER AND ALIGNMENT KEYS



Veeco Wyco

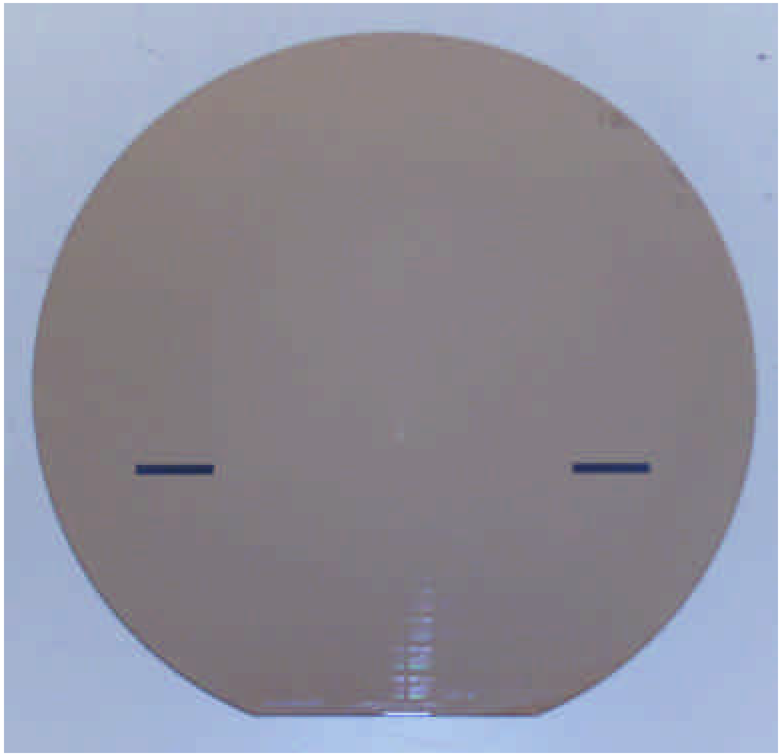
RMS Surface Roughness = 37 nm



Metal two looks white instead of shiny silver due to large grain size

Photograph of alignment keys with no photoresist

TECHNIQUE TO REMOVE METAL TWO OVER ALIGNMENT MARKS ON TWO DIE



Stepper job F081SUBCMOS_Z
Use plain piece of glass for mask

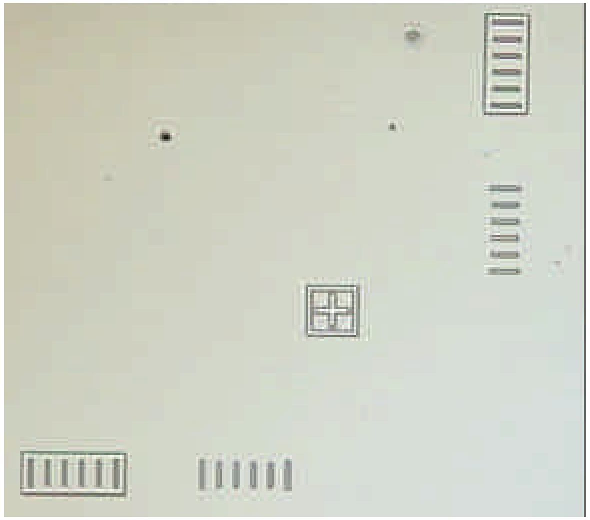
Blade positions in Shot File
Bu = -6mm
Bd = -8mm
Bl = -8mm
Br = 8mm

Skip shots all except two die
Row 6 column 2 and Row 6 Column 8

Use: COATMTL.RCP and DEVMTL.RCP recipes on the SSI track for thicker resist coatings and better step coverage

ALIGNMENT KEYS AFTER REMOVAL OF METAL 2

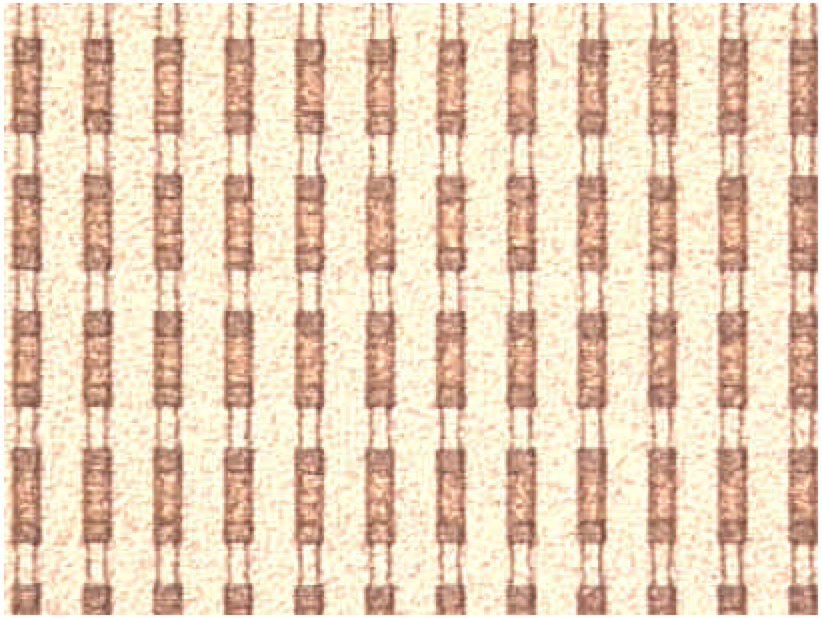
We did a wet etch of the aluminum, rinsed and did a spin/rinse/dry. In those two spots on the wafer we could see the alignment marks as shown below.



We modified the stepper job F081SUBCMOS_M2 so that it used the two die with no metal two for alignment and exposed the wafer using the M2 photomask.

