Microelectromechanical Systems (MEMs) Unit Processes for MEMs Measurement

Dr. Lynn Fuller
Webpage: http://people.rit.edu/lffeee
Microelectronic Engineering
Rochester Institute of Technology
82 Lomb Memorial Drive
Rochester, NY 14623-5604
Tel (585) 475-2035
Fax (585) 475-5041
Email: Lynn.Fuller@rit.edu
Department webpage: http://www.microe.rit.edu

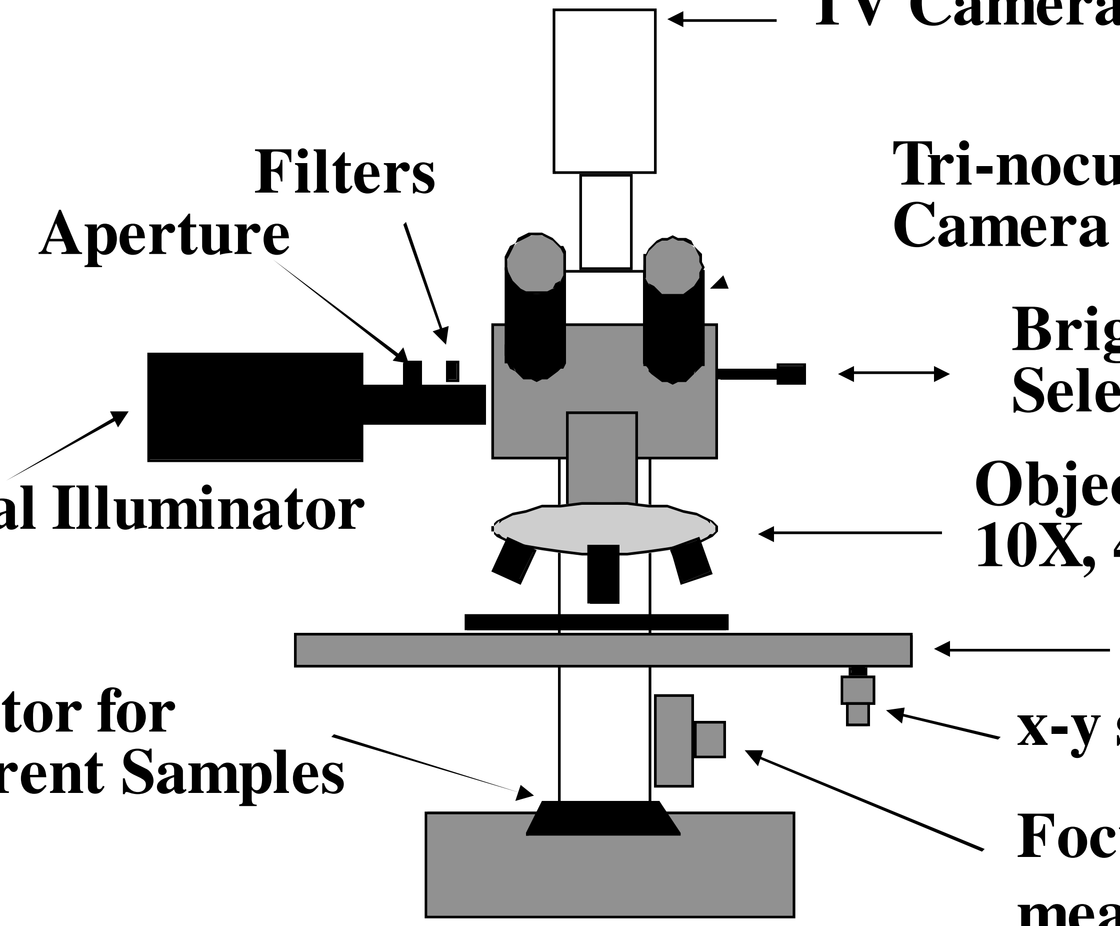
4-25-2012 mem_meas.ppt

OUTLINE

Visual Inspection
  - **Optical Microscopy**
  - **Electron Microscopy**

Linewidth
Thickness
Etch Rate
Resistivity and Sheet Resistance
Selectivity
Stress
References
Homework

OPTICAL MICROSCOPY



TV Camera

Filters

Aperture

Tri-nocular Eyepiece and Camera Mount

Bright Field Dark Fiel Selection mechanism

Coaxial Illuminator

Objective lenses, 5X, 10X, 40X, 100X

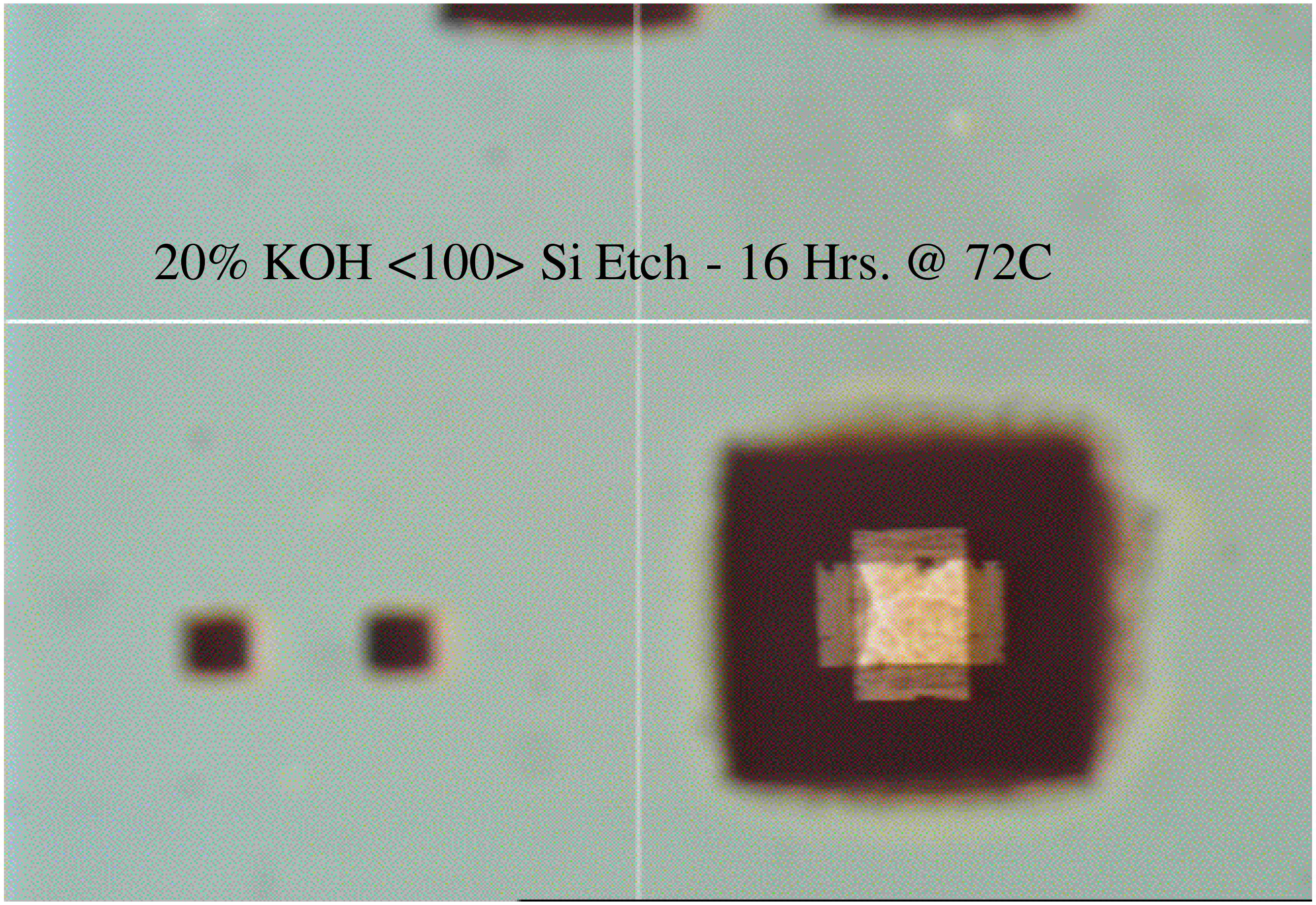
Stage

Illuminator for Transparent Samples

x-y stage movement

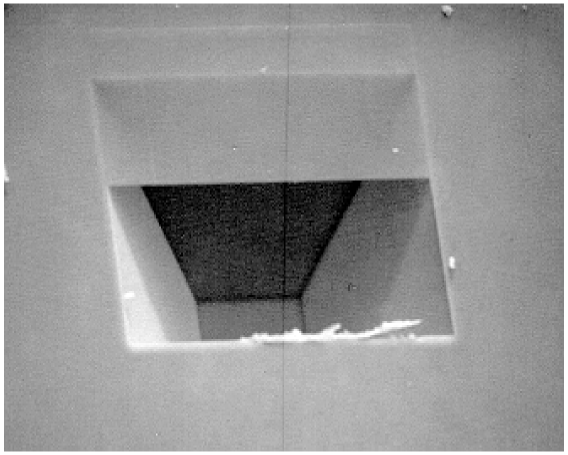
Focus and height measurement each division is 1 µm

