ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING

Physical Vapor Deposition – Evaporation and Sputtering

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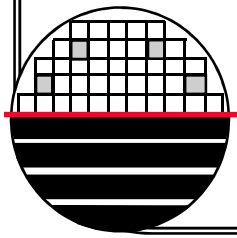
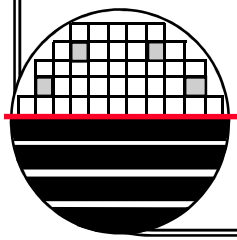


OUTLINE

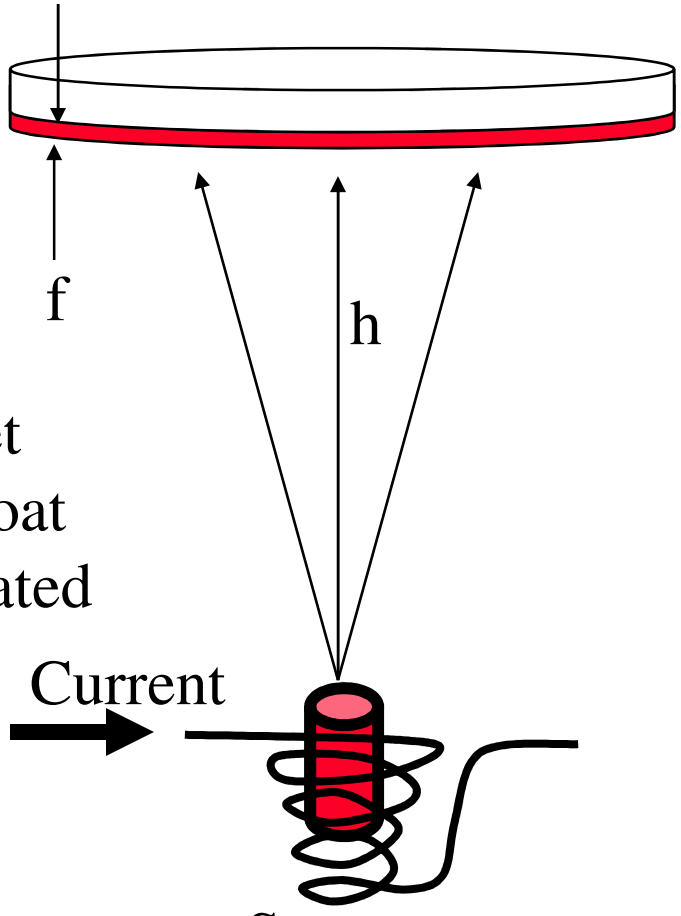
Evaporation
- Recipes and Data

Sputtering
- Recipes and Data

Reactive Sputtering
- Recipes and Data



EVAPORATION



Sources :
Resistance Heated
Wire Basket
Dimpled Boat
Electron Beam Heated

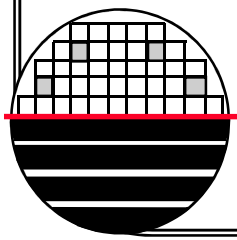
$$f = \frac{m}{4d\,\pi\,h^2}$$

f = film thickness
d = density
h = height
m = mass

EVAPORATION DATA

Material	Formula	Melt pt. °C	Temp °C @ Vapor Pressure 1E-8	1E-6	1E-4
Aluminum	Al	660	677	812	1010
Alumina	Al2O3	2045	1045	1210	1325
Antimony	Sb	630	279	345	425
Arsenic	As	814	107	152	210
Beryllium	Be	1278	710	878	1000
Boron	B	2100	1278	1548	1797
Cadmium	Cd	321	64	120	180
Cadmium Sulfide	CdS	1750			550
Chromium	Cr	1890	837	977	1177
Cobalt	Co	1495	850	990	1200
Gallium	Ga	30	619	742	907
Germanium	Ge	937	812	957	1167

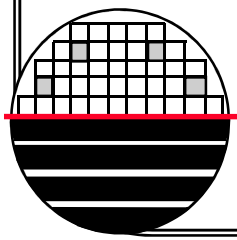
MRC Co., "Evaporation and Sputtering Data Book," Orangeburg, NY
http://www.epimbe.com/pages/vp



EVAPORATION DATA

Material	Formula	Melt pt. °C	Temp °C @ Vapor Pressure 1E-8	1E-6	1E-4
Gold	Au	1062	807	947	1132
Hafnium Oxide	HfO2	2812			2500
Nickel	Ni	1453	927	987	1262
Palladium	Pd	1550	842	992	1192
Platinum	Pt	1769	1292	1492	1747
Selenium	Se	217	89	125	170
Silicon	Si	1410	992	1147	1337
Silicon Dioxide	SiO2	1800			1025
Silicon Nitride	Si3N4				800
Silver	Ag	961	574	617	684
Tantalum	Ta	2966	1960	2240	2590
Titanium	Ti	1668	1067	1235	1453
Tungsten	W	3410	2117	2407	2757
Zirconium	Zr	1852	1477	1702	1987

MRC Co., "Evaporation and Sputtering Data Book," Orangeburg, NY
http://www.epimbe.com/pages/vp



EVAPORATION TECHNIQUES

Aluminum - evaporate copper with tungsten wire basket. One pellet at 20 cm gives about 3000 Å.

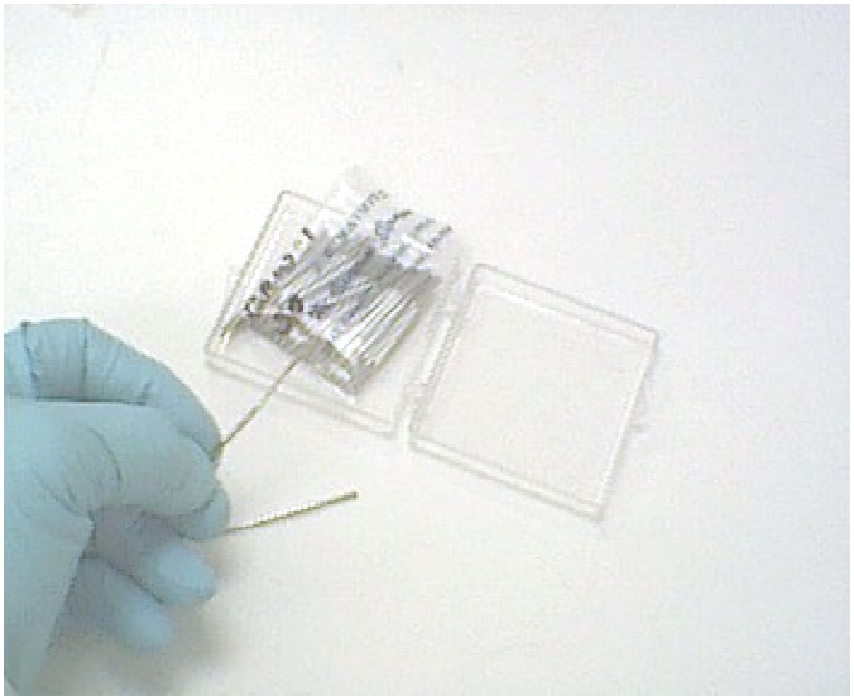
Copper - evaporate copper with tungsten wire basket. The basket needs to be crushed a little so the openings are small and the copper does not fall out of the basket once it is melted. One pellet at 20 cm gives about 3000 A. Dimpled Tungsten boats work great.

Chromium – use special Chromium coated tungsten wire filaments. Current through the filament heats the Cr which sublimes.

Gold - gold or gold/germanium can easily be evaporated from a basket with tightly spaced loops. The basket needs to be crushed a little so the openings are small and the gold does not fall out of the basket once it is melted. Dimpled Tantalum boats work great. Moly boats are good because gold does not wet the Moly thus less gold is lost.

CHROME

Deposit chrome by evaporation (actually sublimation) from special chrome coated tungsten rods. Using the CVC evaporator. Heat rods to red hot by setting filament voltage to 190 on the dial. Then open the shutter for the desired time calculated from rate of 35 Å/sec. (at a distance of 40 cm from source to substrate)



R.D.Mathis
P.O. Box 92916
Long Beach, CA 90809-2916
www.rdmathis.com

Part No. ??
Cost $250/50 qty

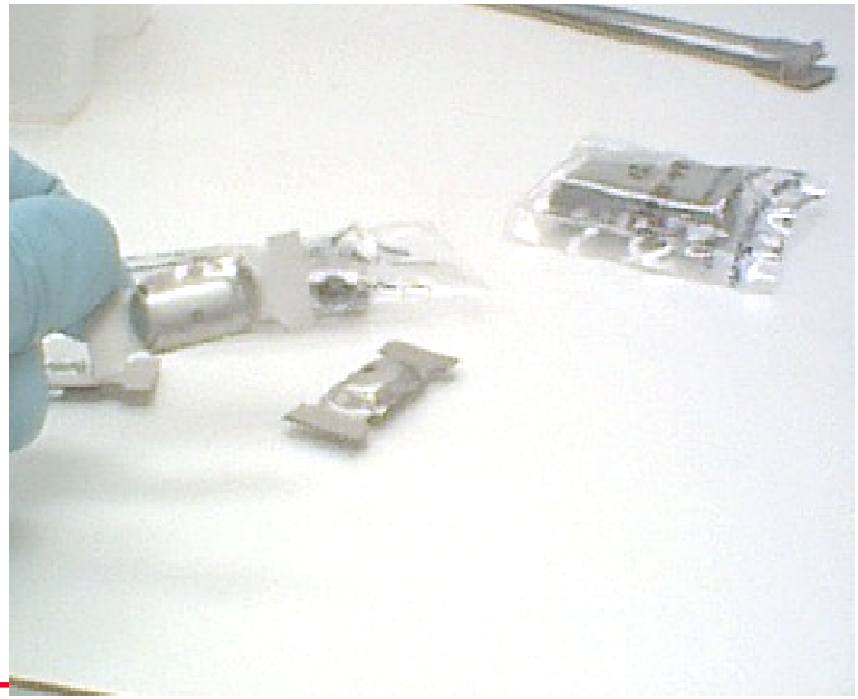
DEPOSITION OF SILICON MONOXIDE (SiO)

