Roll to Roll Inspection Platform:

Development of Optical Inspection for Flexible Thin Films

General Donald R. Keith Memorial Capstone Conference
Submission 47

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UNIVERSITY
STATE UNIVERSITY OF NEW YORK

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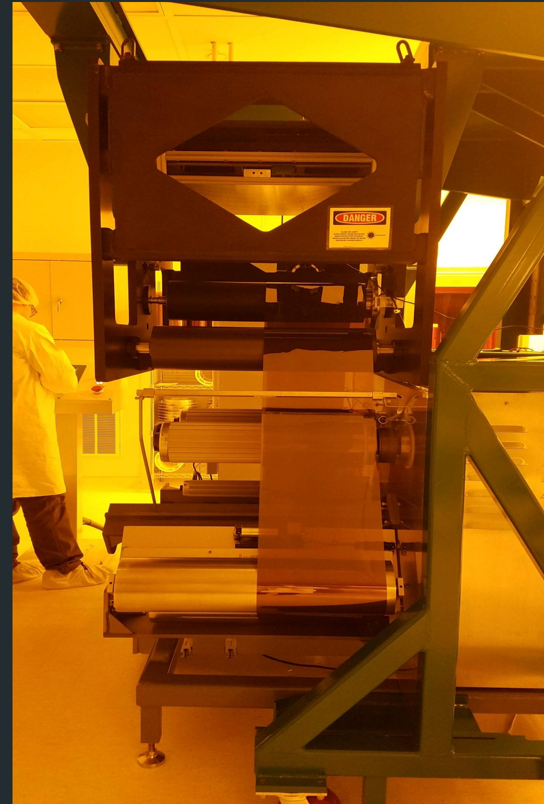
Agenda

- Introduction
  - Background
  - Project Scope
- Implementation and Analysis
  - Defect Detection
  - Thickness Reading
  - Project Budget
- Conclusions

Introduction

- Advancing Microelectronics Manufacturing is needed to meet increasing demand
- Need for inspection due to the “micro”
- Aim: Develop inexpensive inline inspection process

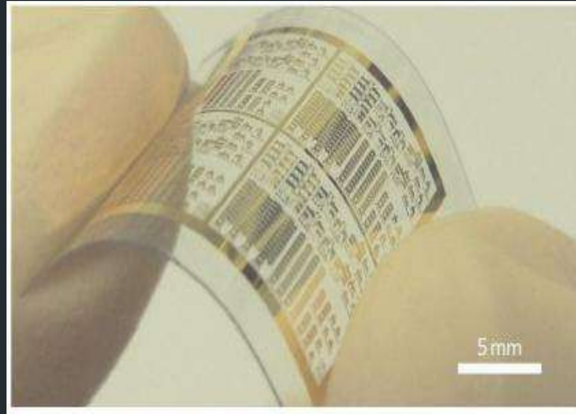


Roll to Roll Conveyance Tool

Background: Microelectronics

- Circuitry
- Display Technology
- Photovoltaic Cells
- Transparent Antennas

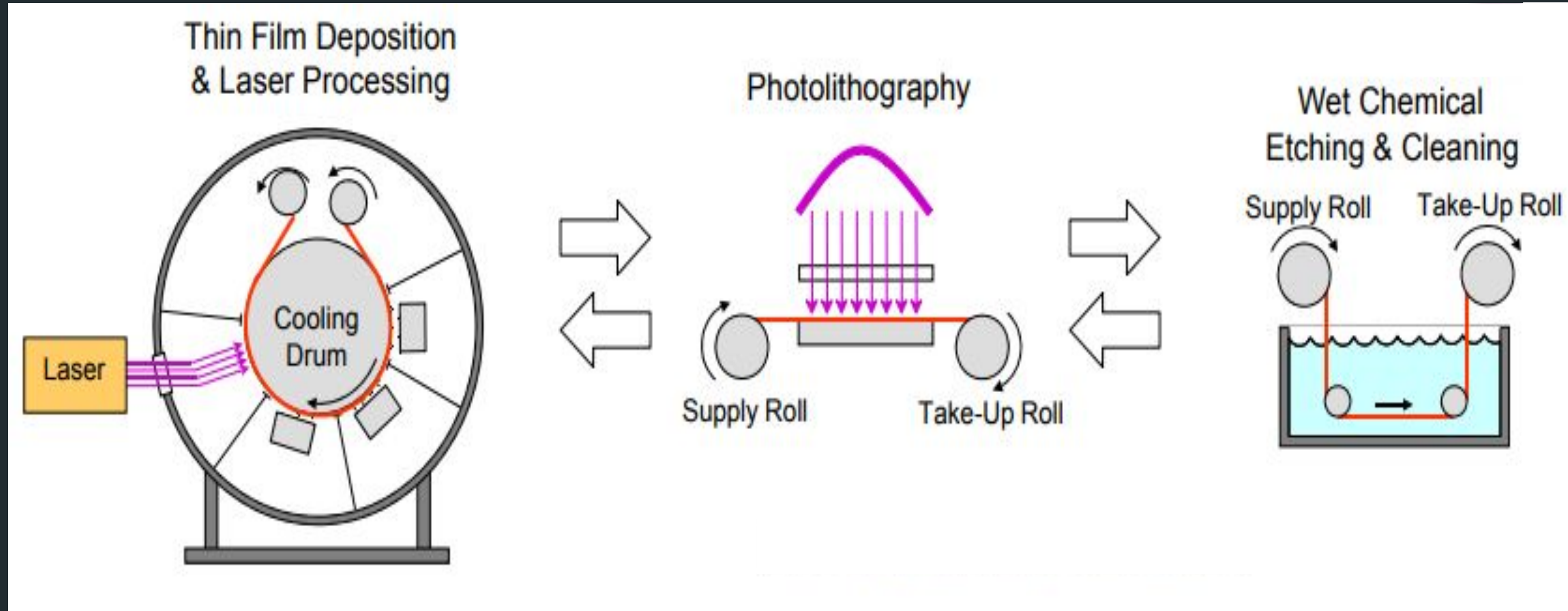
https://www.leadingedgepower.com/images/product/full/Flexible-solar-panel-100W-bent.jpg



https://phys.org/news/2011-02-carbon-nanotube-transistors-inexpensive-flexible.html

http://qeprize.org/createthefuture/oled-screens-technology-future/

Background: Fabrication



Courtesy of Binghamton University

Background: The Need for Thin Film Inspection

Defect Inspection:

Diameter of human hair:

17 - 181 μm

Current Lower Limits for Microelectronics Features:

Width: ~ .007 um = ~ 7nm

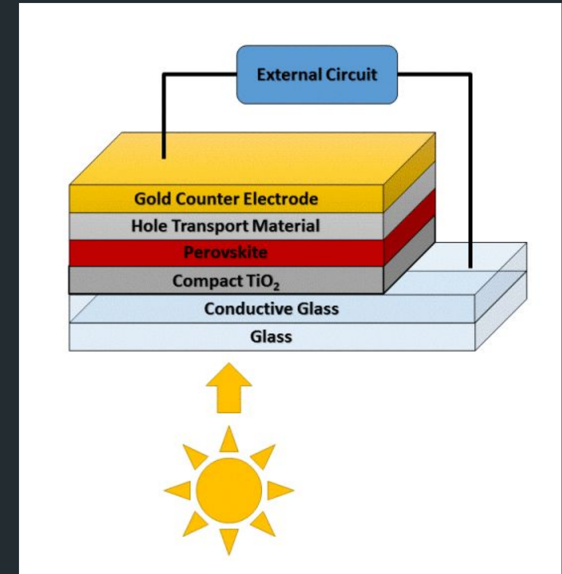
Height: ~ .001 μm = ~.1 nm

Defects may include:
Scratches, dust, skin cells, hair, or other ambient matter

Thickness Inspection:

$$R = \frac{\rho}{t} \frac{L}{W}$$

R : resistance
ρ : resistivity
t : film thickness
L : length
W : width



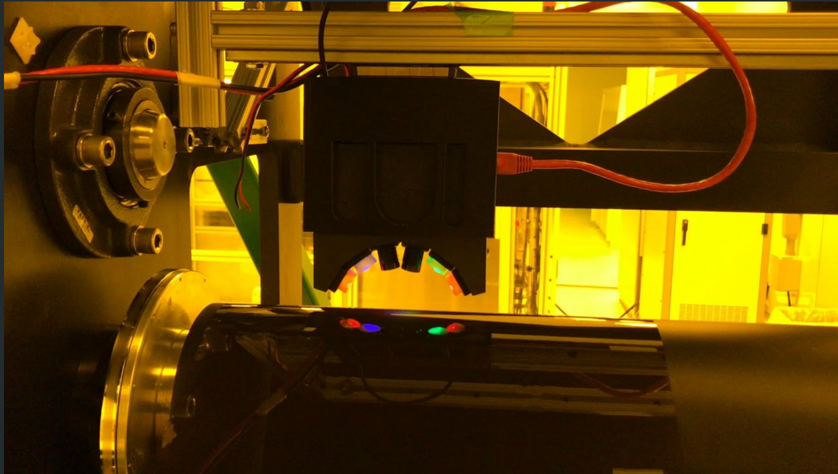
http://www.thesolarspark.co.uk/the-science/solar-power/thin-film/perovskite-solar-cells/

Project Scope: Requirements

Major System Requirement One: Defect Detection	**Major System Requirement Two: Thickness Reading**
The system shall be able to detect standard defects in roll material such as surface voids **(scratches, cracking, flaking)**, uneven material deposition, or contamination from particulate material.	The system shall be able to characterize roll material properties such as **thickness**, surface resistance, and index of refraction.

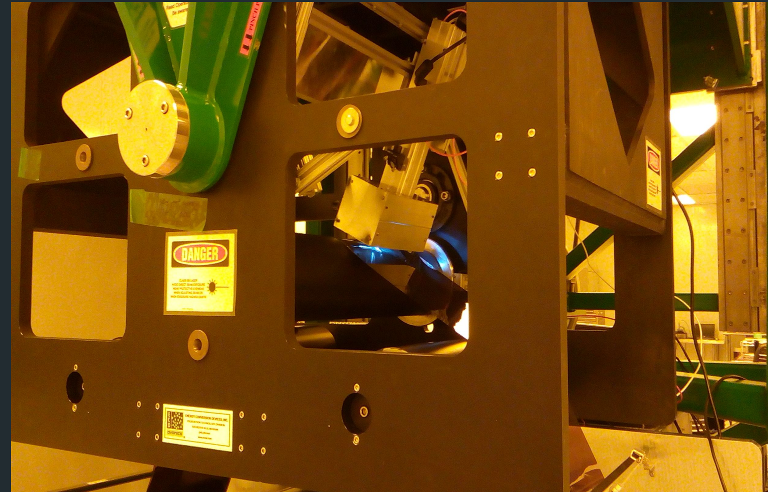
Project Scope: Equipment

Solution to Defect Detection Requirement



Tech: Raspberry PI; Light Scattering; Microscopy

Solution to Thickness Reading Requirement



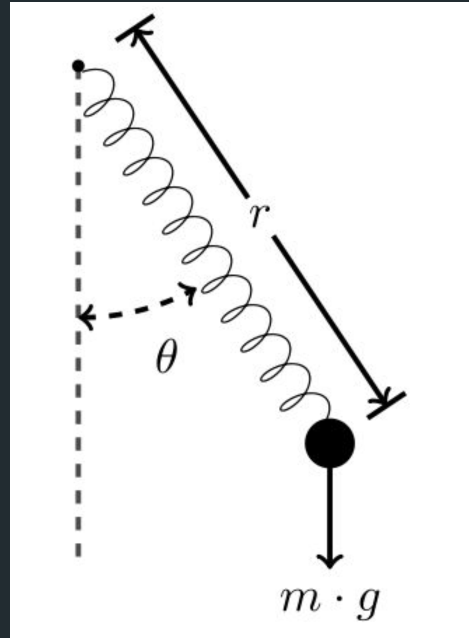
Tech: 400 - 730 nm light source; BitFlow spectrometer; 2X, 10X, 20X objective lens

Defect Detection: Optical Sensor Functionality

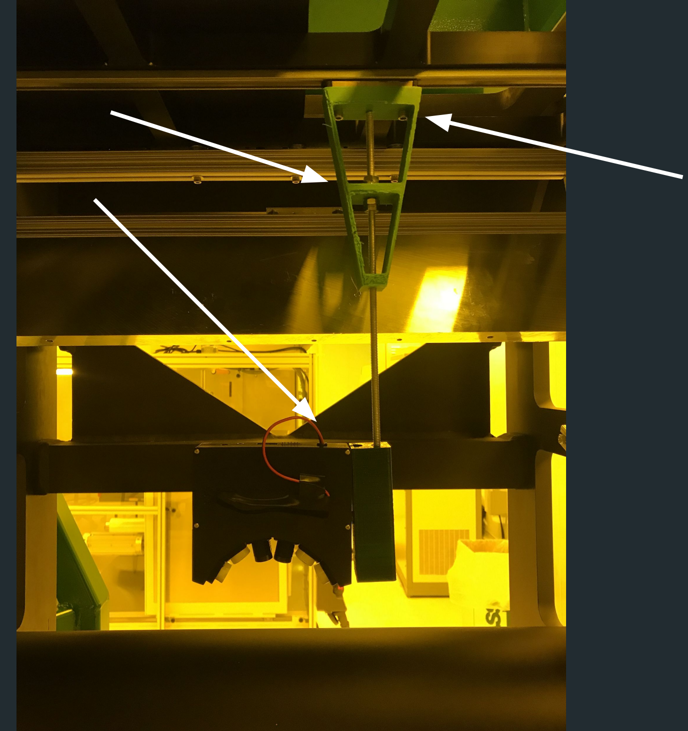
- Detects defects based on binary imaging threshold
- Characterizes defects based on:
  - Area
  - Eccentricity
  - Mean Intensity
- Challenges:
  - Low Usability
  - Must Verify System Accuracy

Defect Detection: Optical Sensor Mounting Fixture (Existing System)

- One point of contact
- Difficult Adjustment
- Loose connection



ths.rwth-aachen.de/wp-content/uploads/sites/4/research/HyPro/pics/spring_pendulum.png