PHOTOS OF WAFER AFTER PHOTO FOR METAL 2

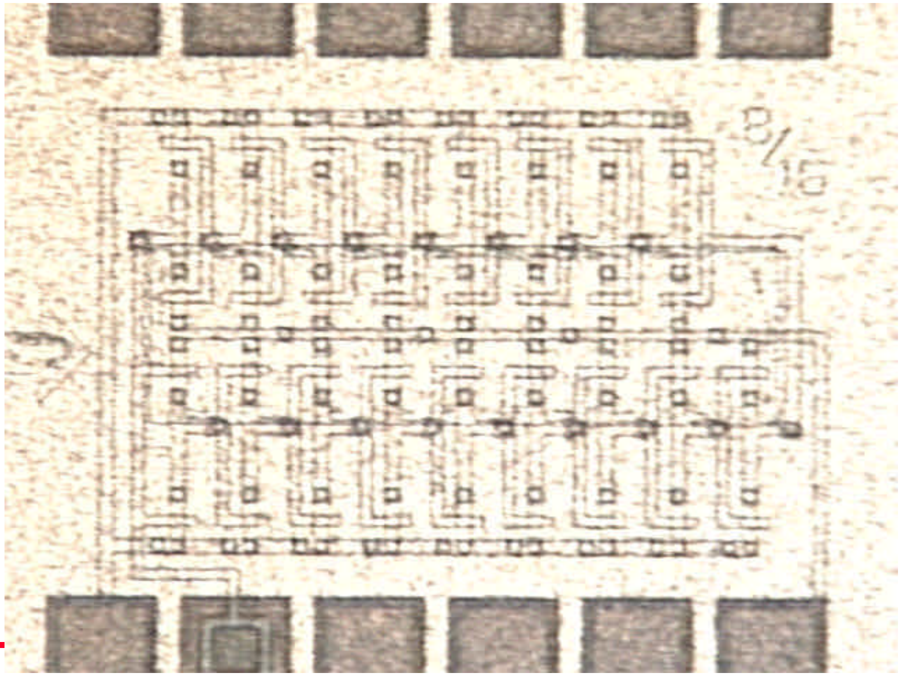
Metal Two
6µm x 24µm Via Chain Links



100X

Excellent alignment, zero overlay error

Metal Two
100µm x 100µm Pads



10X

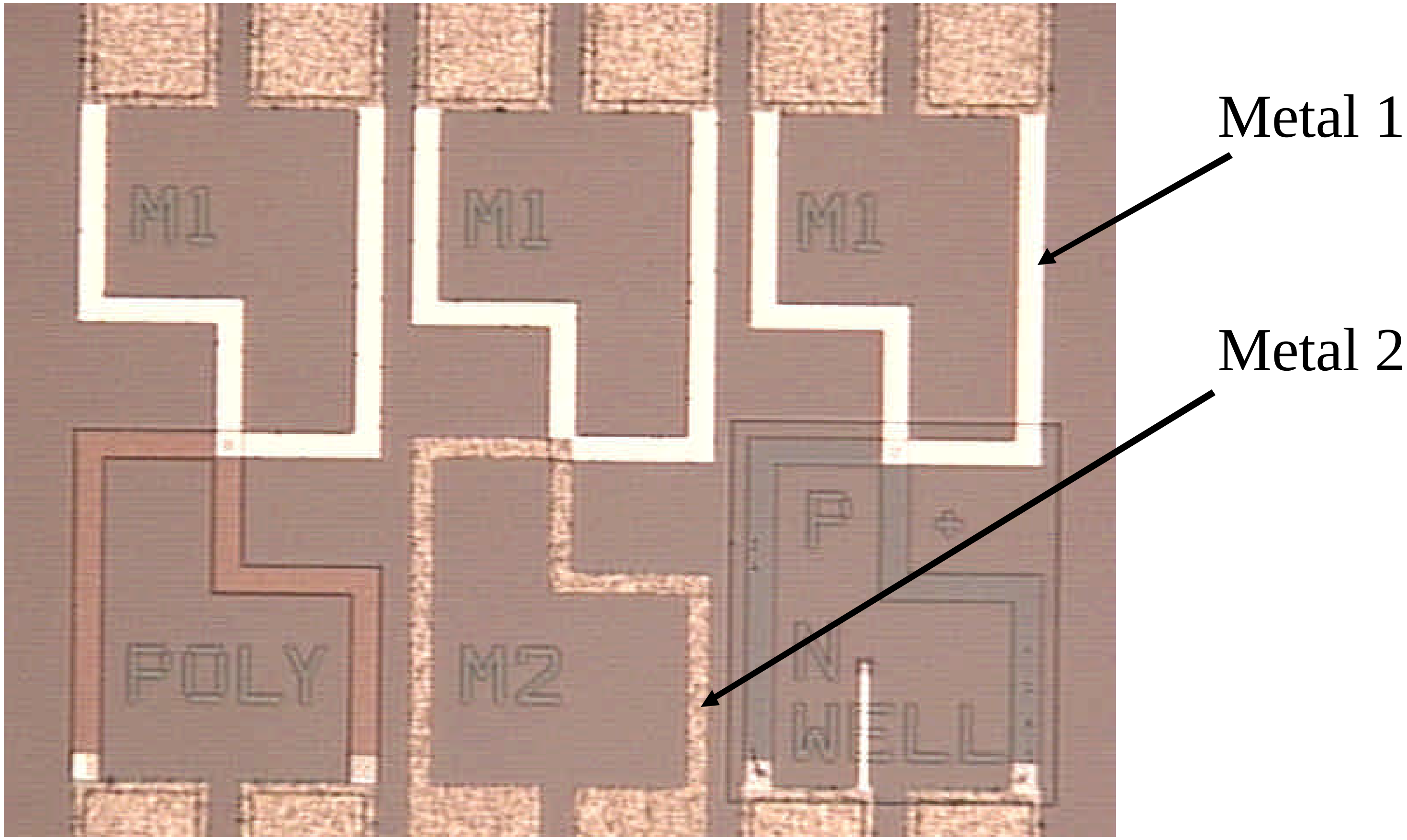
SUMMARY-CONCLUSION PHOTO ON ROUGH AL

1. The Canon stepper can be used to image on rough aluminum.
2. Alignment marks can be made visible by etching the aluminum off of selected die and creating a stepper job to use the alignment marks in only those die for alignment.
3. Resolution and overlay is acceptable.
4. Resist adhesion may not be as good as with smooth films.
5. Best solution is to deposit smooth aluminum.

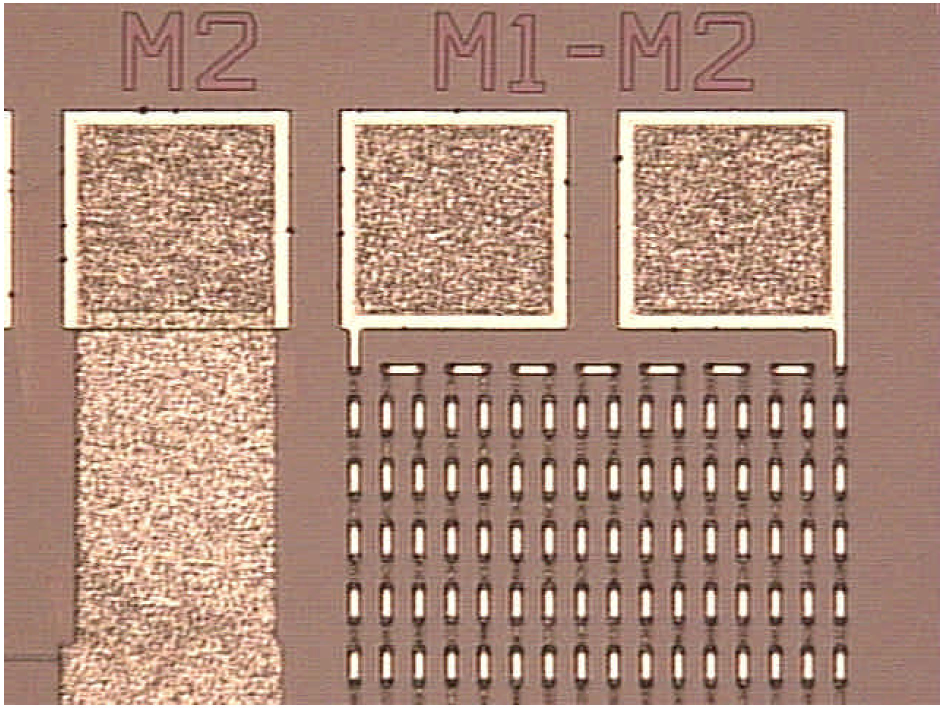
PROBLEMS ETCHING ROUGH ALUMINUM

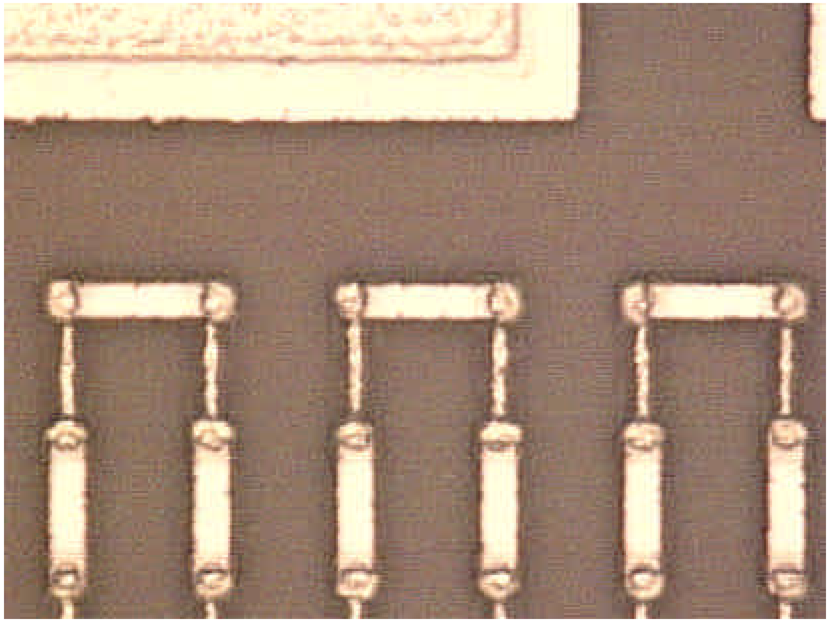
1. Plasma etching using the LAM 4600 undercuts the photoresist significantly.
2. Smooth metal works fine, see metal one, rough metal seems to etch isotropically (may be a resist adhesion issue)
3. Wafer non-uniformity of 22% causes some areas to not etch completely. Over etch is needed to completely etch everywhere.
4. The etch needs to be anisotropic.