Evaporate SiO with Ta boat and cover with hole. The material sublimes and a film will be deposited. It looks like glass and can be measured on the ellipsometer. The ellipsometer gave an index of refraction of 1.88

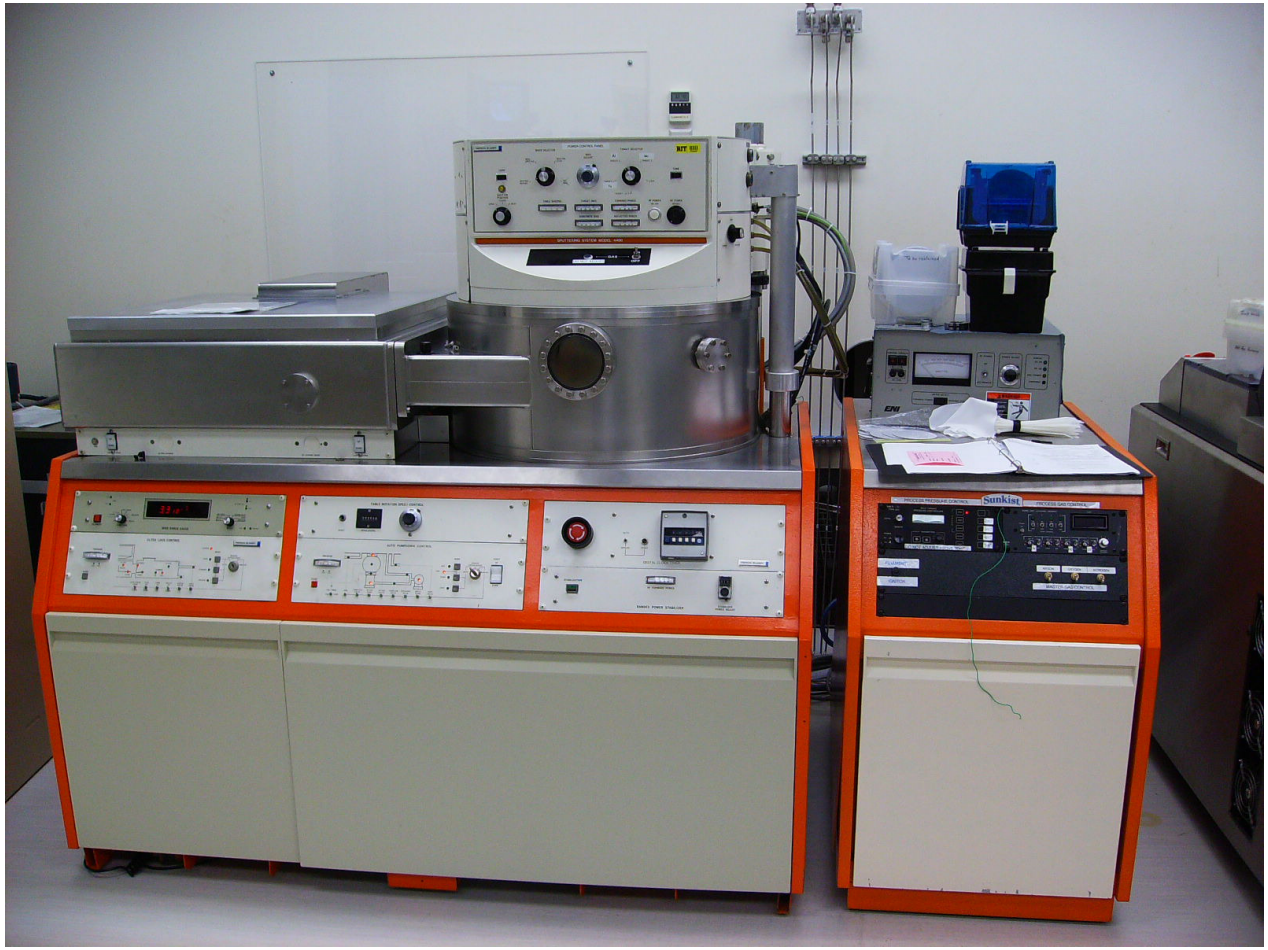
Using the CVC evaporator X mg at 40 cm gives about 300 Å. Set to 250 on the dial.

R.D.Mathis
P.O. Box 92916
Long Beach, CA 90809-2916
www.rdmathis.com

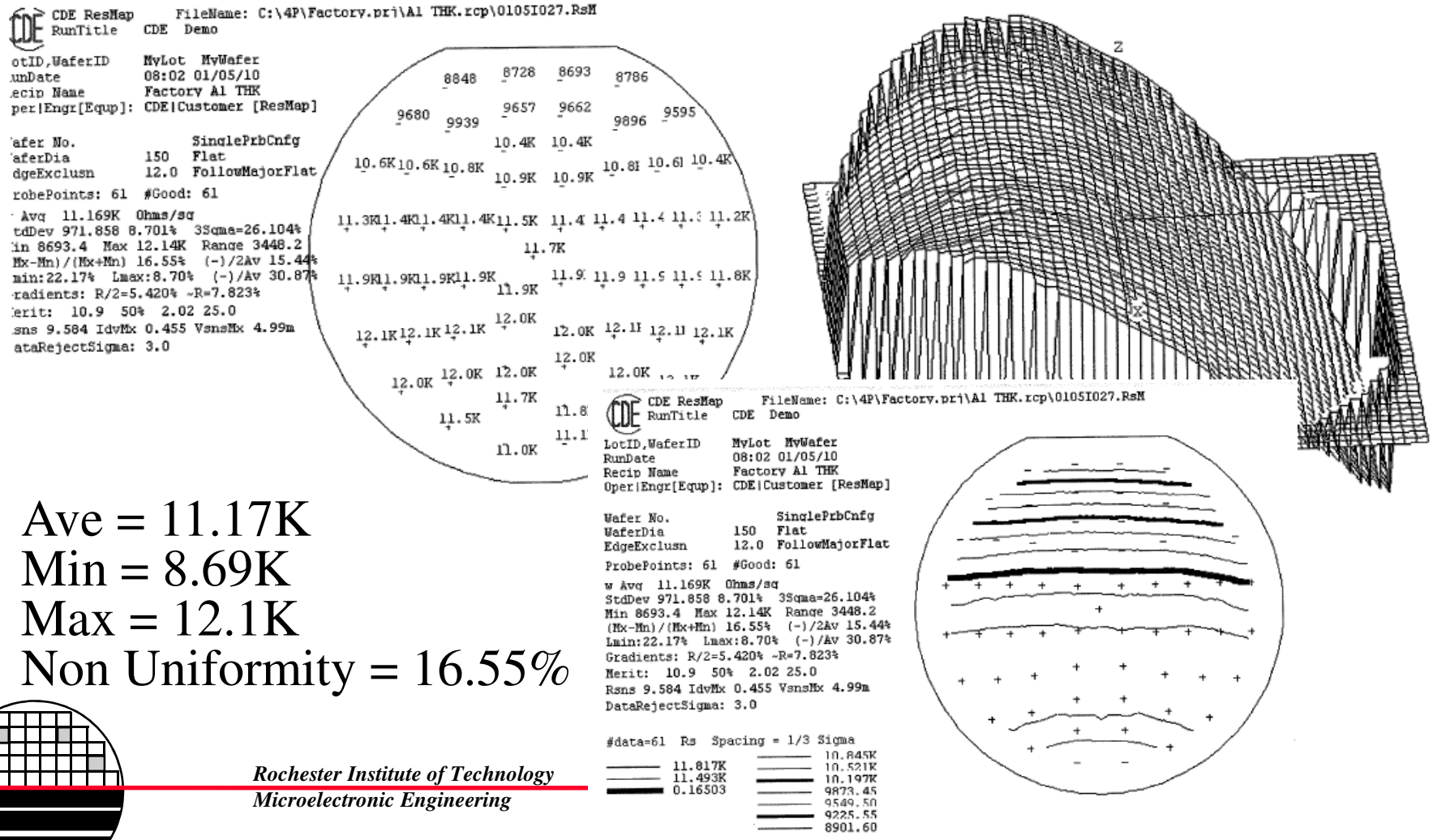
Part No.
Cost



PE4400 SPUTTER / SPUTTER ETCH TOOL



PE4400 – AL THICKNESS NON UNIFORMITY



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

PE4400 SPUTTER ETCH RATE

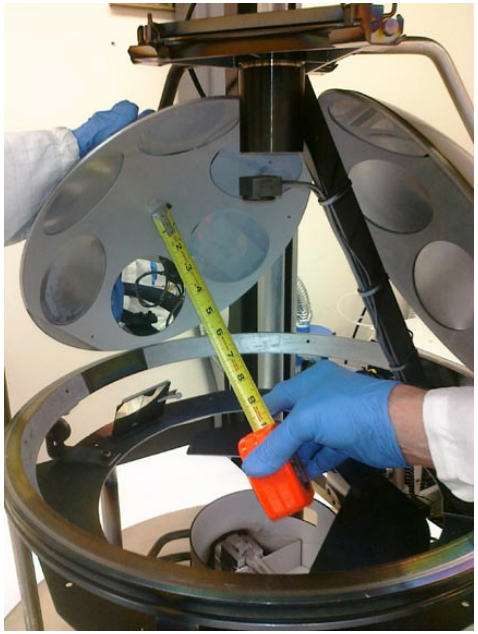
	A	B	C	D	E	F	G	H	I	J
1										
2		Original	Post Etch			Original	Post Etch		Original	Post Etch
3	1	1992	1506		Average	2241.279	1685.459		2242.28	1685.8
4	2	2046	1543		Std. Dev	115.8784	86.18035		116.699	86.524
5	3	2059	1545		Min	1981	1500		1981.3	1500
6	4	2030	1518		Max	2414	1815		2417.3	1815
7	5	1981	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