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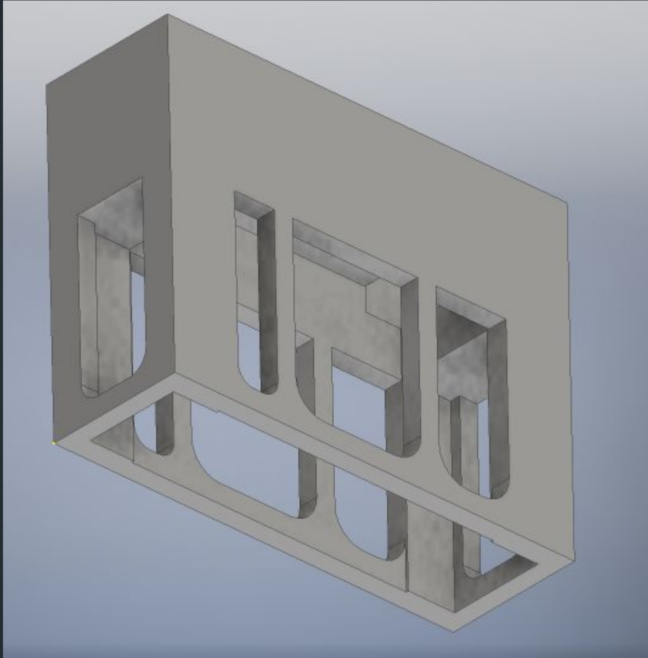
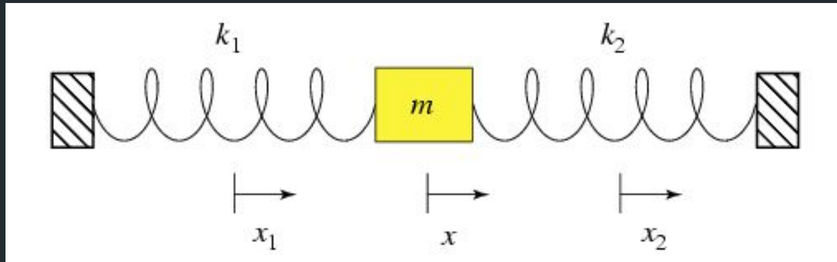
Defect Detection: Optical Sensor Mounting Fixture (Proposed)



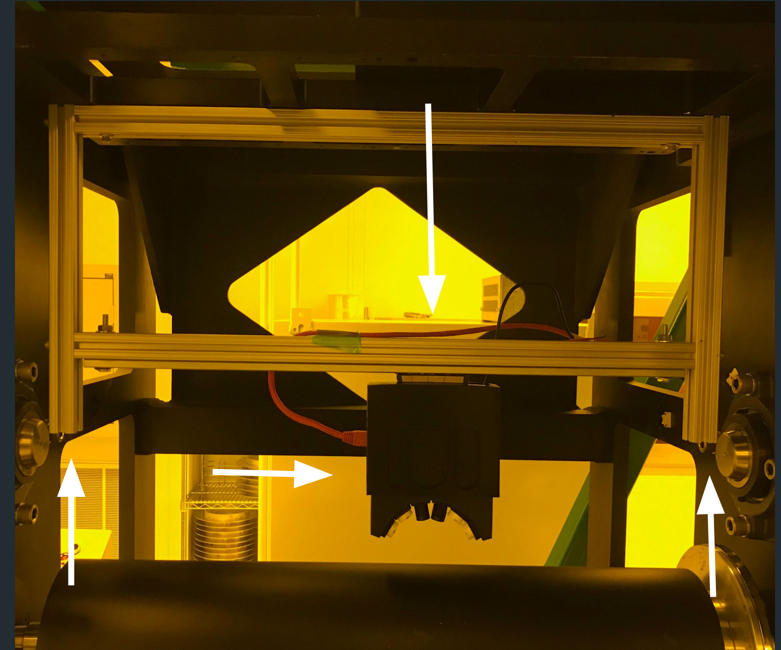
- Features:
  - Material: PLA
  - 30% Infill
  - Friction fit design
- Advantages
  - More stability
  - Low Cost
  - Easy installation and removal

Defect Detection: Optical Sensor Mounting Fixture (Implemented)

- More stability during rolling
- Much easier assembly/disassembly
- Two points of contact
- Easier adjustability



scienceworld.wolfram.com/physics/SpringsTwoSpringsandaMass.html



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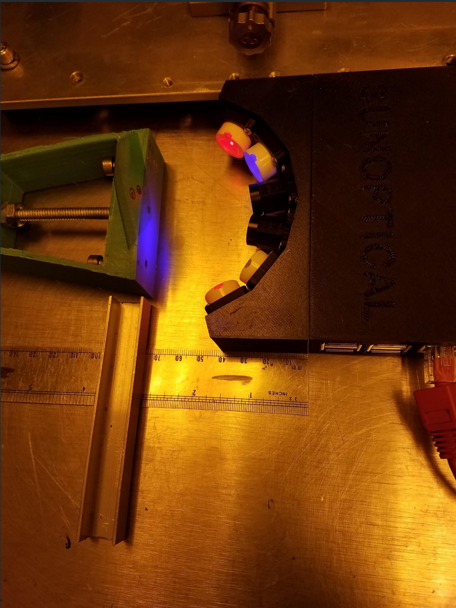
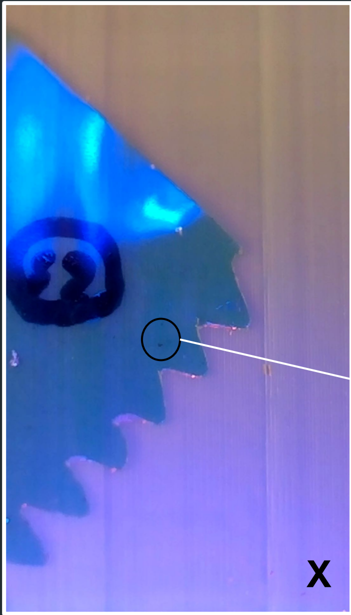
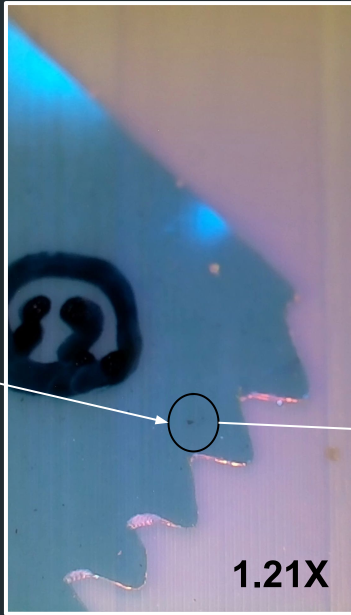
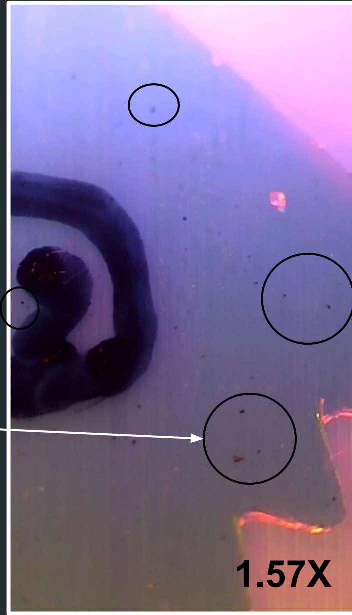
Defect Detection: Focal Range Characterization