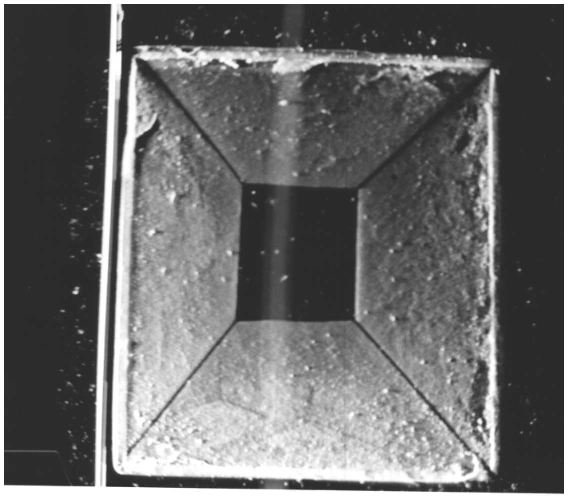
OPTICAL PICTURE OF ETCH PIT



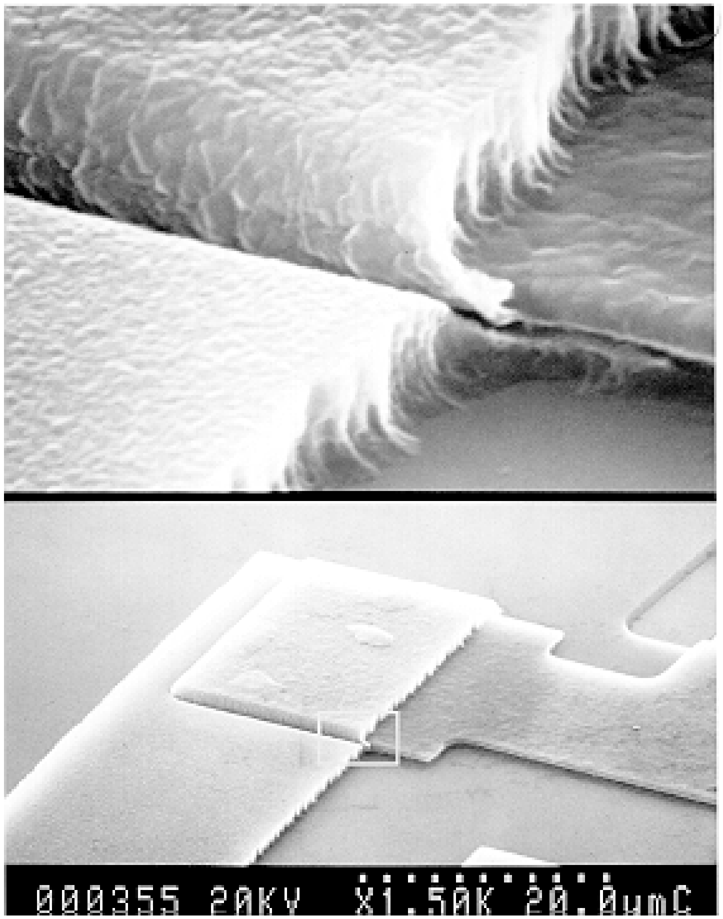
20% KOH <100> Si Etch - 16 Hrs. @ 72C

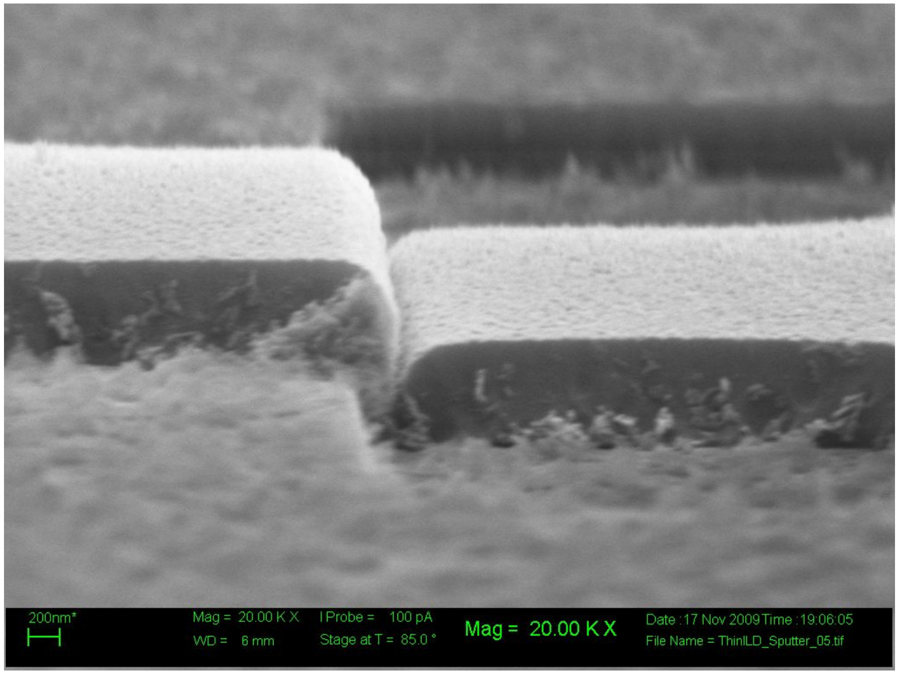
PHILLIPS SEM





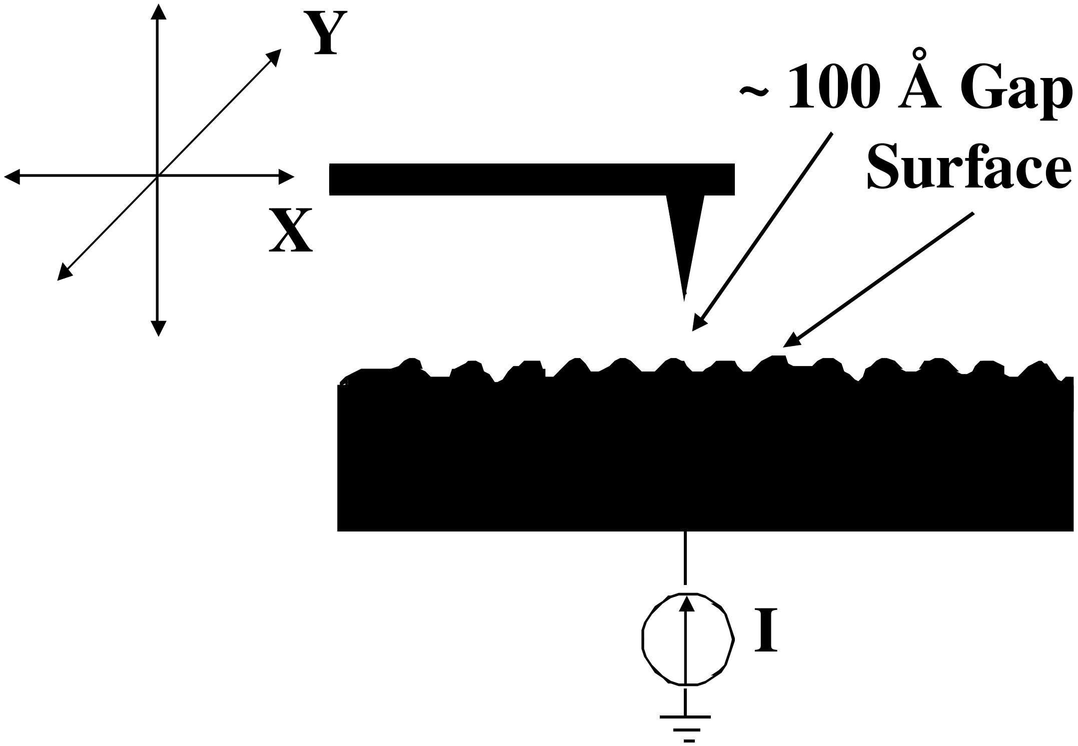
SEM PICTURES

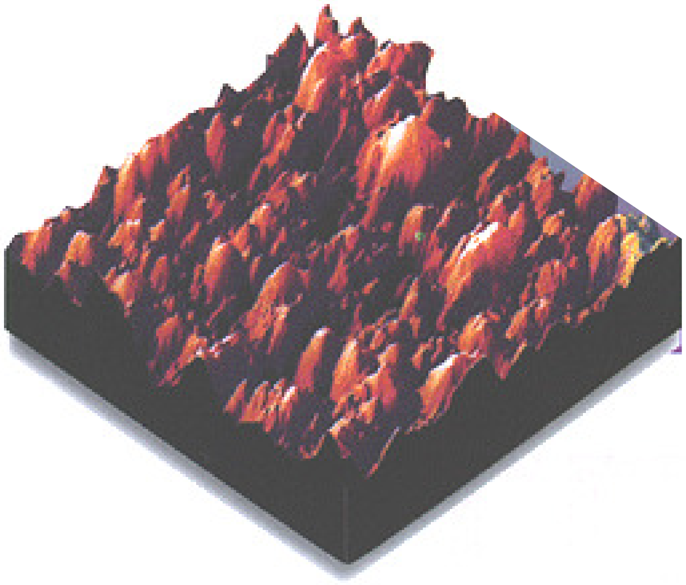




These SEM pictures show typical profiles of aluminum over steps from the CVC601.

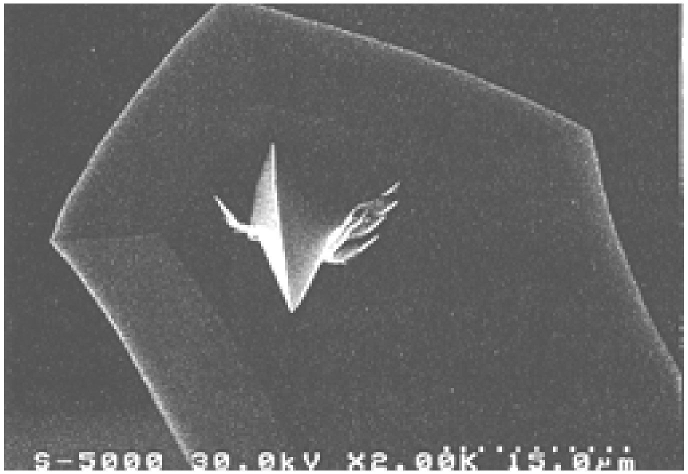
SCANNING TUNNELING MICROSCOPE (STM)

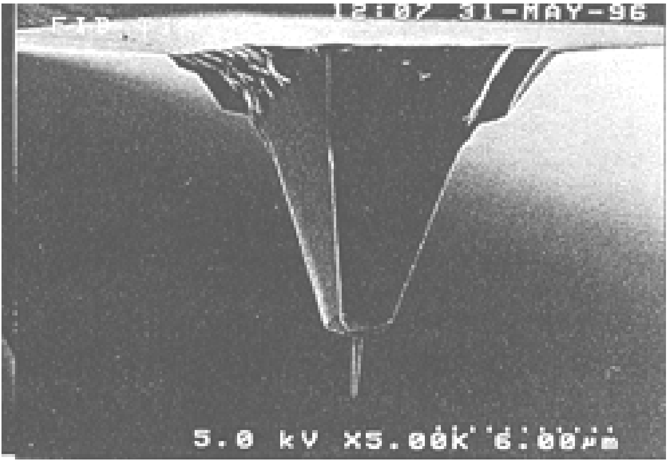


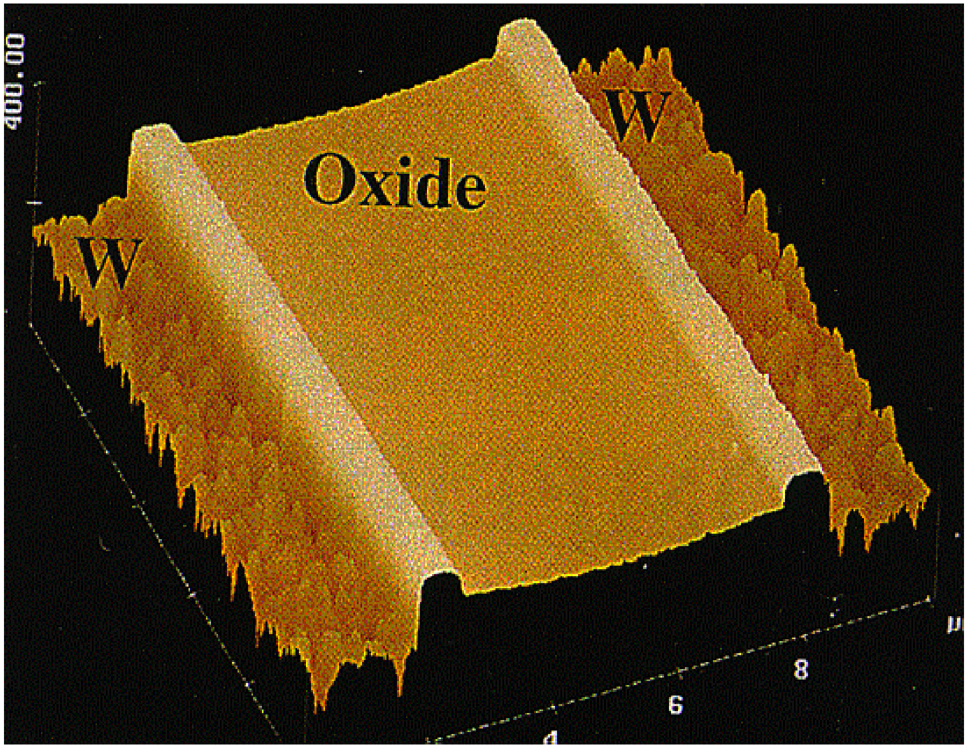


Piezoelectric Motors Scan Tip in X and Y, Electronics control Z such that the Tunneling Current I is Constant. The Control Voltage for Z is a Measure of Surface Topology

ATOMIC FORCE MICROSCOPE (AFM)

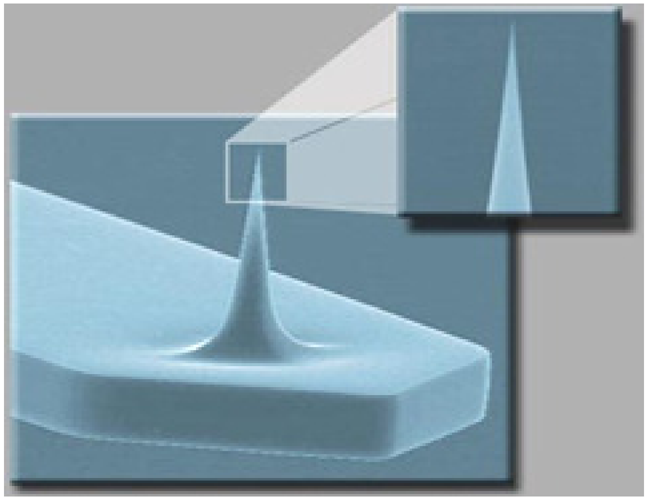


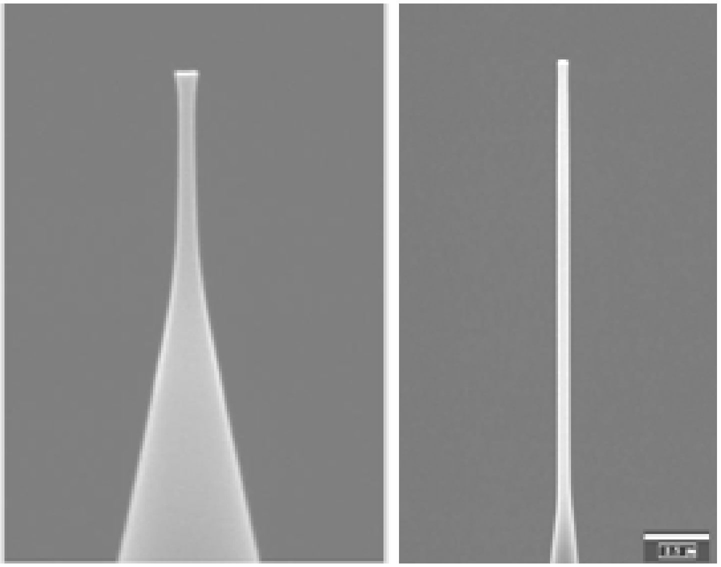




ATOMIC FORCE MICROSCOPE (AFM)

- **Standard**
  - Sharp Apex
  - Slender
  - Long
  - Used in Contact mode
- **CD Mode (Conical and Flared)**
  - Flared tip able to measure undercut sidewalls
  - Used in non-contact mode