PROBLEMS WITH ALUMINUM ETCH OF METAL 2



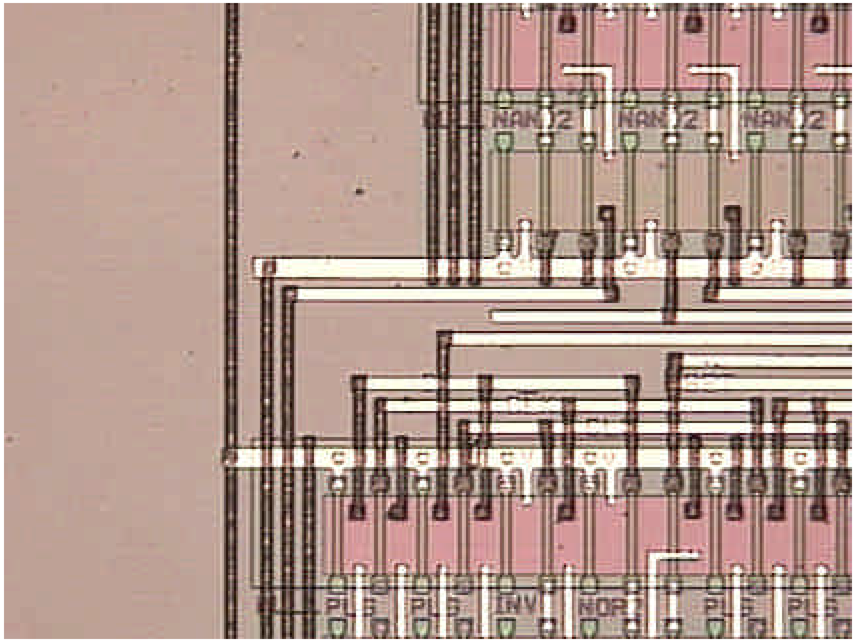
AFTER METAL ETCH AND RESIST STRIP

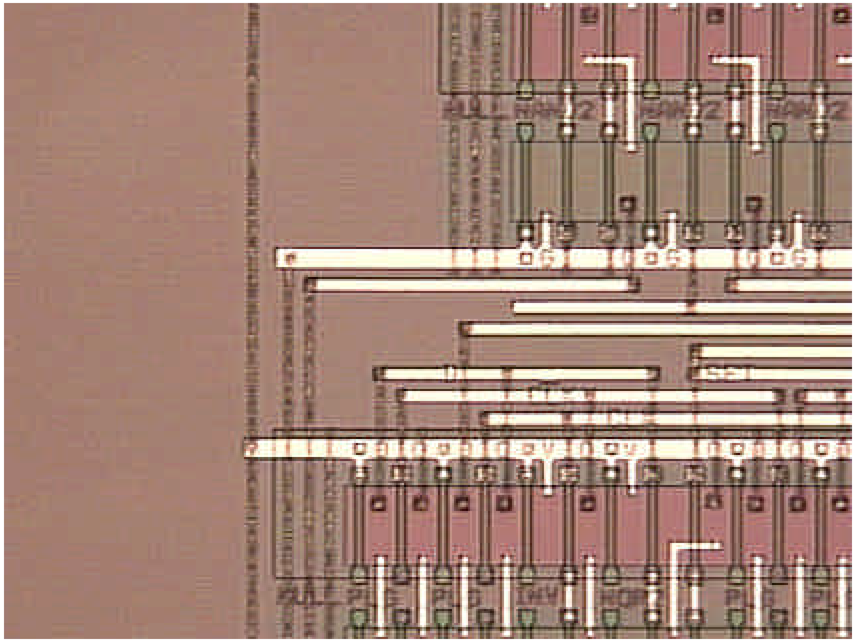




METAL ONE – HORIZONTAL, METAL TWO - VERTICAL

M2 lines run vertical, M1 lines run horizontal, both 0.75µm Thick



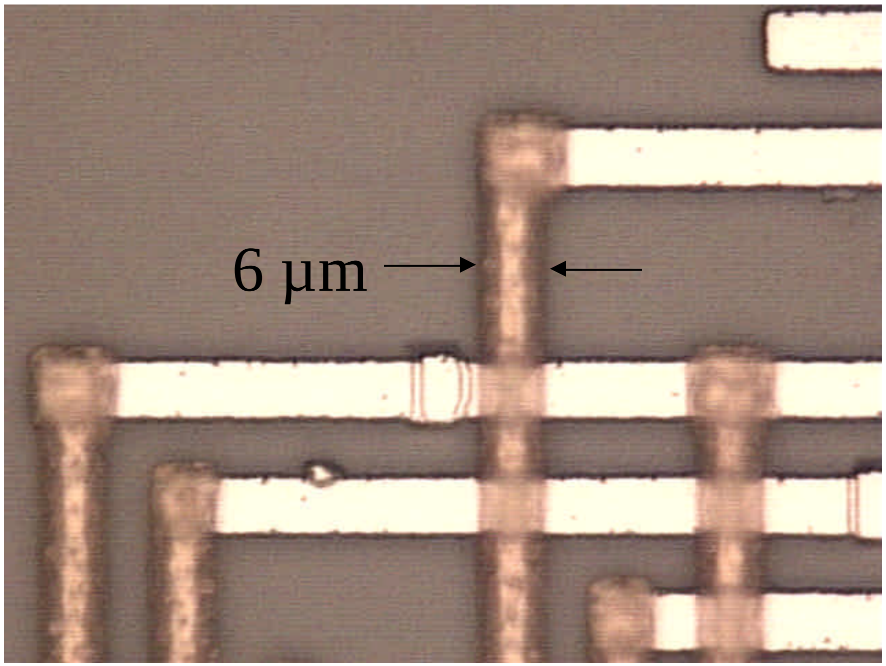


6µm M2 lines with photoresist

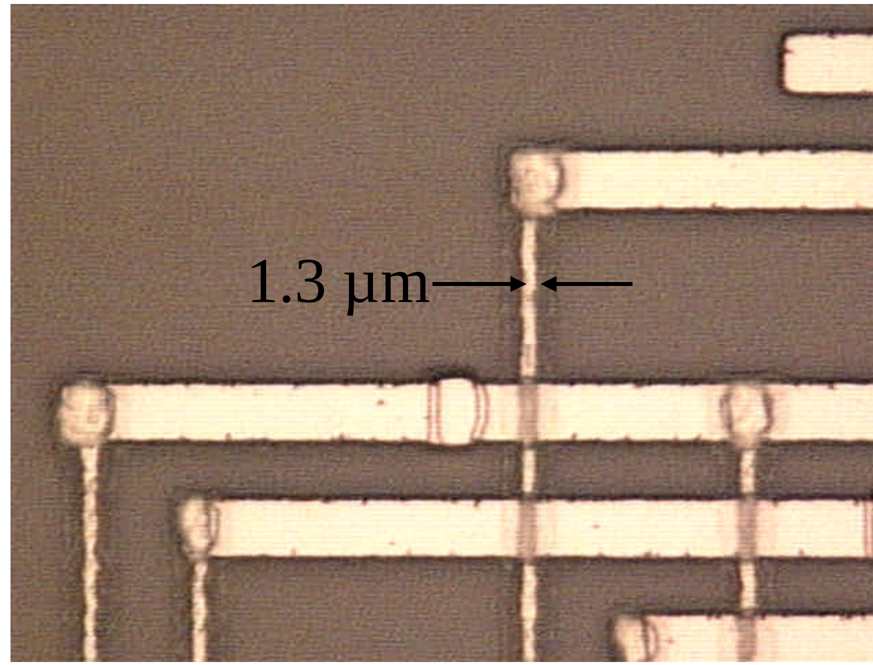
Resist removed show M2 lines are actually 1.3µm