Setup | 78.5mm | 65mm | 50mm



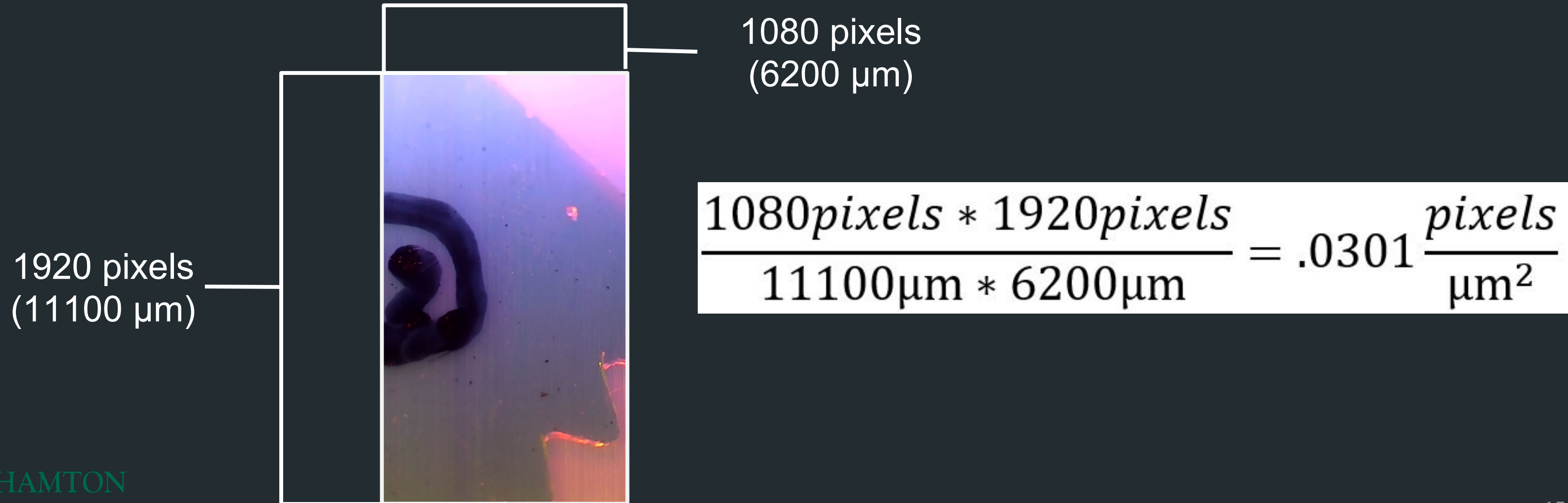






Defect Detection: Pixel Conversion

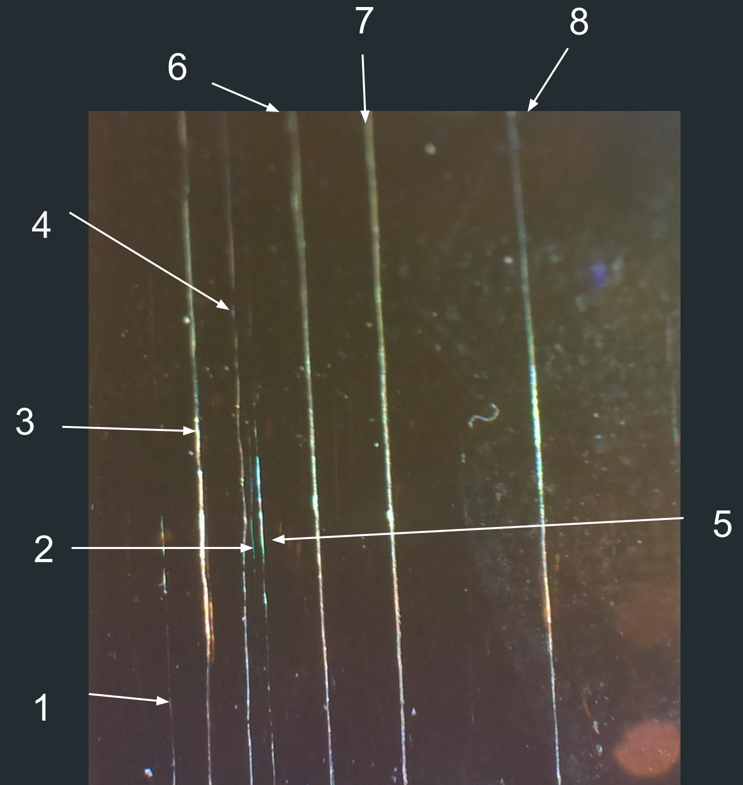
- Statistical analysis has the need for real world measurements
  - Relate the number of pixels to optical area in micrometers (µm)
  - Based on the sensor height, must be recalculated if the area changes



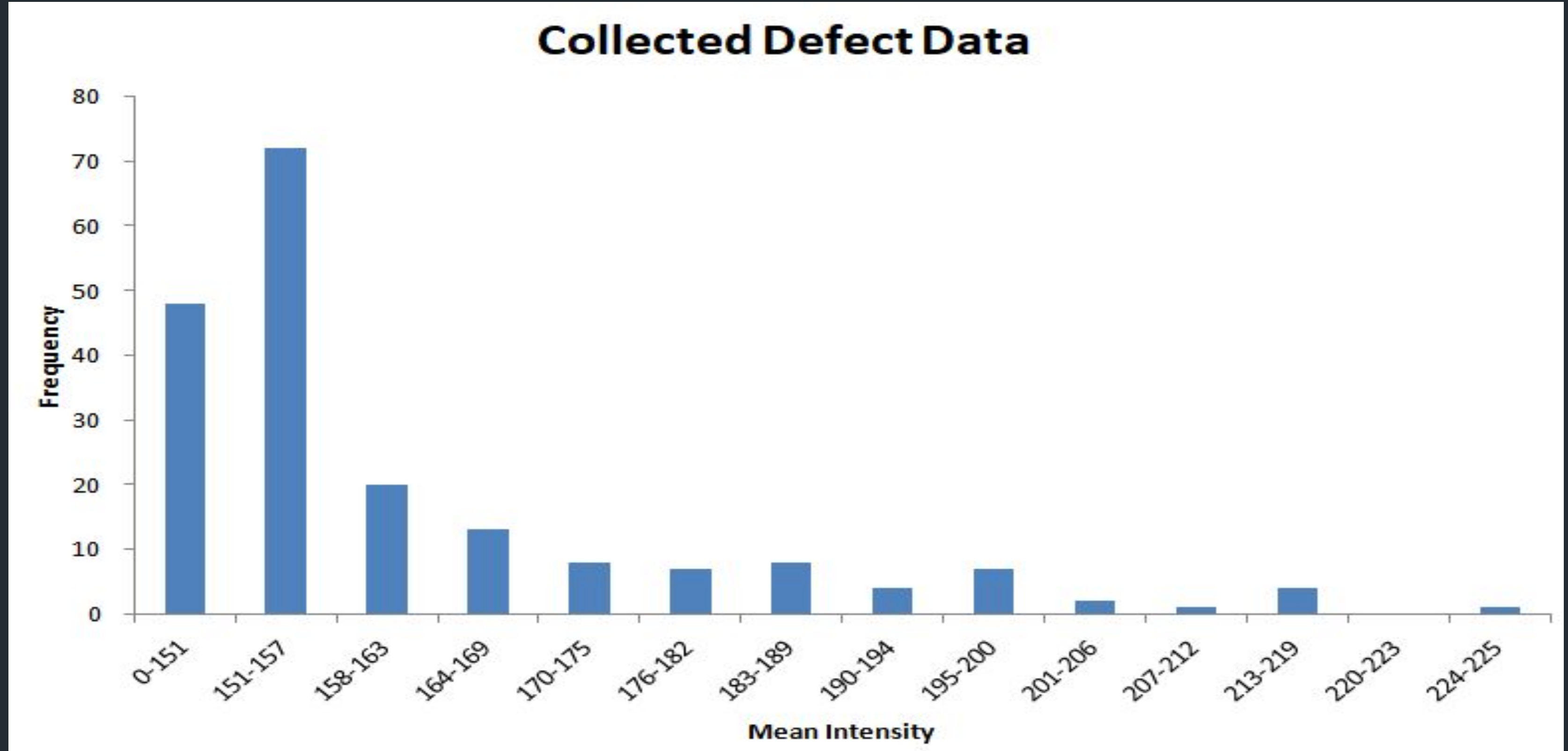
$$\frac{1080 pixels * 1920 pixels}{11100\mu m * 6200\mu m} = .0301 \frac{pixels}{\mu m^2}$$

