J.A. Woollam

ADVANCED TOPICS & REVIEW

SESSION 6

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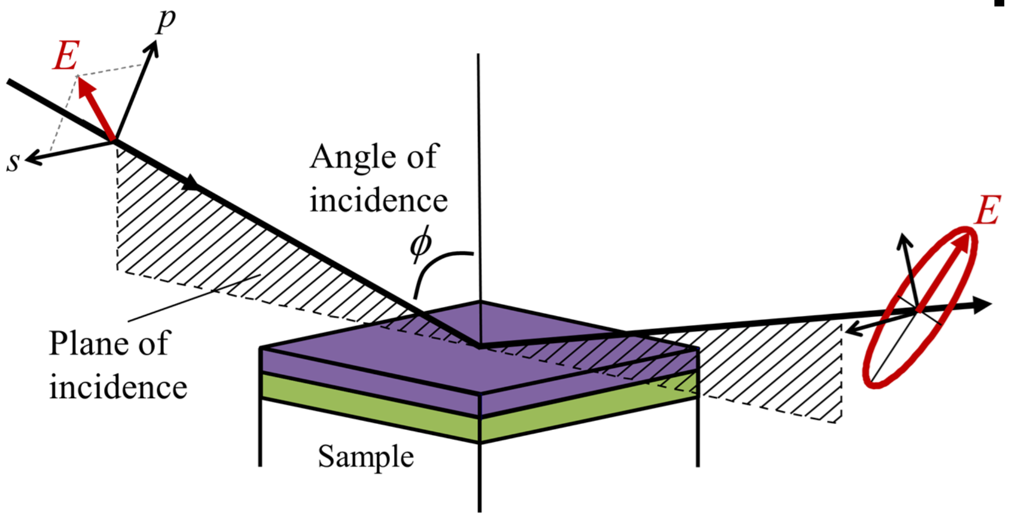
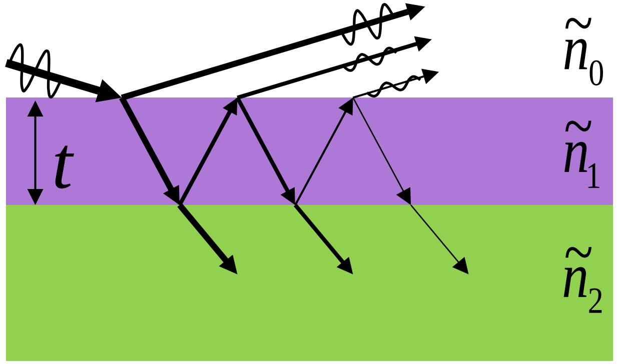
March 2025

COURSE OUTLINE

- Session 1: Introduction to Ellipsometry
- Session 2: Transparent Materials
- Session 3: Materials with Absorption (B-Spline)
- Session 4: Materials with Absorption (Gen-Osc)
- Session 5: Thin Absorbing Films & Multi-Sample Analysis
- **Session 6: Advanced Topics and Review**



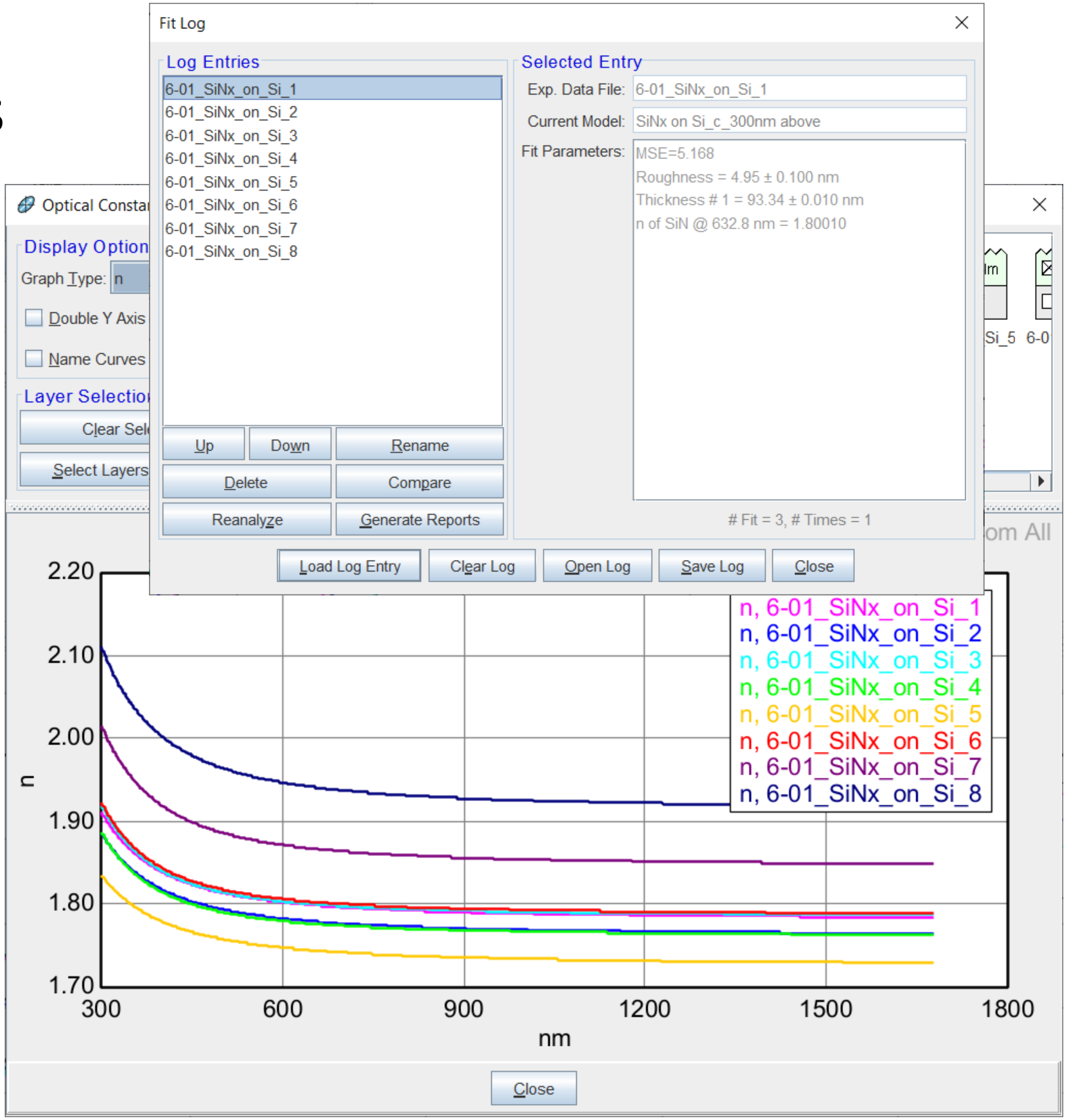


SESSION 6 OUTLINE

- Advanced Topics:
  - #1: Fit Log and Batch Analysis
  - #2: Mapping Data
  - #3: In-Situ Dynamic Data
- REVIEW

Topic #1: Batch Analysis

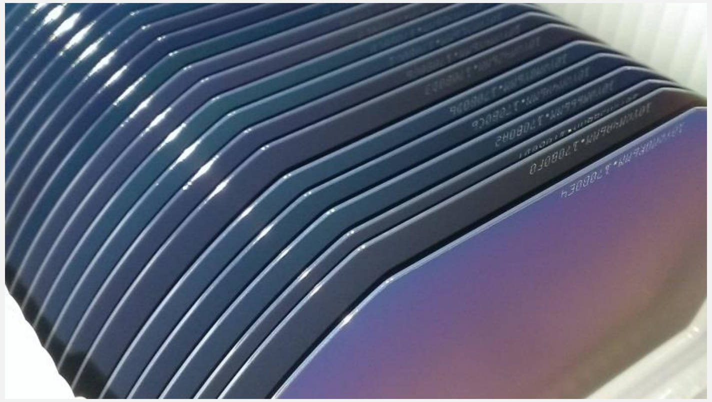
- Automate analysis of multiple data-sets
- Suitable for analyzing and comparing similar samples



- Set up flexible model.
- Analyze multiple data sets
- Report and compare results

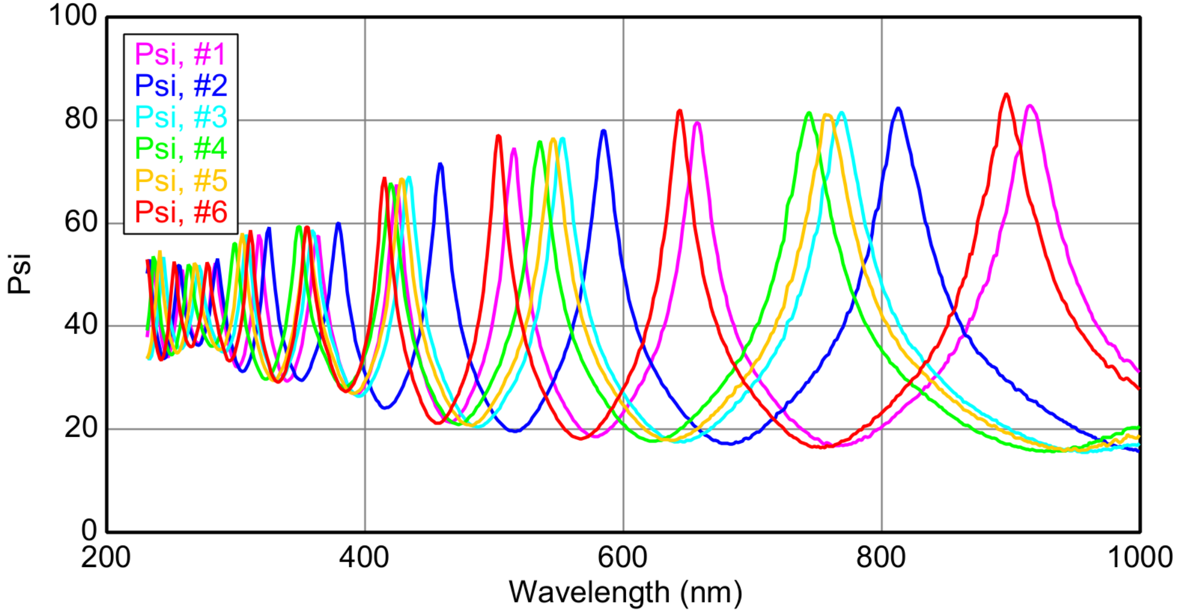
6-01 SiNx on Si (Batch Analysis)

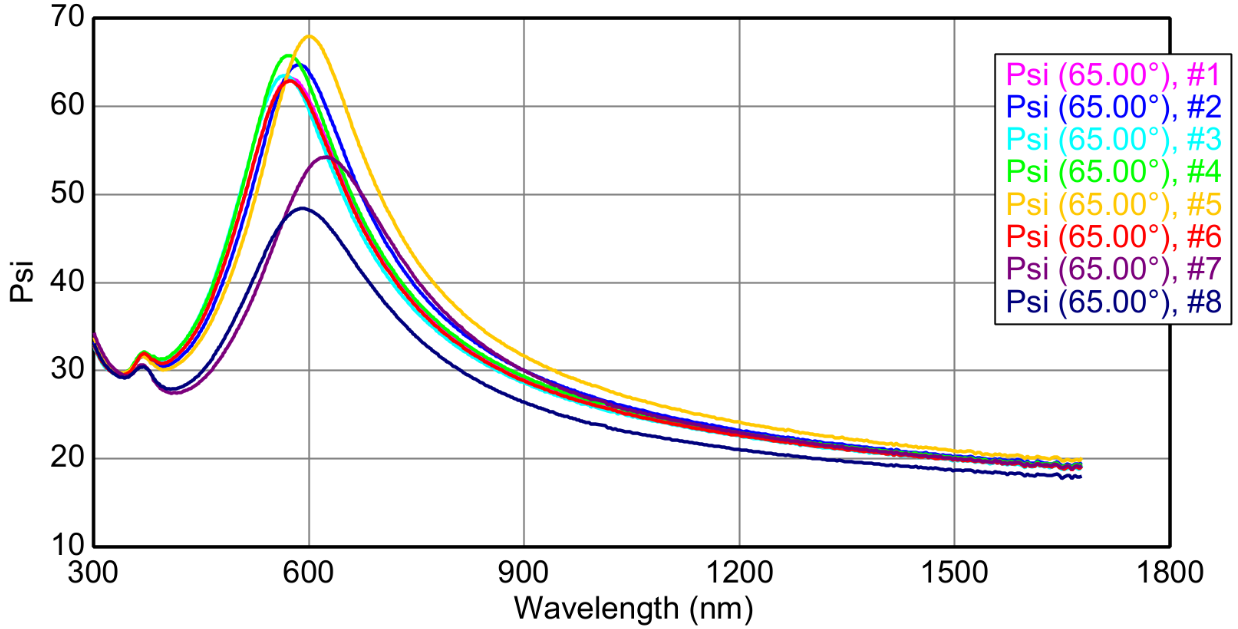
- **Build model & analyze all 8 data sets for thickness and index at 633 nm.**



- Compare table of thicknesses and index at 633 nm.
- Compare index spectra for all wafers.

PREVIEW OF RAW DATA

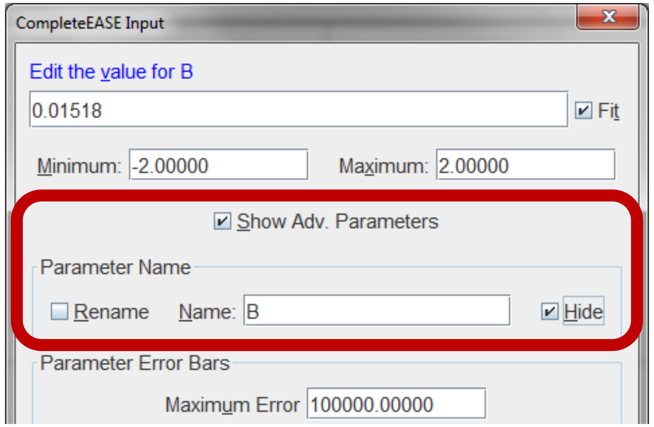




- Observe data spread and variations to guide model setting strategy
  - Thickness and/or refractive index?