ISOTROPIC ETCH

M2 lines run vertical, M1 lines run horizontal, both 0.75µm Thick



6µm M2 lines with photoresist



Resist removed show M2 lines are actually 1.3µm

Note: M1 lines look good,
M2 look over etched

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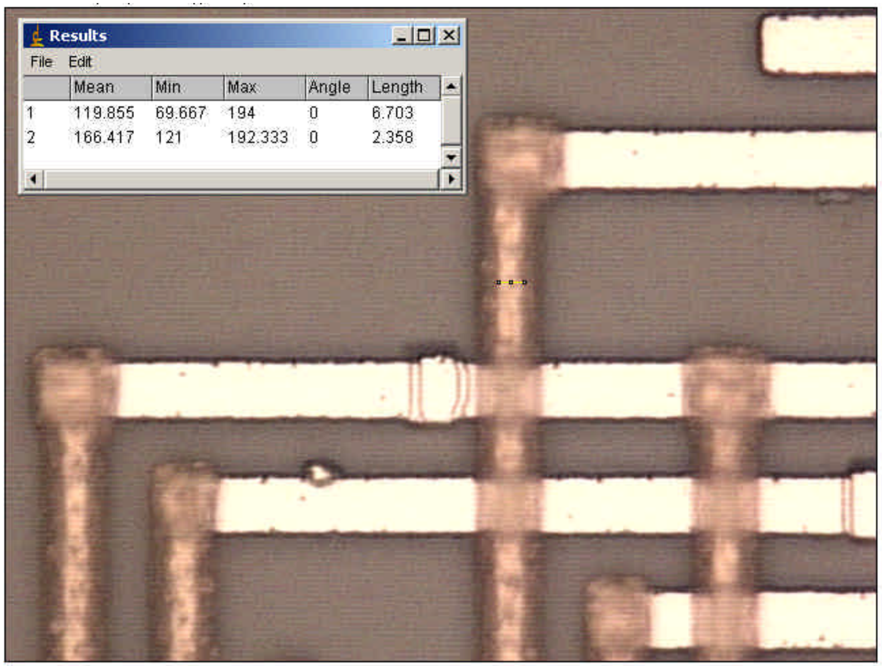
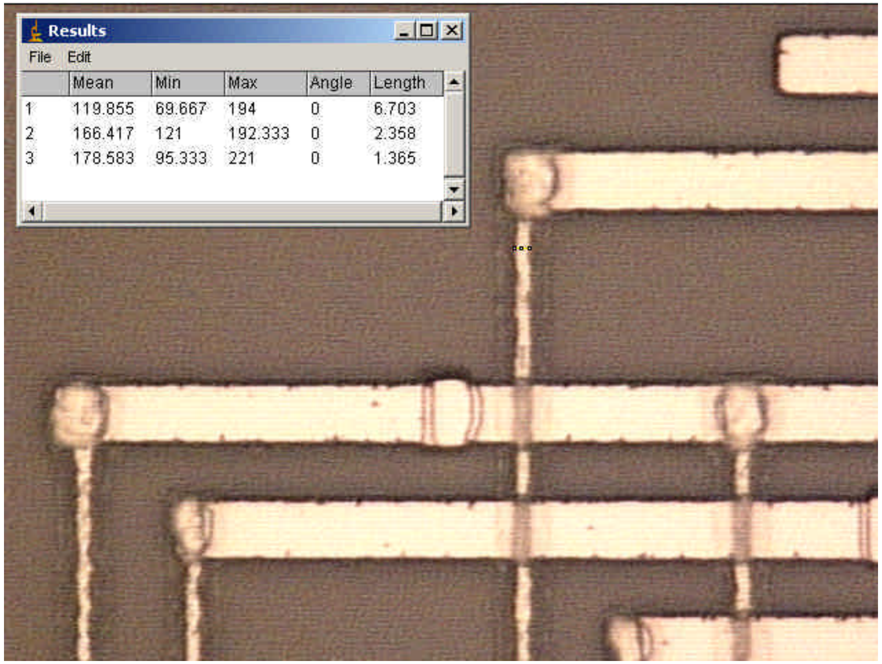
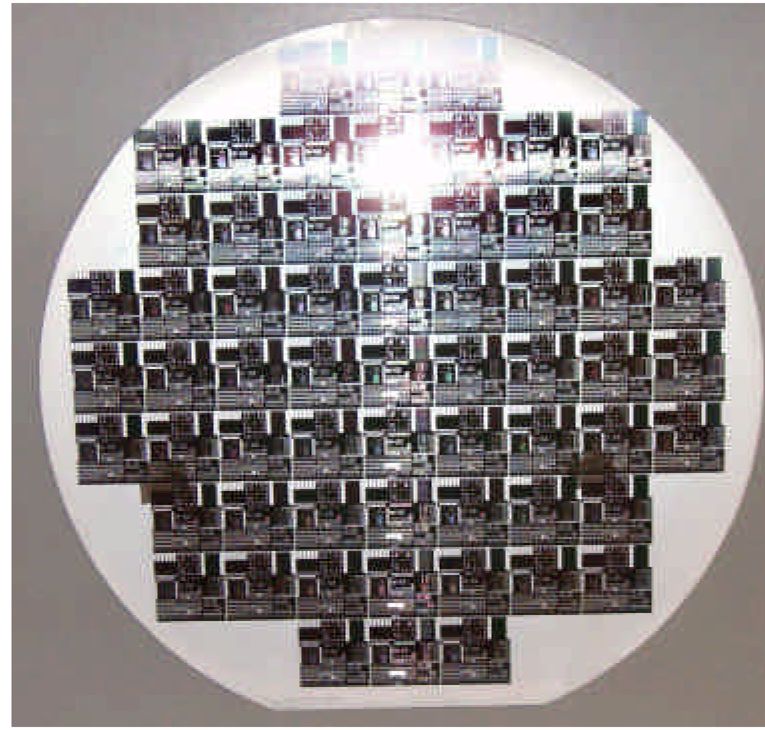
OPTICAL LINE WIDTH MEASUREMENTS





ALUMINUM ETCH USING LAM4600



LAM 4600 ALUMINUM ETCHER

Plasma Chemistry

Cl_2 – Reduces Pure Aluminum

BCl_3 – Etches native Aluminum Oxide

-Increases Physical Sputtering

N_2 – Dilute and Carrier for the chemistry

Chloroform – Helps Anisotropy and reduces Photoresist damage

LAM 4600 OLD RECIPE 122122

Recipe: Number 122122

Step	1	2	3	4	5
Pressure (mtorr)	300	300	300	300	0
RF Top (W)	0	0	0	0	0
RF Bottom (W)	0	250	125	125	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	Oetch	time
time (s)	15	8	130	10%	15

Rate ~50Å/s

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

Gianni Franceschinis, May 2005

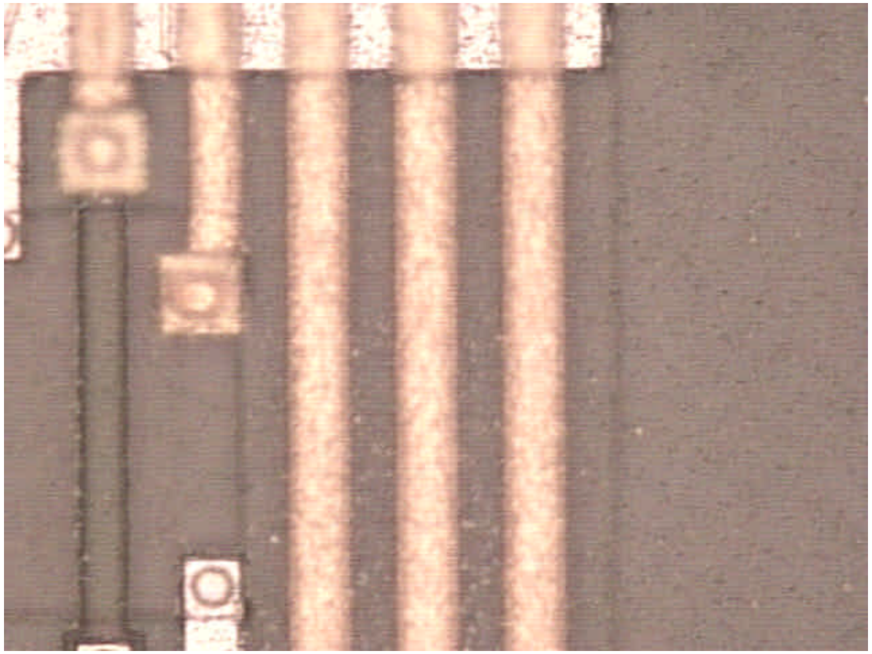
LAM4600 ANISOTROPIC ALUMINUM ETCH

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
N2	13	13	20	25	25
BCl	50	50	25	25	0
Cl2	10	10	30	23	0
Ar	0	0	0	0	0
CFORM	8	8	8	8	8
Complete	Stabl	Time	Endpoint	Oetch	Time
Time (s)	15	8	180	10%	15

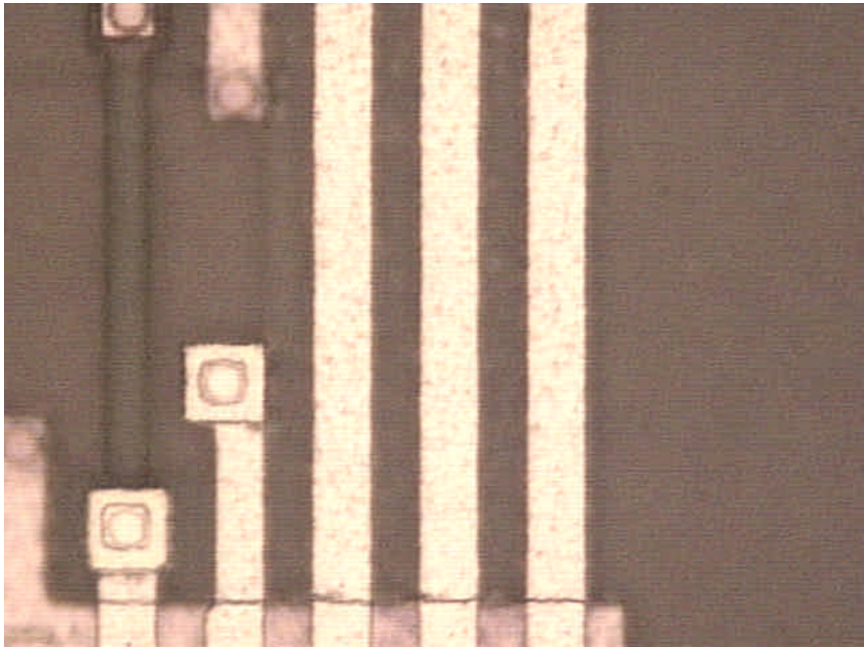
Channel	B
Delay	130
Normalize	10 s
Norm Val	5670
Trigger	105%
Slope	+