Defect Detection:Testing & Verification

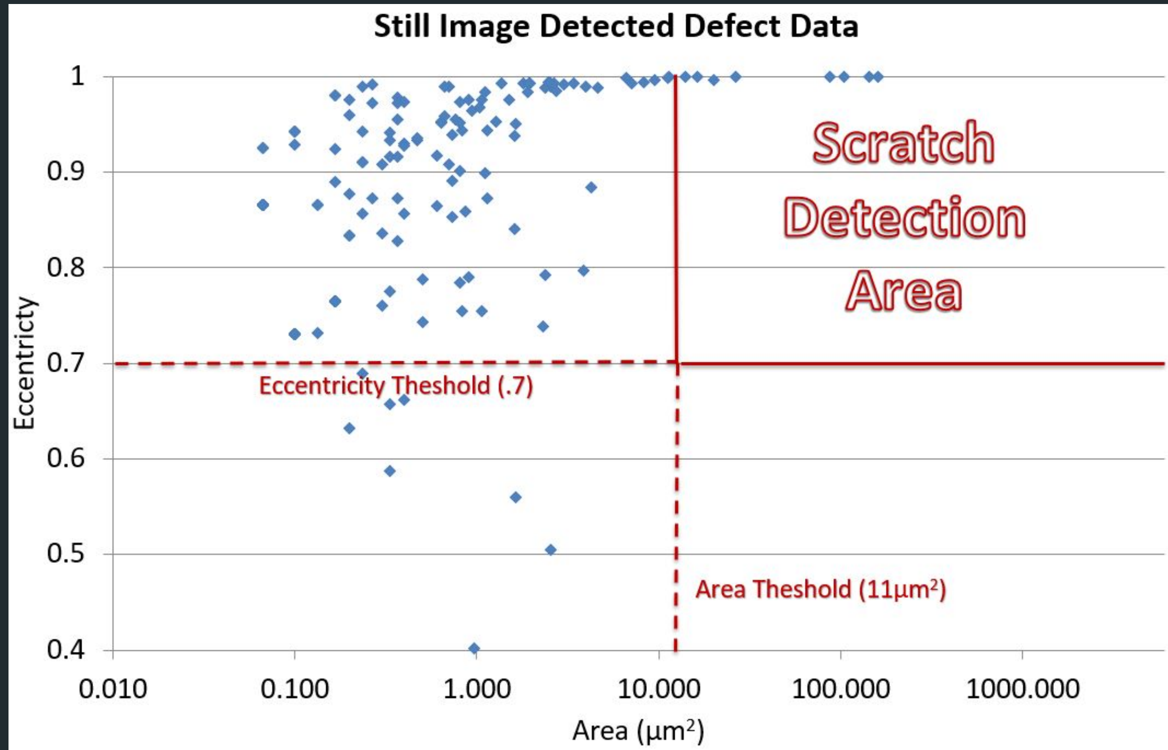
- Material:
    - Polyimide Upilex 125-S
- Thickness
    - 125μm
- Visually
    - 8 scratches



Defect Detection: Mean Intensity Histogram



Defect Detection: Image Detection Array



- Characterizes defects that have area > 11μm^2 and eccentricity > .7 as scratches
- All other data points are either insignificant or negligible

Defect Detection: MATLAB Output

```
Running analyze.m...
Done
The number of Scratches is: 8
The number of Particulates is: 0
>>
```

Defect #1 has
Diameter = 0.9 micrometers
Area = 20.174 micrometers^2
Eccentricity = 0.9968
MeanIntensity = 216.2318

Defect #2 has
Diameter = 1.9 micrometers
Area = 86.673 micrometers^2
Eccentricity = 0.9996
MeanIntensity = 230.5322

Defect #3 has
Diameter = 0.8 micrometers
Area = 16.299 micrometers^2
Eccentricity = 0.9997
MeanIntensity = 194.5758

Defect #4 has
Diameter = 1.1 micrometers
Area = 26.587 micrometers^2
Eccentricity = 0.9996
MeanIntensity = 213.2952

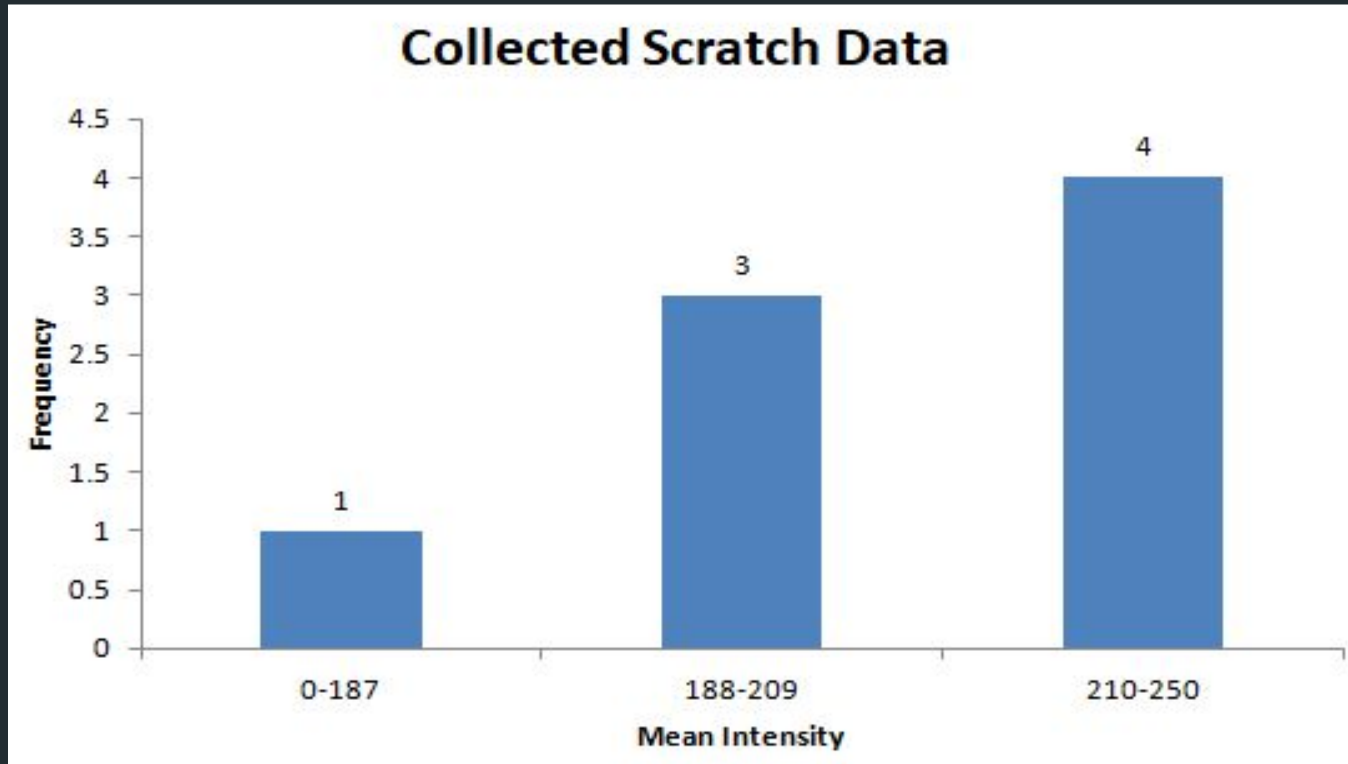
Defect #5 has
Diameter = 2.1 micrometers
Area = 103.707 micrometers^2
Eccentricity = 0.9999
MeanIntensity = 207.6860