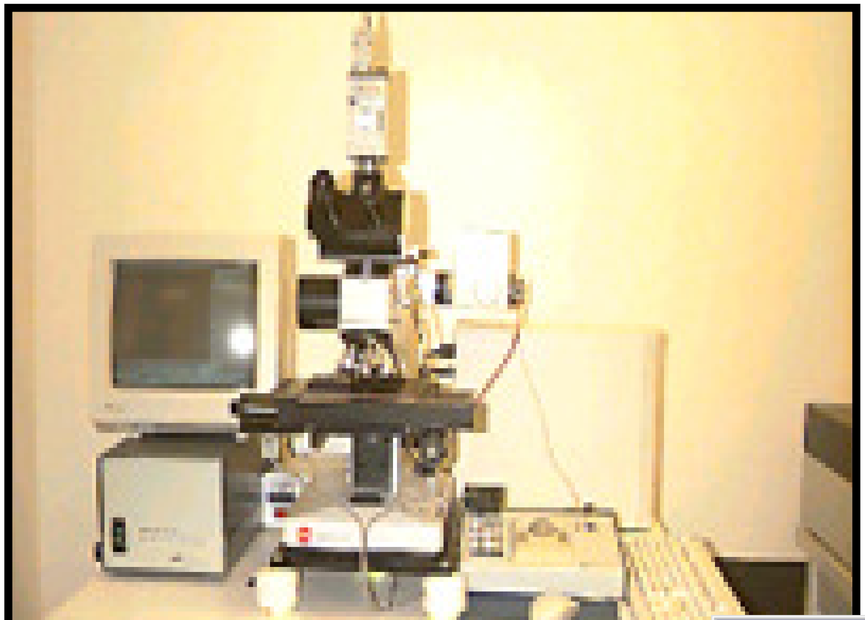


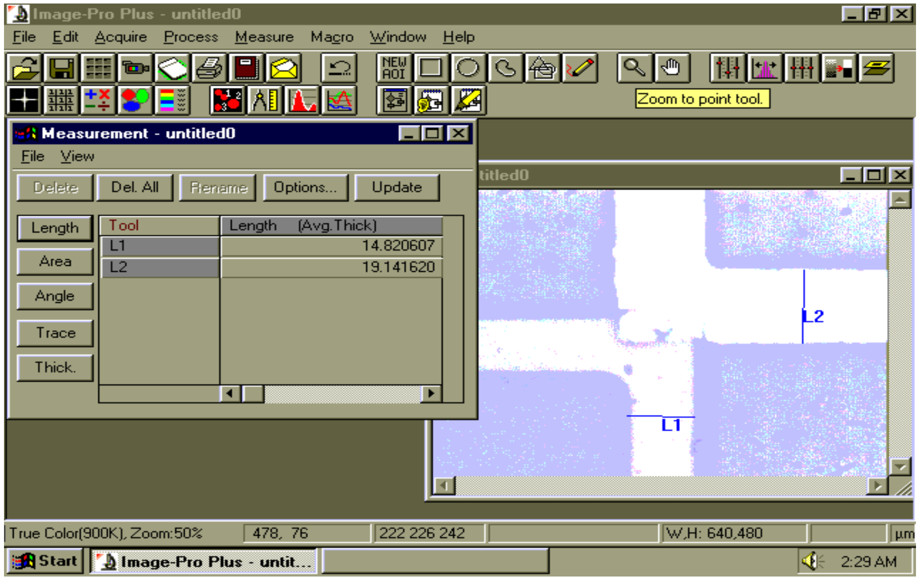
LINEWIDTH MEASUREMENT

Calibrate the output device for the microscope for a known size object. Then display unknown device and determine size by comparing the unknown to the known size.

A filar eyepiece is an eyepiece with a mechanical dial that moves a hairline across the field of view. The markings on the dial are calibrated by measuring a known size object. Unknown size objects are measured by positioning the hairline on one edge of the object, reading the dial and positioning the hairline on the other side of the object and reading the difference. Then calculating the size knowing the calibration. This technique is limited to objects small enough to fit within the field of view. For larger objects a calibrated traveling stage with a fixed hairline within the eyepiece can be used. Newer systems use CCD camera pixel counting rather than a mechanical eyepiece.

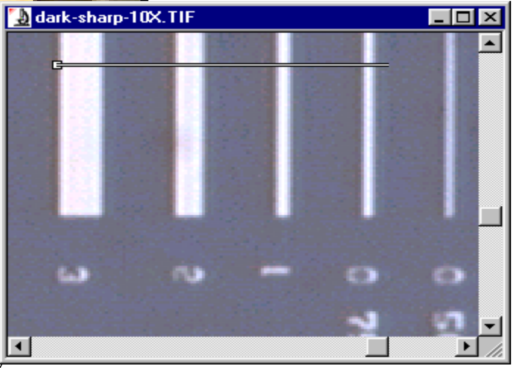
LINEWIDTH MEASUREMENT SYSTEM

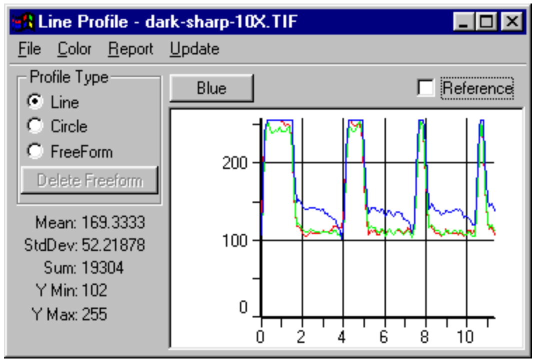




Tool	Length (Avg.Thick)
L1	14.820607
L2	19.141620

True Color(900K), Zoom:50% | 478, 76 | 222 226 242 | W,H: 640,480 | µm

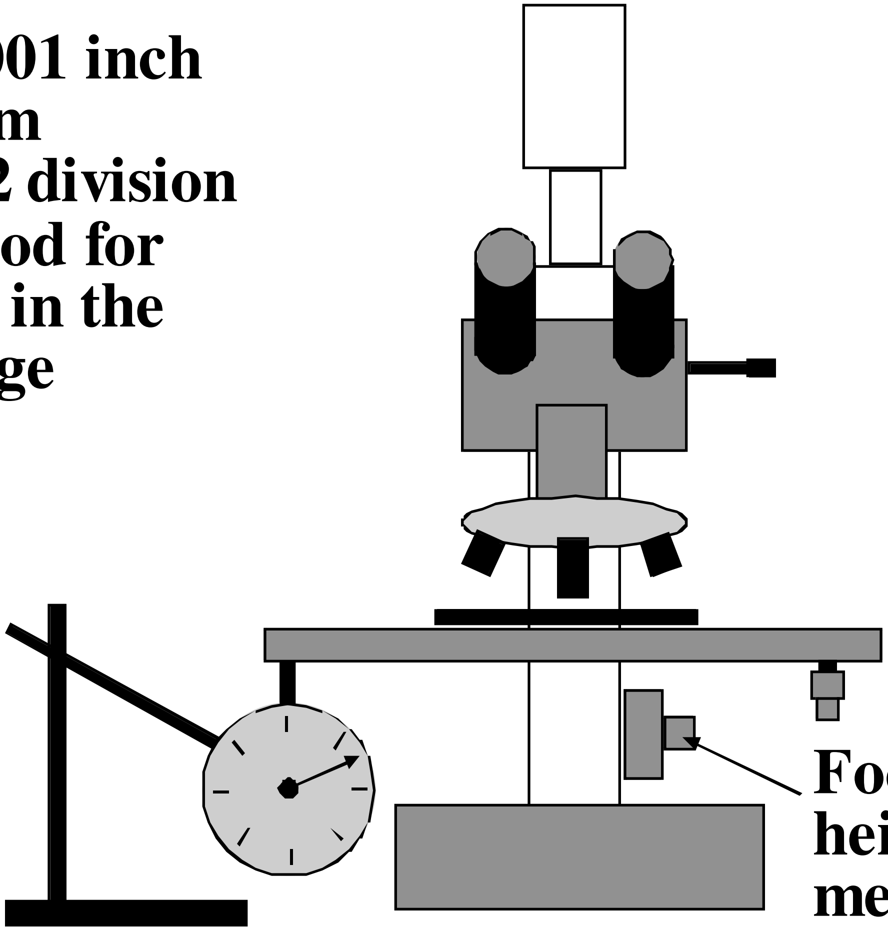




Mean: 169.3333
StdDev: 52.21878
Sum: 19304
Y Min: 102
Y Max: 255

HEIGHT MEASUREMENT USING OPTICAL MICROSCOPE

Dial divisions are 0.001 inch units equal to 25.4 µm accuracy is about 1/2 division or 12.5 µm, this is good for measuring thickness in the 100's of microns range



Focus and height measurement each division is 1 µm

HEIGHT MEASUREMENT USING OPTICAL MICROSCOPE

Put object on the microscope and obtain an image then place the micrometer under the stage as shown to measure the height change as the focus knob is turned

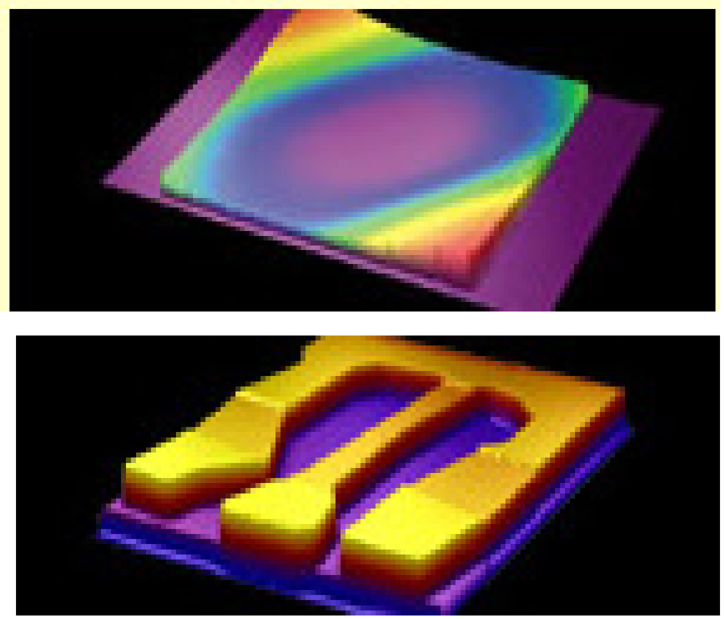
Use the 100 x Objective Lens for smallest depth of focus

Focus on top of object and set micrometer dial to zero

Focus on bottom of object and read the height on the micrometer dial.

OPTICAL TECHNIQUES FOR HEIGHT AND DISPLACEMENT

3D Surface Topography
Heights 0.1 nm to 5 mm
Resolution 0.1 nm

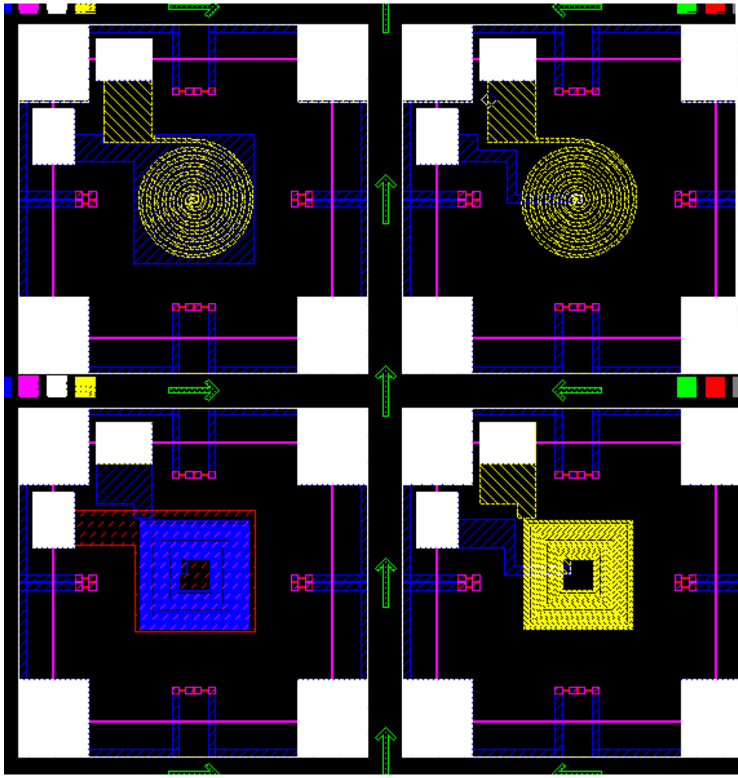


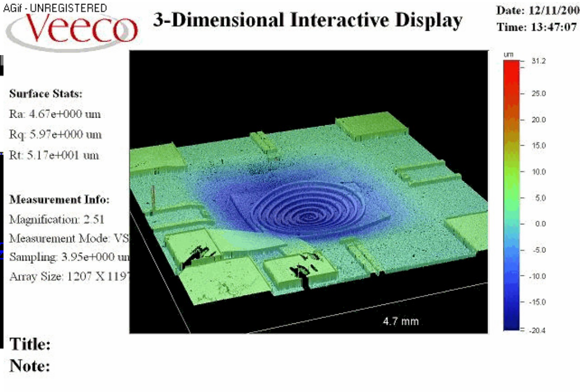
http://www.veeco.com

RIT's VEECO WYCO NT1100 OPTICAL PROFILOMETER

Used to measure RMS surface roughness

VEECO DYNAMIC OPTICAL PROFILER





AGif - UNREGISTERED

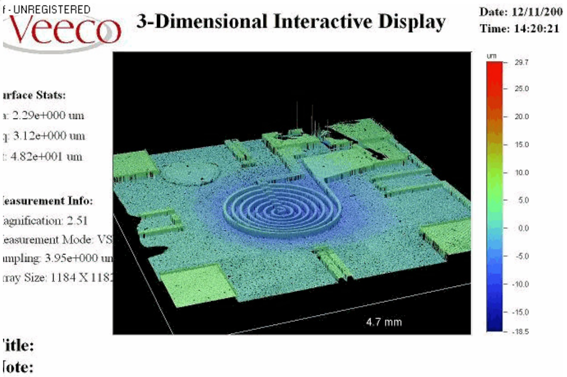
3-Dimensional Interactive Display

Date: 12/11/200
Time: 13:47:07

Surface Stats:
Ra: 4.67e+000 um
Rq: 5.97e+000 um
Rt: 5.17e+001 um

Measurement Info:
Magnification: 2.51
Measurement Mode: VS
Sampling: 3.95e+000 u
Array Size: 1207 X 119