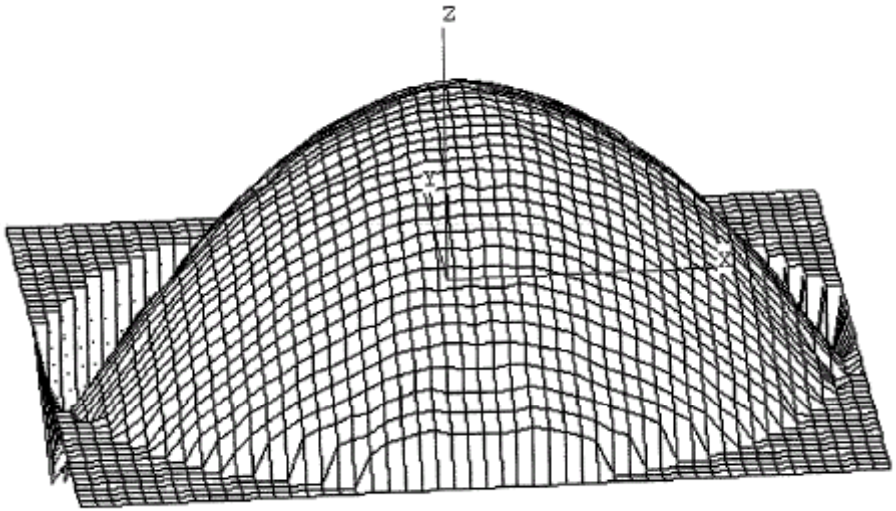
The sputter etch rate was calculated from measured aluminum thickness before and after sputter etch. Measurements were made using 4point probe thickness technique on the CDE resistivity mapper. The sputter etch rate of aluminum was 18 Å per minute.

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

CHA FLASH EVAPORATOR



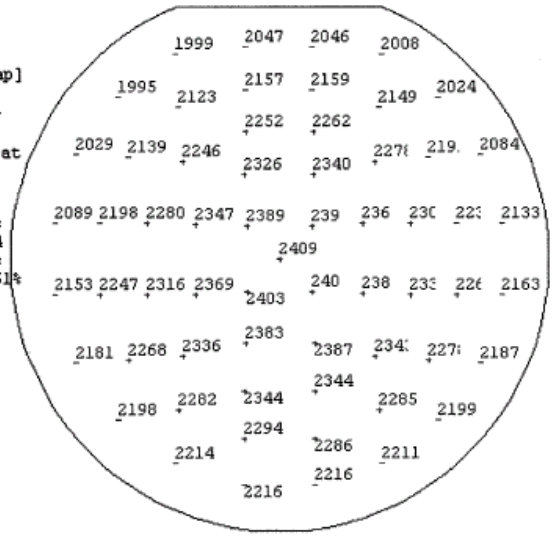
FLASH EVAPORATOR THICKNESS UNIFORMITY



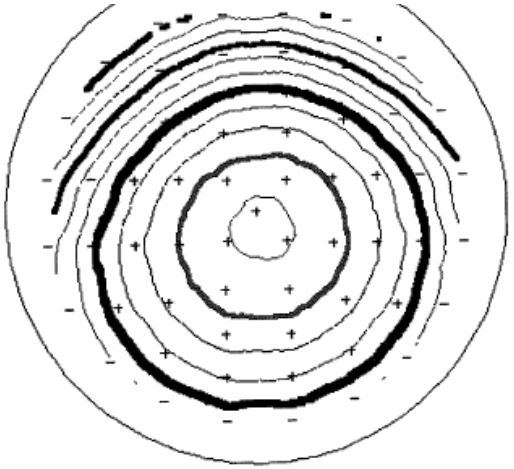
CDE ResMap FileName: C:\4P\Factory.pr1\Al THK.rcp\9C27K048.RsM
RunTitle CDE Demo

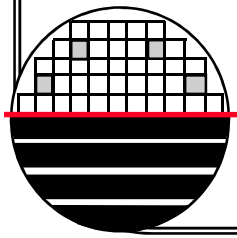
LotID,WaferID MyLot MyWafer
RunDate 10:05 12/27/09
Recip Name Factory Al THK
Oper|Engr[Equp]: CDE|Customer [ResMap]

Wafer No. SinglePrbCnfg
WaferDia 150 Flat
EdgeExclusn 12.0 FollowMajorFlat
ProbePoints: 61 #Good: 61
Avg 2237.62 Ohms/sq
StdDev 115.504 5.162% 3Sgma=15.486%
Min 1995.0 Max 2409.2 Range 414.14
(Mx-Mn)/(Mx+Mn) 9.40% (-)/2Av 9.25%
Lmin:10.84% Lmax:7.67% (-)/Av 18.51%
Gradients: R/2=5.736% -R=12.089%
Merit: 59.5 22% 29.5 77.9
Rsns 9.584 IdvMx 0.714 VsnsMx 37.7m
DataRejectSigma: 3.0



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

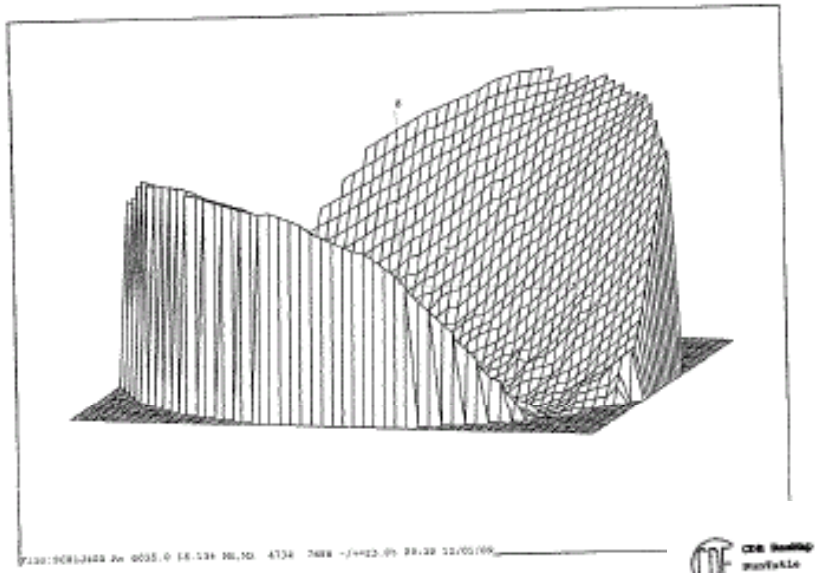


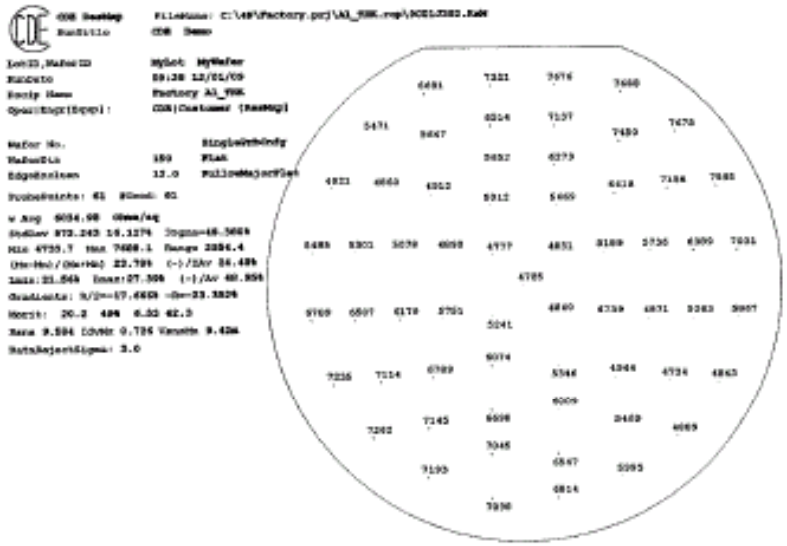


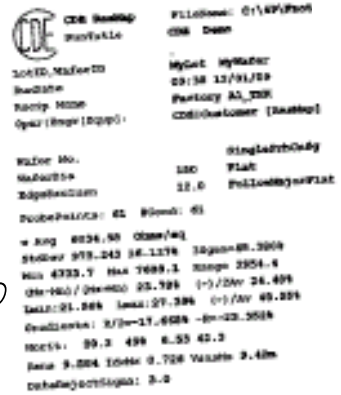
CVC601

Thickness 7500Å
Dep Rate ~300 A/min
Pressure 5 mT
Ar Flow 28 sccm
Time ~ 25 min

CVC601 THICKNESS UNIFORMITY







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

MEASUREMENT OF METAL THICKNESS USING FOUR POINT PROBE

The existing four point probe with a more sensitive voltmeter (20 mV full scale) can be used to measure the sheet resistance of a metal film. The film thickness (t) equals the bulk resistivity divided by the sheet resistance (Rhos). The bulk resistivity from tables of materials properties can be used as a starting value but thin films often have resistivities a high as two times the value of the published bulk resistivity.