PREPARING MODEL FOR AUTOMATION

- Make sure it fits all data.
  - Thickness Pre-fit
  - Global Fit
  - Limit Wavelength range / Angles for fit
- Customize what to report.
  - Rename / Hide Fit Parameters
  - Add Derived Parameters
- Save the model



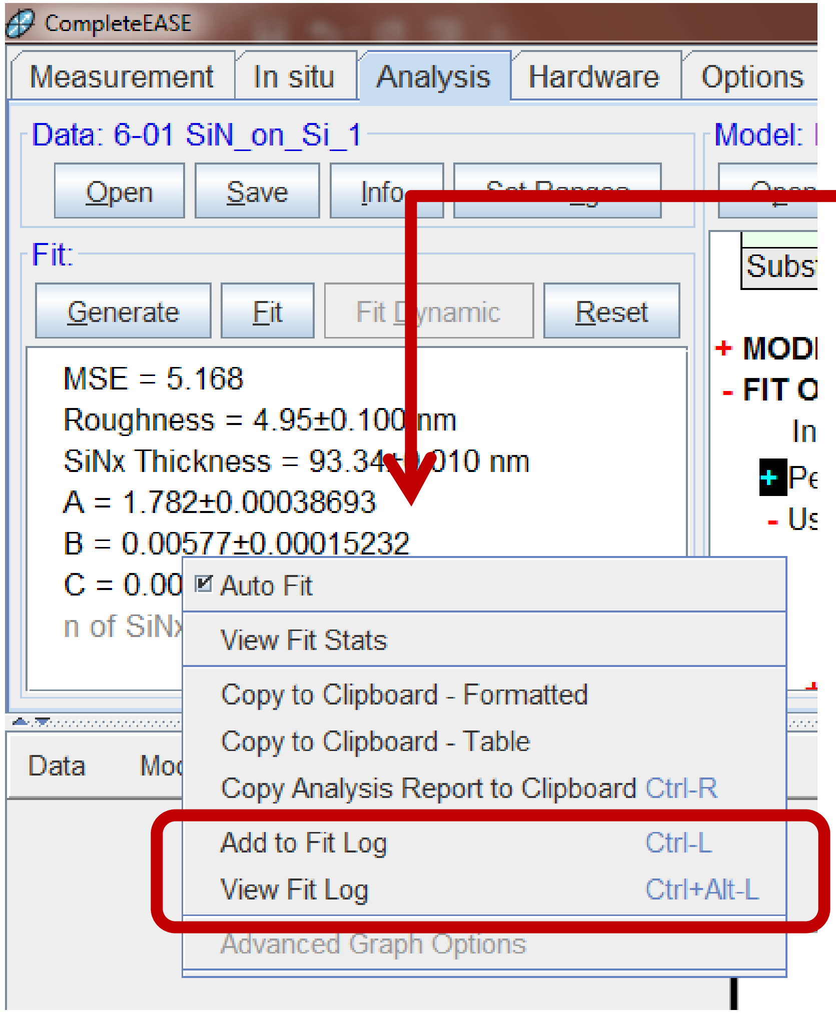
Roughness = 4.95 nm (fit)
- Layer # 1 = Cauchy Film Thickness # 1 = 93.34 nm (fit)
  A = 1.782 (fit) B = 0.00576 (fit) C = 0.00053061 (fit)
  + Urbach Absorption Parameters

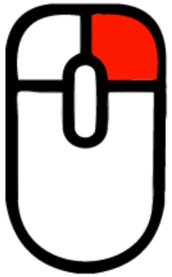
Substrate = SI_JAW

+ MODEL Options
- FIT Options
  + Perform Thickness Pre-Fit = ON
  - Use Global Fit = ON
    Parameters: Add Delete All
    x Param. #1 = A
    Min. = 1.500 Max. = 2.500 # Guesses = 10
    + Customize Global Fit
  Fit Weight = N,C,S
  Limit Wvl. for Fit = ON Range = 300.0 nm - 1700.0 nm
  Limit Angles for Fit = OFF
  Max. Acceptable MSE = 100.000
  - Include Derived Parameters = ON
    Add Derived Parameter
    1: Type = n Layer # = 1 Wavelength = 632.8 nm Name = n of SiN @ 632.8 nm
    # of Decimal Places = 5
    Low Spec. = 0.00 High Spec. = 0.00

Set Max. Acceptable MSE to warn when fit fails

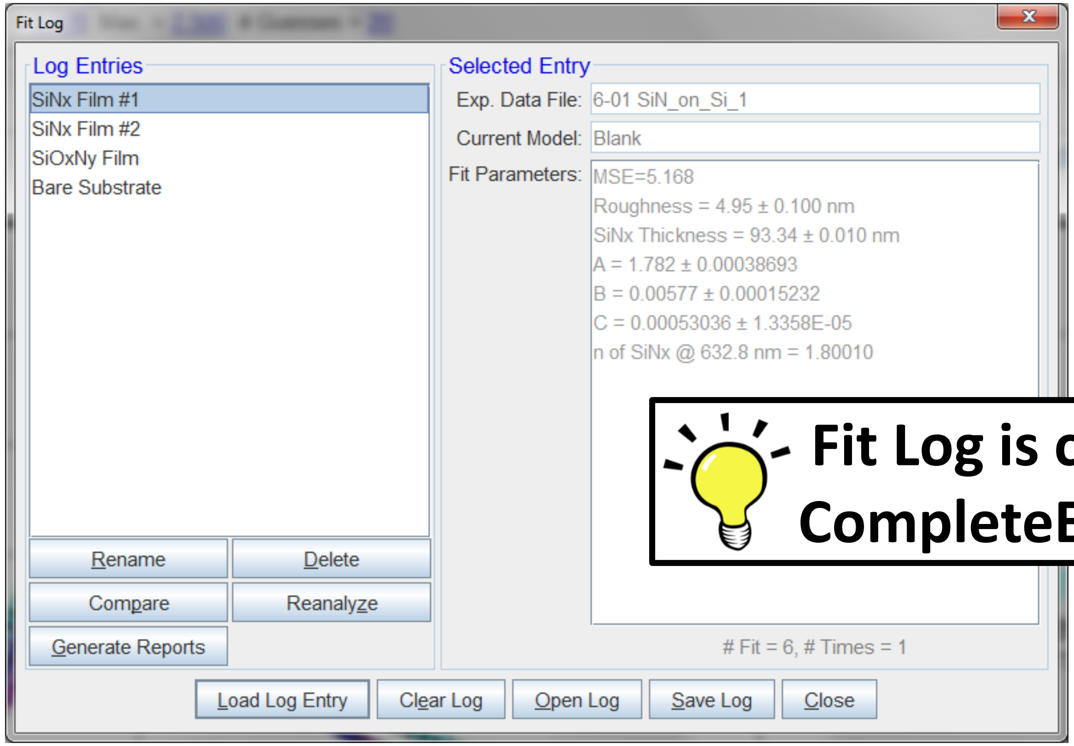
FIT LOG





Right-click in fit panel:

- Add to Fit Log (Ctrl-L)
- View Fit Log (Ctrl+Alt-L)

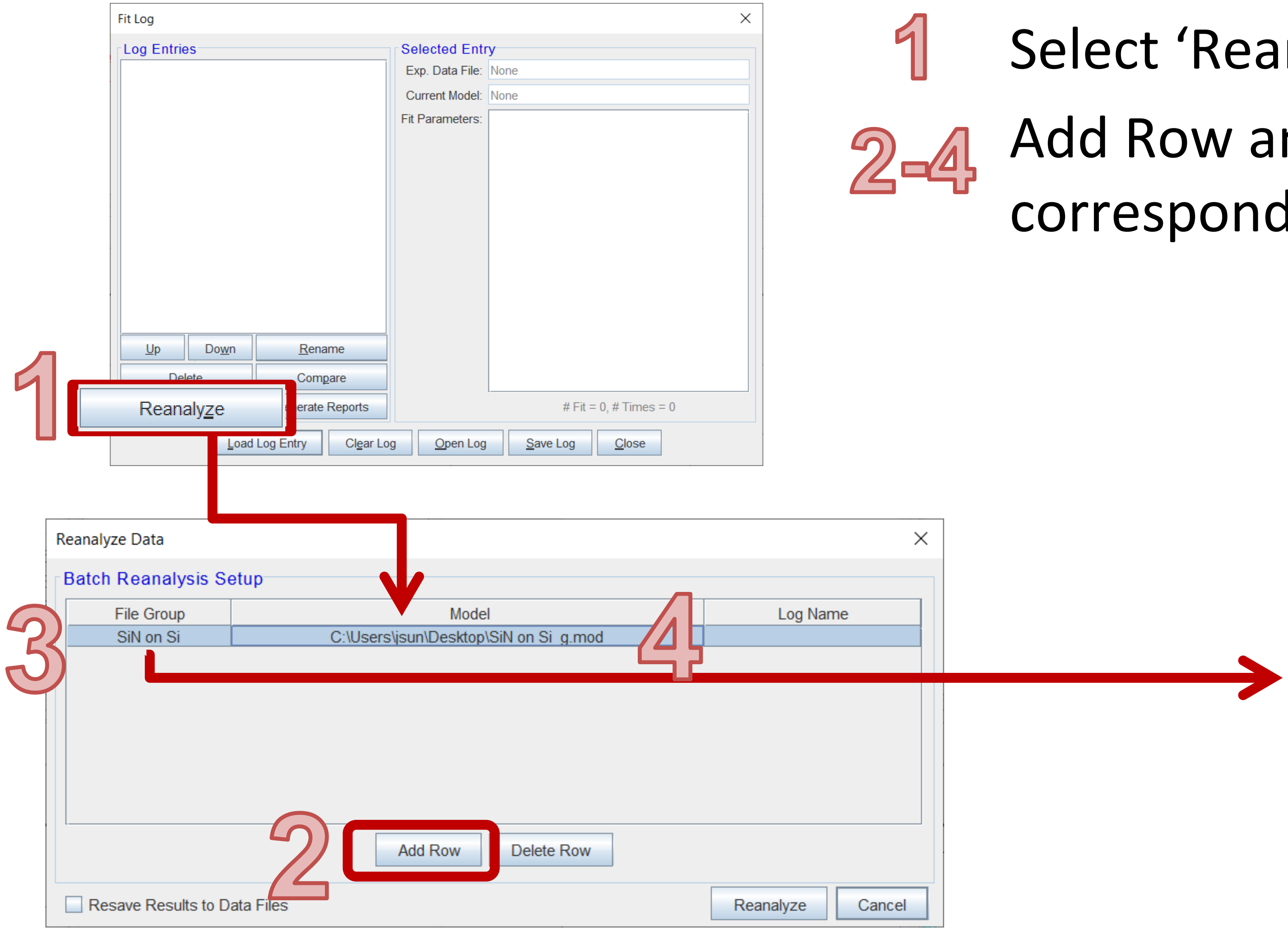


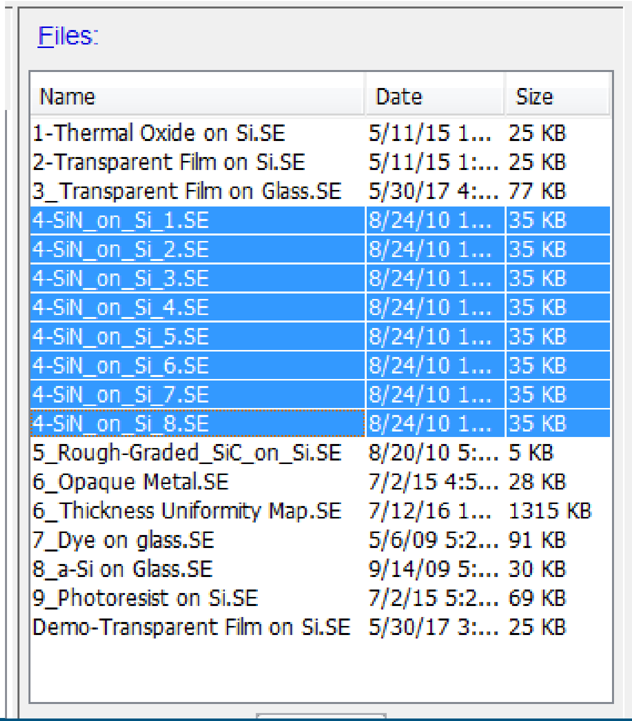
Fit Log is cleared when CompleteEASE is closed

BATCH ANALYSIS (FROM FIT LOG)

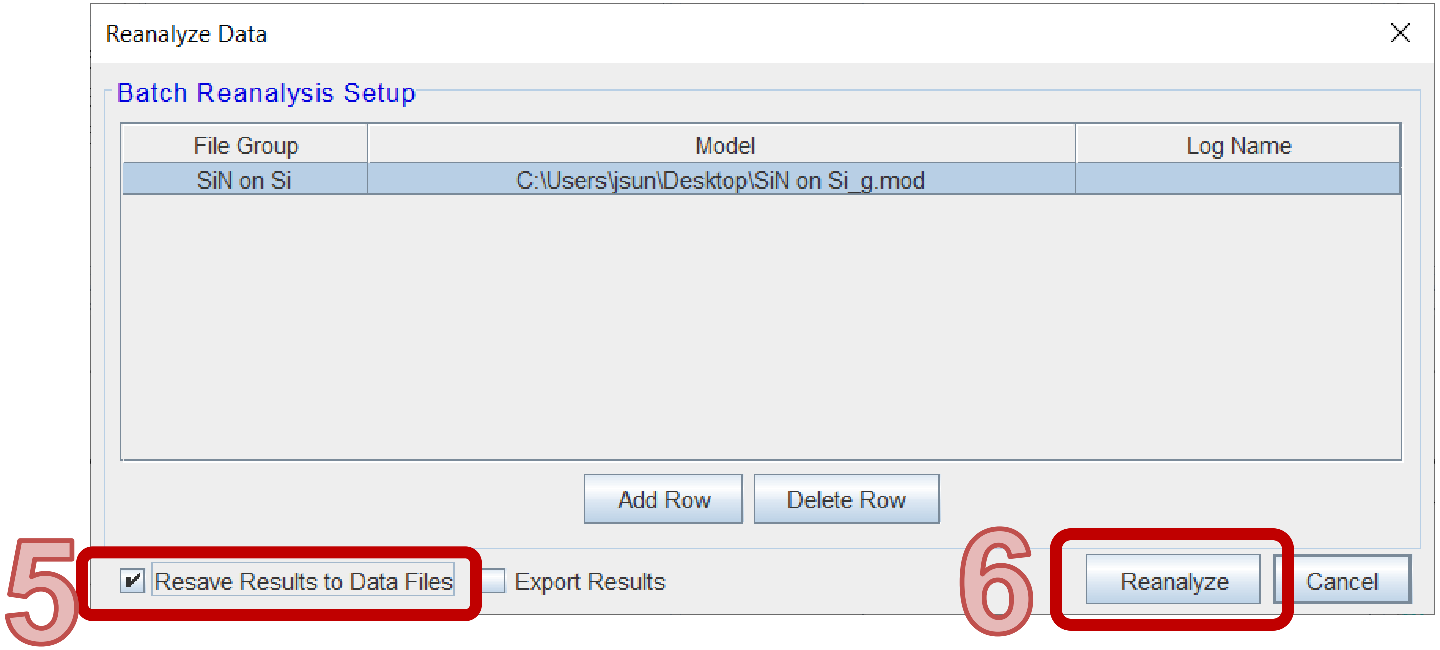
1 Select ‘Reanalyze’ from Fit Log

2-4 Add Row and populate with data sets & corresponding model.