Title:
Note:



f - UNREGISTERED

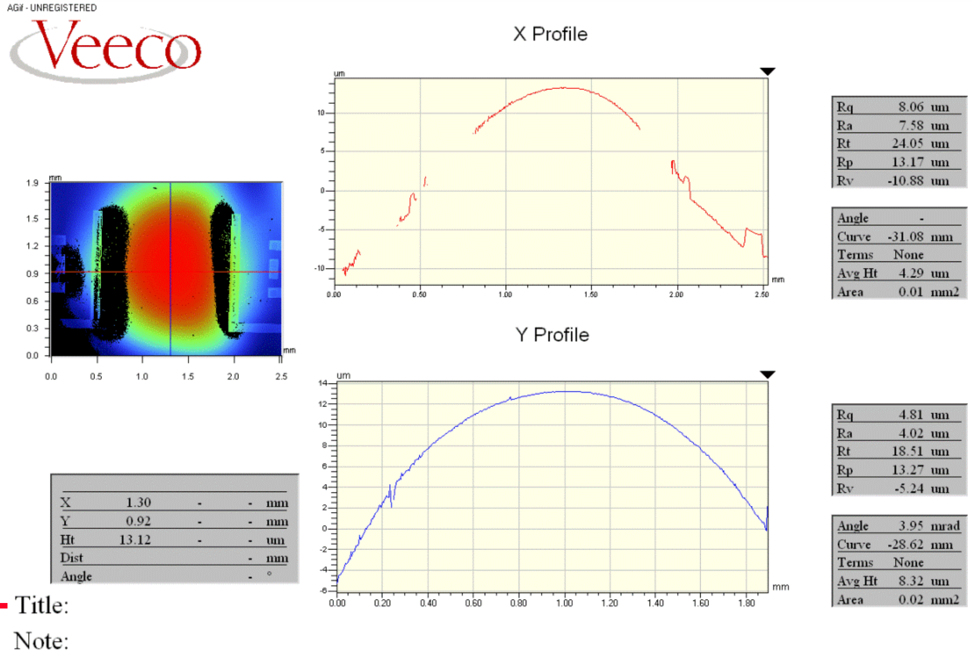
3-Dimensional Interactive Display

Date: 12/11/200
Time: 14:20:21

rface Stats:
a: 2.29e+000 um
q: 3.12e+000 um
: 4.82e+001 um

easurement Info:
agnification: 2.51
easurement Mode: VS
mpling: 3.95e+000 u
ray Size: 1184 X 118

itle:
ote:



AGif - UNREGISTERED

X Profile

Rq	8.06	um
Ra	7.58	um
Rt	24.05	um
Rp	13.17	um
Rv	-10.88	um

Angle	-	
Curve	-31.08	mm
Terms	None	
Avg Ht	4.29	um
Area	0.01	mm2

Y Profile

Rq	4.81	um
Ra	4.02	um
Rt	18.51	um
Rp	13.27	um
Rv	-5.24	um

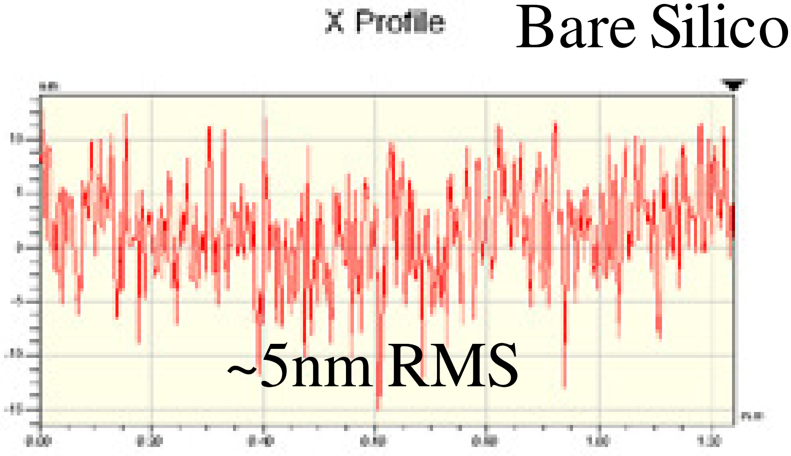
Angle	3.95	mrad
Curve	-28.62	mm
Terms	None	
Avg Ht	8.32	um
Area	0.02	mm2

X	1.30	-	-	mm
Y	0.92	-	-	mm
Ht	13.12	-	-	um
Dist			-	mm
Angle			-	°

Title:
Note:

SURFACE ROUGHNESS DATA

Bare Silicon Wafer

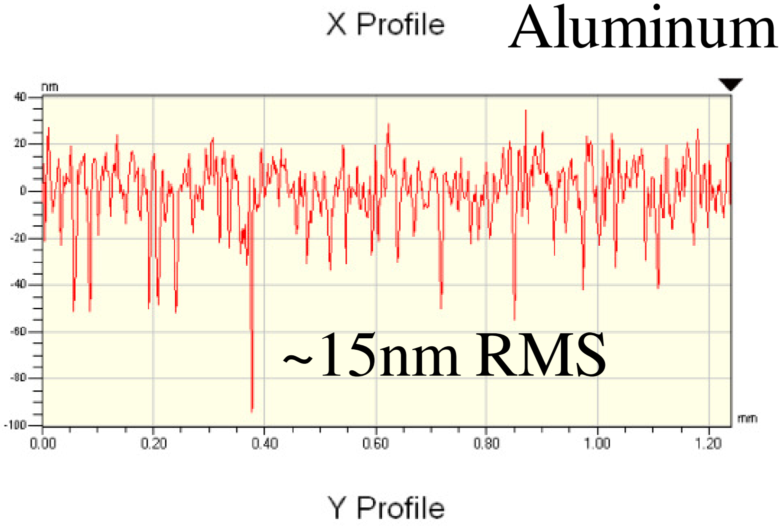


~5nm RMS

Rq	4.64	nm
Ra	3.66	nm
Rt	27.75	nm
Rp	12.67	nm
Rv	-15.09	nm

Angle	-1.03	urad
Curve	48.49	m
Terms	None	
Avg Ht	1.44	nm
Area	1.78	um2

Aluminum CVC 601 – 6800Å



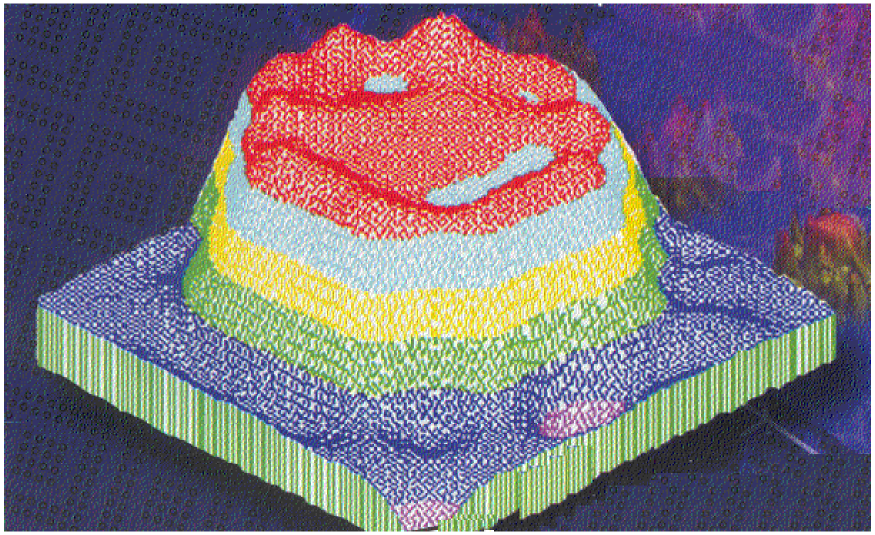
~15nm RMS

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

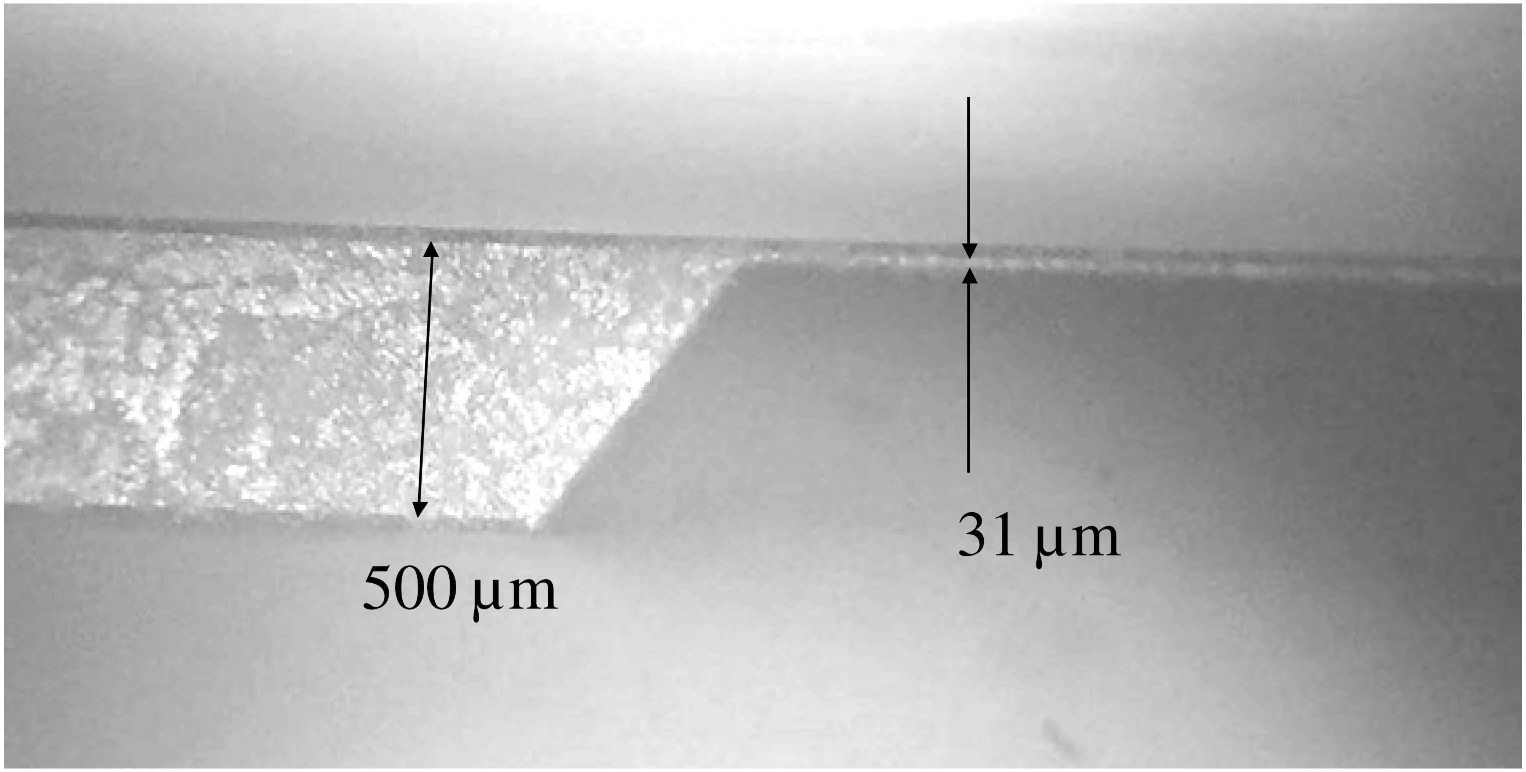
Angle	-9.13	urad
Curve	97.02	m
Terms	None	
Avg Ht	-0.79	nm
Area	-0.97	um2