Example: A sputtered Aluminum film was measured with the four point probe. The current and voltage were found to be I=102.2 mA, V=1.296 mV. Using the published bulk resistivity of 2.65E-6 ohm-cm find t.

Rhos = 4.532 V/I = 0.0572 ohms/sq

t = Rho/Rhos = 2.65E-6 ohm-cm / 0.0572 ohm = 4633 Å

The Alpha step measured thickness was 7800 Å so the corrected value of resistivity that should be used for sputtered aluminum/1%Si films is Rho=4.46E-6 ohm-cm, Another data point gave Rho of 6.3E-6 and a third gave Rho of 5.01E-6

t = Rho/Rhos = 5E-6 ohm-cm / 0.0572 ohm = 8741 Å

Rho for Cu films=3.1E-6

4 PT PROBE WAFER THICKNESS MEASUREMENTS

CDE Resistivity Mapper

CDE ResMap FileName: C:\4P\CDE_Demo.prj\6in49pt.rcp\3220K051.RsM
RunTitle CDE ResMap Demo Recipes

LotID,WaferID F021111D1 MyWafer
RunDate 10:05 02/20/03
Recip Name CDE_Demo 6in49pt
Oper|Engr[Equp]: CDE|Customer [ResMap]

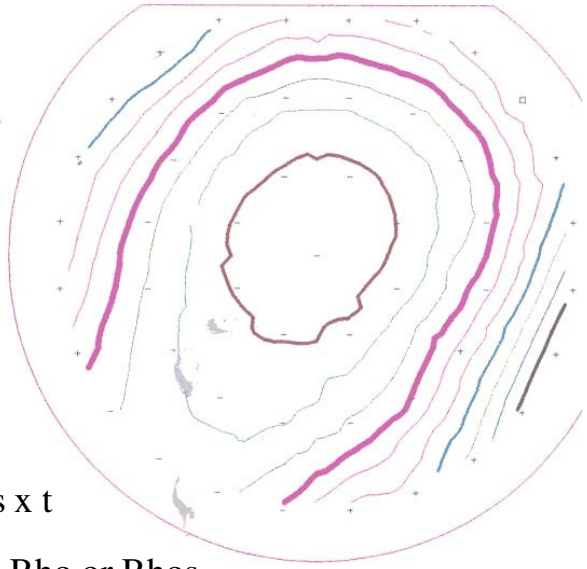
Wafer No. DualPrbCnfg
WaferDia 100 Flat
EdgeExclusn 8.0 FollowMajorFlat

ProbePoints: 49 #Good: 48

Rs Avg 105.301 Ohms/sq
StdDev 10.5959 10.063% 3Sgma=30.188%
Min 90.039 Max 130.19 Range 40.156
(Mx-Mn)/(Mx+Mn) 18.23% (-)/2Av 19.07%
Imin:14.49% Imax:23.64% (-)/Av 38.13%
Gradients: R/2=7.652% ~R=22.245%
Merit: 61.6 21% 42.6 89.6
Rsns 10.0K IdvMx 0.74m VsnsMx 14.3m
DataRejectSigma: 3.0

#data=49 Rs Spacing = 1/3 Sigma

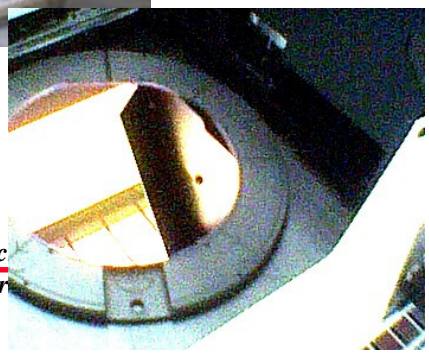
126.493
122.961
119.429
115.897
112.365
108.833
105.301
101.769
98.2367
94.7048



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

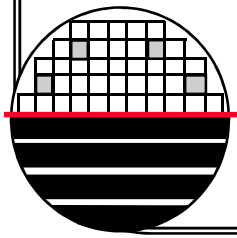
$$\text{Thickness} = \frac{\text{Known Bulk Resistivity}}{\text{Measured Sheet Resistance}}$$

Bulk Resistivity is assumed to be known

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

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

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



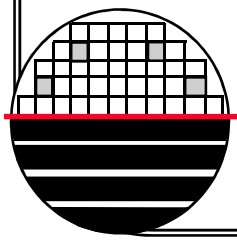
MODELING OF BULK RESISTIVITY

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

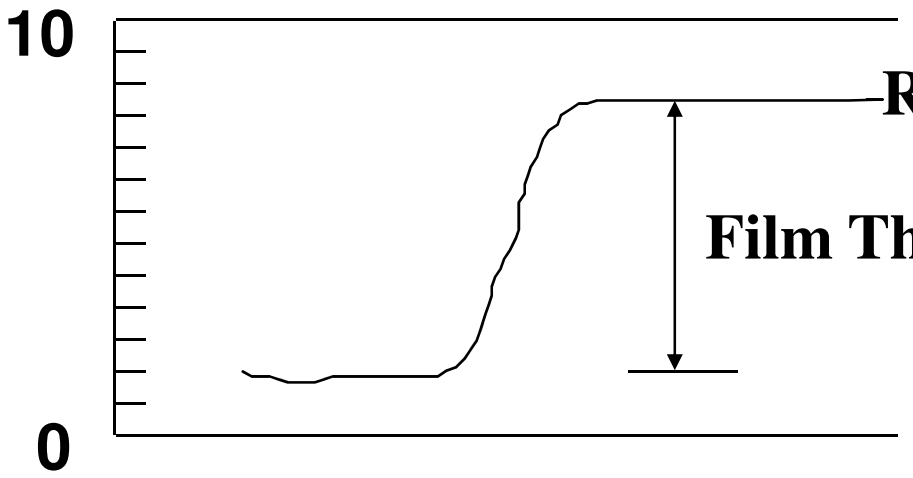
Where the pre exponential value may be different for different film deposition techniques (i.e. evaporation, RF sputtering, DC sputtering, etc.)

	x	y	Rho ohm-Å
CDE Manual	**337.17**	**-0.92401**	**133.8**
PE4400 (300watts)	**412**	**-0.92401**	**163.5**
CVC601	**540**	**-0.92401**	**214.3**
Flash Evaporator	**490**	**-0.92401**	**194.5**