Fuller, December 2009

RESULTS FROM NEW ALUMINUM PLASMA ETCH



Photoresist on Metal Two



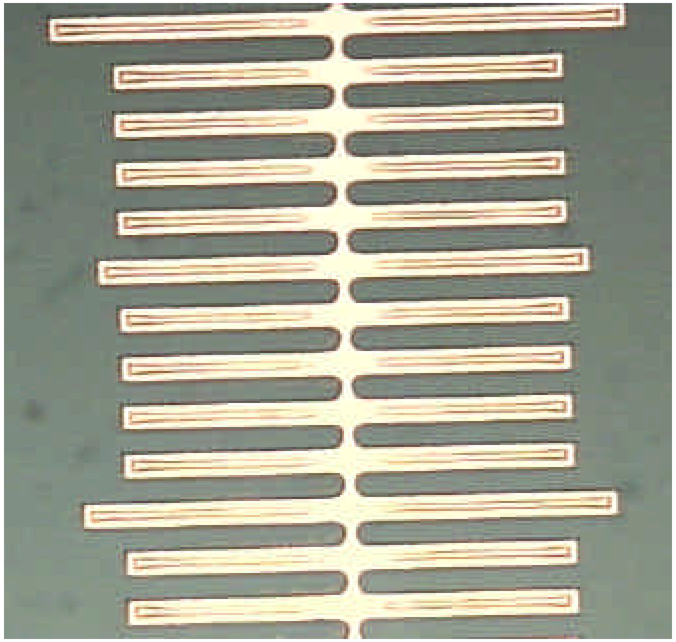
Photoresist Removed

RESIST REMOVAL POST CHLORINE RIE ALUMINUM ETCH

Problem: Photoresist is hardened (and chemically changed) in Chlorine RIE during Aluminum etch and ashing is ineffective in removing the resist.

Solution: Use a Solvent based photoresist stripper process. (similar to Baselinc CMOS process at U of California at Berkeley)

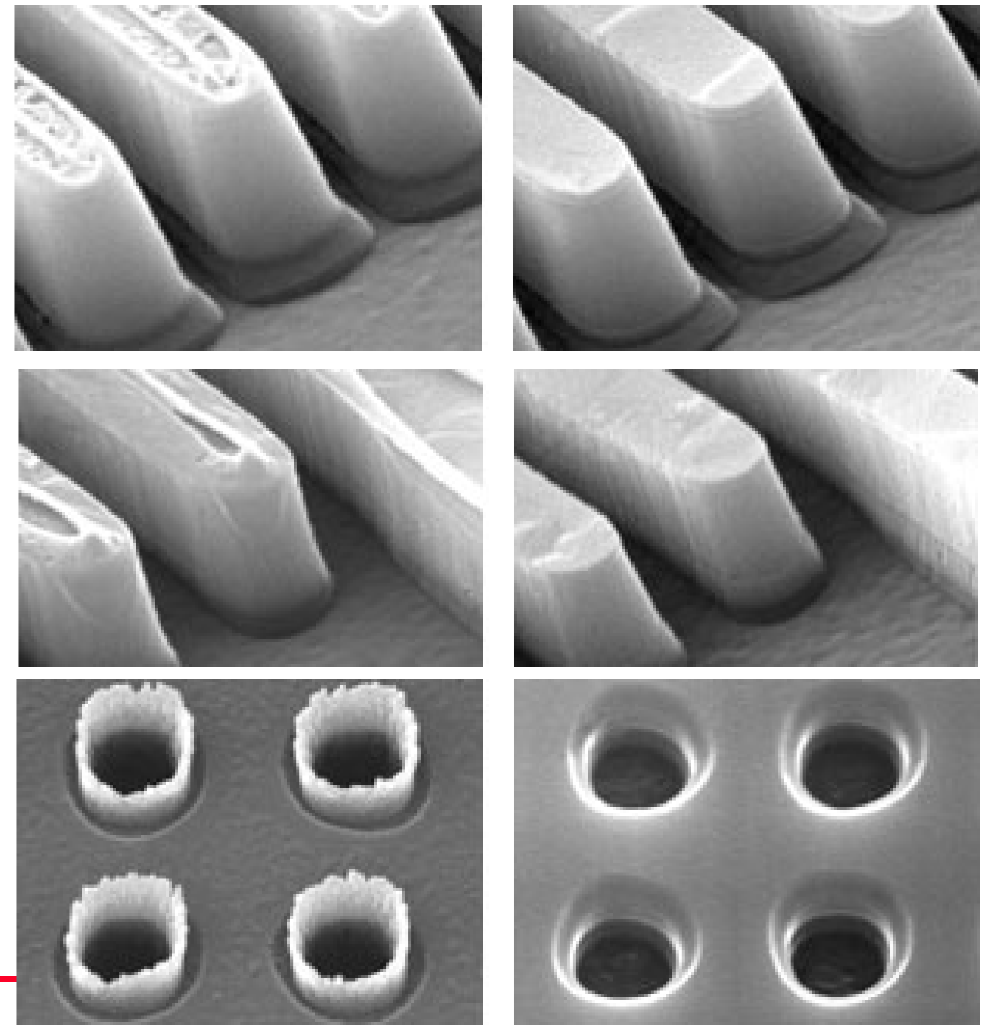
Picture of aluminum wafers post chlorine RIE and after ashing. Note resist remaining on aluminum. Even very long ashing (60 min.) does not remove residue.



Germain Fenger

MORE PICTURES OF RESIST SCUM PROBLEM

Pictures on left show resist residue after ashing. Pictures on right show effectiveness of ACT 935 solvent strip process.



From: [ACT-CMI Data Sheet]

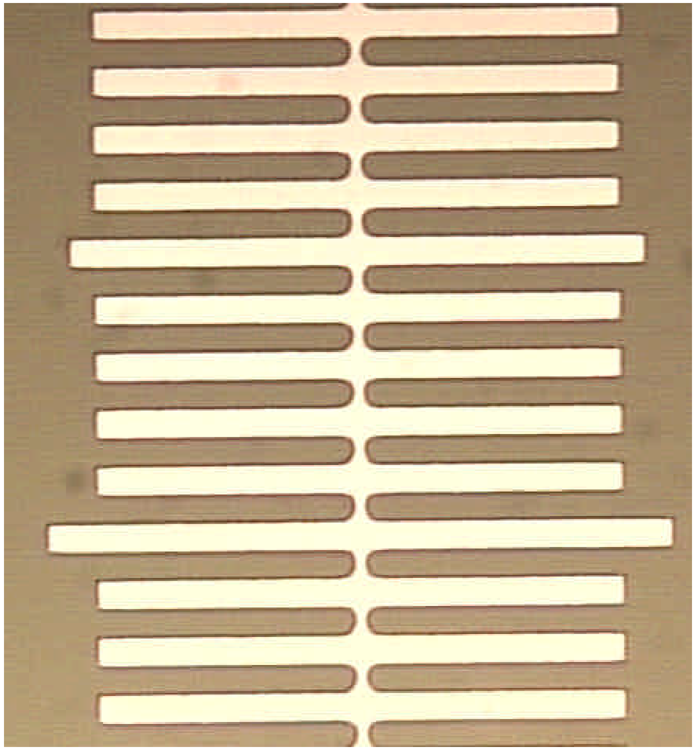
RESIST REMOVAL AFTER PE4600 PLASMA ETCH

Obserations:

A solvent based photoresist stripper followed by a plasma ash is effective at removing Chlorine "burned resist"

Recommendations:

PRS2000 at 90C for 10 min
Rinse 5 min. / SRD
Follow up with 6" Factory ash on the Branson Asher