Defect #6 has
Diameter = 2.6 micrometers
Area = 160.087 micrometers^2
Eccentricity = 1.0000
MeanIntensity = 203.4275

Defect #7 has
Diameter = 2.5 micrometers
Area = 144.289 micrometers^2
Eccentricity = 0.9999
MeanIntensity = 212.6468

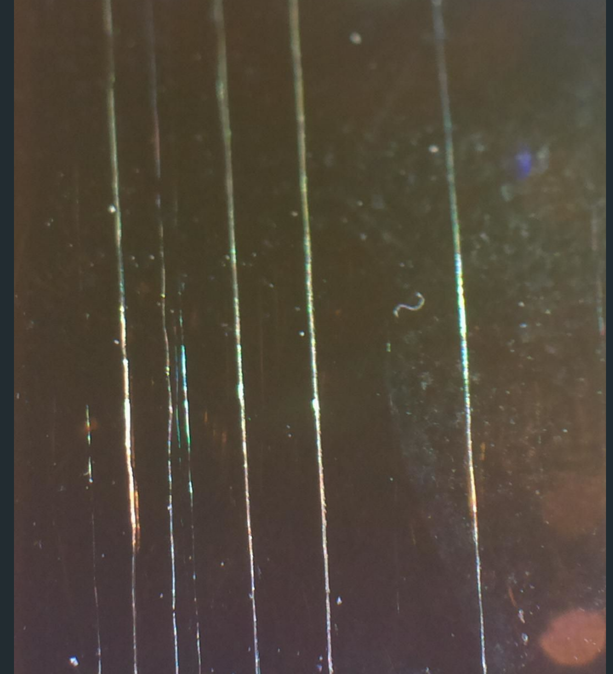
Defect #8 has
Diameter = 0.8 micrometers
Area = 13.928 micrometers^2
Eccentricity = 0.9993
MeanIntensity = 187.1775

Defect Detection: Collected Data Analysis



Defect Detection: System Verification

- Analytical and Diagnostics Laboratory
  - Wyko NT1100 Optical Profiling System
- Polyimide Sample
  - Three different scratches
- Goals: Optical Profiler Results
  - Use as a baseline for comparison and verification of Inspection Platform

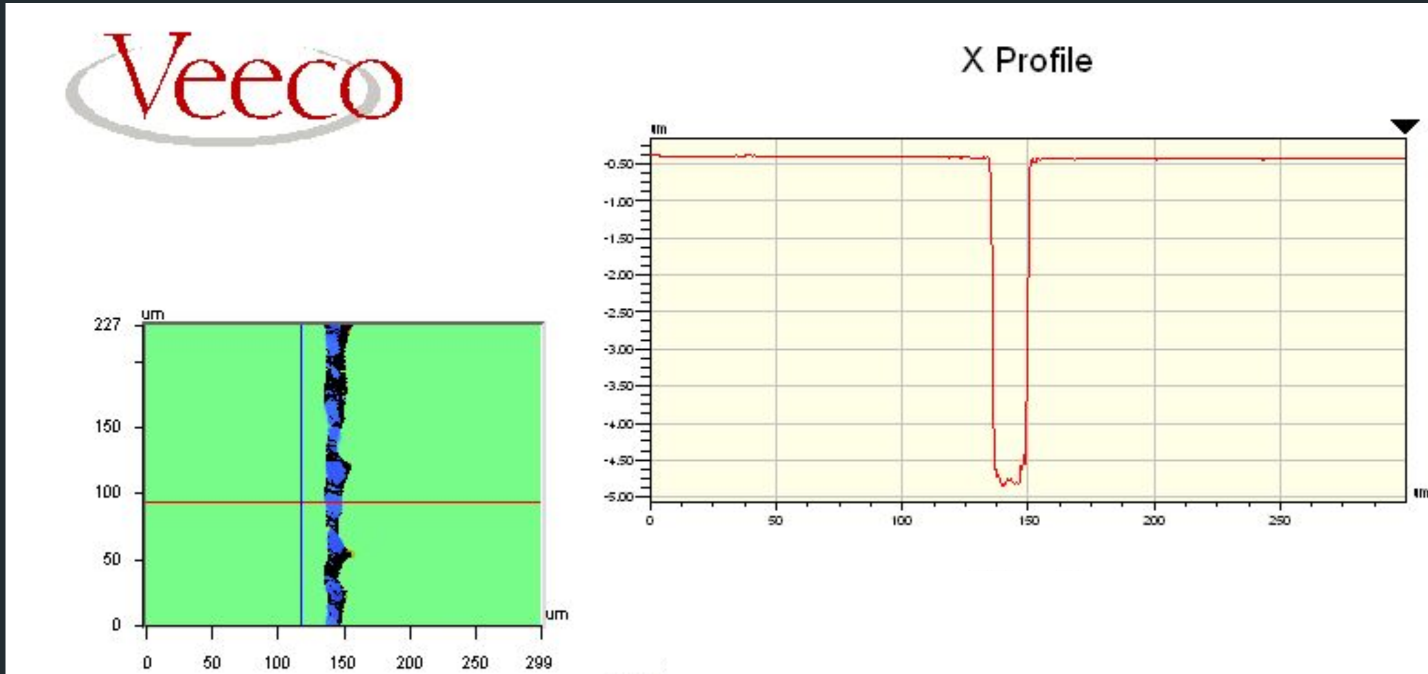


Defect Detection: Wyko NT1100 Optical Profiler

- Accurate Non-Contact Surface Metrology Machine
- Optical Phase Shifting and White Light Vertical Scanning
    - Measure vertical distances of hills and valleys
- Six Objective Zooms
    - 1.5X to 50X
- Five Field of View Lenses
    - 0.5X to 2.0X