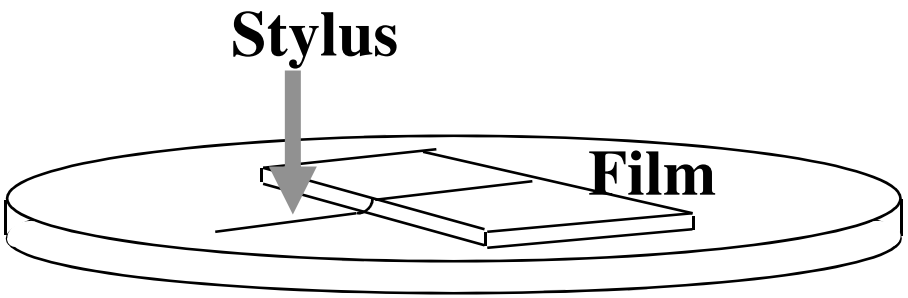
Note: bulk Aluminum Rho = 270 ohm-Å



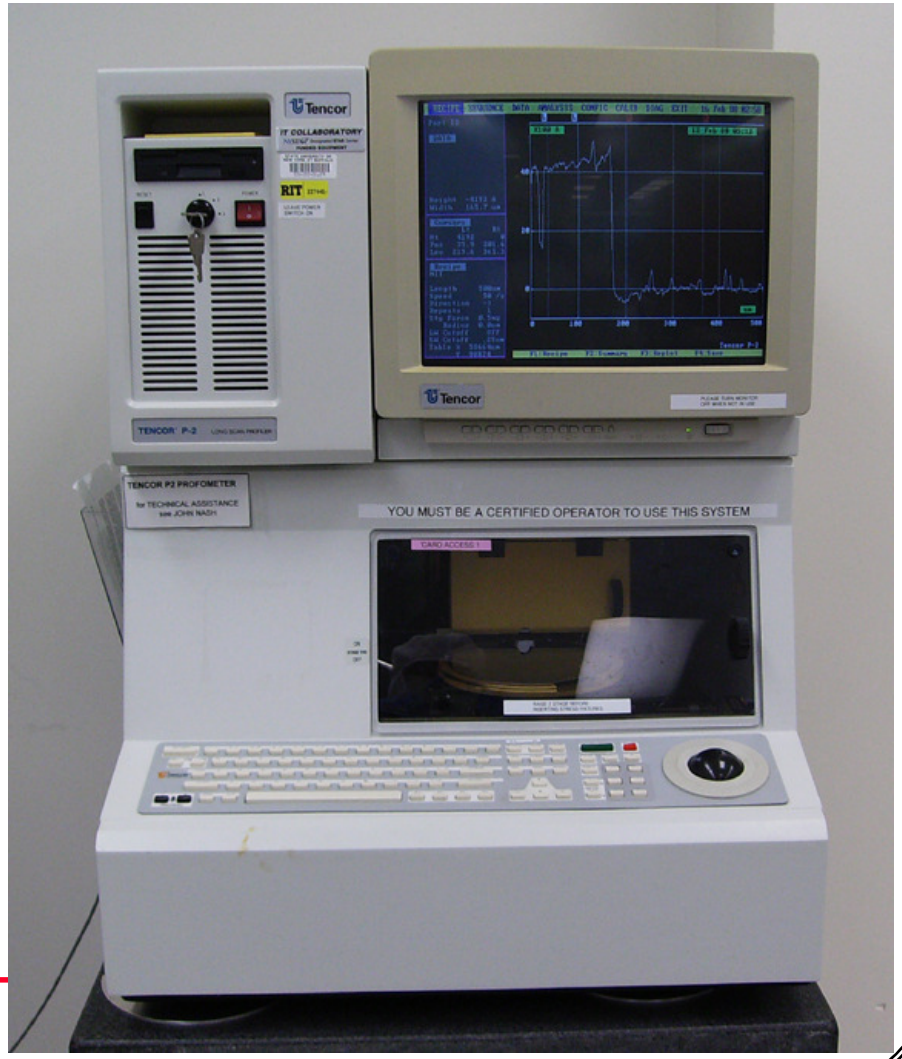
SURFACE PROFILOMETER



1,000 Å < Max < 1,000,000 Å



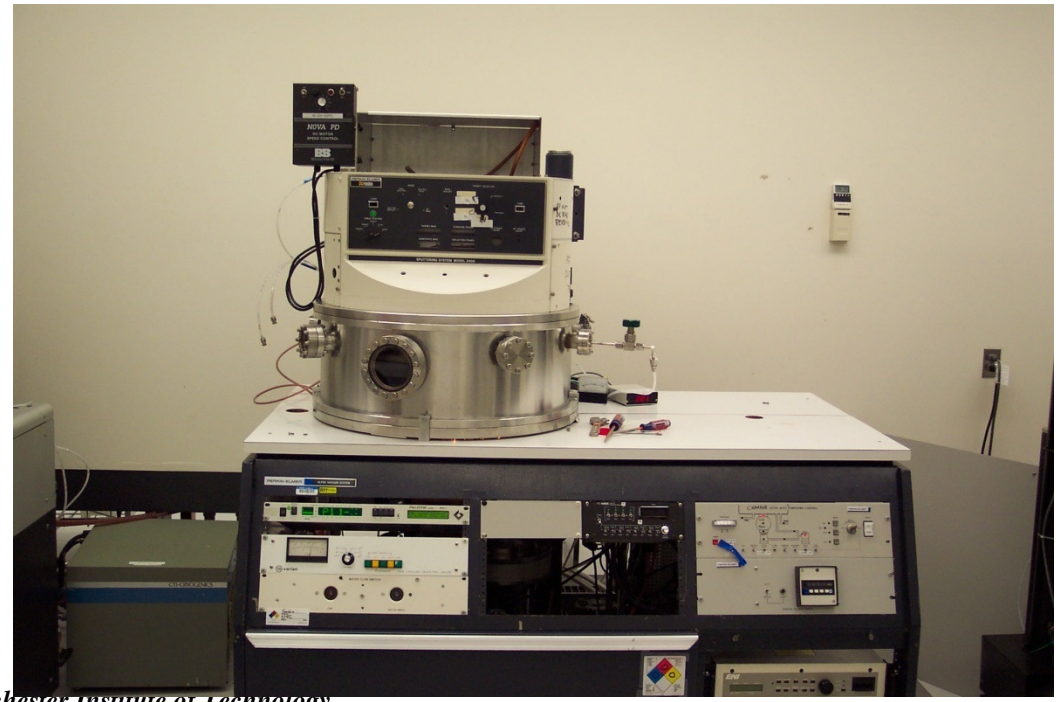
VERIFICATION USING THE TENCORE P2



Ti DEPOSITION USING P&E 2400B

OBJECTIVE

To develop a Ti Deposition process using Perkin Elmer 2400B sputtering tool (a factory backup process for CVC 601 tool)



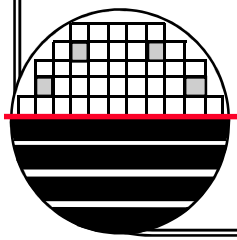
Rochester Institute of Technology
Microelectronic Engineering

Shrinivas J Pandharpure

Ti DEPOSITION USING P&E 2400B

RESULTS

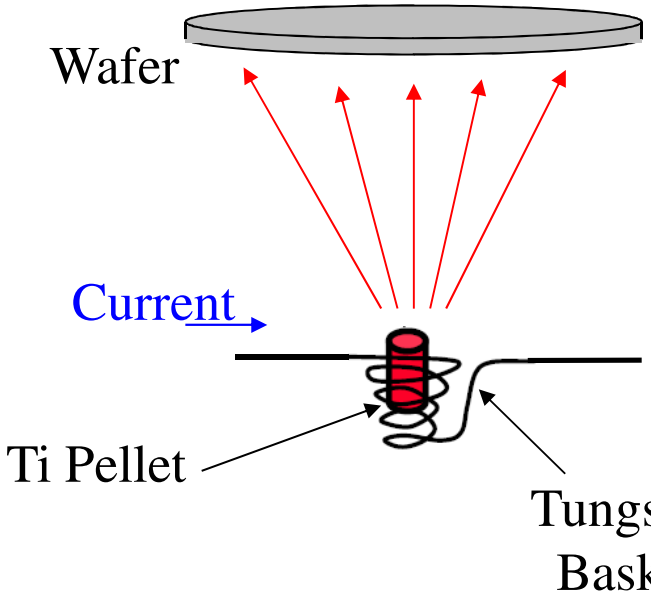
- **Sputtering Power: 500 W for 158 Å/min**
- **Base Pressure: < 5 x 10^{-6} Torr**
- **Sputtering Pressure: 8 mTorr (Argon flow:15 sccm)**
- **Deposition Time: 380 Seconds to get 1000Å Thickness**
- **Thickness standard deviation 4% (30 Å)**
- **Pre-Sputtering: 5 minutes same power**



Ti DEPOSITION USING CVC EVAPORATOR

OBJECTIVE

To develop a Ti Deposition process using CVC Evaporator
(a factory backup process for CVC 601 tool)



$$f = \frac{m}{4d\,\pi\,h^2}$$

f = film thickness
d = density
h = height
m = mass

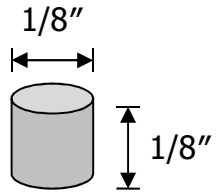

CVC 601

Jirachai Getpreecharsawas

PHYSICAL PROPERTIES OF TI AND W

- **Titanium (Ti) : Melting point, T_{melt} = 1675 °C**

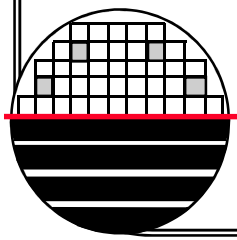
Vapor Pressure (Torr)	T_{vapor} (°C)
10^{-4}	1453
10^{-6}	1235
10^{-8}	1067



99.995% pure
0.108 gram/pellet

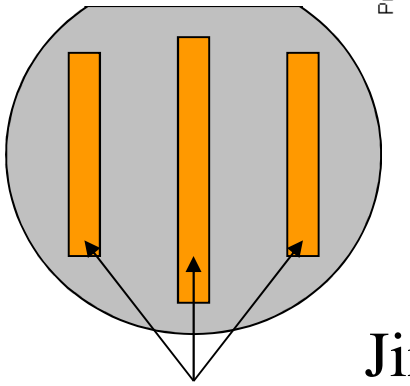
Note: Ti sublimes since **Tvapor < Tmelt**

- **Tungsten (W): Melting point , T_{melt} = 3410 °C**

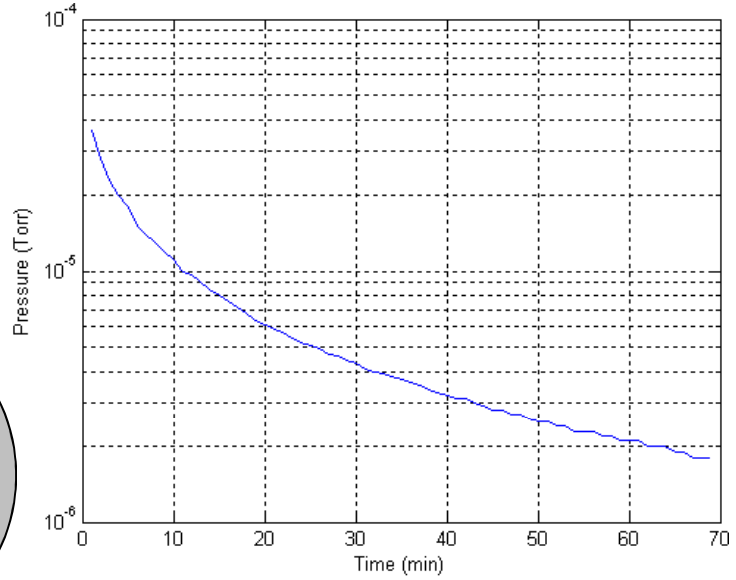


Ti DEPOSITION USING CVC EVAPORATOR

Load wafer, 1 or 2 pellets of Ti in a tungsten bo
Pump ~60 min to reach base pressure <2E-6T
Start deposition with shutter closed
(open after filament is hot)
Evaporate at Variac setting of ~245
Wait 5 min.
Turn down Variac to zero
Shut off filament power.
Remove wafer
Measure thickness on
Tencore alpha step 200