BATCH ANALYSIS (FROM FIT LOG)



5 - optional

"Resave Results to Data Files" will add fit results to data files

- It will overwrite previous fit results saved with the raw data
- Be sure to rename files if overwritten is not desirable

6 "Reanalyze": fit all data sets to the corresponding model and add results to the Fit Log.

6-01 SiNx on Si "Batch": Results

Roughness = 3.95 nm (fit)
- Layer # 1 = SiNx SiNx Thickness = 87.64 nm (fit)
  A = 1.915 (fit) B = 0.00932 (fit) C = 0.00075636 (fit)
  + Urbach Absorption Parameters
Substrate = Si_JAW

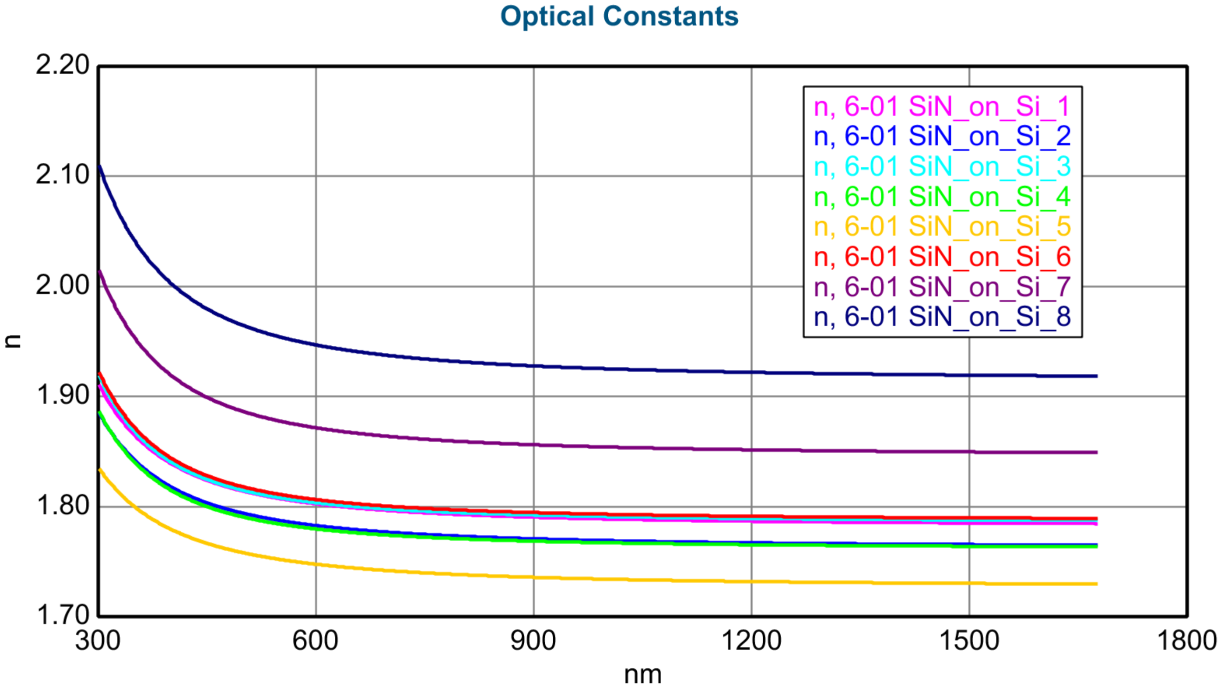
Comparison

Entry Comparison Table

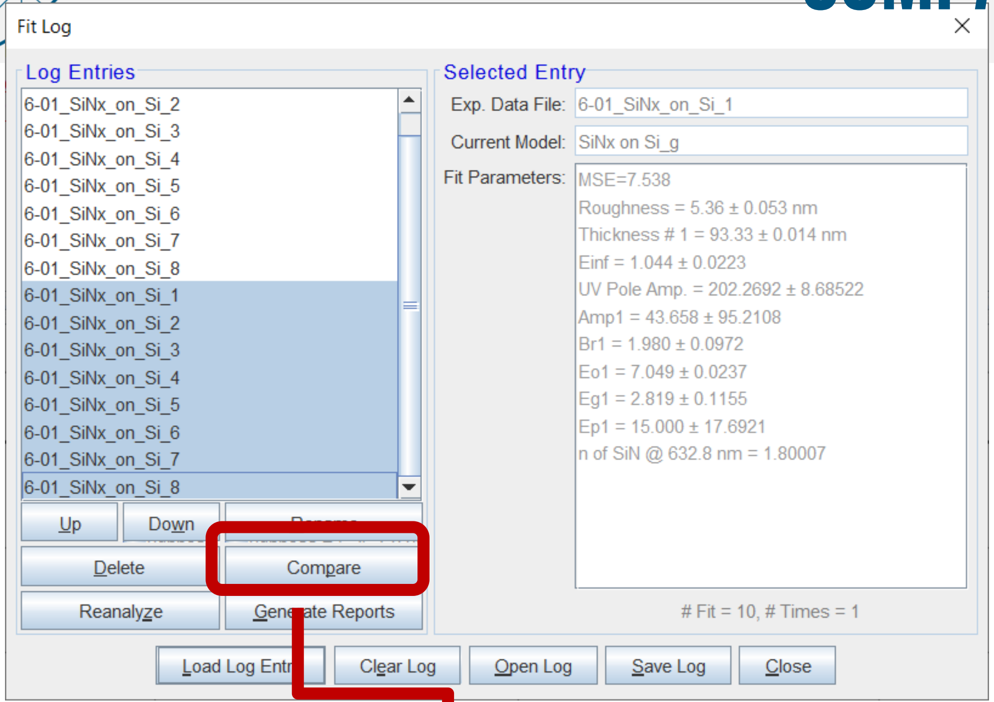
	MSE	SiNx Thickness (nm)	Roughness (nm)	n of SiNx @ 632.8 nm
6-01 SiN on Si 1	5.168	93.34	4.95	1.80010
6-01 SiN on Si 2	5.168	96.50	4.60	1.78035
6-01 SiN on Si 3	7.147	92.09	5.46	1.80121
6-01 SiN on Si 4	6.566	94.44	4.96	1.77741
6-01 SiN on Si 5	3.886	101.45	4.43	1.74532
6-01 SiN on Si 6	6.822	92.96	5.10	1.80391
6-01 SiN on Si 7	7.059	96.95	4.72	1.86848
6-01 SiN on Si 8	6.196	87.64	3.95	1.94308
Average	6.00124	94.421	4.771	1.81498
Std. Dev.	1.15414	4.049	0.456	0.06241

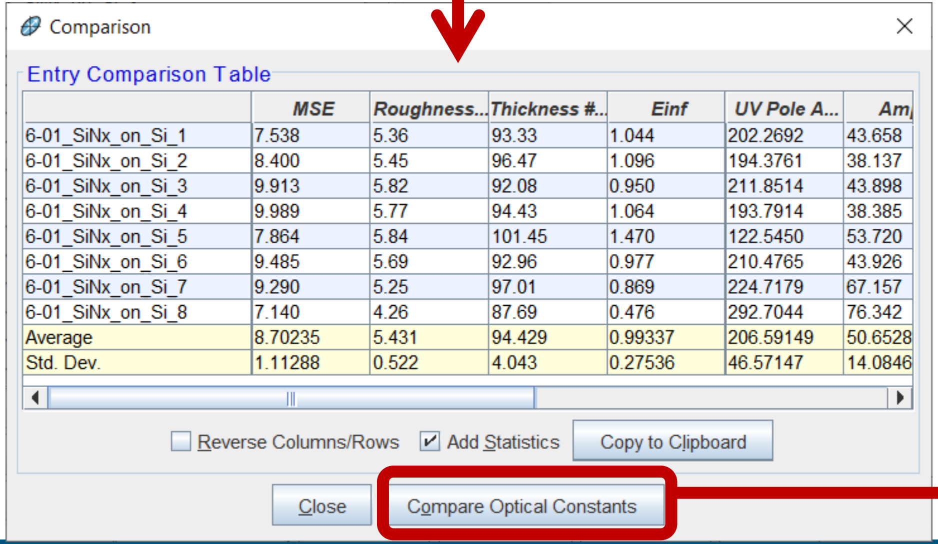
☐ Reverse Columns/Rows ☑ Add Statistics [Copy To Clipboard]

[Close] [Compare Optical Constants]

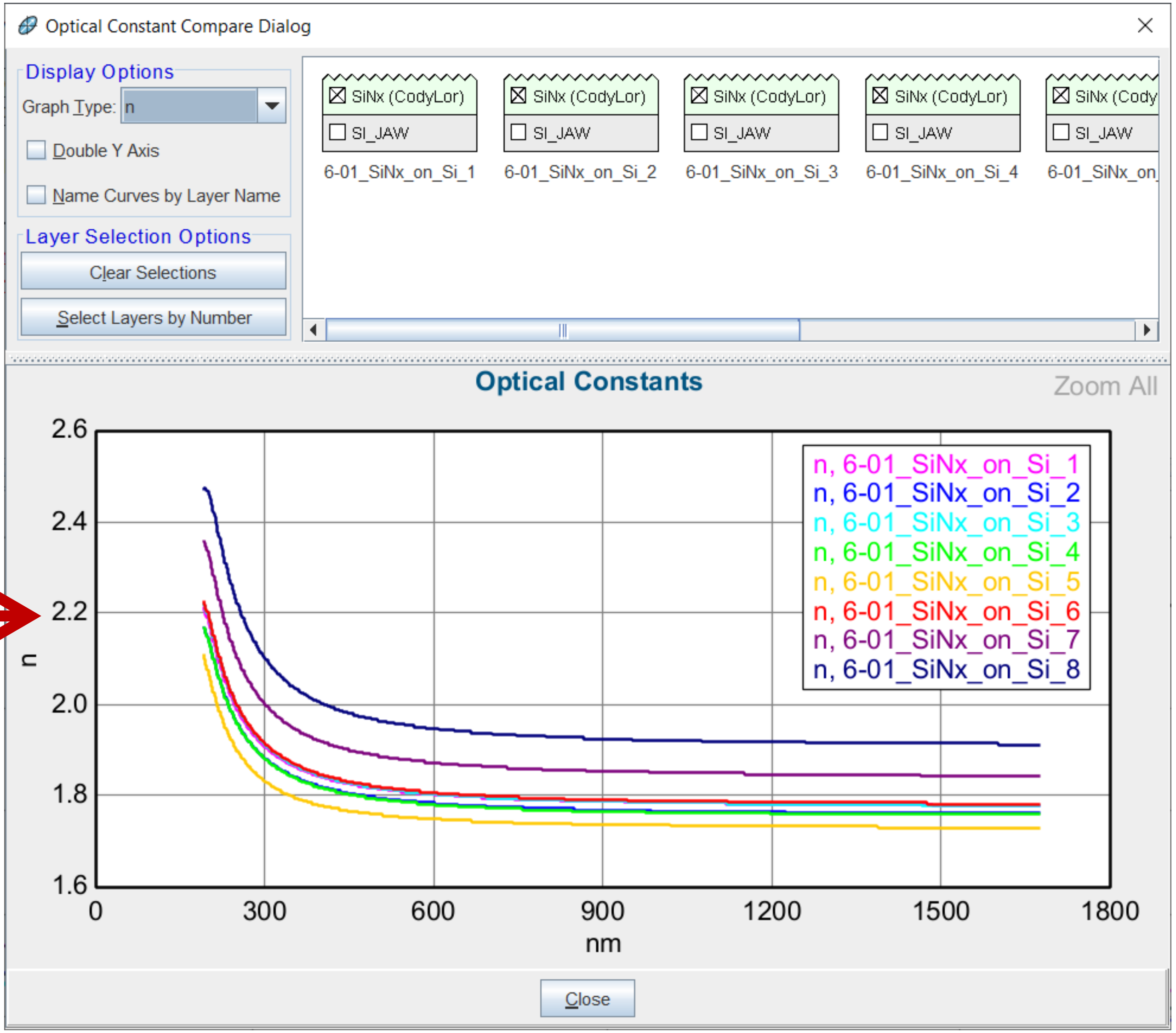


COMPARING RESULTS (IN FIT LOG)