Rochest
Microele

RIT’S OTHER WYCO HEIGHT MEASUREMENT TOOL



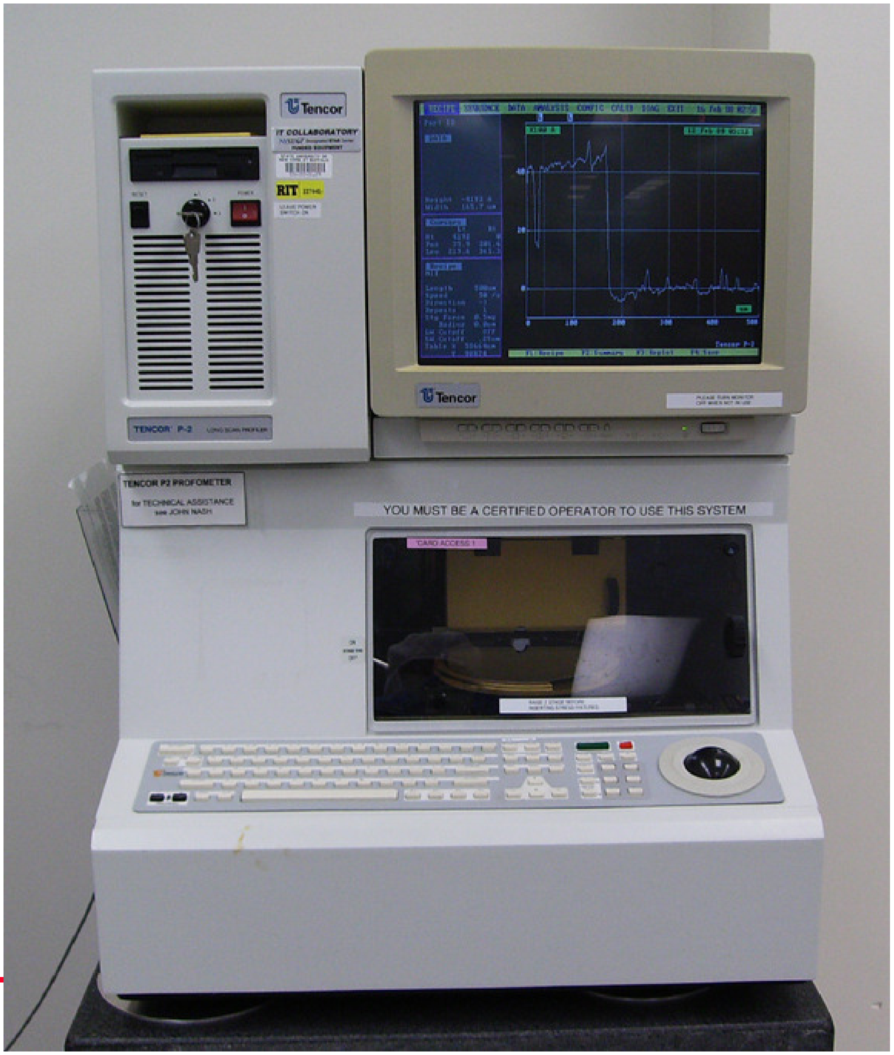
HEIGHT MEASUREMENT USING OPTICAL MICROSCOPE



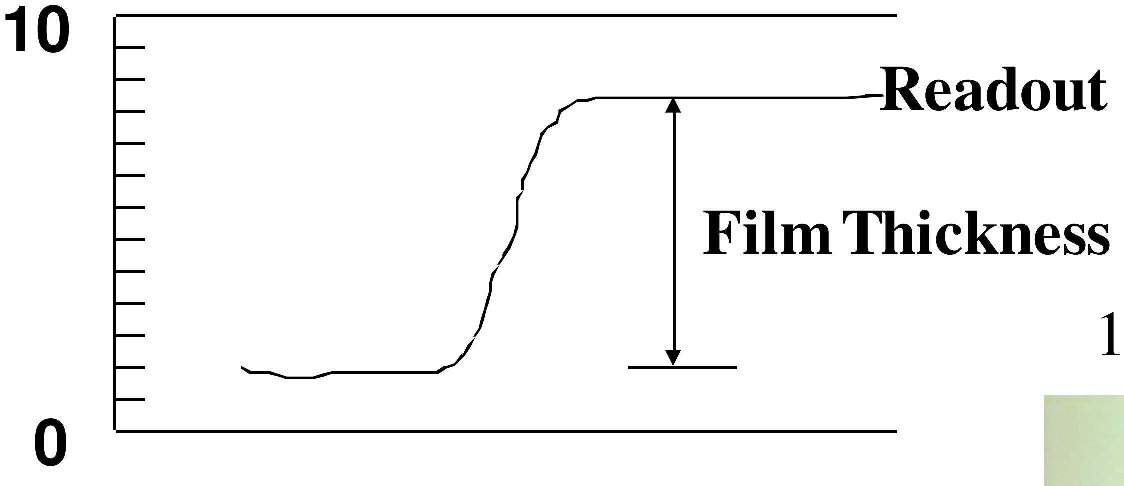
20% KOH Etch, @ 72 C, 10 Hrs.

TENCORE P2 LONG SCAN PROFILOMETER

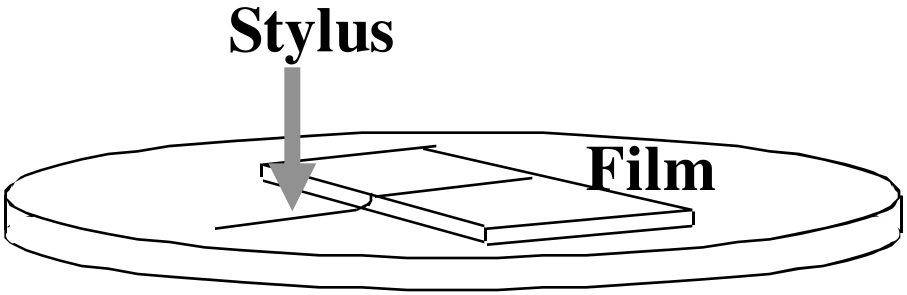
```
Part ID
DATA

Height  -4192 A
Width    165.7 um

Cursors
        Lt       Rt
Ht    4192        0
Pos   35.9    201.6
Lev  219.6    365.3

Recipe
NIT

Length      500um
Speed        50 /s
Direction     ->
Repeats        1
Sty Force   0.5mg
   Radius   0.0um
LW Cutoff     OFF
SW Cutoff    .25um
Table X   58664um
      Y    98874
```



STYLUS SURFACE PROFILOMETER



1,000 Å < Max < 1,000,000 Å



OXIDE THICKNESS COLOR CHART

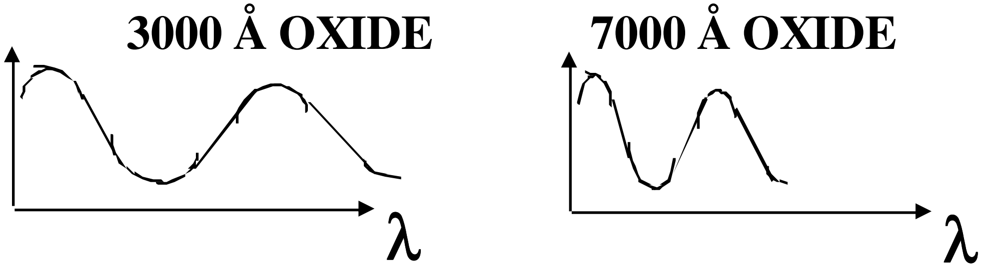
Thickness	Color
500	Tan
700	Brown
1000	Dark Violet - Red Violet
1200	Royal Blue Blue
1500	Light Blue - Metallic Blue
1700	Metallic - very light Yellow Green
2000	LIght Gold or Yellow - Slightly Metallic
2200	Gold with slight Yellow Orange
2500	Orange - Melon
2700	Red Violet
3000	Blue - Violet Blue
3100	Blue 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

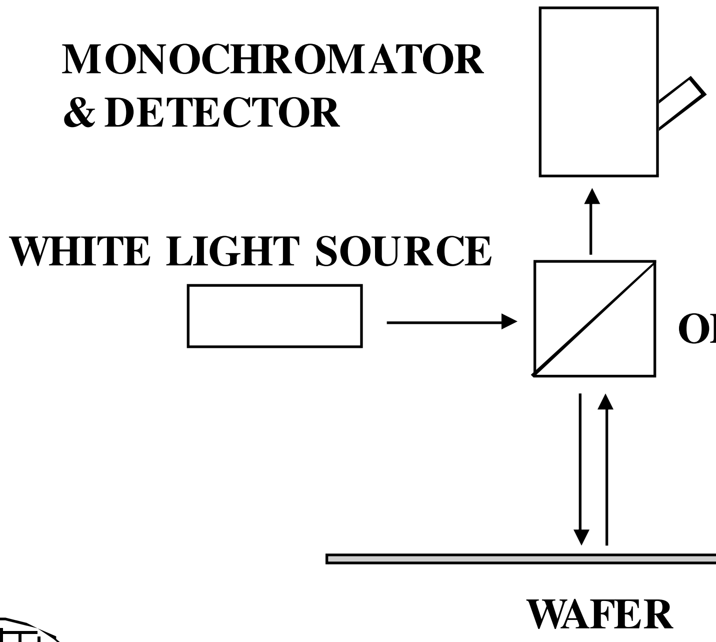
Thickness	Color
4900	Blue Blue
5000	Blue Green
5200	Green
5400	Yellow Green
5600	GreenYellow
5700	Yellow -"Yellowish"(at times appears to be Lt gray or matel
5800	Light Orange or Yellow - Pink
6000	Carnation Pink
6300	Violet Red
6800	"Bluish"(appears violet red, Blue Green, looks Blue
7200	Blue Green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

Nitride Thickness = (Oxide Thickness)(Oxide Index/Nitride Index)
Eg. Yellow Nitride Thickness = (2000)(1.46/2.00) = 1460

(REFLECTANCE SPECTROMETER) *NANOSPEC THICKNESS MEASUREMENT*

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

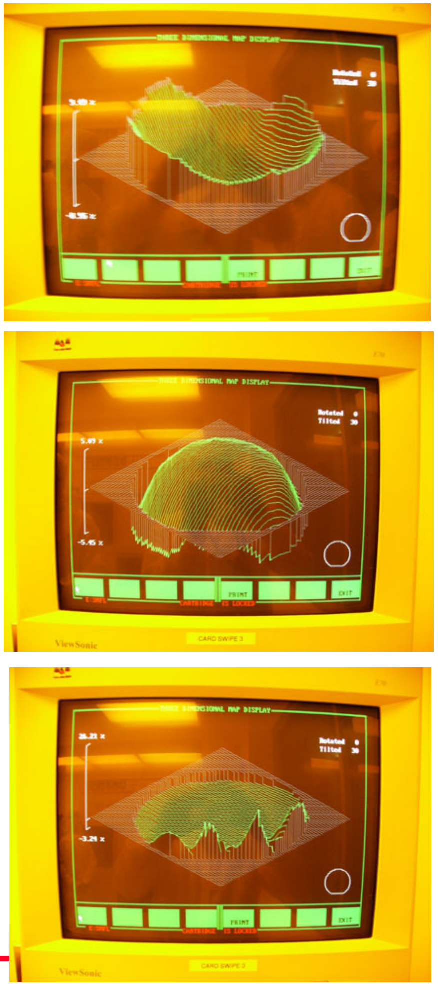




Oxide on Silicon	400-30,000 Å
Nitride	400-30,000
Neg Resist	500-40,000
Poly on 300-1200 Ox	400-10,000
Neg Resist on Ox 300-350	300-3500
Nitride on Oxide 300-3500	300-3500
Thin Oxide	100-500
Thin Nitride	100-500
Polyimide	500-10,000
Positive Resist	500-40,000
Pos Resist on Ox 500-15,000	4,000-30,000