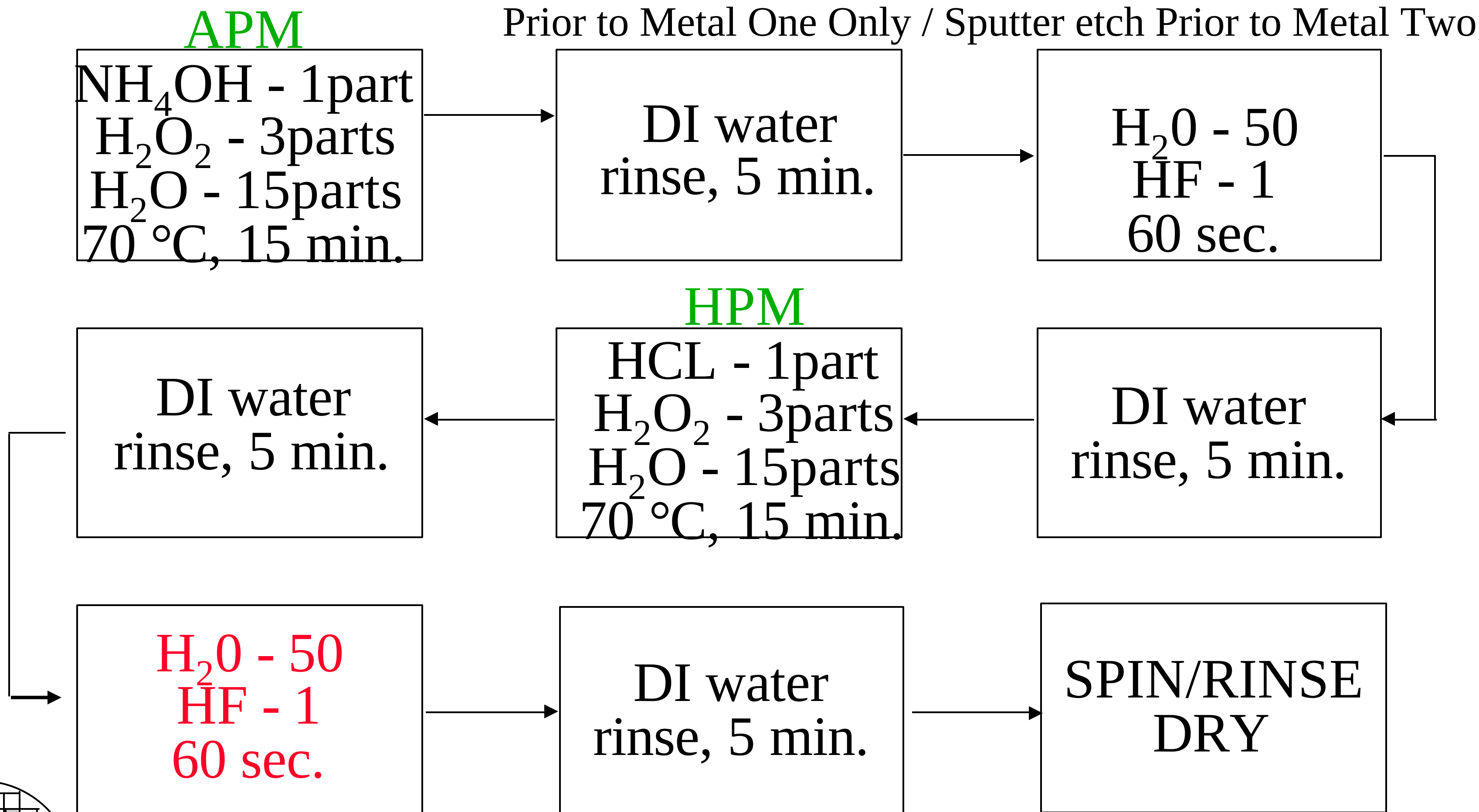
No photoresist was found on wafers

Germain Fenger

SUMMARY – CONCLUSION PLASMA ETCH OF AL

1. Smooth metal is necessary for good plasma etching.
2. Aluminum film non-uniformity of less than 10% is needed to give best results.
3. A new plasma etch recipe that is more anisotropic was created and shown to work for wafers with non uniformity of ~22%
4. The vias were plasma etched.
5. Resist strip using solvent strip followed by oxygen plasma strip is effective after chlorine plasma etch of aluminum.

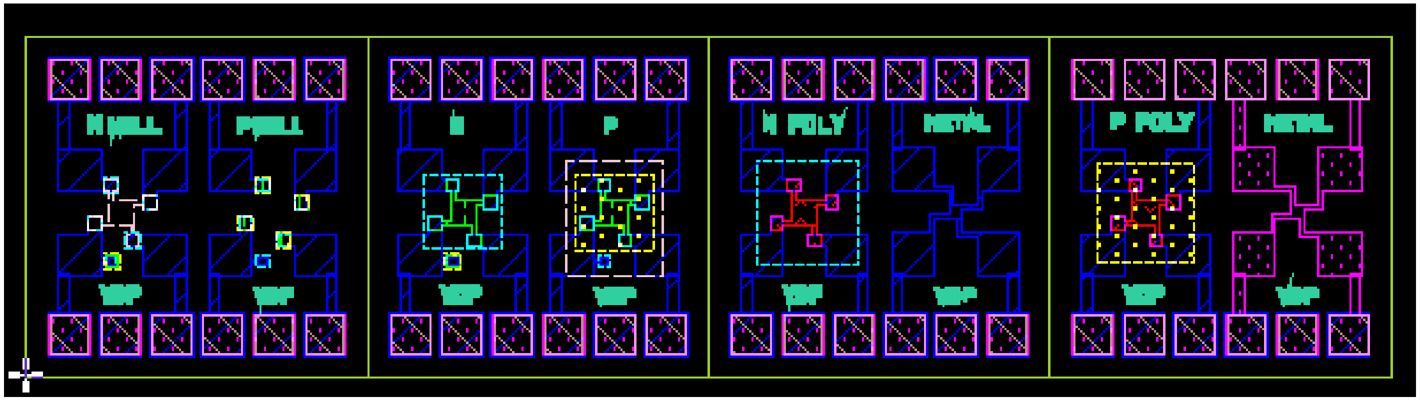
SPECIAL RCA CLEAN PRIOR TO METAL ONE



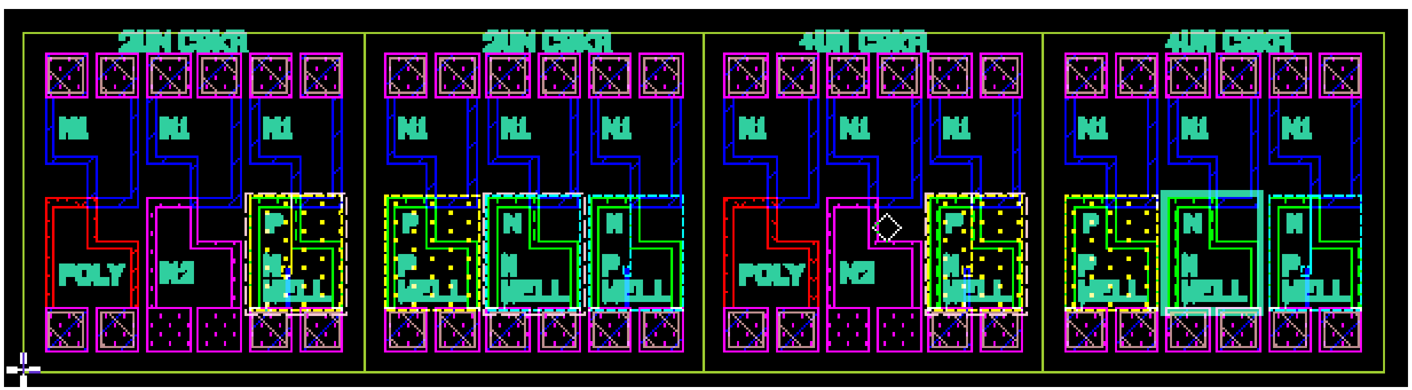
Rochester Institute of Technology
Microelectronic Engineering

Clean includes 50:1 HF Dip twice once after each bath to remove chemically grown oxide