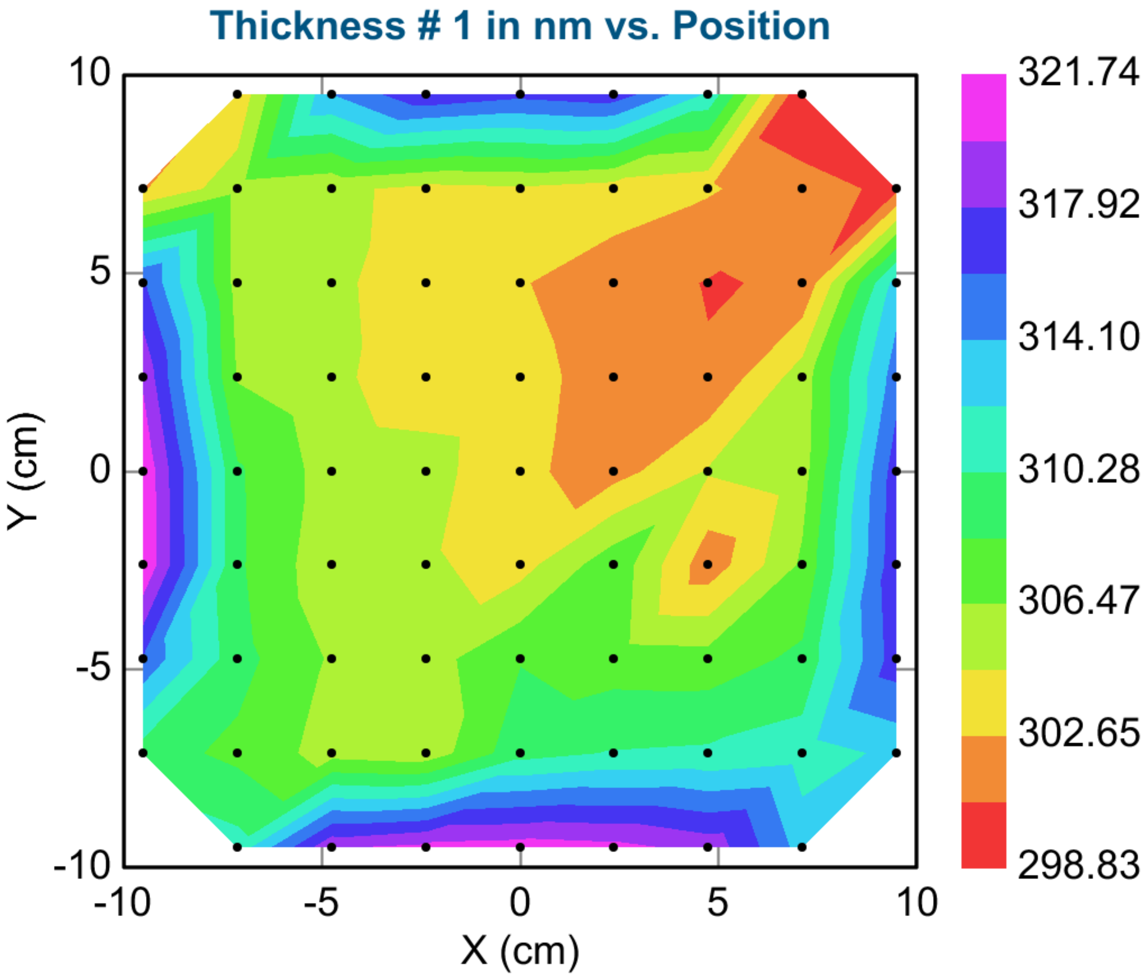
	MSE	Roughness...	Thickness #...	Einf	UV Pole A...	Am
6-01_SiNx_on_Si_1	7.538	5.36	93.33	1.044	202.2692	43.658
6-01_SiNx_on_Si_2	8.400	5.45	96.47	1.096	194.3761	38.137
6-01_SiNx_on_Si_3	9.913	5.82	92.08	0.950	211.8514	43.898
6-01_SiNx_on_Si_4	9.989	5.77	94.43	1.064	193.7914	38.385
6-01_SiNx_on_Si_5	7.864	5.84	101.45	1.470	122.5450	53.720
6-01_SiNx_on_Si_6	9.485	5.69	92.96	0.977	210.4765	43.926
6-01_SiNx_on_Si_7	9.290	5.25	97.01	0.869	224.7179	67.157
6-01_SiNx_on_Si_8	7.140	4.26	87.69	0.476	292.7044	76.342
Average	8.70235	5.431	94.429	0.99337	206.59149	50.6528
Std. Dev.	1.11288	0.522	4.043	0.27536	46.57147	14.0846



Topic #2: Mapping Data

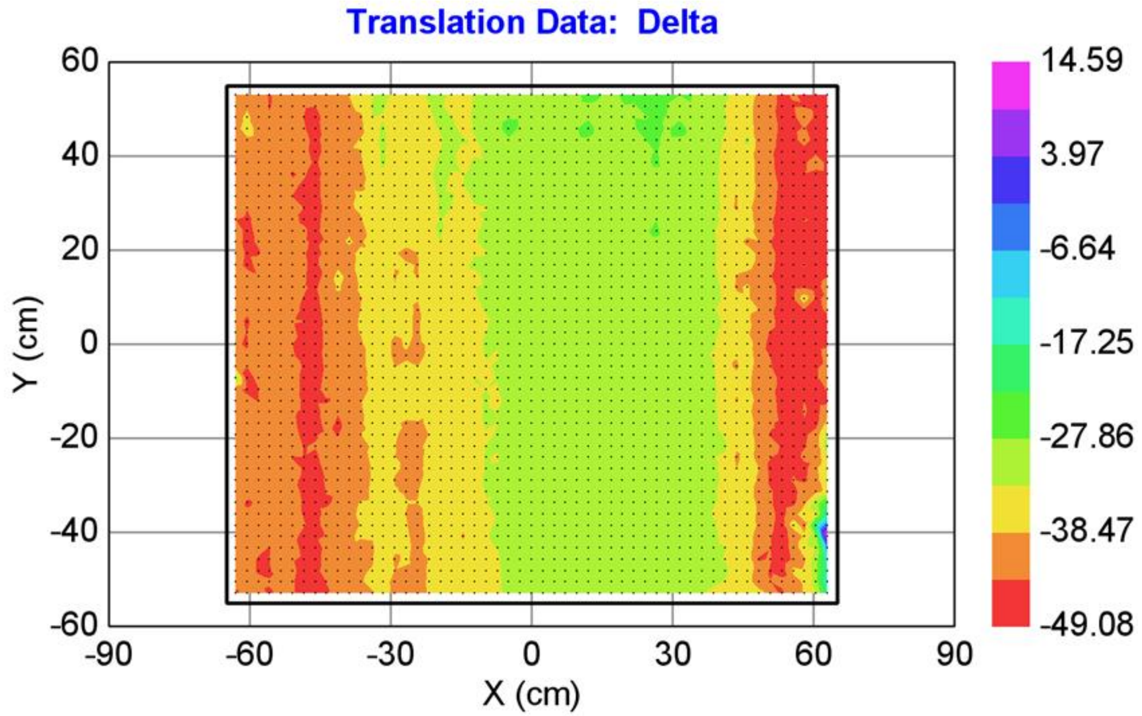
- Analyze data from multiple sites across sample to study thin film uniformity.

- Set up flexible model.
- Fit all points from map.
- View results.

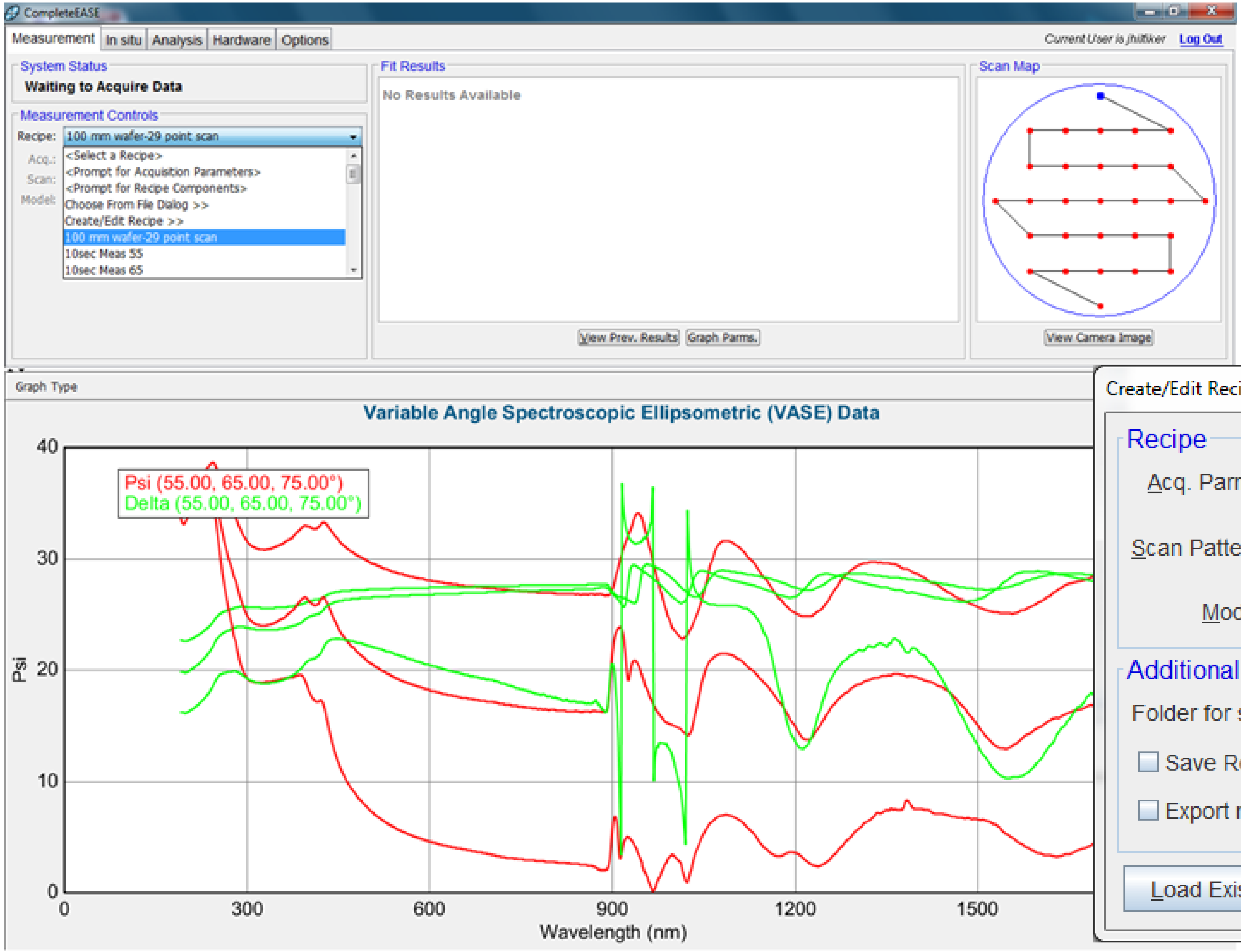


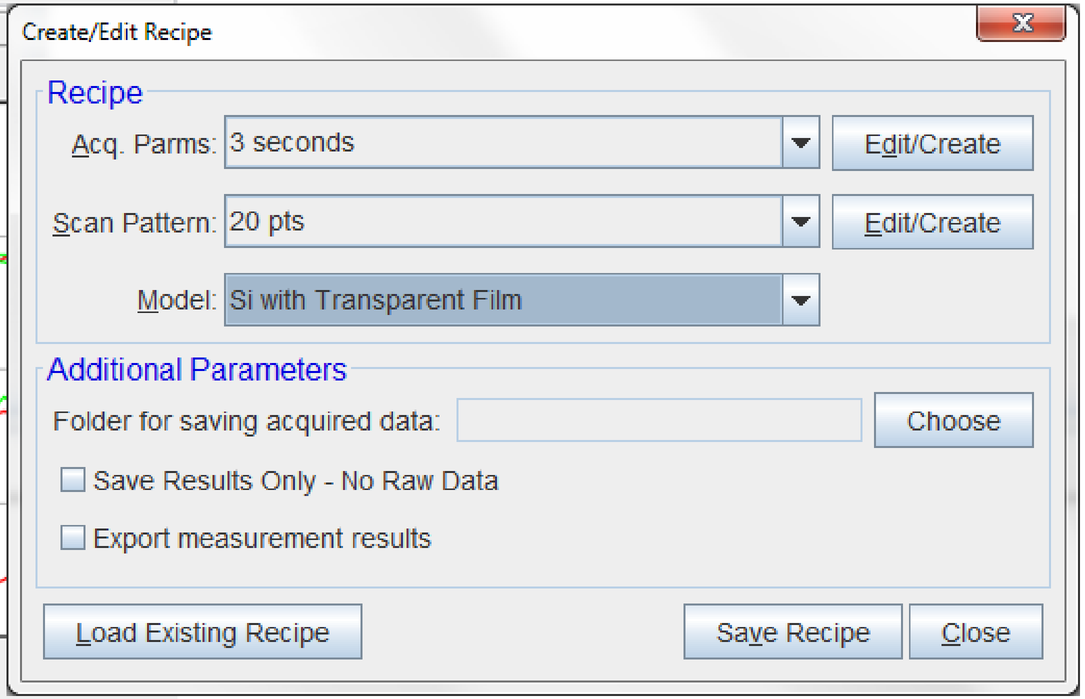
MAPPING DATA

- Analysis Procedure:
  1. Develop model from single point data
  2. Test/Optimize at multiple points.
  3. Fit All Points.
  4. View Results.