cmi.epfl.ch/metrology/img/Wyko/NT1100.jpg

Defect Detection: Sample Optical Profiler Results

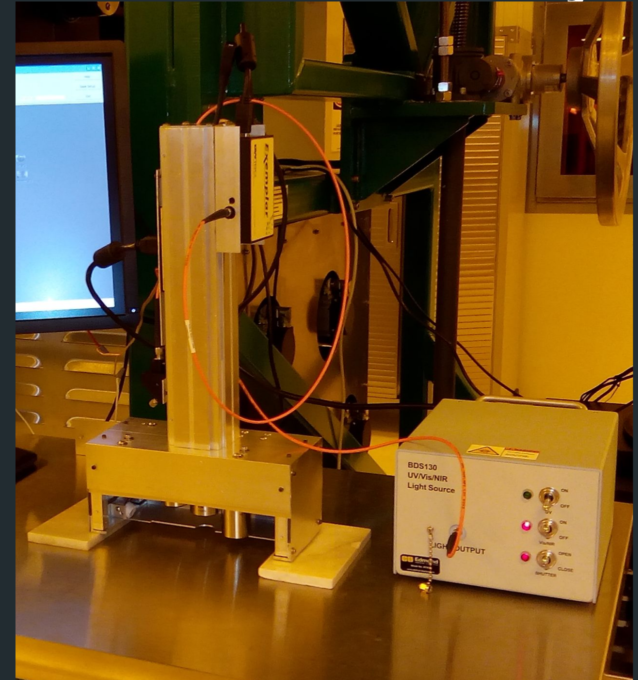


Defect Detection: System Verification

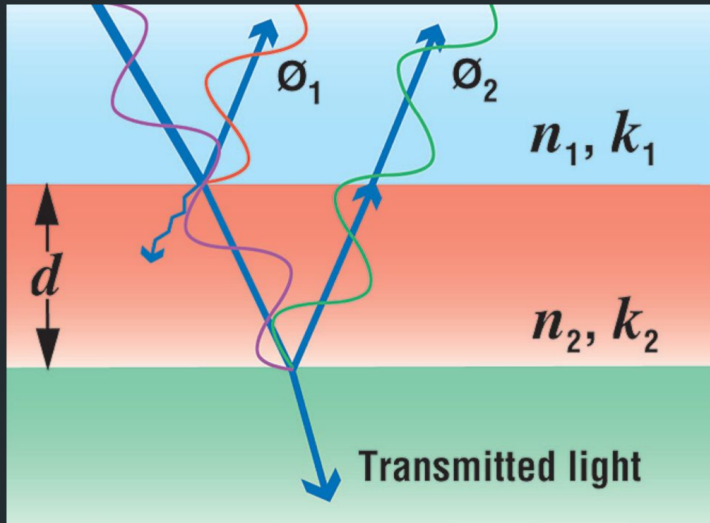
Defect	Optical Profilometer Measurement (μm)	ECD Inspection Platform Measurement (mean intensity)
2	2.08799	230.5322
6	1.44469	203.4275
8	1.044135	187.1775

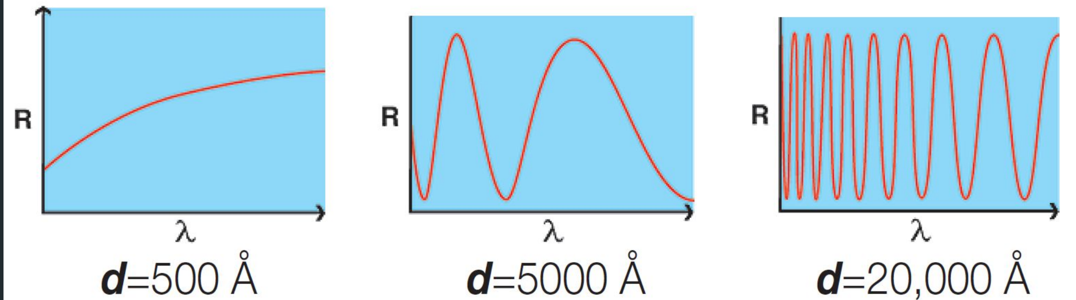
Thickness Reading: Spectroscopic Reflectometry

- SunOptical Inline Spectroscopic Reflectometer
- SiO_2 coated Si wafers for testing and calibration
- Filmetrics Reflectometer for verification



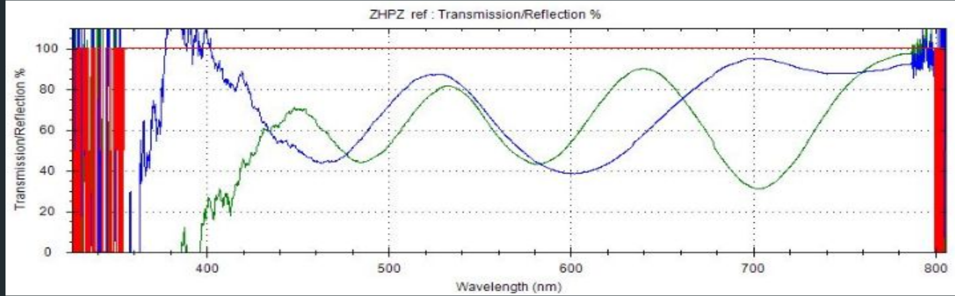
Thickness Reading: The Concept





Nenkov, M. R., Tamara, G.P., (2008). Determination of thin film refractive index and thickness by means of film phase thickness. *Central European Journal of Physics, 6*(2), 332-343.

Thickness Reading: Spectral Peaks Analysis



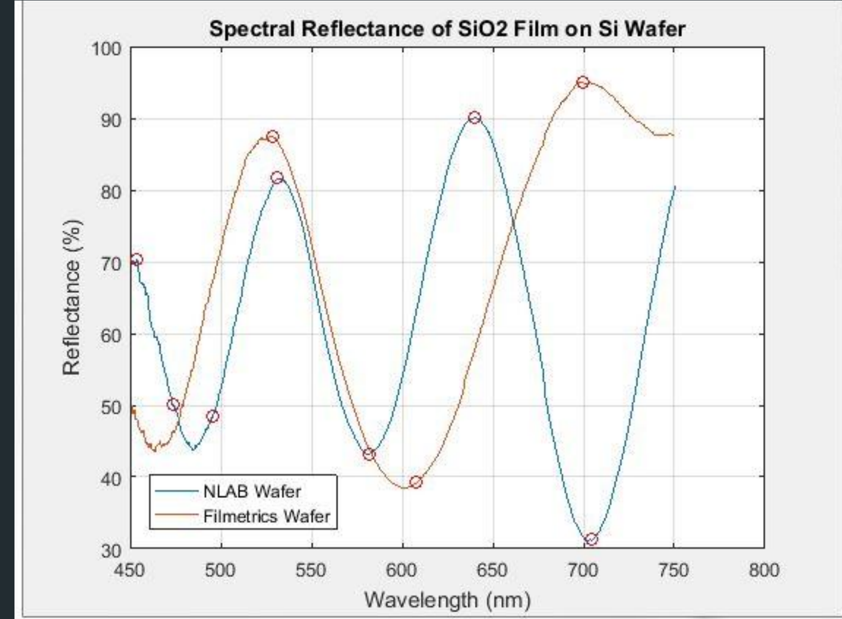
$$\frac{4\pi}{\lambda_1} * dn = 2\pi i$$

