Microelectromechanical Systems (MEMs)
Unit Processes for MEMs
Measurement

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OUTLINE

Visual Inspection
  Optical Microscopy
  Electron Microscopy
Linewidth
Thickness
Etch Rate
Resistivity and Sheet Resistance
Selectivity
Stress
References
Homework
OPTICAL MICROSCOPY

- Tri-nocular Eyepiece and Camera Mount
- Bright Field Dark Field Selection mechanism
- Objective lenses, 5X, 10X, 40X, 100X
- Stage
- x-y stage movement
- Focus and height measurement each division is 1 µm

- Coaxial Illuminator
- Illuminator for Transparent Samples
- TV Camera
- Filters
- Aperture

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OPTICAL PICTURE OF ETCH PIT

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

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These SEM pictures show typical profiles of aluminum over steps from the CVC601.
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.
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
MEMs Unit Processes - Measurement

VEECO DYNAMIC OPTICAL PROFILER

3-Dimensional Interactive Display

Surface Stats:
Rq: 5.278um
Rs: 5.173um

Measurement Info:
Magnification: 2.01
Measurement Mode: 3D
Sampling Rate: 0.020mm
Area Size: 1200 X 1024

Title: Note:

X Profile

Y Profile

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**SURFACE ROUGHNESS DATA**

**Bare Silicon Wafer**

- \( R_q \approx 4.64 \) nm
- \( R_a \approx 8.66 \) nm
- \( R_t \approx 27.75 \) nm
- \( R_p \approx 12.67 \) nm
- \( R_v \approx -15.09 \) nm

\ (~5nm RMS ~)

**Aluminum CVC 601 – 6800Å**

- \( R_q \approx 14.59 \) nm
- \( R_a \approx 10.58 \) nm
- \( R_t \approx 128.34 \) nm
- \( R_p \approx 34.18 \) nm
- \( R_v \approx -94.15 \) nm

\ (~15nm RMS ~)
RIT’S OTHER WYCO HEIGHT MEASUREMENT TOOL
HEIGHT MEASUREMENT USING OPTICAL MICROSCOPE

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

500 µm

31 µm
TENCORE P2 LONG SCAN PROFILOMETER
STYLUS SURFACE PROFILOMETER

Film Thickness

1,000 Å < Max < 1,000,000 Å
### OXIDE THICKNESS COLOR CHART

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>Tan</td>
</tr>
<tr>
<td>700</td>
<td>Brown</td>
</tr>
<tr>
<td>1000</td>
<td>Dark Violet - Red Violet</td>
</tr>
<tr>
<td>1200</td>
<td>Royal Blue</td>
</tr>
<tr>
<td>1500</td>
<td>Light Blue - Metallic Blue</td>
</tr>
<tr>
<td>1700</td>
<td>Metallic - very light Yellow Green</td>
</tr>
<tr>
<td>2000</td>
<td>Light Gold or Yellow - Slightly Metallic</td>
</tr>
<tr>
<td>2200</td>
<td>Gold with slight Yellow Orange</td>
</tr>
<tr>
<td>2500</td>
<td>Orange - Melon</td>
</tr>
<tr>
<td>2700</td>
<td>Red Violet</td>
</tr>
<tr>
<td>3000</td>
<td>Blue - Violet Blue</td>
</tr>
<tr>
<td>3100</td>
<td>Blue</td>
</tr>
<tr>
<td>3200</td>
<td>Blue - Blue Green</td>
</tr>
<tr>
<td>3400</td>
<td>Light Green</td>
</tr>
<tr>
<td>3500</td>
<td>Green - Yellow Green</td>
</tr>
<tr>
<td>3600</td>
<td>Yellow Green</td>
</tr>
<tr>
<td>3700</td>
<td>Yellow</td>
</tr>
<tr>
<td>3900</td>
<td>Light Orange</td>
</tr>
<tr>
<td>4100</td>
<td>Carnation Pink</td>
</tr>
<tr>
<td>4200</td>
<td>Violet Red</td>
</tr>
<tr>
<td>4400</td>
<td>Red Violet</td>
</tr>
<tr>
<td>4600</td>
<td>Violet</td>
</tr>
<tr>
<td>4700</td>
<td>Blue Violet</td>
</tr>
<tr>
<td>4900</td>
<td>Blue</td>
</tr>
<tr>
<td>5000</td>
<td>Blue Green</td>
</tr>
<tr>
<td>5200</td>
<td>Green</td>
</tr>
<tr>
<td>5400</td>
<td>Yellow Green</td>
</tr>
<tr>
<td>5600</td>
<td>GreenYellow</td>
</tr>
<tr>
<td>5700</td>
<td>Yellow - &quot;Yellowish&quot; <em>(at times appears to be Lt gray or metallic)</em></td>
</tr>
<tr>
<td>5800</td>
<td>Light Orange or Yellow - Pink</td>
</tr>
<tr>
<td>6000</td>
<td>Carnation Pink</td>
</tr>
<tr>
<td>6300</td>
<td>Violet Red</td>
</tr>
<tr>
<td>6800</td>
<td>&quot;Bluish&quot; <em>(appears violet red, Blue Green, looks)</em> Blue</td>
</tr>
<tr>
<td>7200</td>
<td>Blue Green - Green</td>
</tr>
<tr>
<td>7700</td>
<td>&quot;Yellowish&quot;</td>
</tr>
<tr>
<td>8000</td>
<td>Orange</td>
</tr>
<tr>
<td>8200</td>
<td>Salmon</td>
</tr>
<tr>
<td>8500</td>
<td>Dull, Light Red Violet</td>
</tr>
<tr>
<td>8600</td>
<td>Violet</td>
</tr>
<tr>
<td>8700</td>
<td>Blue Violet</td>
</tr>
<tr>
<td>8900</td>
<td>Blue</td>
</tr>
<tr>
<td>9200</td>
<td>Blue Green</td>
</tr>
<tr>
<td>9500</td>
<td>Dull Yellow Green</td>
</tr>
<tr>
<td>9700</td>
<td>Yellow - &quot;Yellowish&quot;</td>
</tr>
<tr>
<td>9900</td>
<td>Orange</td>
</tr>
<tr>
<td>10000</td>
<td>Carnation Pink</td>
</tr>
</tbody>
</table>