RECIPES IN COMPLETEEASE

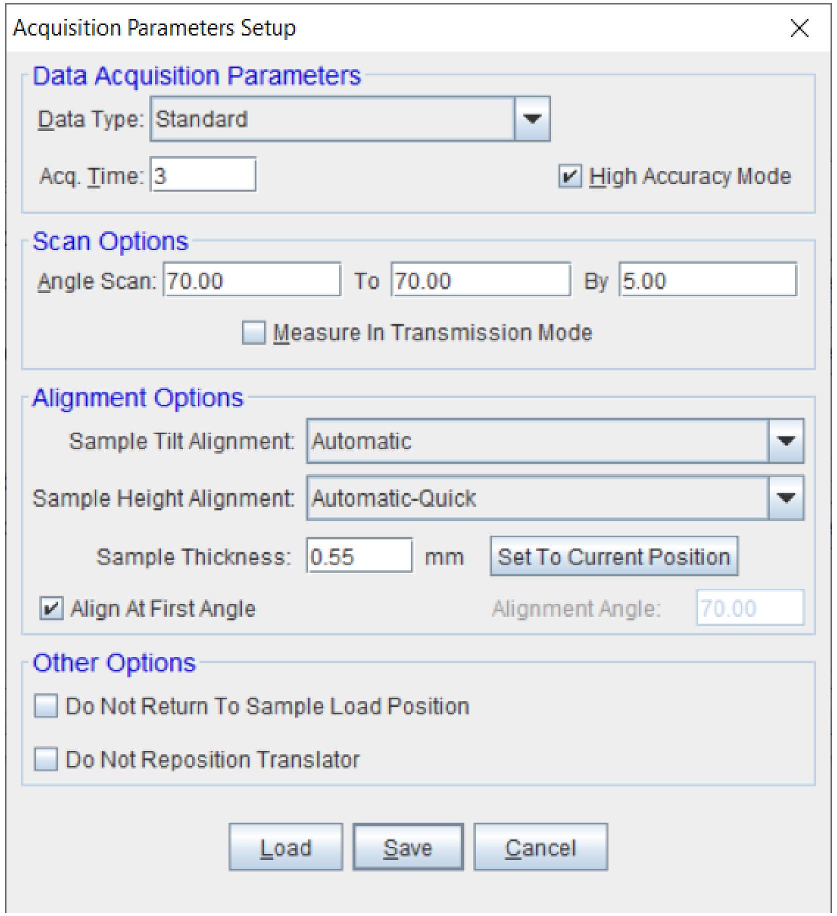




RECIPE COMPONENTS

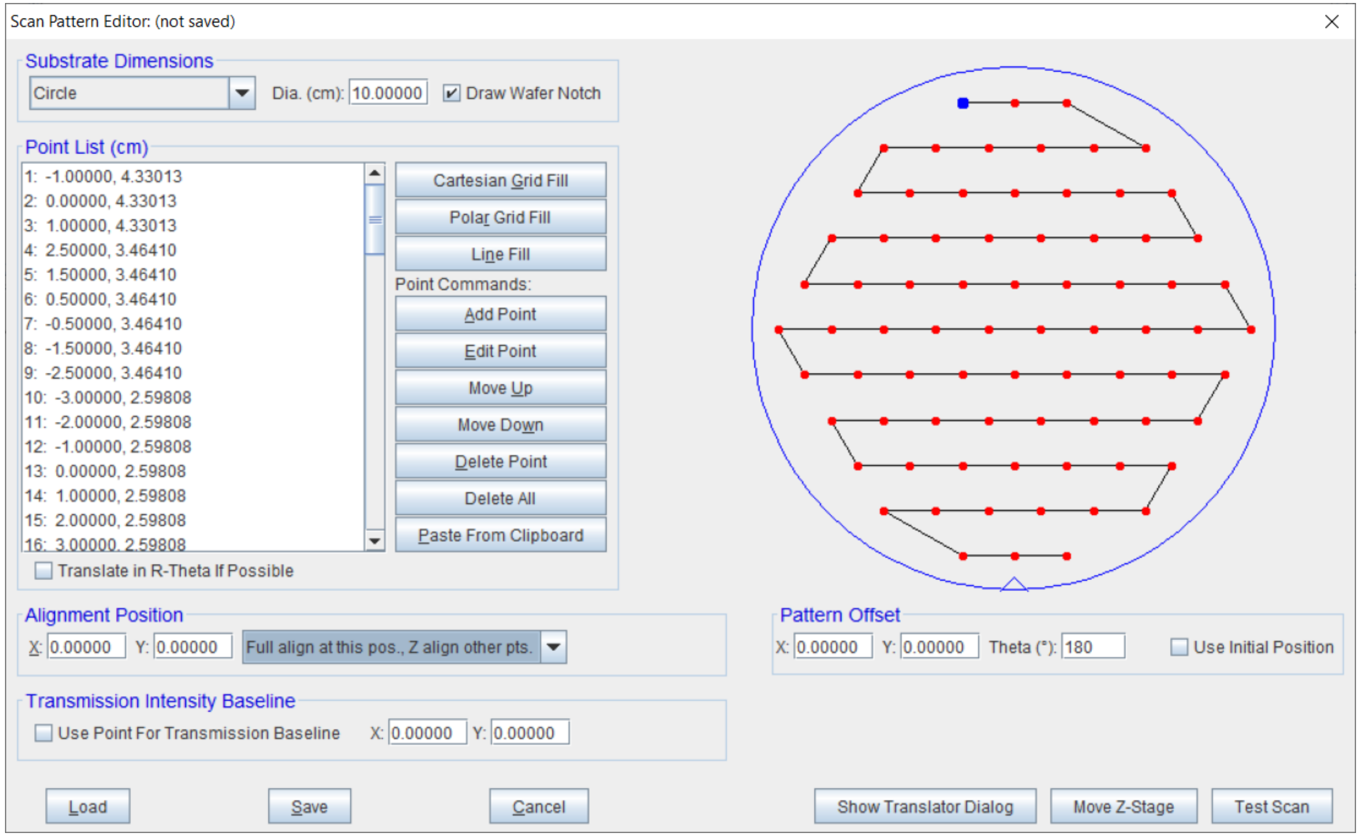
Acquisition Parameters

How to collect the data

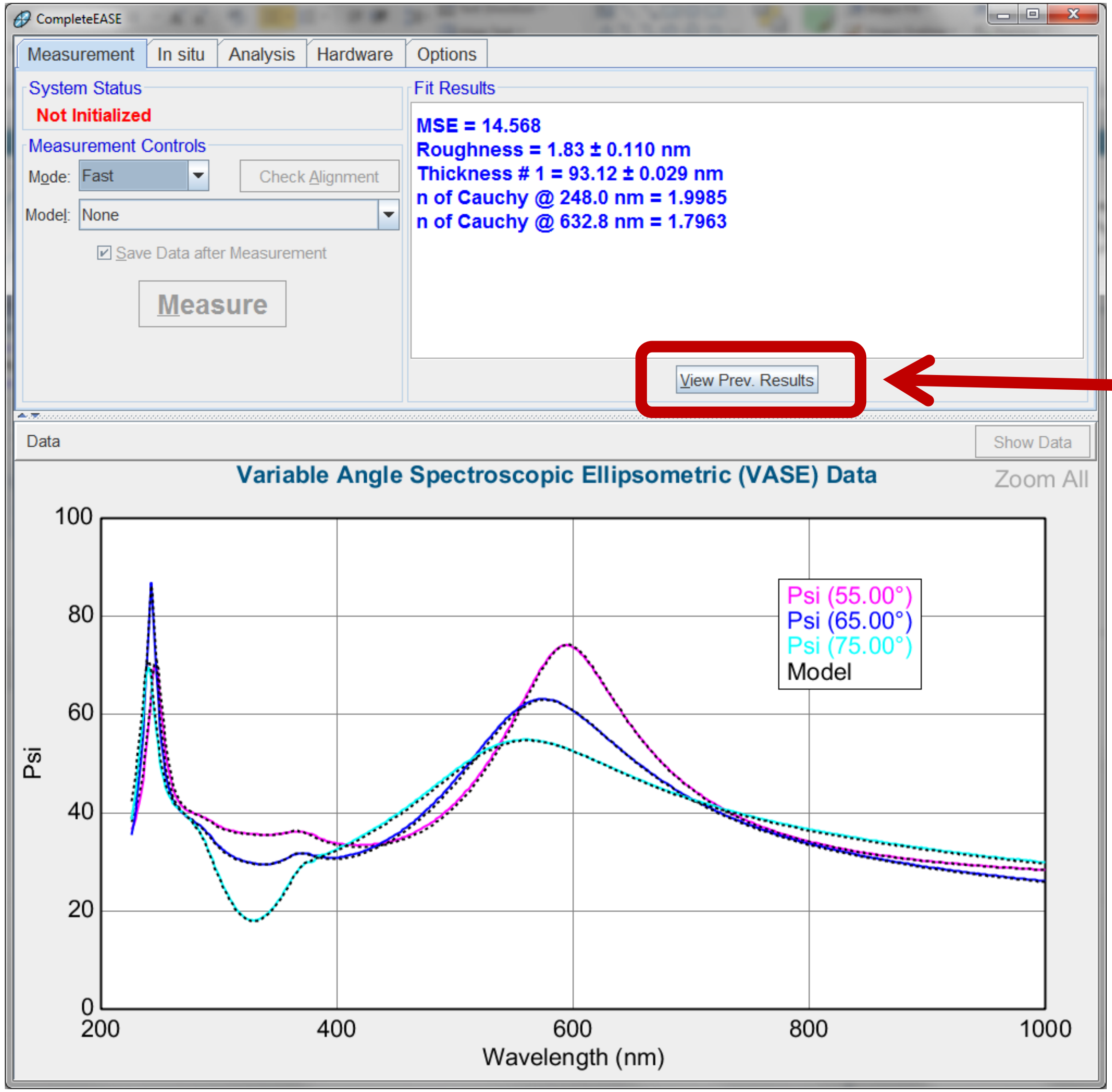


Scan Pattern

Where to collect data



VIEWING PREVIOUS RESULTS

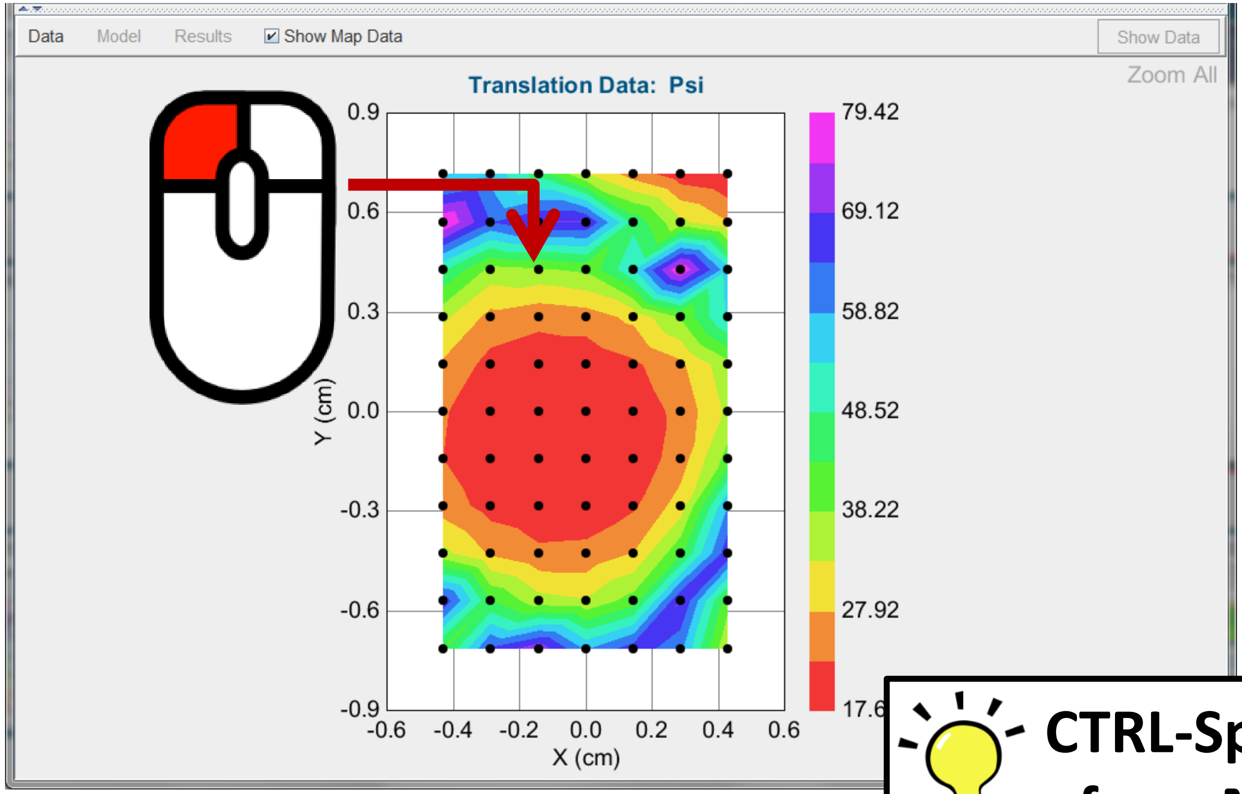


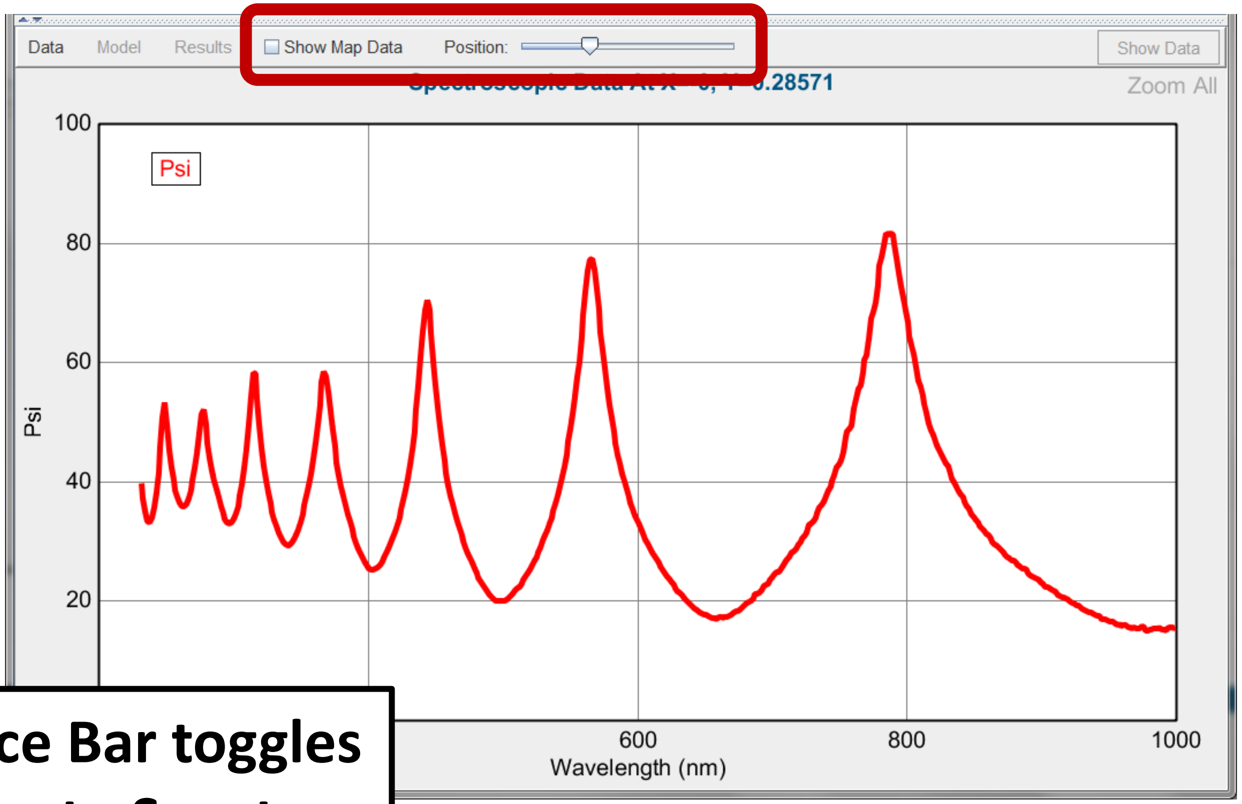
Show results saved by in data files

Data files (.SE) also contain modeling results when optical model presents in recipe

SELECTING SINGLE DATA POINT

- Left-click any point to view spectroscopic data.
- Move through points with slider.
- Check-box returns to Map view.