NANOSPEC FILM THICKNESS MEASUREMENT TOOL

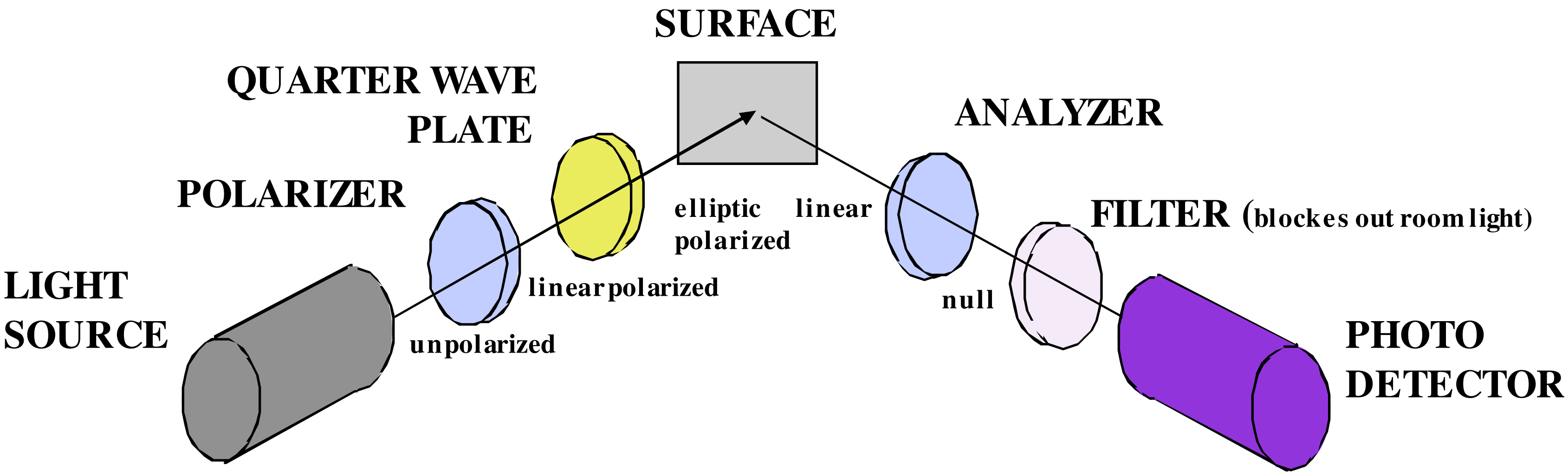
TENCORE SPECROMAP



Record:

Mean
Std Deviation
Min
Max
No of Points

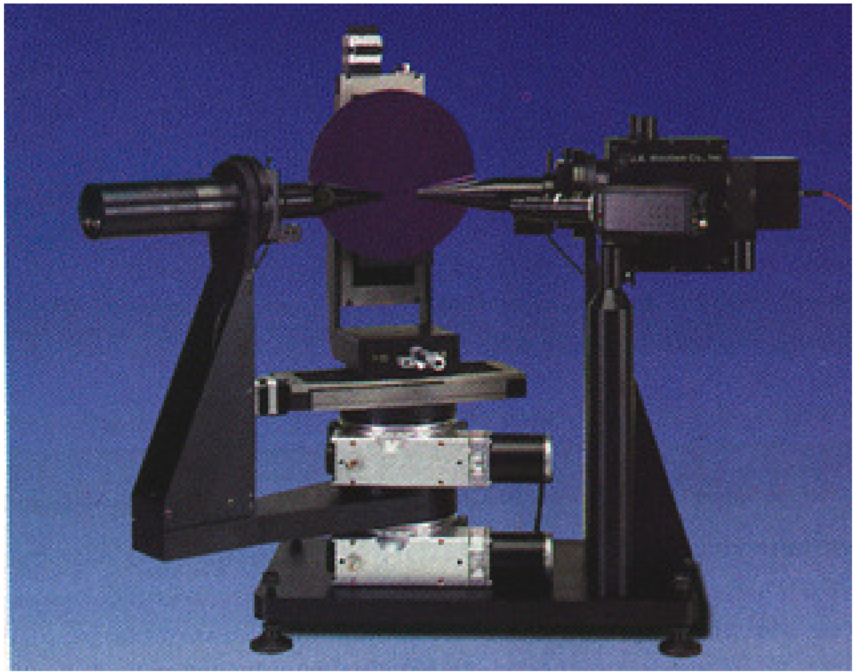
ELLIPSOMETRY



The light source is unpolarized, upon traversing the polarizer the light becomes linearly polarized. Turning the polarizer adjusts the azimuth of linearly polarized light with respect to the fast axis of the quarter-wave plate in such a way as to vary the ellipticity of the light incident on the surface. This ellipticity is adjusted until it is just cancelled by the ellipticity introduced by the reflection. The result is again linearly polarized light. The analyzer polarizing prism is rotated until its axis of polarization is perpendicular to the azimuth of the linearly polarized light, creating a null. Thus no light is transmitted to the dedector. The common technique is to fix the quarter-wave plate with fast axis at 45° to the plane of incidence, and to alternately move the polarizer and analyzer, continuously reducing the transmitted light until a null is reached. The relevant light parameters Δ and Ψ are readily calculated from the instrument parameters (P, polarizer angle, Q, quarter-wave plate angle, and A, analyzer angle. Values for film thickness and index of refraction are found. Thickness values that correspond to these parameters repeat with multiples of the light source wavelength so the approximate thickness must be known.

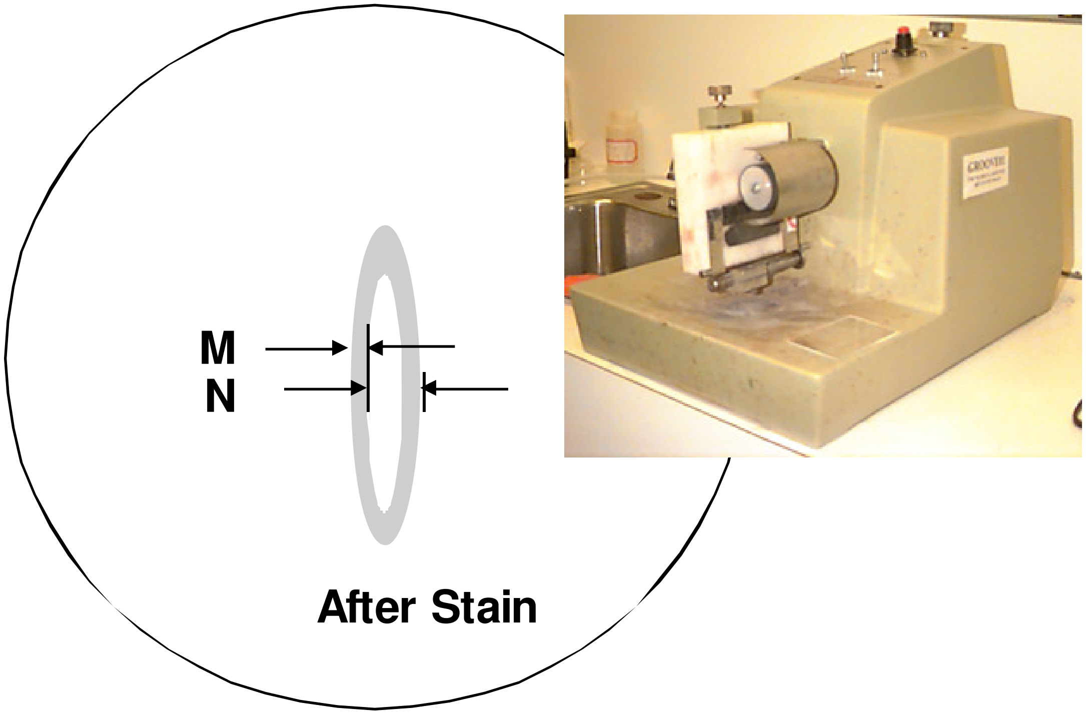
ELLIPSOMETER

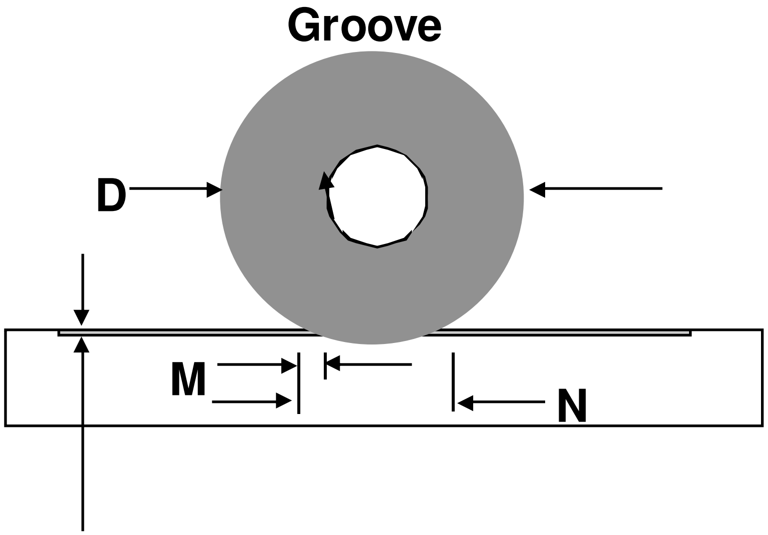
Rudolph Ellipsometer



Variable Angle Spectroscopic Ellipsometer

GROOVE and STAIN FIND Xj AFTER PRE DEPOSIT OR DRIVE-IN





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

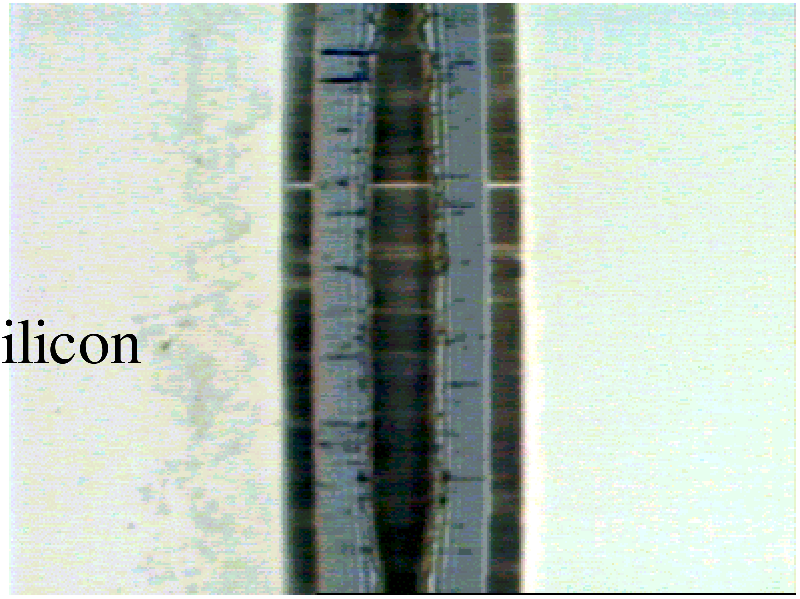
Staining Solution - 1 Vol part HF, 2 Vol part Nitric Acid, 12 Vol part Acetic Acid After mixing drop a penny in solution for about 10 sec. result in a light blue color. Safety Stain - (does not have HF) is available from Philtec Instrument Co. Philadelphia, PA 19129-1651, (215) 848-4500, Signatone makes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

TRAVELING STAGE MICROSCOPE

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

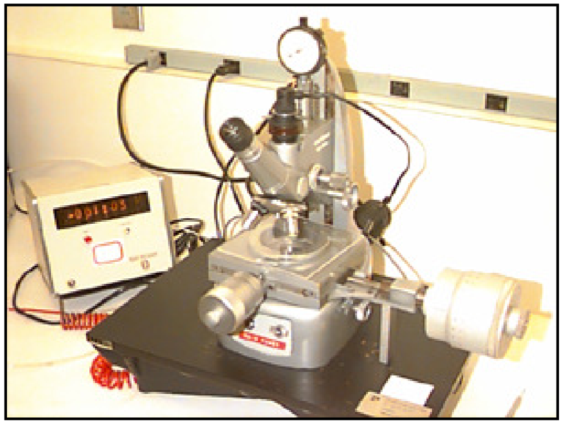
Xj = (N * M) / D

= (0.025 * 0.003)/1.532 inch)
= 0.0000472 inch
= 1.20 µm

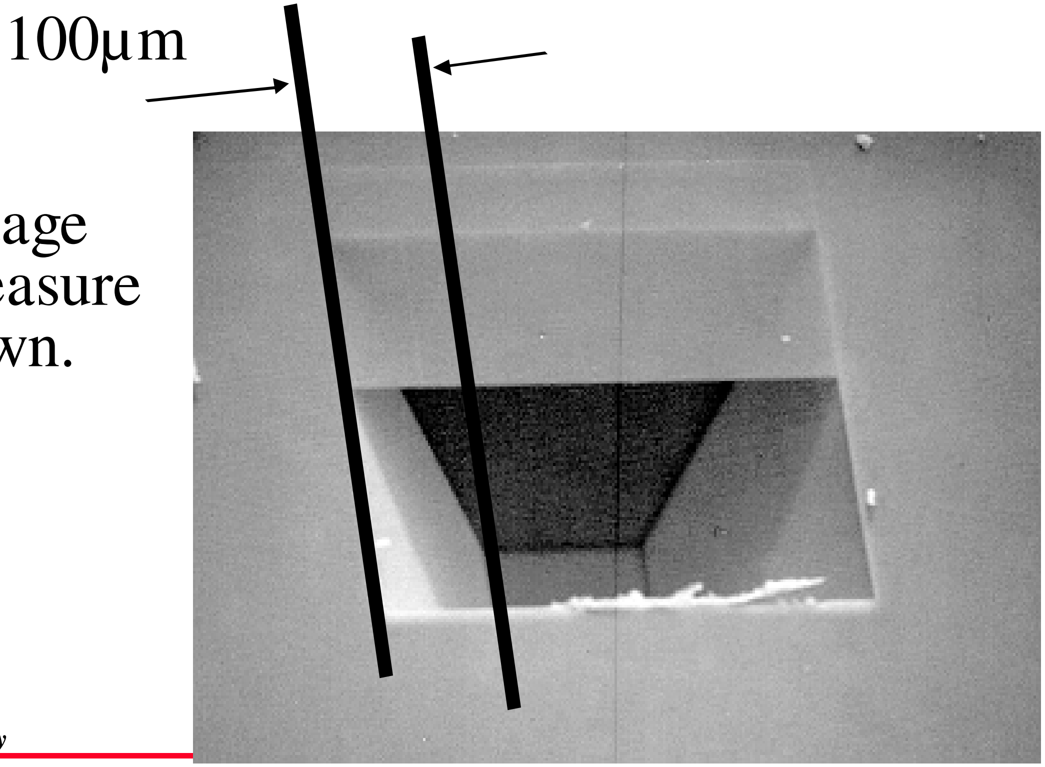


Poly on Oxide on Silicon
(no stain)