$$\frac{4\pi}{\lambda_2} * dn = 2\pi(i-1)$$

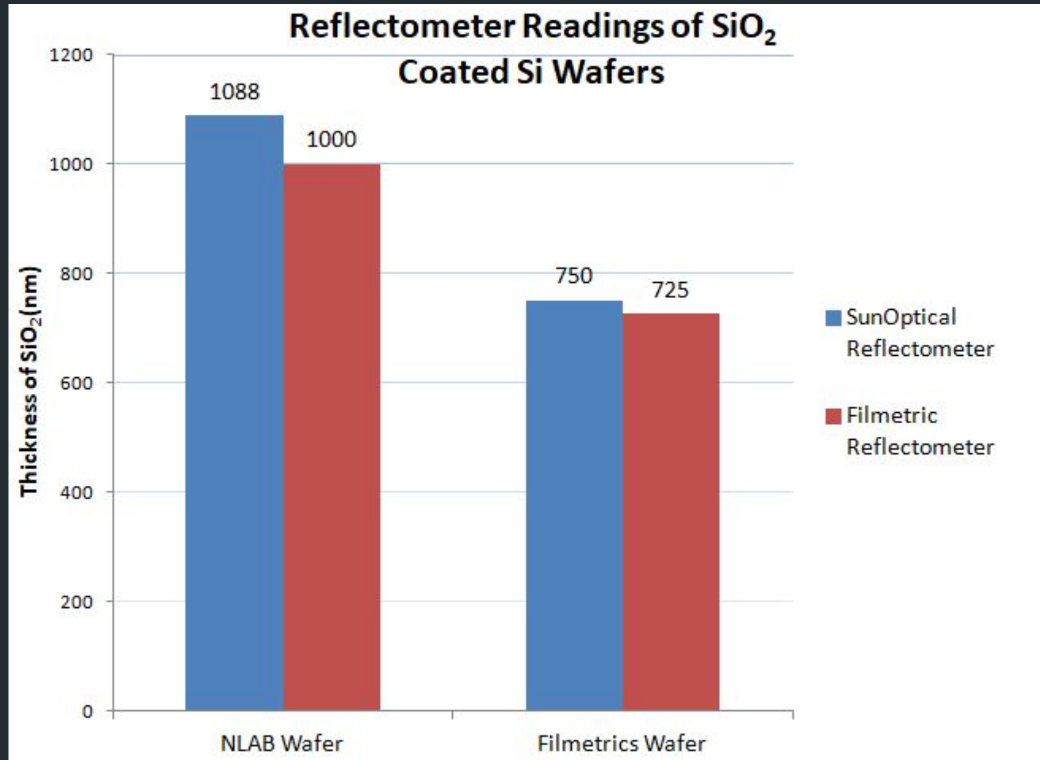
λ_1 : Wavelength of Peak One

λ_2 : Wavelength of Peak Two

d : Thickness
n : Index of Refraction
i : Wavenumber

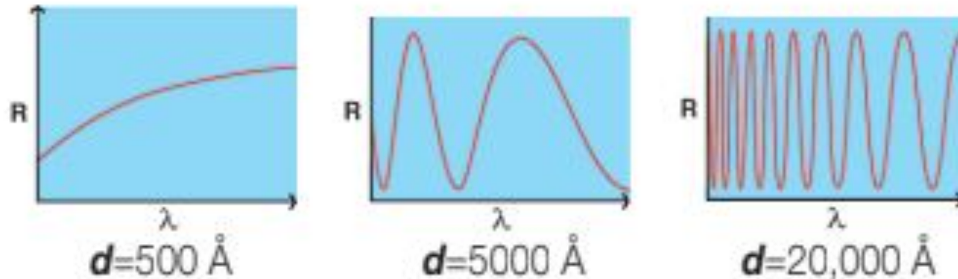


Thickness Reading: Margin of Error



Material	Error (%)
NLAB Wafer	8.8
Filmetric Wafer	3.4

Thickness Reading: Future Modeling



In the thinnest case (far left),

Intermediate Modeling Step is required to create at least two peaks

$$R = A + B * \cos\left(\frac{4\pi}{\lambda}\right) * nd$$

A, B : Fitting Parameters
Lambda : Wavelength

n : Index of Refraction
d : Film Thickness

Nenkov, M. R., Tamara, G.P., (2008). Determination of thin film refractive index and thickness by means of film phase thickness. *Central European Journal of Physics, 6*(2), 332-343.

Project Budget

Item	Original Estimate ($)	Actual to Date ($)
Defect Sensor *	3434.00	3434.00
Reflectometer *	7895.00	7895.00
Mount Redesign	100.00	21.50
Optical Profilometer Usage	200.00	180.00
Total	11629.00	11530.5

*Note: Sensors were already purchased prior to project start

Conclusions

- Developed and Analyzed Inspection Process for Roll to Roll Microelectronics
  - Defect sensor tested and analyzed (Requirement One)
    - Improved sensor casing and fixture
    - Verified the defect detection accuracy
  - Reflectometer tested for base case (Requirement Two)
- Remained Under Budget

References

www.hypertextbook.com/facts/1999/BrianLey

www.filmetrics.com/thicknessmeasurement/f20

Filmetrics, Inc. (2012). Understanding Film-Thickness Measurements. Retrieved April 03, 2018, from https://www.filmetrics.com/technology

Nenkov, M. R., Tamara, G.P., (2008). Determination of thin film refractive index and thickness by means of film phase thickness. *Central European Journal of Physics, 6*(2), 332-343.

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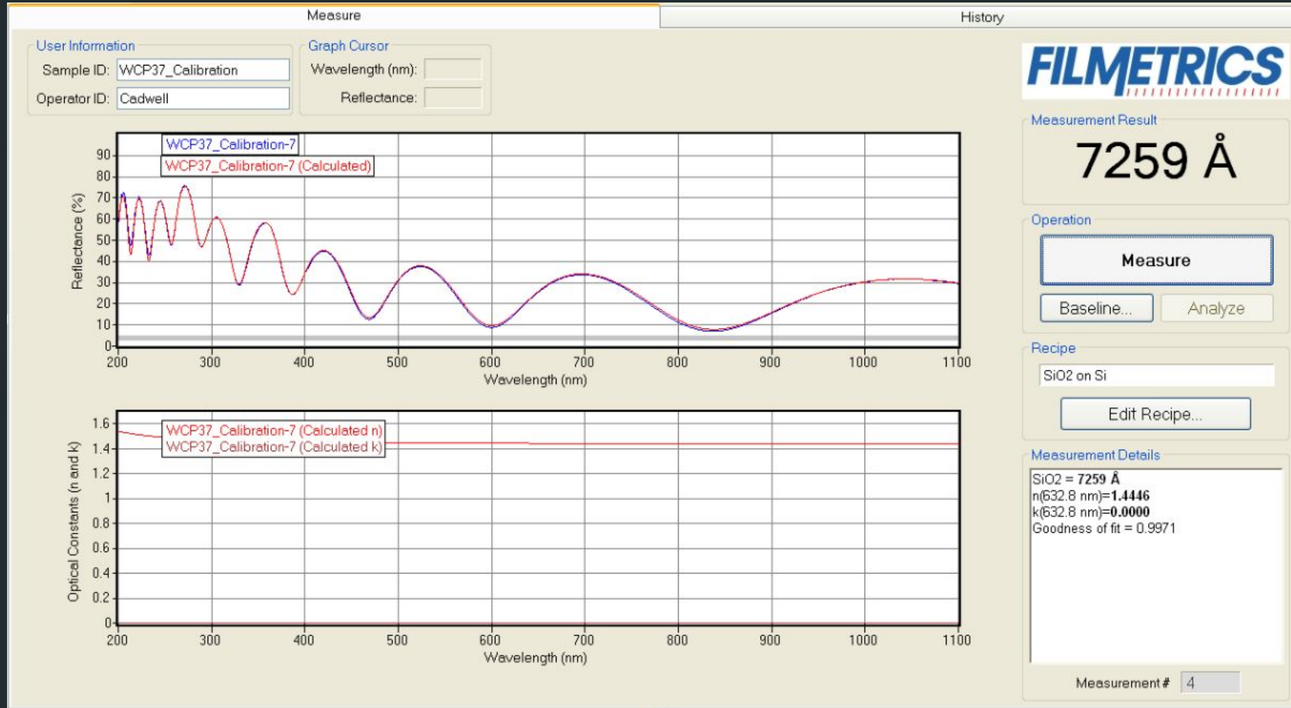
Watson Staff/Faculty

FAQ

Spectroscopic Reflectometer: Baseline



- Verification Reading
- Index of Refraction found for our SiO2 test sample