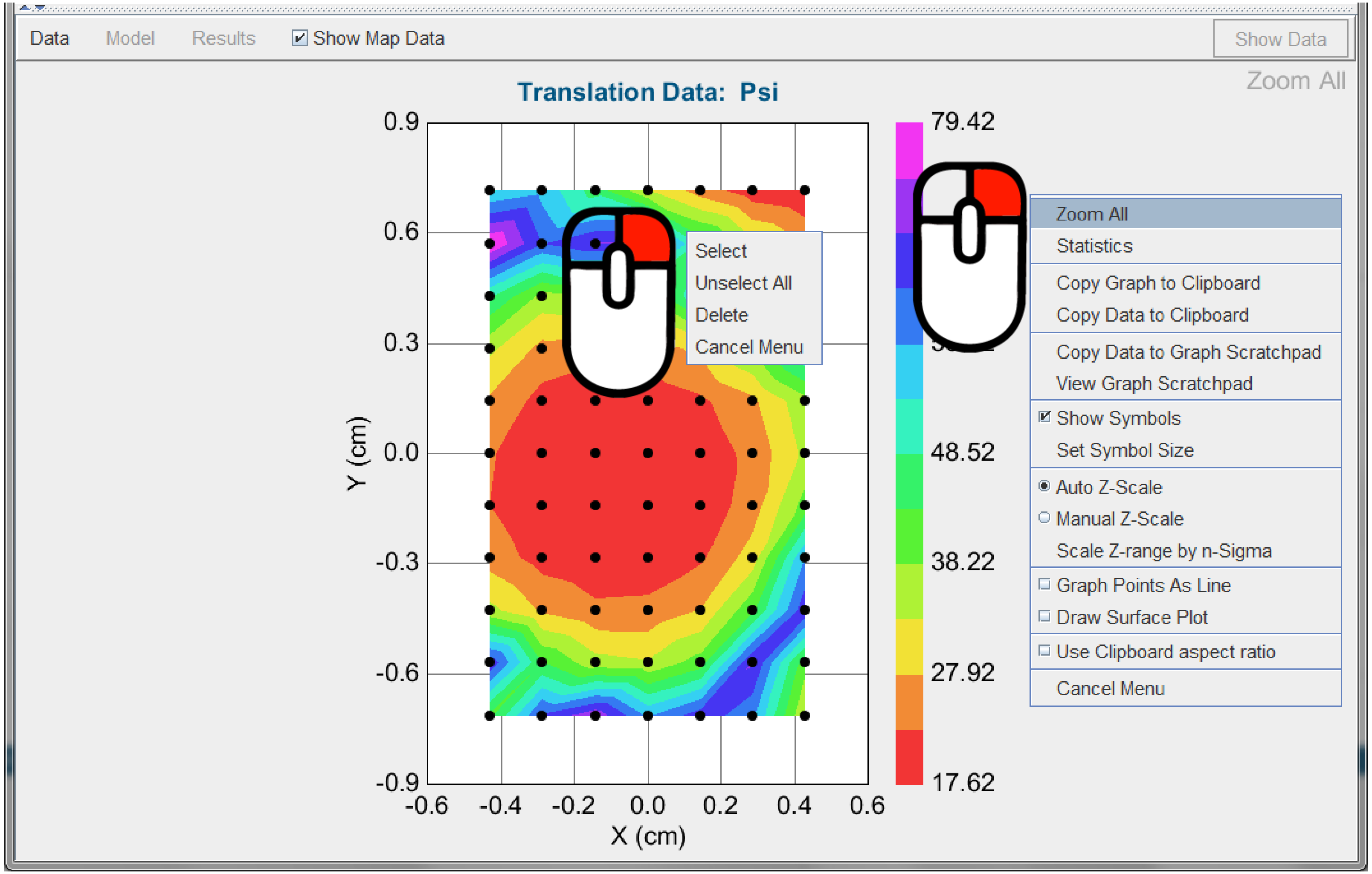




CTRL-Space Bar toggles from Map to Spectra

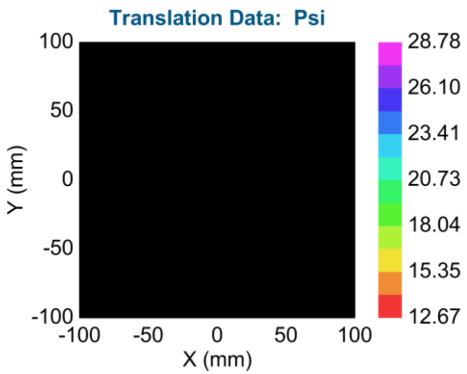
WORKING WITH MAPPING DATA

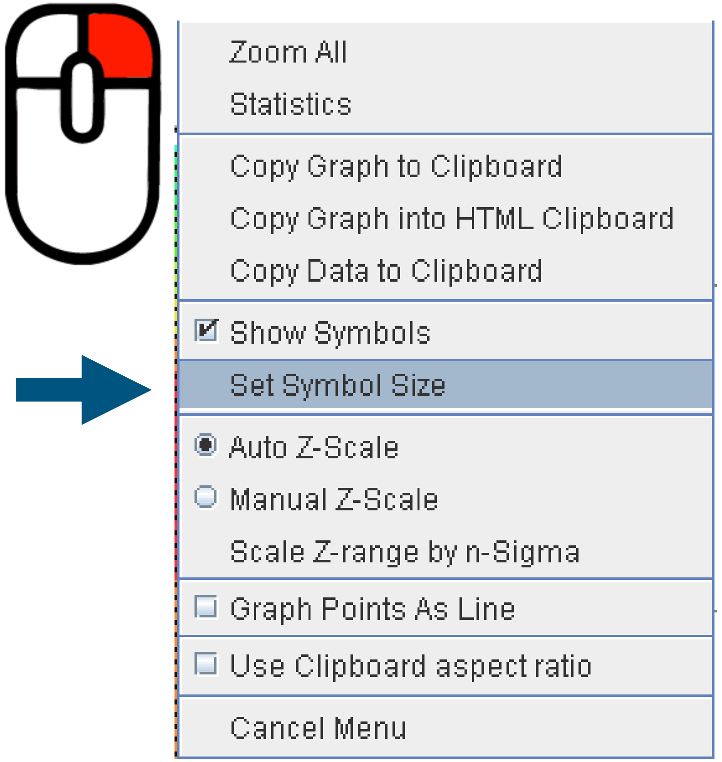
- Right-click menu on individual point is different from right-click menu outside the graph.

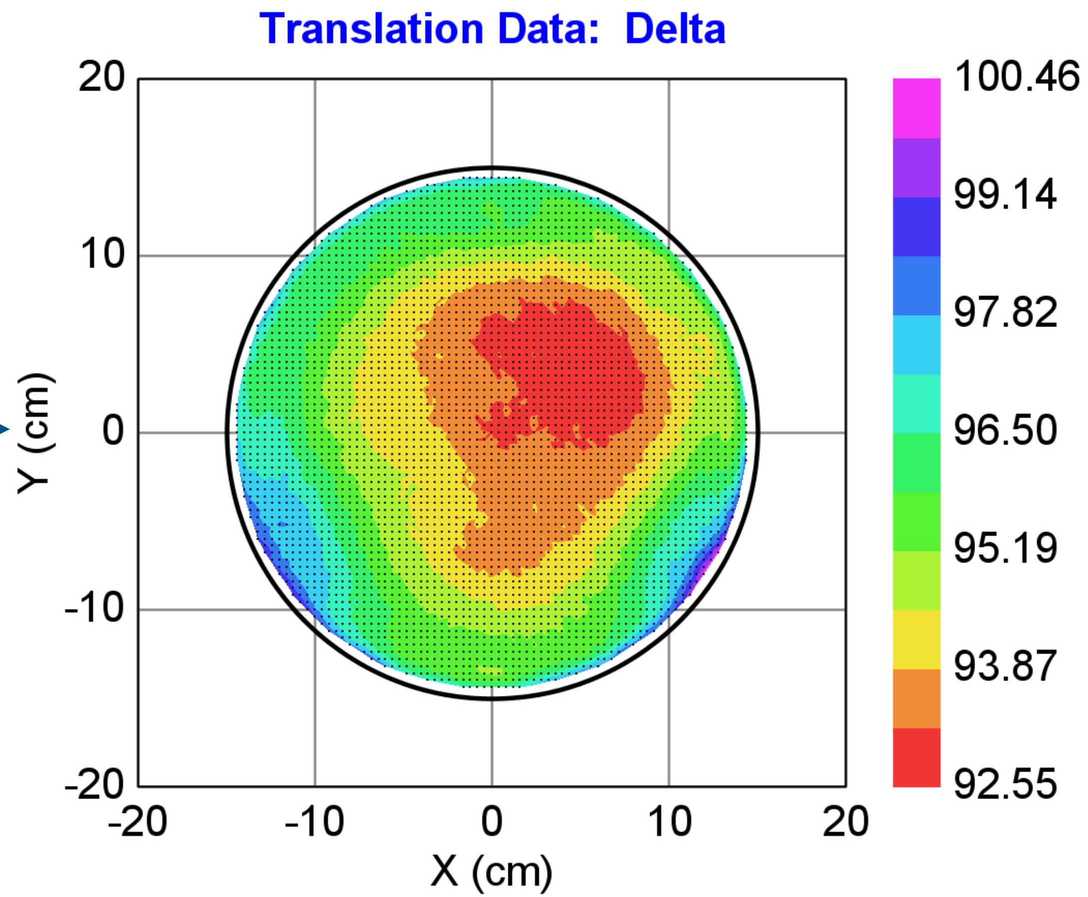


CHANGING THE SYMBOL SIZE

- Change point symbol size on graph with right-click menu outside of the measurement points.

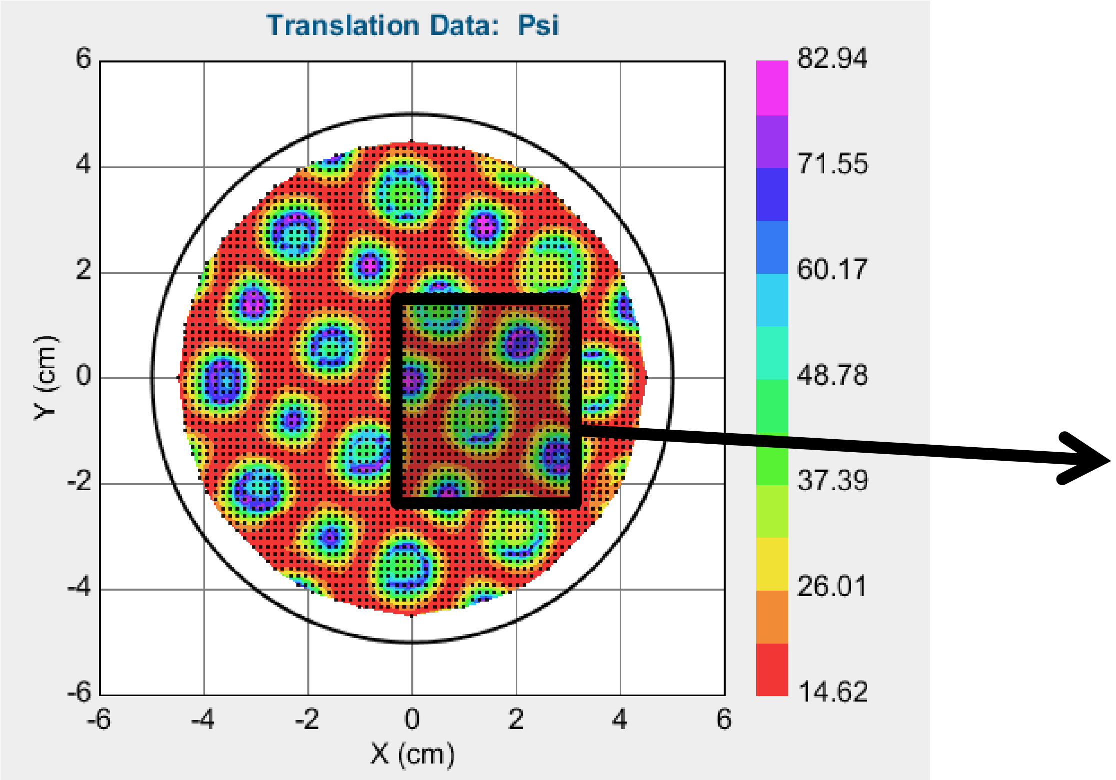




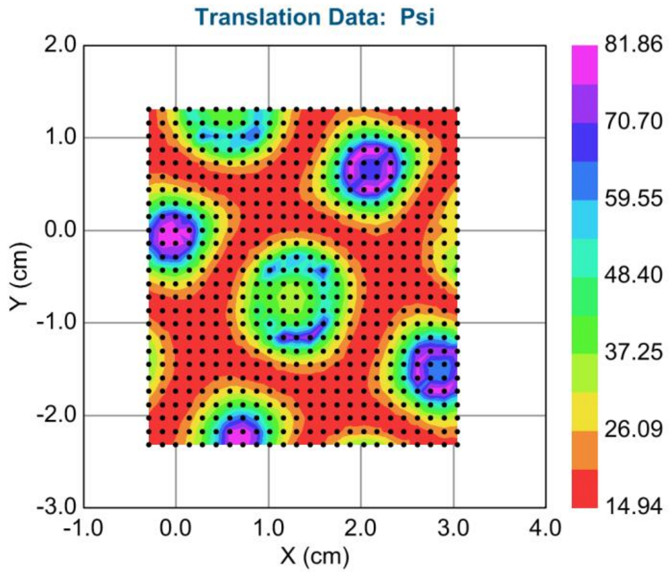


ZOOMING/SAVING WITH GRAPHS

- DRAG across graph to Zoom into a smaller range
  - This does not select points, but only zooms the graph.