VAN DER PAUWS AND CBKR's

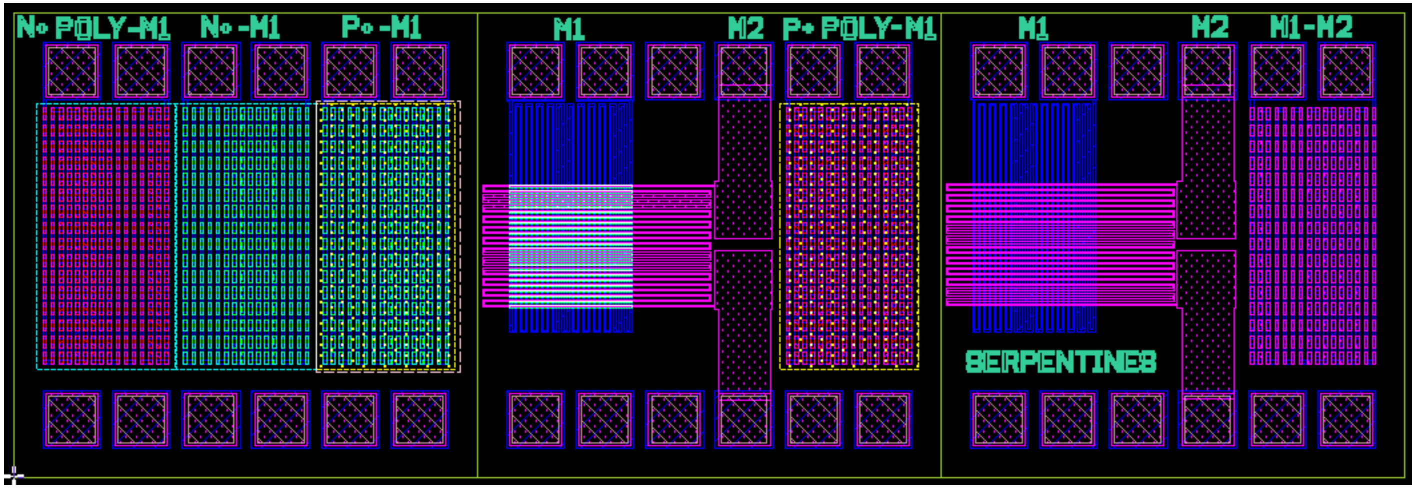


NWELL PWELL N+ P+ N-POLY M1 P-POLY M2

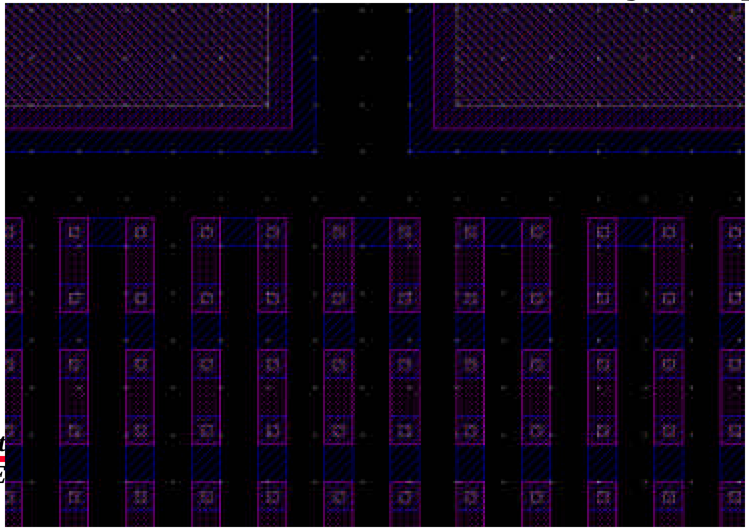


2µm M1toPoly	2µm M1toP+	4µm M1toPoly	4µm M1toP+
2µm M1toM2	2µm M1toN+	4µm M1toM2	4µm M1toN+
2µm M1toP+	2µm M1toN+	4µm M1toP+	4µm M1toN+

SERPENTINES, COMBS, AND VIA CHAINS



To evaluate metal1, metal2, CC and Via layer quality.



Via Chain has 512 Vias

DRYTEK QUAD ETCH RECIPE FOR CC AND VIA

Recipe Name:		FACCUT
Chamber		3
Power		200W
Pressure		100 mTorr
Gas 1	CHF_3	50 sccm
Gas 2	CF_4	10 sccm
Gas 3	Ar	100 sccm
Gas 4	O_2	0 sccm

(could be changed to N_2)

US Patent 5935877 - Etch process for forming contacts over titanium silicide

TEOS Etch Rate	494	Å/min
Annealed TEOS	450	Å/min
Photoresist Etch Rate:	117	Å/min
Thermal Oxide Etch Rate:	441	Å/min
Silicon Etch Rate	82	Å/min
$TiSi_2$ Etch Rate	1	Å/min

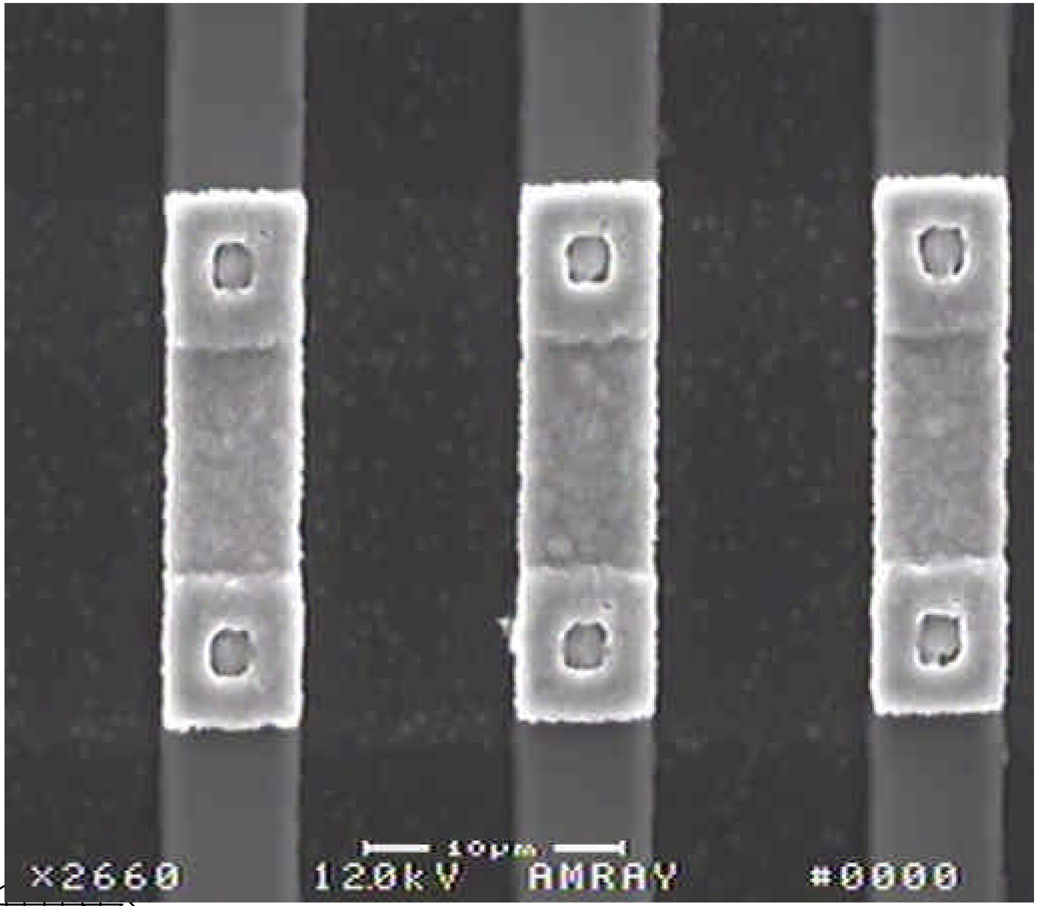

Drytek Quad

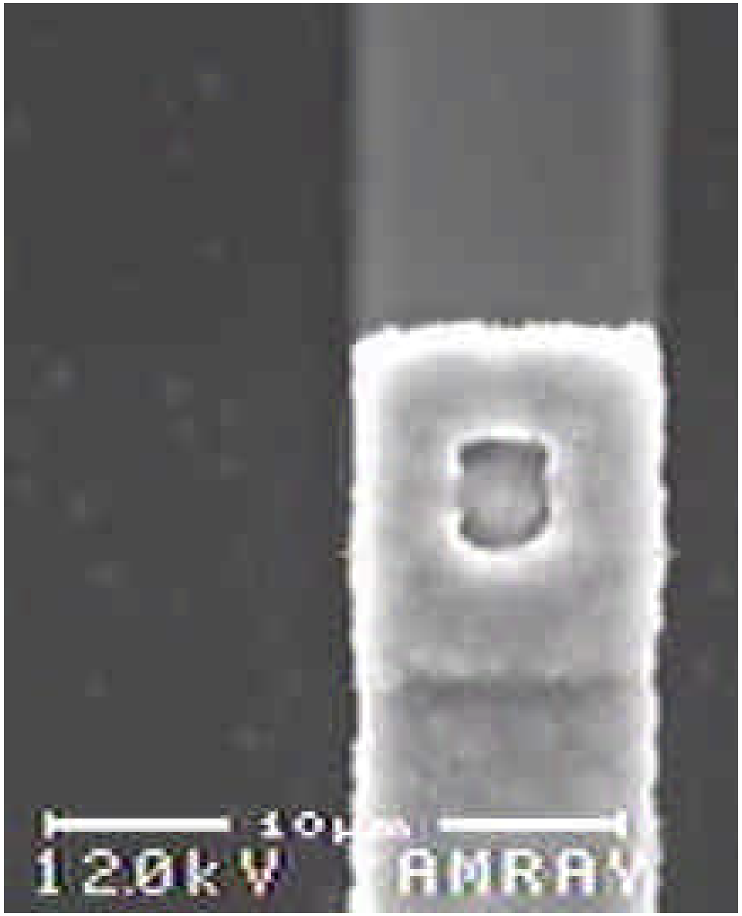
CONTACT CUT ETCH RECIPE

Theory: The CHF3 and CF4 provide the F radicals that do the etching of the silicon dioxide, SiO2. The high voltage RF power creates a plasma and the gasses in the chamber are broken into radicals and ions. The F radical combines with Si to make SiF4 which is volatile and is removed by pumping. The O2 in the oxide is released and also removed by pumping. The C and H can be removed as CO, CO2, H2 or other volatile combinations. The C and H can also form hydrocarbon polymers that can coat the chamber and wafer surfaces. The Ar can be ionized in the plasma and at low pressures can be accelerated toward the wafer surface without many collisions giving some vertical ion bombardment on the horizontal surfaces. If everything is correct (wafer temperature, pressure, amounts of polymer formed, energy of Ar bombardment, etc.) the SiO2 should be etched, polymer should be formed on the horizontal and vertical surfaces but the Ar bombardment on the horizontal surfaces should remove the polymer there. The O2 (O radicals) released also help remove polymer. Once the SiO2 is etched and the underlying Si is reached there is less O2 around and the removal of polymer on the horizontal surfaces is not adequate thus the removal rate of the Si is reduced. The etch rate of SiO2 should be 4 or 5 times the etch rate of the underlying Si. The chamber should be cleaned in an O2 plasma after each wafer is etched.