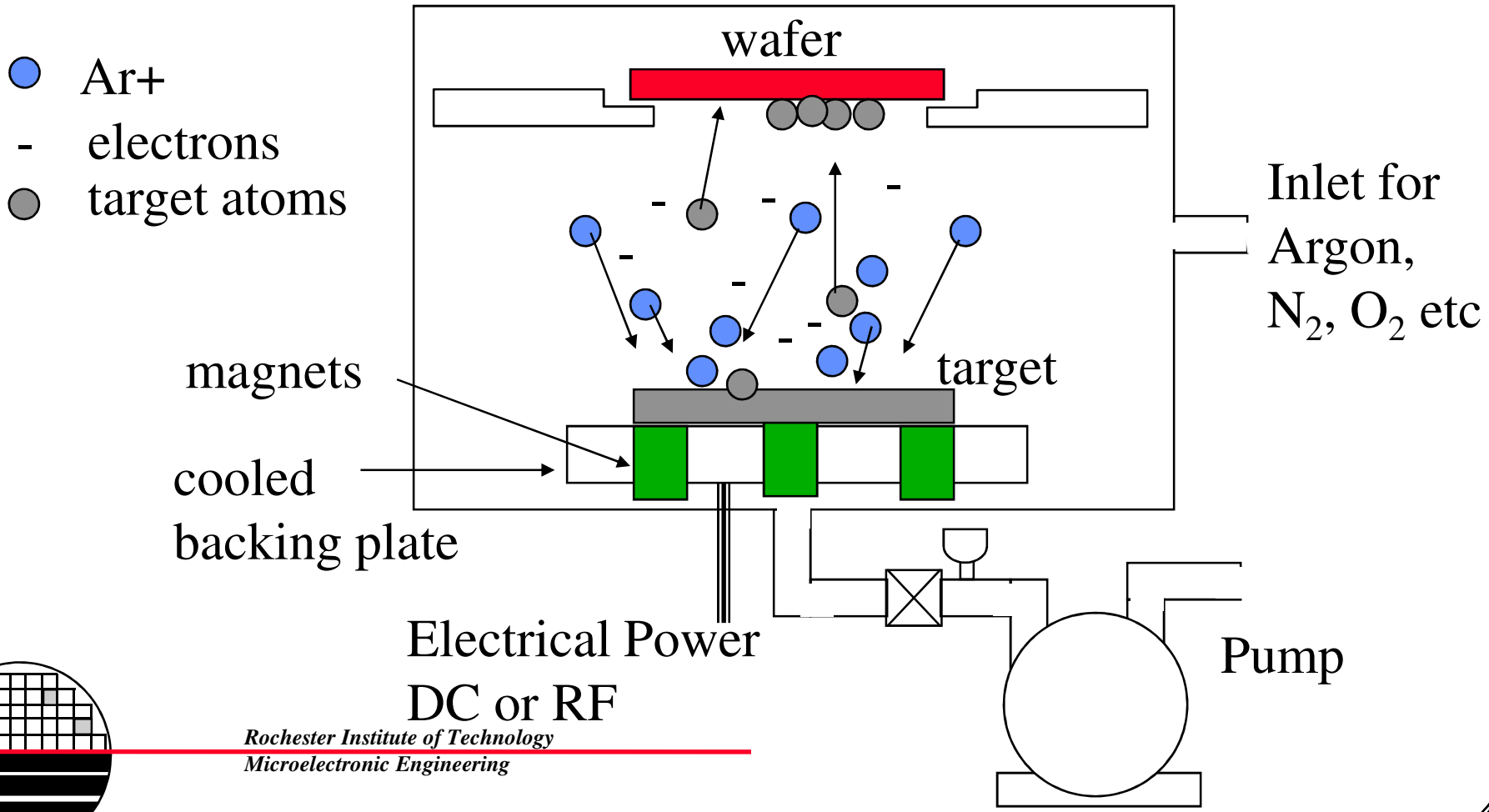
Kapton Tape



Jirachai Getpreecharsawas

Pressure (Torr)	1 Pellet of Ti		2 Pellets of Ti	
	Mean (Å)	STD	Mean (Å)	STD
3.4×10^{-6}	321.67	176.16	469.44	138.48
1.6×10^{-6}	340.00	84.84	1366.67	163.58

SPUTTERING


Ar+
- electrons
target atoms
wafer
Inlet for Argon, N_2, O_2 etc
magnets
target
cooled backing plate
Electrical Power DC or RF
Pump

CVC 601 SPUTTER TOOL

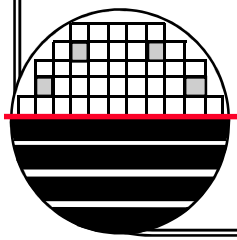
CVC 601 Sputter Tool
Loading 6 inch wafers

Thickness 10,000Å
Dep Rate ~300 A/min
Pressure 5 mT
Ar Flow 28 sccm
Time ~ 33 min

SPUTTERING

DC Sputtering - Sputtering can be achieved by applying large (~2000) DC voltages to the target (cathode). A plasma discharge will be established and the Ar+ ions will be attracted to and impact the target sputtering off target atoms. In DC sputtering the target must be electrically conductive otherwise the target surface will charge up with the collection of Ar+ ions and repel other argon ions, halting the process.

RF Sputtering - Radio Frequency (RF) sputtering will allow the sputtering of targets that are electrical insulators (SiO2, etc). The target attracts Argon ions during one half of the cycle and electrons during the other half cycle. The electrons are more mobile and build up a negative charge called self bias that aids in attracting the Argon ions which does the sputtering.

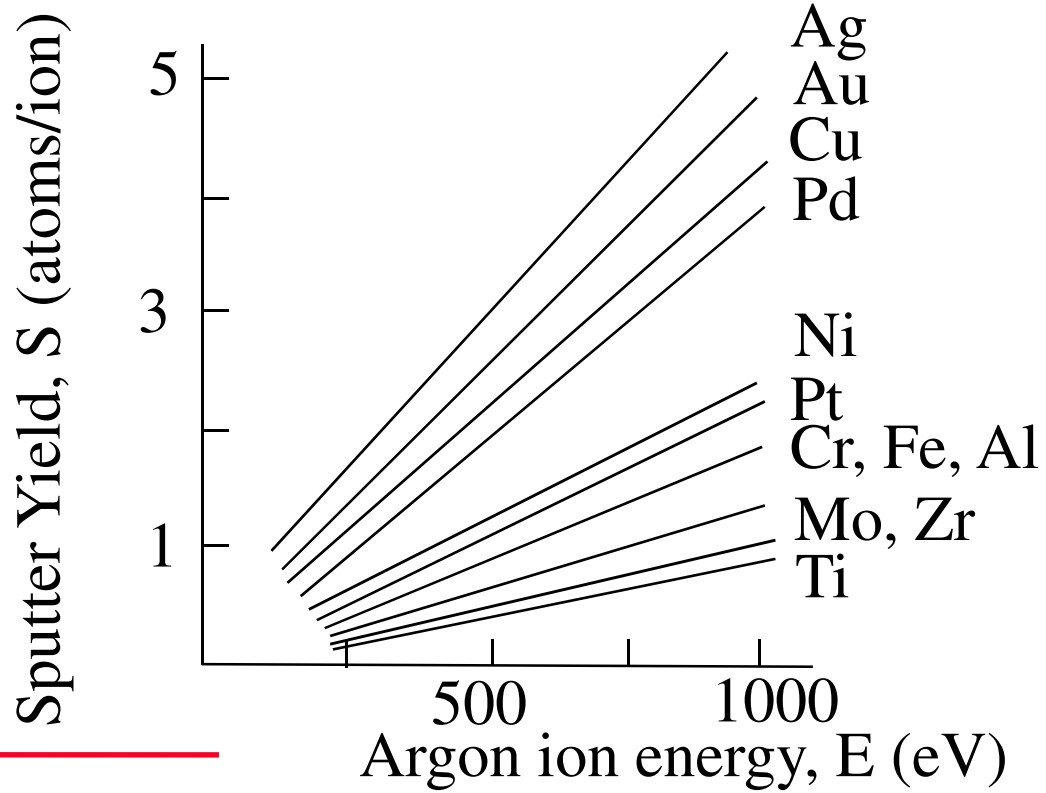


SPUTTERING

Magnetron Sputtering - Magnets buried in the baseplate under the target material cause the argon ions and electrons to concentrate in certain regions near the surface of the target. This increases the sputtering rate.