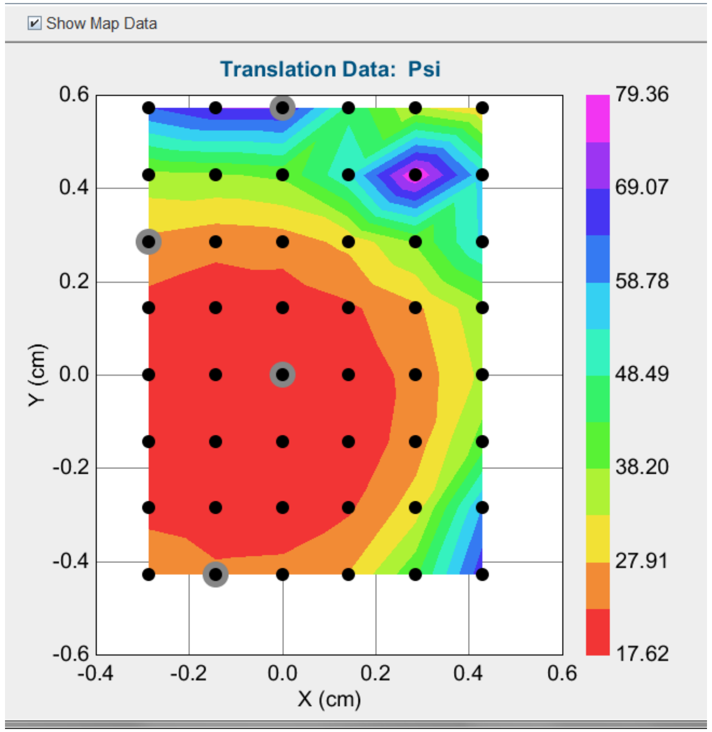
Right-Click on Data 'Save' to "Save Subset", which is the smaller map

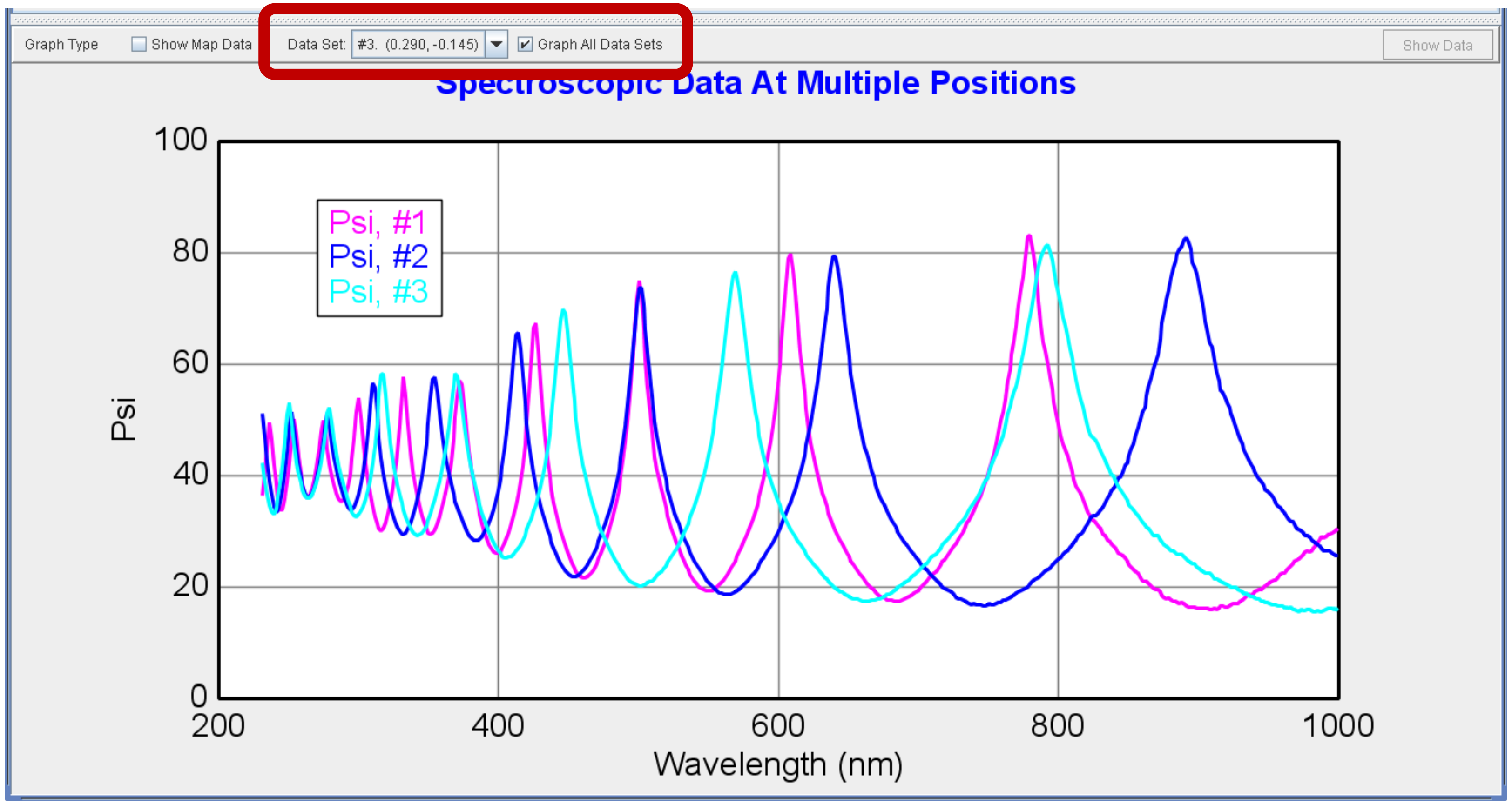


- Use CTRL+DRAG across graph to select multiple points

COMPARE DATA AT MULTI-POINTS

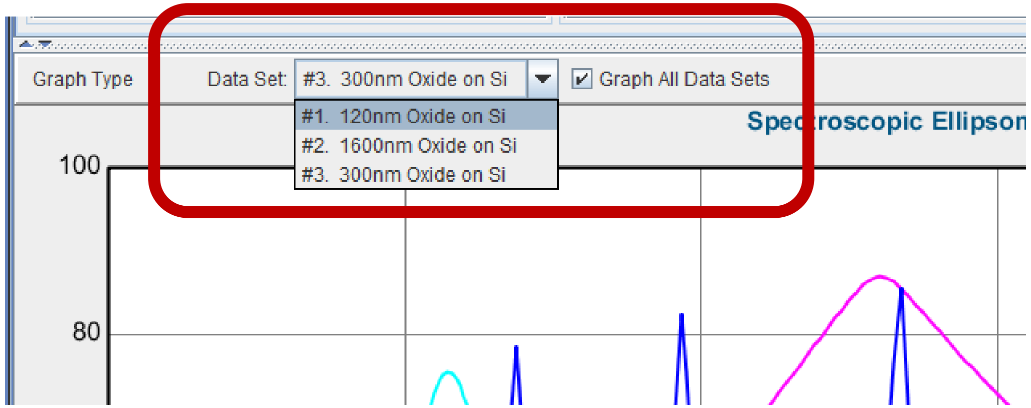
- CTRL+Click or right-click > “select” on multiple points to setup *Multi-Data Set Mode*
  - select “Graph All Data Sets”



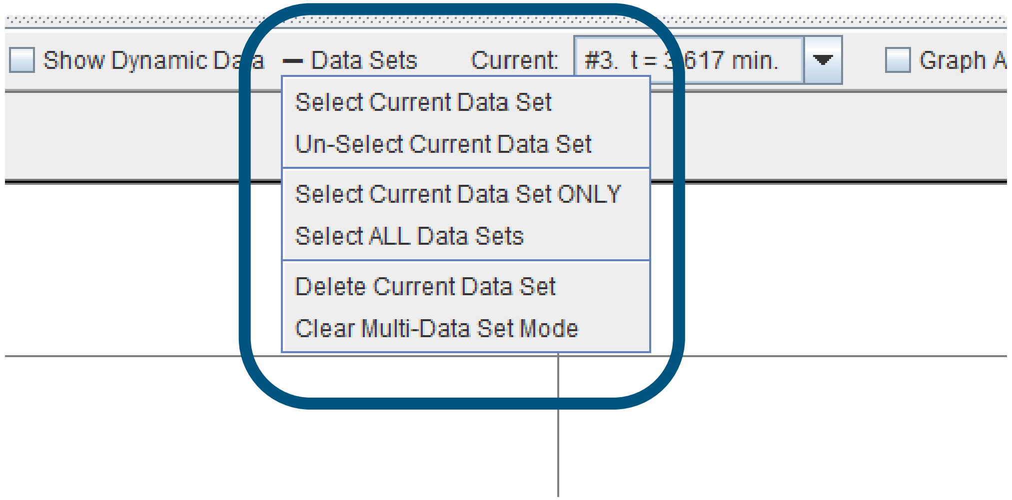


MULTI-DATA SETS

- Graphing and Handling

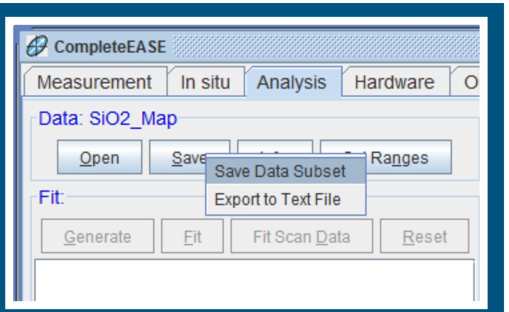


Drop Down Menu for Data Sets

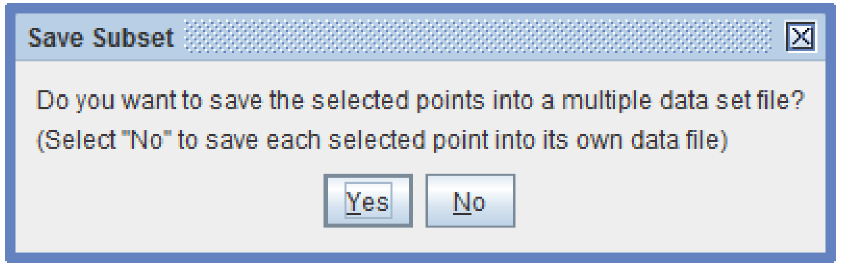


- Saving

Right-click over Data 'Save' button and press "Save Data Subset"



Save Data Subset as Individual or Multi-Data Set file

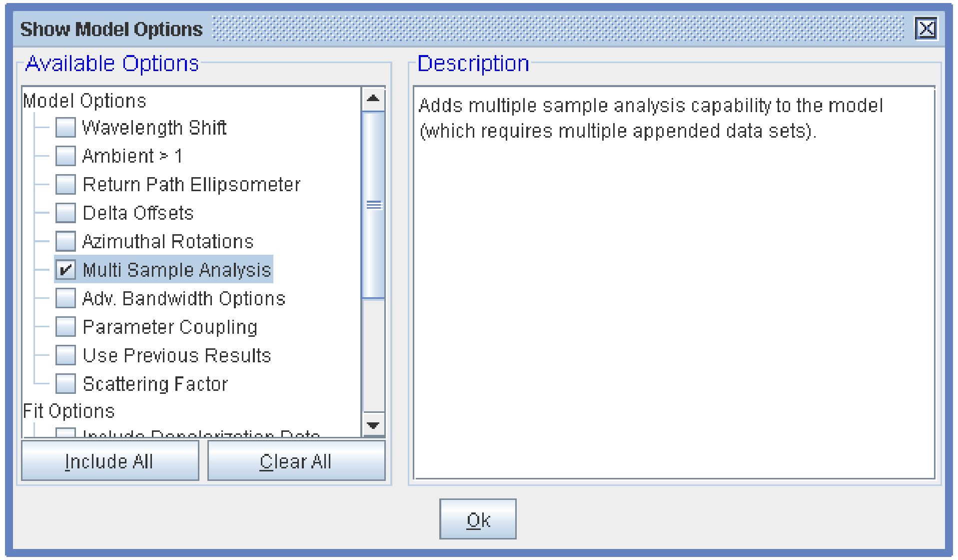


SETTING UP MULTI-SAMPLE ANALYSIS

- Need to tell CompleteEASE which parameters to vary between multiple data sets

Configure Options

Layer Commands: Add Delete Save
Include Surface Roughness = OFF
Substrate = none
Angle Offset = 0.000
\+ MODEL Options
\+ FIT Options
\+ OTHER Options
Configure Options
Turn Off All Fit Parameters



Add Fit Parameter

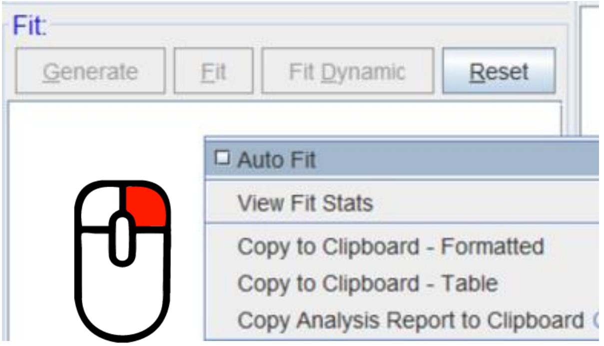
\- MODEL Options
Include Substrate Backside Correction = OFF
Model Calculation = Ideal
\- Multi Sample Analysis
Add Fit Parameter Delete All Parms

Data Set	Thickness # 1
#1	100.00 nm
#2	100.00 nm
#3	100.00 nm

Roll Mouse over each Fit Parameter and choose which to fit

CHECK MODEL AT MULTIPLE POINTS

- Test model on different areas of map.
- Thickness Pre-Fit is helpful when thickness greatly varies.
- Do all optical constant parameters need to vary?
- Turn Fit Parameters reset ON to avoid parameter lost due to singularities at some locations



Hint: Turn off "Auto-Fit".

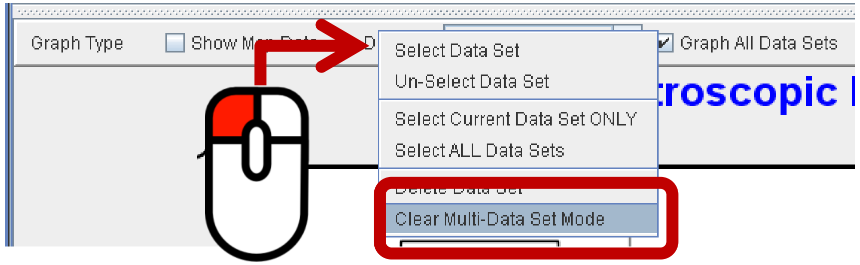
FIT Options

+ Perform Thickness Pre-Fit = ON
Use Global Fit = OFF
Fit Weight = N,C,S
Limit Wvl. for Fit = ON Range = 400.0 nm - 1000.0 nm
Limit Angles for Fit = ON Included Angles = 65
Max. Acceptable MSE = 100.000
Skip Data Points in Fit = 5 Max. Fit Iterations = 50
Auto Fit Parameter Reset = OFF

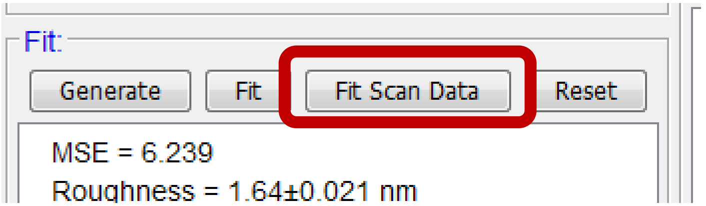
Configure Options> "More Fit Options"