DEPTH WITH TRAVELING STAGE MICROSCOPE



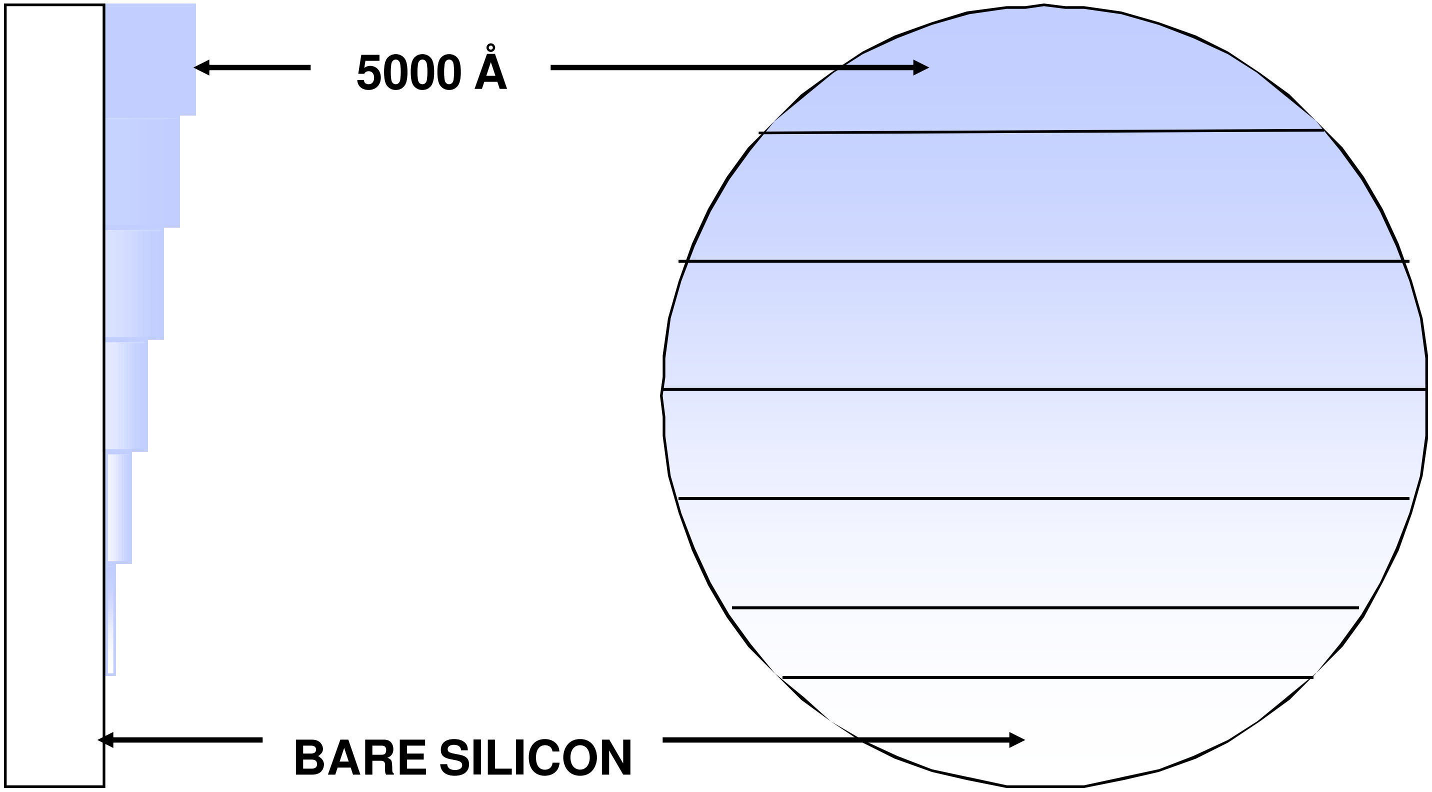
KOH etches silicon along the (111) crystal plane giving a 53° angle.



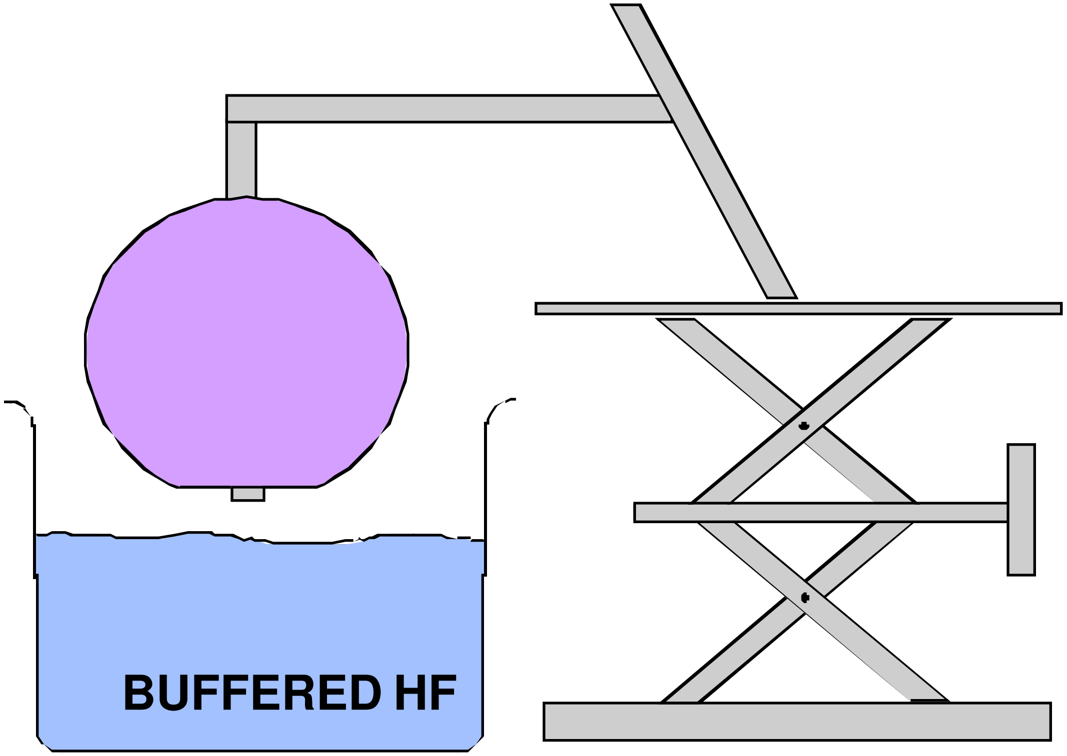
Example: the traveling stage microscope is used to measure the 100 µm distance shown. The depth is calculated.