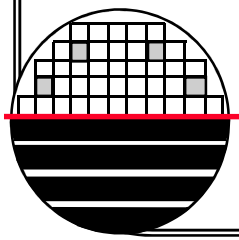
Deposition Rate ~ JSE

J is current density
S is sputter yield
E is ion energy



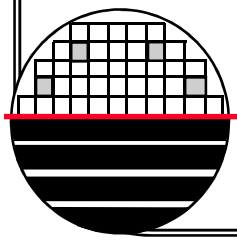
SPUTTERING PLATINUM

Platinum is easy to sputter in a DC Argon plasma. Platinum is an expensive metal. We purchased a Platinum foil of 50mm by 50mm by 100 um for $1,100. The foil was mounted in our Denton sputter coater which we normally used to gold coat samples for our Scanning Electron Microscope. Sputtering Pt is straight forward using the normal settings used for Gold. The Denton sputter coater provided a sputter rate of 100 to 200 Å/min. The coating is very non uniform and varies from center to edge of the wafer. The coating at the center of the wafer was twice as thick as at the edge of the wafer. The coating thickness is the main parameter that determines the sheet resistance. This problem can be solved with different equipment including, larger foil target, substrate rotation, etc.



SPUTTER GOLD

Deposit gold 500 Å, Denton Sputter Tool, 40 mA, 50 mTorr, 2 min.



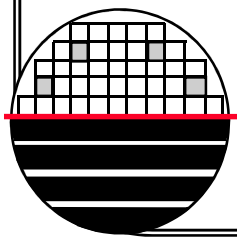
AVAILABLE SPUTTER TARGETS

8" Bonded for CVC-601
Aluminum 100%
Aluminum Oxide
Aluminum/1% Silicon
Chrome
Chrome Oxide
Copper
Molybdenum
Tantalum
Titanium
Titanium10%/Tungsten 90%
Silicon Dioxide
Silicon
Indium Tin Oxide

8"Unbonded for CVC-601
Molybdenum/Titanium
Titanium/Al 1%/Silicon 2%

4" Unbonded for CVC 601
Chrome
Indium 90%/Tin 10%
Nickel
Titanium
Tantalum
Tin
Nickel-Chromium 80%/20%
108E-6 ohm cm, TCR 110 E-6/°C
$450- 4"x1/4" Mel Hollander, Research and PVD Materials Corp. (973) 575-4245

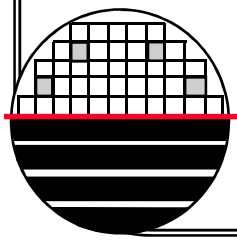
2" Unbonded for Denton
Gold
Palladium



AVAILABLE SPUTTER TARGETS

PE 2400/4400 Targets

Au	Ta2O5
Zr	Cr
SiO2 Qty2	Ta
Si Qty2	Mg
TiO2	NiFe
Nb2O5	CrSiO
In2O5 Qty2	Nb
Permalloy	SnO2
Fe	Al2O3
AlNi	MgF2
NiFeMg	MgO
Ni	Target Insulators 3
Co	Backing Plates6



RIT CVC601 SPUTTERING DATA

Material	Head	Power (watts)	Rate
Aluminum	8”	2000	240 Å/min.
Nickel	4”	500	170
Chromium	8”	1350	350
InSn + O2	4”	100	80
Copper	8”	325	110
Gold*	2”	40 mA,50mTorr	250
Tantalum	4”	500	190
Titanium	8”	1350	220
Titanium	4”	500	100
Tungsten	4”	500	100
Tungsten	8”	1000	115
Palladium#	2”	10mA, 90 mTorr	100

This data is for the CVC 601 Sputter System at 5 mTorr Argon Pressure, Base Pressure Prior to Sputter <1E-5
*Denton Sputter Machine, # Technics Hummer VI

CVC 601 SPUTTERING RECIPES

CVC601 Alpha Phase Tantalum -Place Kapton Dot on wafer surface for thickness measurement

Tantalum 4" target, Alpha Phase Tantalum 30 uOhm-cm, Positive TCR ~ 825ppm/°C
Thin layer of reactively sputtered TaN followed by Ta only
Radiant heating, 200 C, entire time starting 5 min prior to pre sputter
Pre Sputter 4" Ta target at 500 watts, 5.5 mTorr, 43.6 sccm Ar, 16.3sccm N2, 5 min.
Tantalum 4" target, 175 watts, 5.5 mTorr, 43.6 sccm Ar, 16.3 sccm N2, 2 min. ~100Å TaN
Tantalum 4" target, 200 watts, 5.5 mTorr, 43.6 sccm Ar, 30 min. Gives ~2500Å Ta

CVC 601 Tantalum 4" target, Beta Phase Tantalum 200 uOhm-cm, Negative TCR ~ -200ppm
Tantalum 4" target, 500 watts, 5.5 mTorr, 43.6 sccm Ar, 15 min. Gives ~2800Å Ta

CVC 601 Aluminum at 2000 watts, 5 mTorr, 25 min gives ~7500 Å, 20% nonuniformity

CVC 601 Copper, 8" target, 6000 Å 5 min pre sputter, Power = 325 watts, 650 volts, 0.5 A, 5 mTorr Pressure, Time = 20 min. Note: Runs made at 25 and 50 min had problems with copper adhesion and stress in the copper film causing it to roll and peel up. 50 min very bad, recipe needs more work

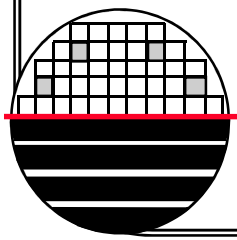
RIT PE4400 SPUTTERING RECIPES

PE 4400 Nickel 400 watts, 5 mTorr, 40sccm, 43.3 Å/min, 60 min for ~2600 Å

PE 4400 Aluminum 400 watts, 5 mTorr, 40 sccm, 125 min gives ~7500 Å

PE 4400 Titanium 400 watts, 5 mTorr, 25 sccm, 15 min gives ~750 Å

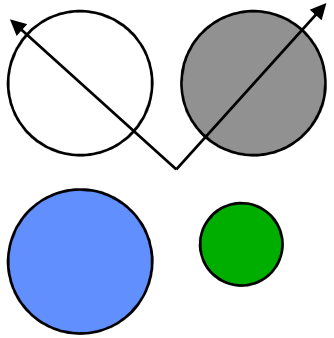
PE 4400 Sputter Etch prior to Metal Two, 500 watts, 40sccm, 5mTorr, 20 min



CVC-601 SUBSTRATE ROTATION

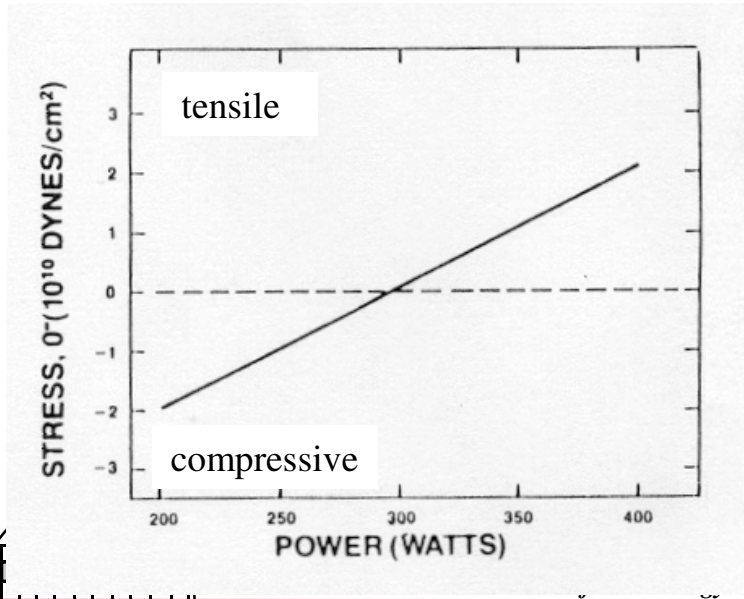
Continuous rotation of the substrate holder in the CVC601 is achieved with the Superior Electric Indexer Unit ON and the left-most knob set to EXT. Then, activating the rotostrate toggle switch results in continuous rotation. If you rotate the knob to - or + for clockwise/counterclockwise rotation, then you disable the rotostrate toggle switch and need to depress the execute Function switch on the superior electric Indexer Unit to achieve rotation. The rotation distance is controlled by the settings of five numbered dials on the Indexer Unit.

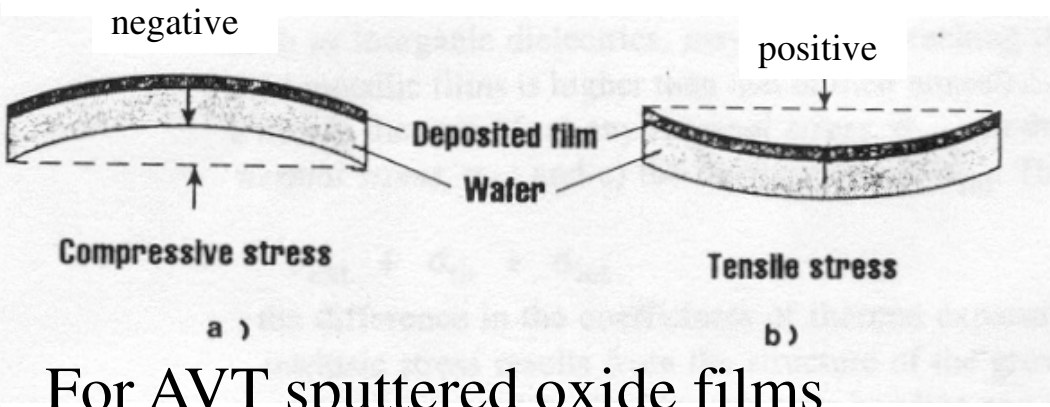
00209 setting will give a 90° rotation each time the execute function switch is pressed



STRESS IN SPUTTERED FILMS

Compressively stressed films would like to expand parallel to the substrate surface, and in the extreme, films in compressive stress will buckle up on the substrate. Films in tensile stress, on the other hand, would like to contract parallel to the substrate, and may crack if their elastic limits are exceeded. In general stresses can be negative or positive or near zero depending on many parameters.