Nitride Thickness = (Oxide Thickness)(Oxide Index/Nitride Index)
Eg. Yellow Nitride Thickness = (2000)(1.46/2.00) = 1460
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
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 detector. 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 $\Delta$ and $\Psi$ 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
After Stain

\[ X_j = \frac{N \times M}{D} \]
(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
Example: If M=.003 inches and N=0.025 inches, find xj.

\[
X_j = \frac{N \times M}{D}
\]

\[
= \frac{(0.025 \times 0.003)}{1.532 \text{ inch}}
\]

\[
= 0.0000472 \text{ inch}
\]

\[
= 1.20 \mu m
\]
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.

\[ \tan 53^\circ = \frac{\text{depth}}{100\mu\text{m}} \]

\[ \text{depth} = 133 \mu\text{m} \]
ETCH STEPS IN OXIDE TO FIND ETCH RATE

5000 Å

BARE SILICON
STEP ETCH APPARATUS

BUFFERED HF

Lower 1/4 inch every 45 seconds
GROOVE AND STAIN AND 4PT PROBE FIND SHEET RESISTANCE AND RESISTIVITY FOR A DIFFUSED LAYER

\[ \text{Rhos} = \frac{V}{I} \times \frac{\pi}{\ln 2} = 4.532 \frac{V}{I} \text{ ohms/square} \]

\[ \rho = \text{Rhos} \times X_j \text{ ohm-cm} \]

\[ X_j = \frac{N \times M}{D} \]

After Stain

Groove

4PT PROBE

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FOUR POINT PROBE - RESISTIVITY

\[ Rho = \frac{\pi}{\ln 2} \times W \times \frac{V}{I} \text{ ohm-cm} \]

if \( S << W \) and \( S << \text{Wafer Diameter} \)

\( S = \) probe spacing

\( W = \) wafer thickness
4 PT PROBE METAL 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

\[ t = \frac{\text{Rho}}{\text{Rhos}} \]
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

<table>
<thead>
<tr>
<th>Flow</th>
<th>Stress x E 9 dynes/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:1</td>
<td>+14.63</td>
</tr>
<tr>
<td>5:1</td>
<td>+14.81</td>
</tr>
<tr>
<td>2.5:1</td>
<td>+12.47</td>
</tr>
<tr>
<td>1:1</td>
<td>+10.13</td>
</tr>
<tr>
<td>1:2.5</td>
<td>+7.79*</td>
</tr>
<tr>
<td>1:5</td>
<td>+3</td>
</tr>
<tr>
<td>1:10</td>
<td>0</td>
</tr>
</tbody>
</table>

*standard recipe

Stress: \( \sigma = \frac{E}{(6(1-v))} \left( \frac{D^2}{rt} \right) \) where E is Young's modulus, \( v \) is Poisson's ratio, \( D \) and \( t \) are substrate and film thickness, \( r \) is radius of curvature (- for tensile)


10 dyne/cm² = 1 newton/m² = 1 Pascal
REFERENCES

   [http://www.veeco.com](http://www.veeco.com)
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?