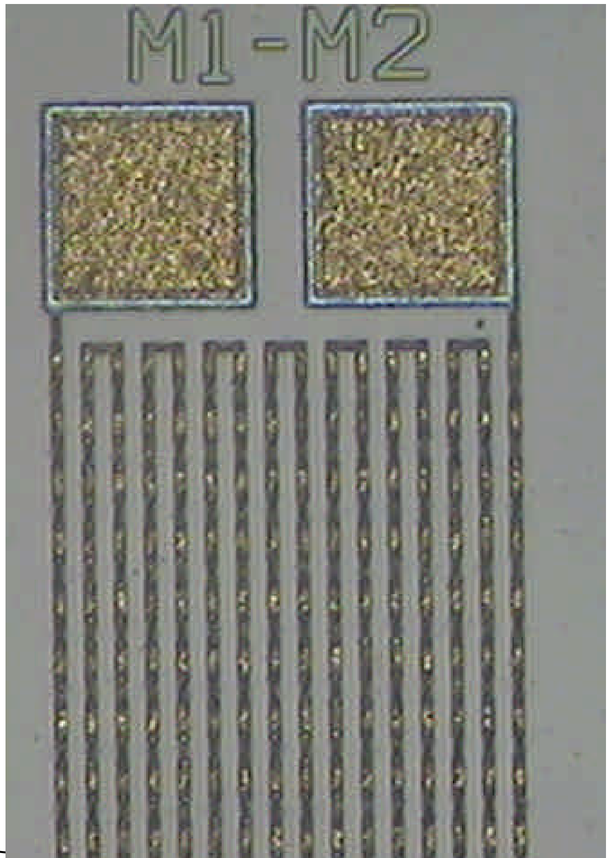
US Patent 5935877 - Etch process for forming contacts over Titanium Silicide

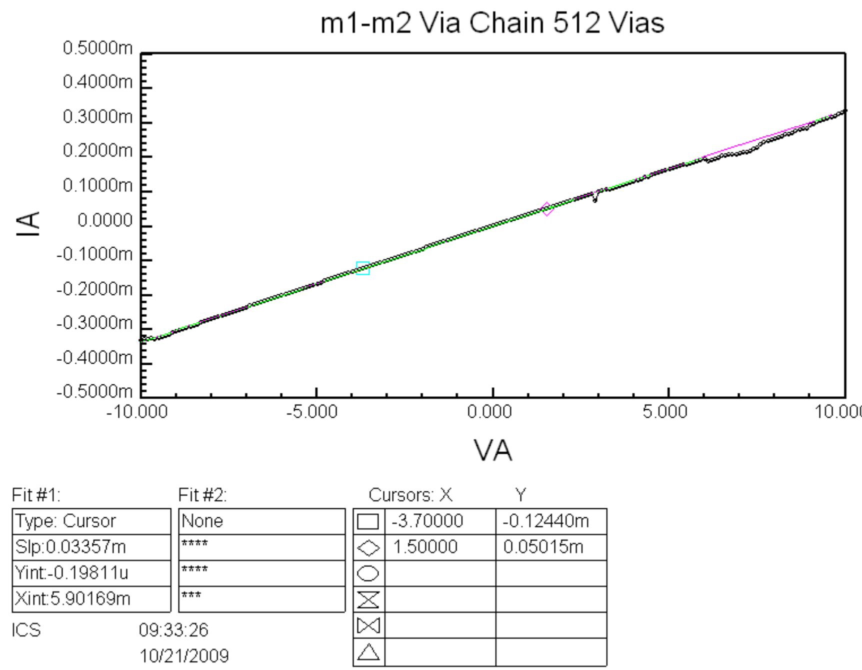
SEM OF 6µm LINES / 2X2µm VIAS





M1-M2 VIA CHAIN



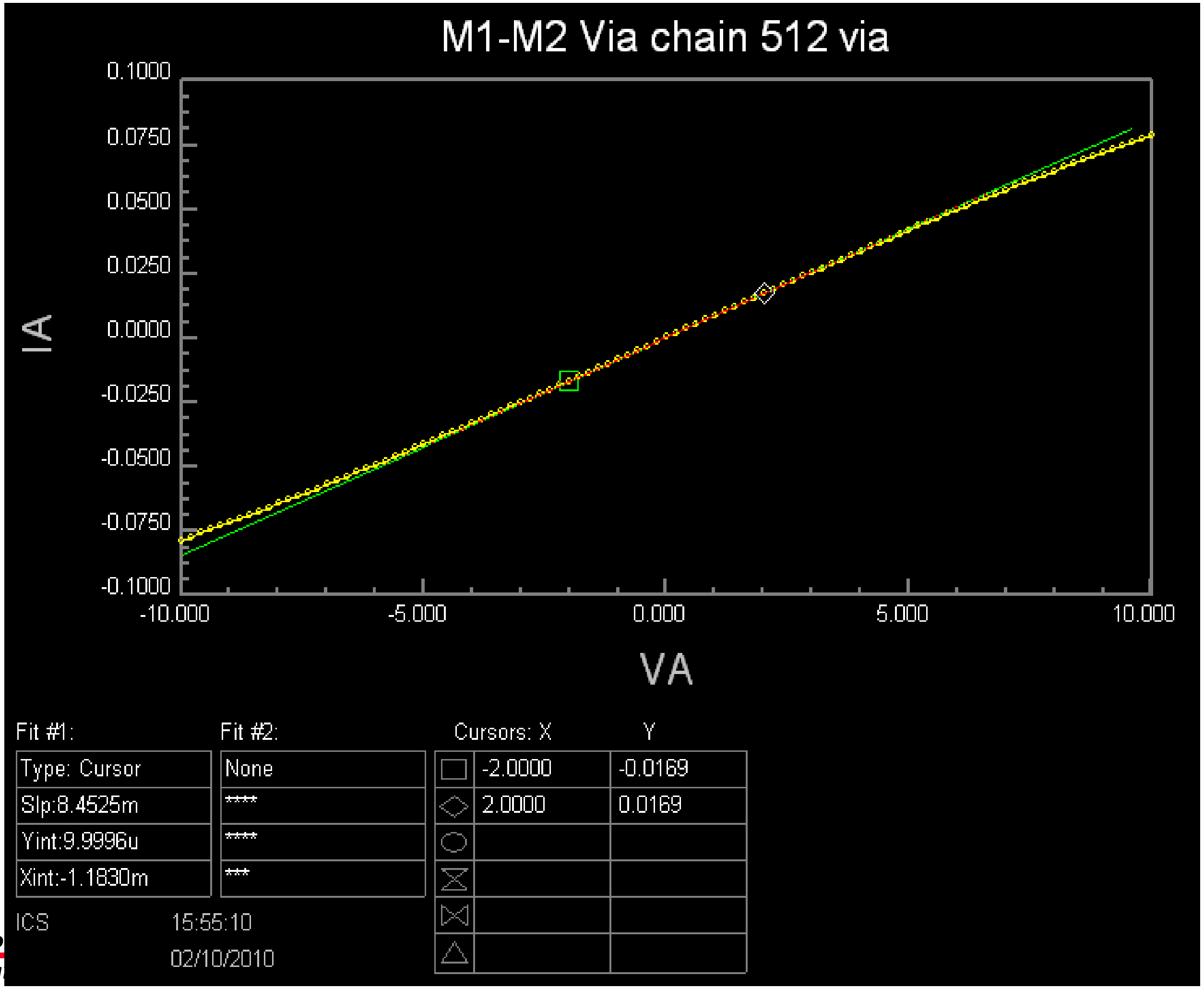


Before improved aluminum etch recipe R = 58 ohm per via

M1-M2 VIA CHAIN

F081201

M1-M2 Via chain with 512 Vias and total resistance of 118 ohms or 0.231 ohms per contact



SUMMARY

A two layer aluminum metal process has been developed and has been shown to work. New processes for CC and Via etch, Metal Deposition, Sputter Etch, Lithography, Metal Plasma Etch, Resist Removal and Cleans were developed.

ACKNOWLEDGEMENTS

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Michael Kassis
Justin Delmonte
Chris Shea
Germain Fenger
Mike Aquilino
John Nash

Thank You !!

REFERENCES

1. "Silicon Processing", Stanley Wolf
2. EMCR650/731/732 lecture notes on line at http://people.rit.edu/lffeee