Tan 53° = depth/100µm
depth = 133 µm

ETCH STEPS IN OXIDE TO FIND ETCH RATE

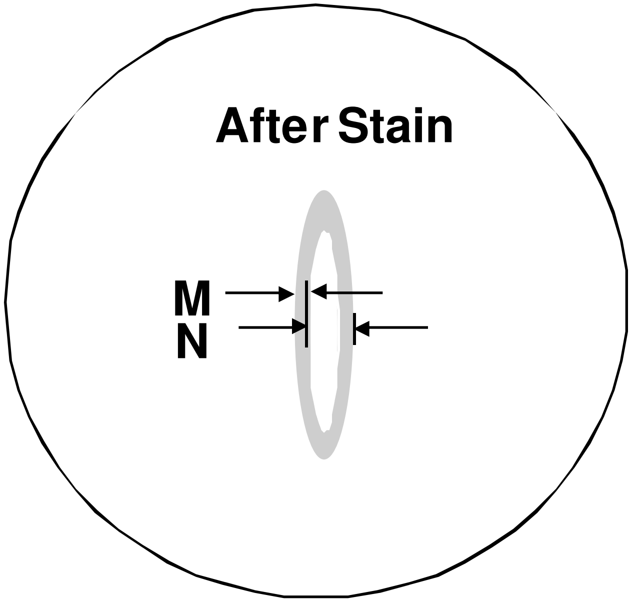


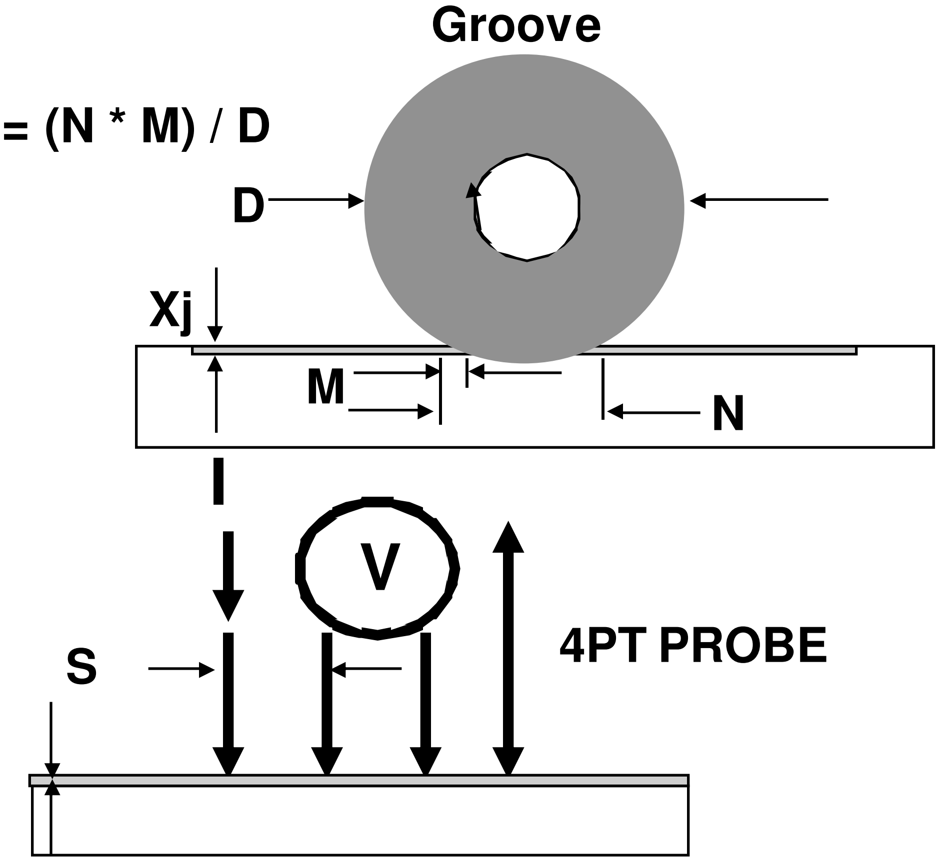
STEP ETCH APPARATUS



Lower 1/4 inch every 45 seconds

GROOVE AND STAIN AND 4PTPROBE FIND SHEET RESISTANCE AND RESISTIVITY FOR A DIFFUSED LAYER





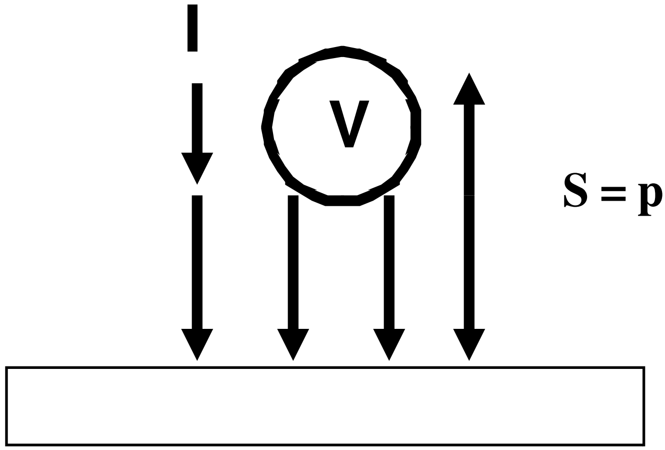
$Xj = (N * M) / D$

$Rhos = V / I * \pi / \ln 2 = 4.532\ V/I$ ohms/square

$Rho = Rhos\ Xj$ ohm-cm

FOUR POINT PROBE - RESISTIVITY

FOUR POINT PROBE



S = probe spacing

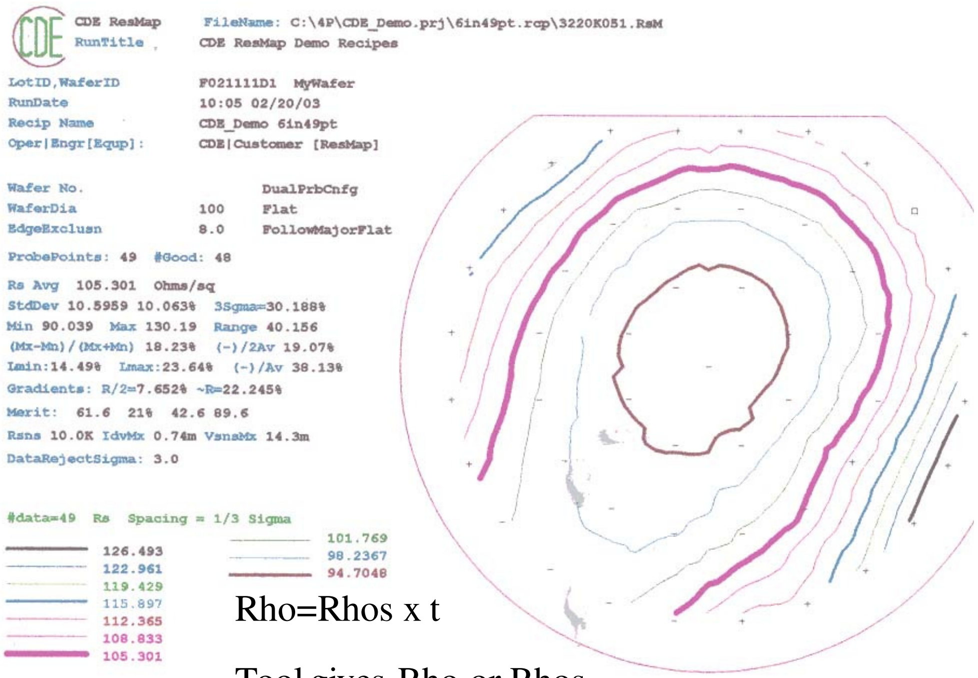
W = wafer thickness

Rho = π/ln2 x W x V / I ohm-cm

if S<<W and S<<Wafer Diameter

4 PT PROBE METAL THICKNESS MEASUREMENTS

CDE Resistivity Mapper

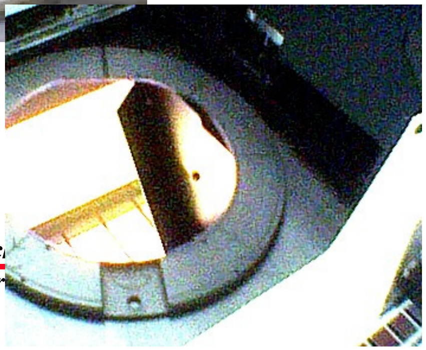


```
CDE ResMap      FileName: C:\4P\CDE_Demo.prj\6in49pt.rcp\3220K051.RsM
RunTitle ,      CDE ResMap Demo Recipes

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
                                 101.769
126.493                          98.2367
122.961                          94.7048
119.429
115.897
112.365
108.833
105.301
```

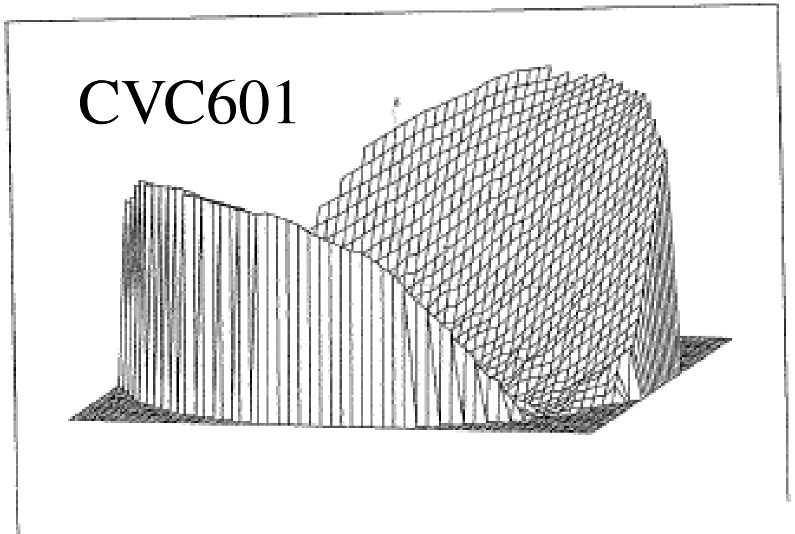
Rho=Rhos x t

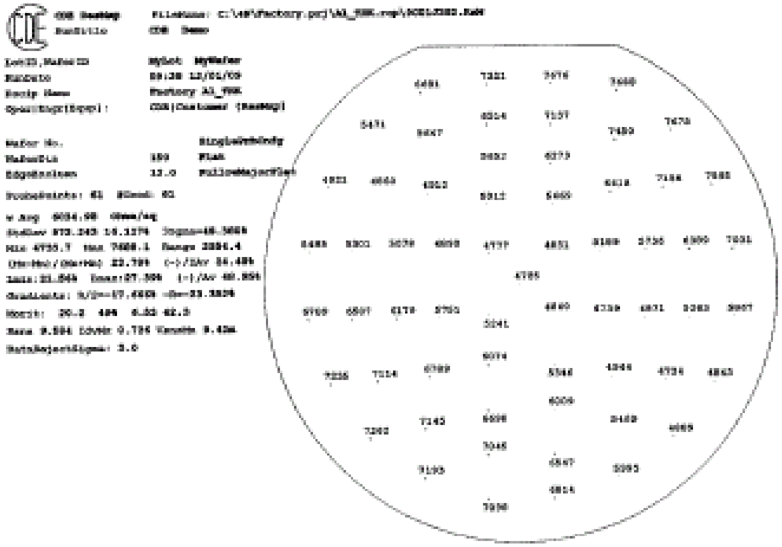
Tool gives Rho or Rhos depending on recipe used, automatically adjusts correction factors for wafer thickness

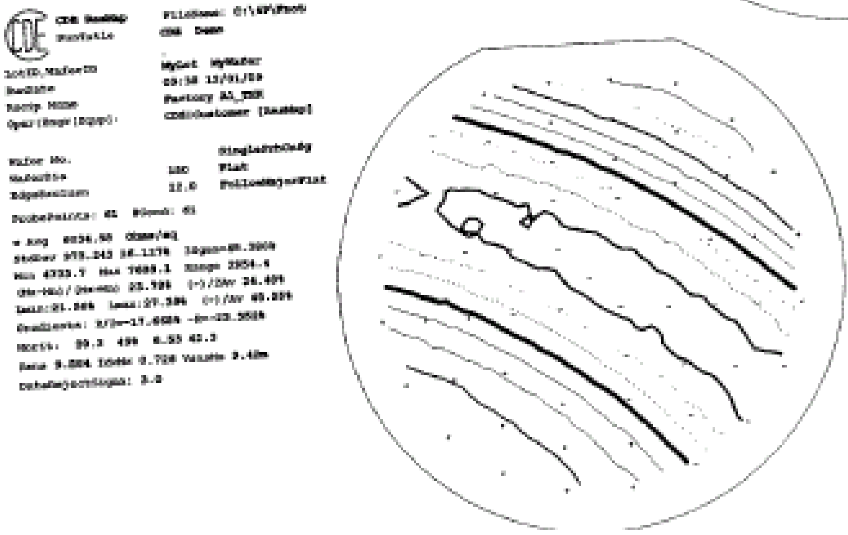
t = Rho/Rhos



SPUTTERED ALUMINUM THICKNESS UNIFORMITY

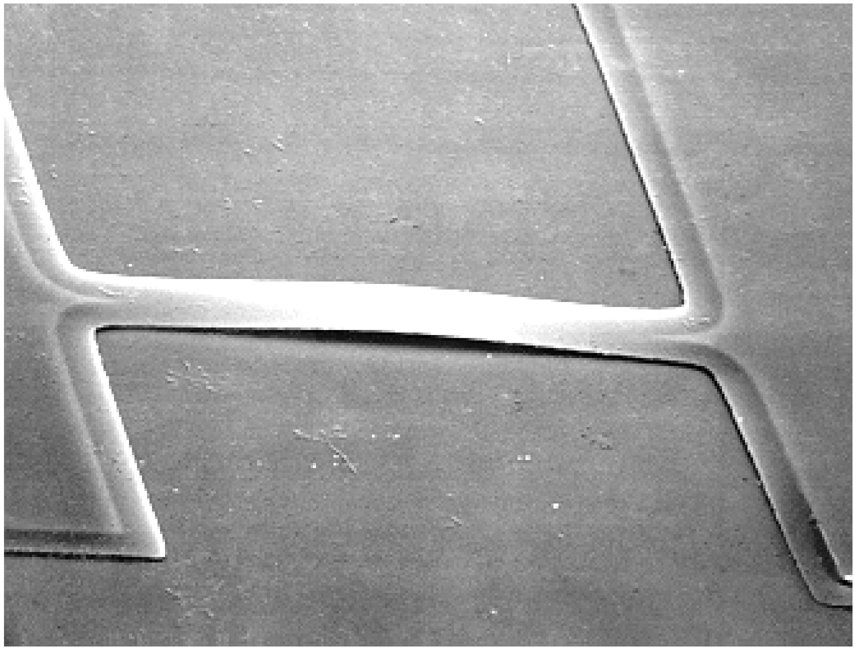




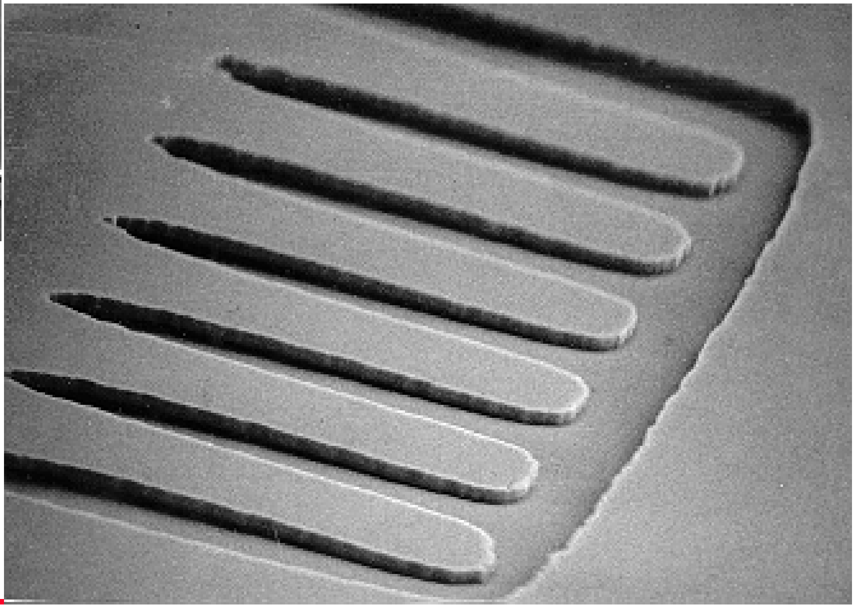


Ave = 6.03K
Min = 4.73K
Max = 7.68K
Non Uniformity = 23.78%

STRESS IN POLY AND NITRIDE FILMS



Test Structures for Measuring stress in Silicon Nitride Films



LOW STRESS SILICON RICH Si3N4

ADE Measured stress for various Ammonia: Dichlorosilane Flow Ratios

Flow	Stress x E 9 dynes/cm2
10:1	+14.63
5:1	+14.81
2.5:1	+12.47
1:1	+10.13
1:2.5	+7.79*
1:5	+3
1:10	0

*standard recipe

Stress: $\sigma = (E/(6(1-v)))*(D^2/(rt))$

where E is Youngs modulus,
v is Poissons ratio,
D and t are substrate and film thickness
r is radius of curvature (- for tensile)

T.H Wu, "Stress in PSG and Nitride Films as Related to Film Properties and Annealing", Solid State Technology, p 65-71,May '92

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

REFERENCES

1. Mechanics of Materials, by Ferdinand P. Beer, E. Russell Johnston, Jr., McGraw-Hill Book Co.1981, ISBN 0-07-004284-5
2. “Etch Rates for Micromachining Processing”, Journal of Microelectromechanical Systems, Vol.5, No.4, December 1996.
3. “Crystalline Semiconductor Micromachine”, Seidel, Proceedings of the 4th Int. Conf. on Solid State Sensors and Actuators 1987, p 104
4. Optical height measurements, http://www.keyence.com http://www.veeco.com

HOMEWORK - MEASUREMENTS FOR MEMS

1. Derive the equation used in the groove and stain technique for measuring junction depth.

2. Describe 5 ways to estimate/measure the thickness of a polysilicon film that you deposit.

3. How does the nanospec work? What is the difference in its operation for thin oxides compared to thicker oxides? Why?