For AVT sputtered oxide films Dr. Grande found Compressive -18MPa stress, 1-29-2000

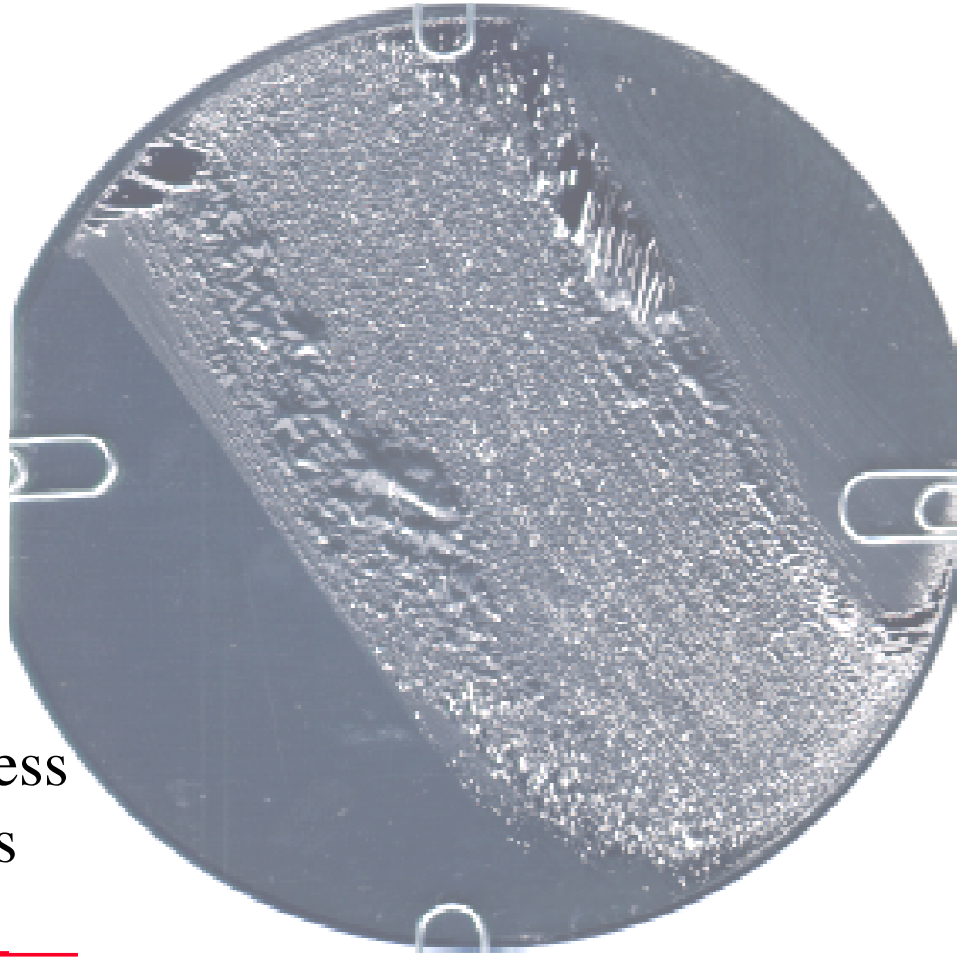
Microelectronic Engineering

10 dyne/cm^2 = 1 newton/m^2 = 1 Pascal

STRESS IN SPUTTERED TUNGSTEN FILMS

Tungsten

- CVC 601
- 4” Target
- 500 Watts
- 50 minutes
- 5 mTorr Argon
- Thickness ~ 0.8 µm



Blisters - Compressive Stress

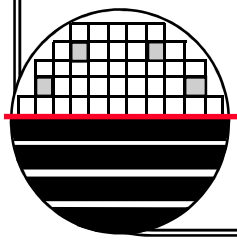
Cracking – Tensile Stress

Picture from scanner in gowning

REACTIVE SPUTTERING

Reactive Sputtering - introducing gases such as oxygen and nitrogen during sputtering can result in the deposition of films such as indium tin oxide (ITO) or titanium nitride TiN (other examples include AlN, Al_2O_3, AnO Ta_2O_5)

Unwanted Background Gases in Sputtering - Most Films are very reactive when deposited. Water and oxygen cause rougher films, poorer step coverage, discoloration (brown aluminum), poorer electrical properties, etc.



REACTIVE SPUTTERING RECIPES

Deposition of Reactive Sputtered Ta2O5

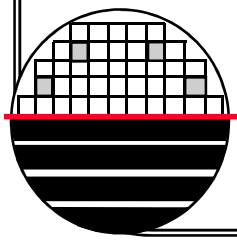
CVC 601, 25% Oxygen, 75% Argon, 90 min, 500 watts, 4 inch target resulting in ~5000 Å, nanospec should use index of refraction of 2.2

Deposition of Reactive Sputtered TaN

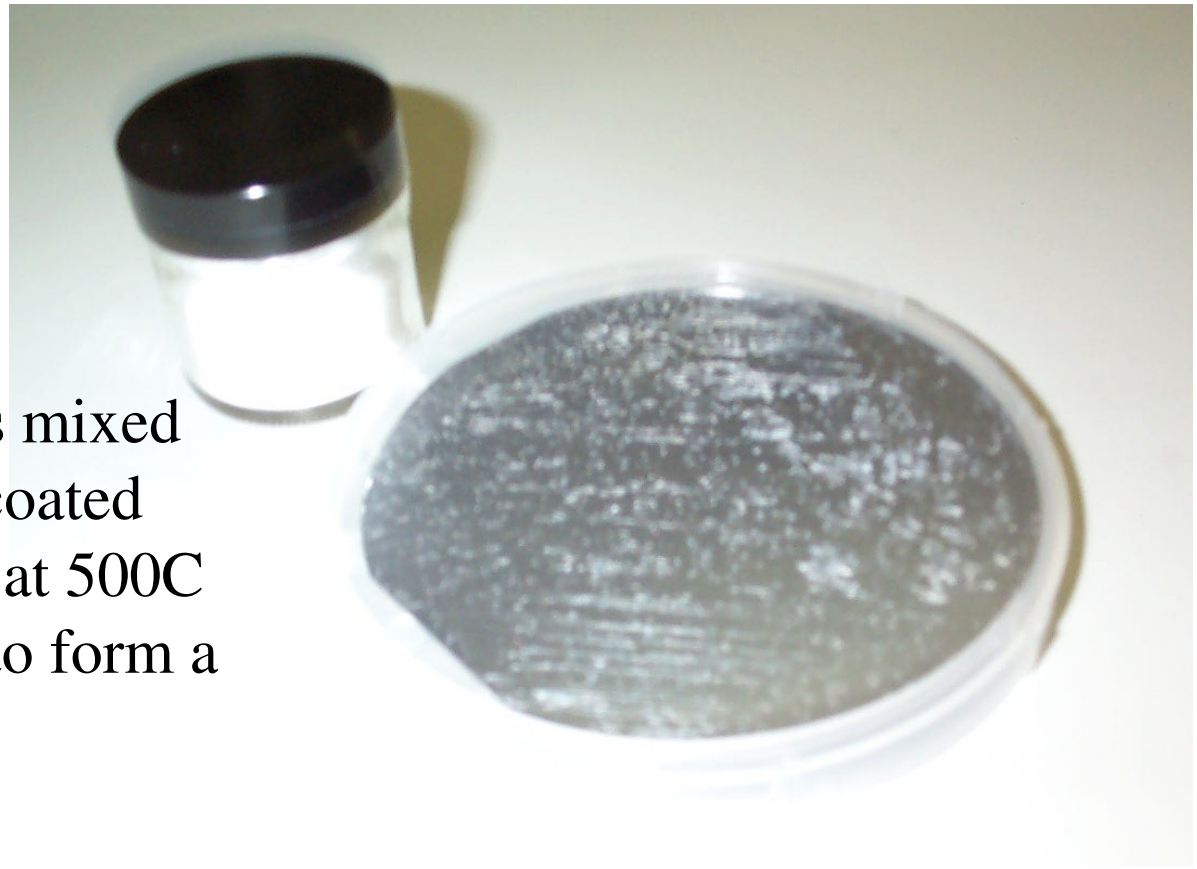
CVC 601, 8" Target of Ta, Ar 170 sccm, N2 34 sccm, Pressure = 4 mTorr, 2000 W, Rate ~900 Å/15 min

Deposition of Reactive Sputtered TaN

CVC 601, 4" Target of Ta, Ar 62 sccm, N2 34 sccm, Pressure = 6 mTorr, 500 W, Rate=157 Å/min, Rhos=228 ohms



FRIT GLASS SPUTTER TARGETS



Frit Glass Powder is mixed
With DI water and coated
On wafer then fired at 500C
And cooled slowly to form a
Sputter target.

REFERENCES

1. Supplier of evaporation and sputtering supplies, R.D.Mathis, P.O. Box 92916 Long Beach, CA 90809-2916, www.rdmathis.com