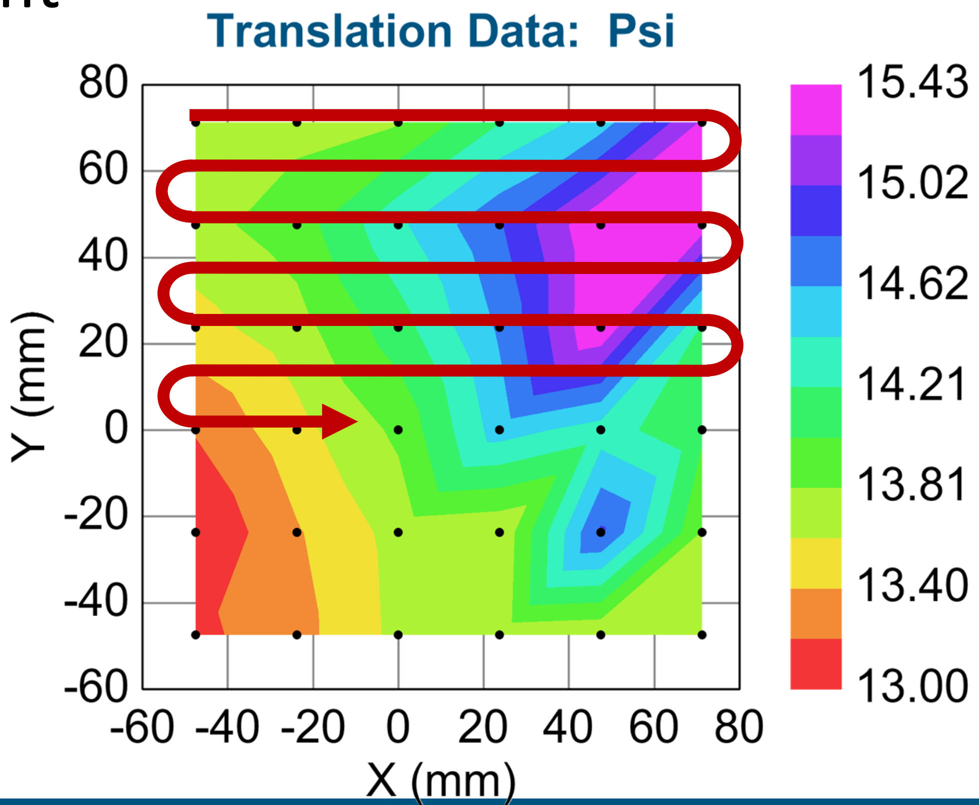
FITTING THE ENTIRE MAP

- Clear Multi-Data Set Mode before fitting entire map



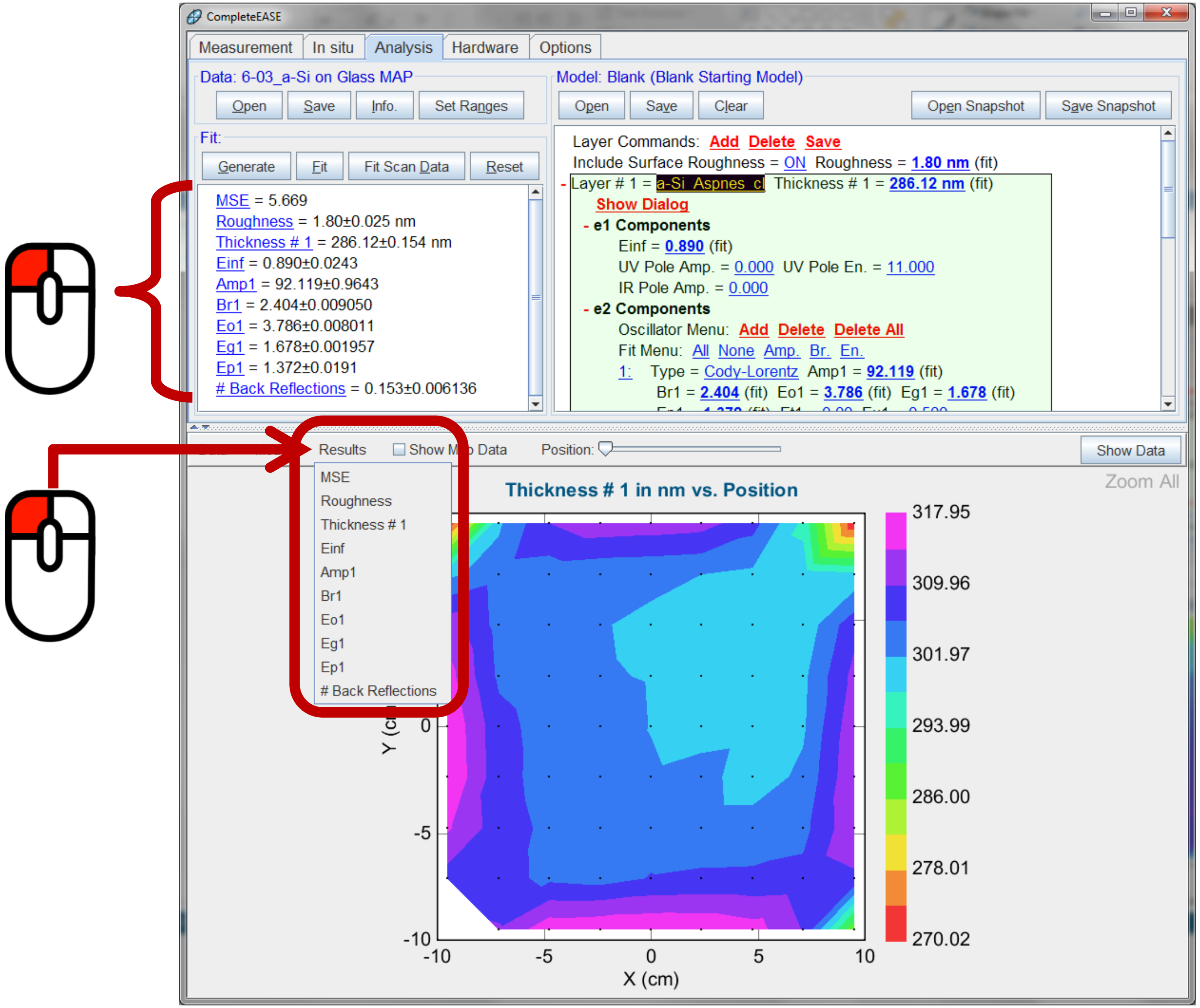
- "**Fit Scan Data**" performs sequential fit for a every data point on map





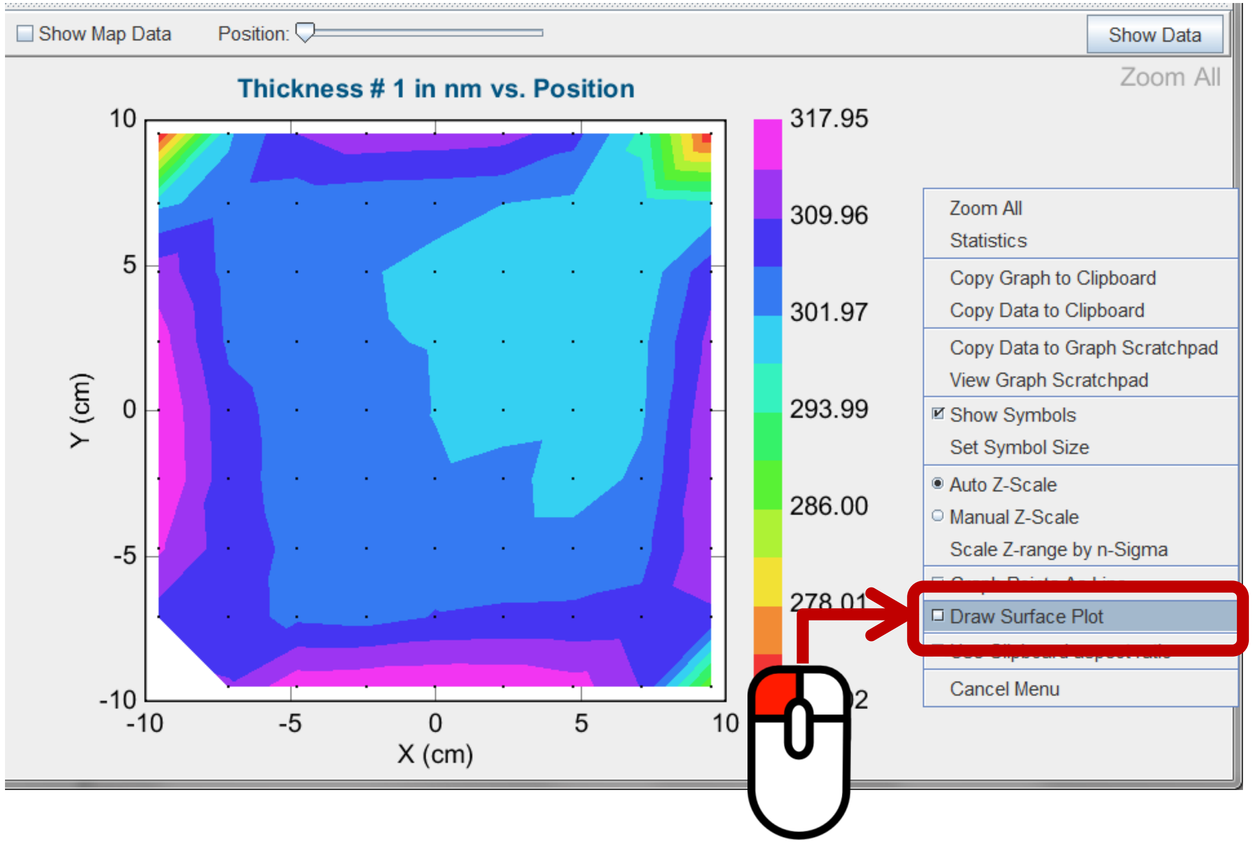
VIEWING RESULTS

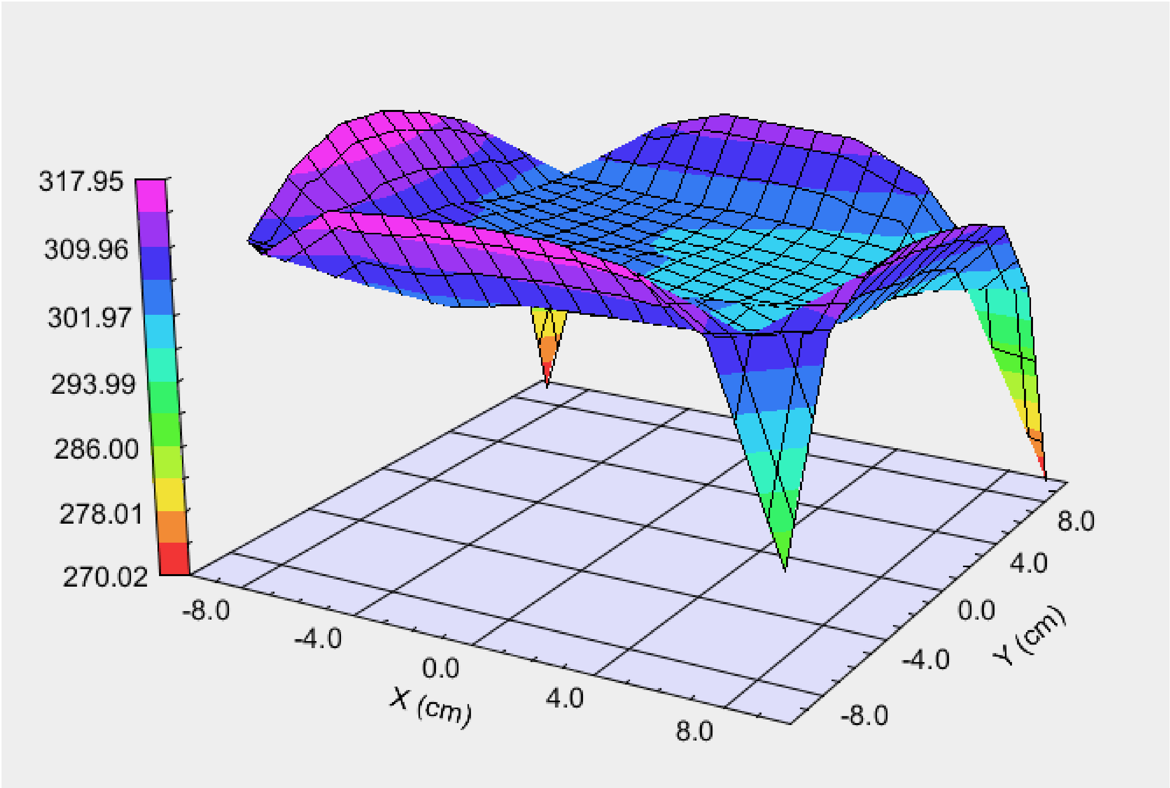
- 2 ways to graph results:
  - Click on fit parameters (in blue)
  - Select from “Results” drop-down menu



SURFACE PLOTS

- Right-click outside graph > “Draw Surface Plot”

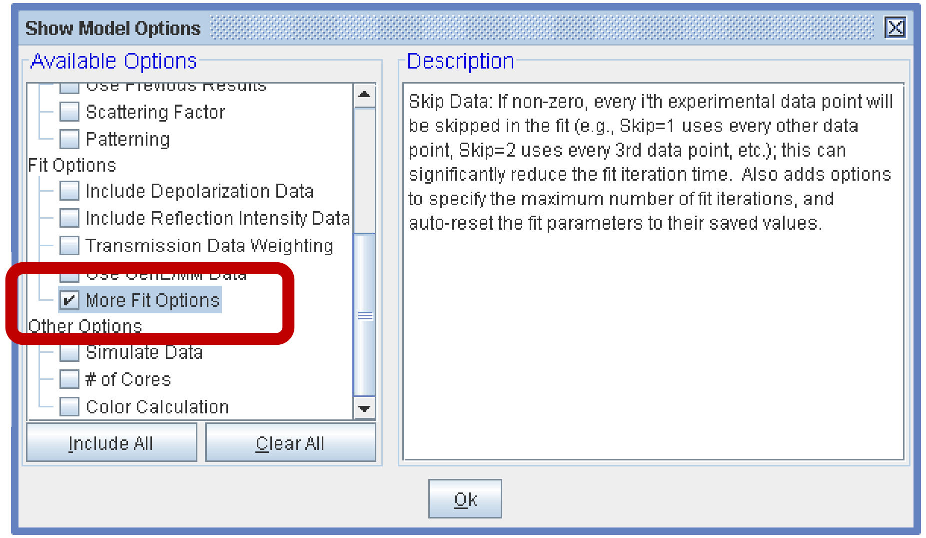




REDUCE ANALYSIS TIME

- Skip Wavelengths
- Reduce Wavelength Range
- Reduce Angles
- Reduce fit parameters
- Turn-off Global fit

Configure Options>
"More Fit Options"



- FIT Options

+ Perform Thickness Pre-Fit = ON
  Use Global Fit = OFF
  Fit Weight = N,C,S
  Limit Wvl. for Fit = ON Range = 400.0 nm - 1000.0 nm
  Limit Angles for Fit = ON Included Angles = 65
  Max. Acceptable MSE = 100.000
  Skip Data Points in Fit = 5 Max. Fit Iterations = 50
  Auto Fit Parameter Reset = OFF
+ Include Derived Parameters = ON

MAPPING DATA SHORT-CUTS

Shortcut	Function
CTRL-Click on Point	Select / De-Select Point
CTRL-ALT-Click on Point	Delete Point
CTRL-ALT-SHIFT-Click on Point	Show camera image from point (when available)
CTRL-Spacebar	Switch view from single-point to map
ALT-#	Switch between Data Sets (when multiple selected)

6-02 CVD SiO_2 Map (on Si)

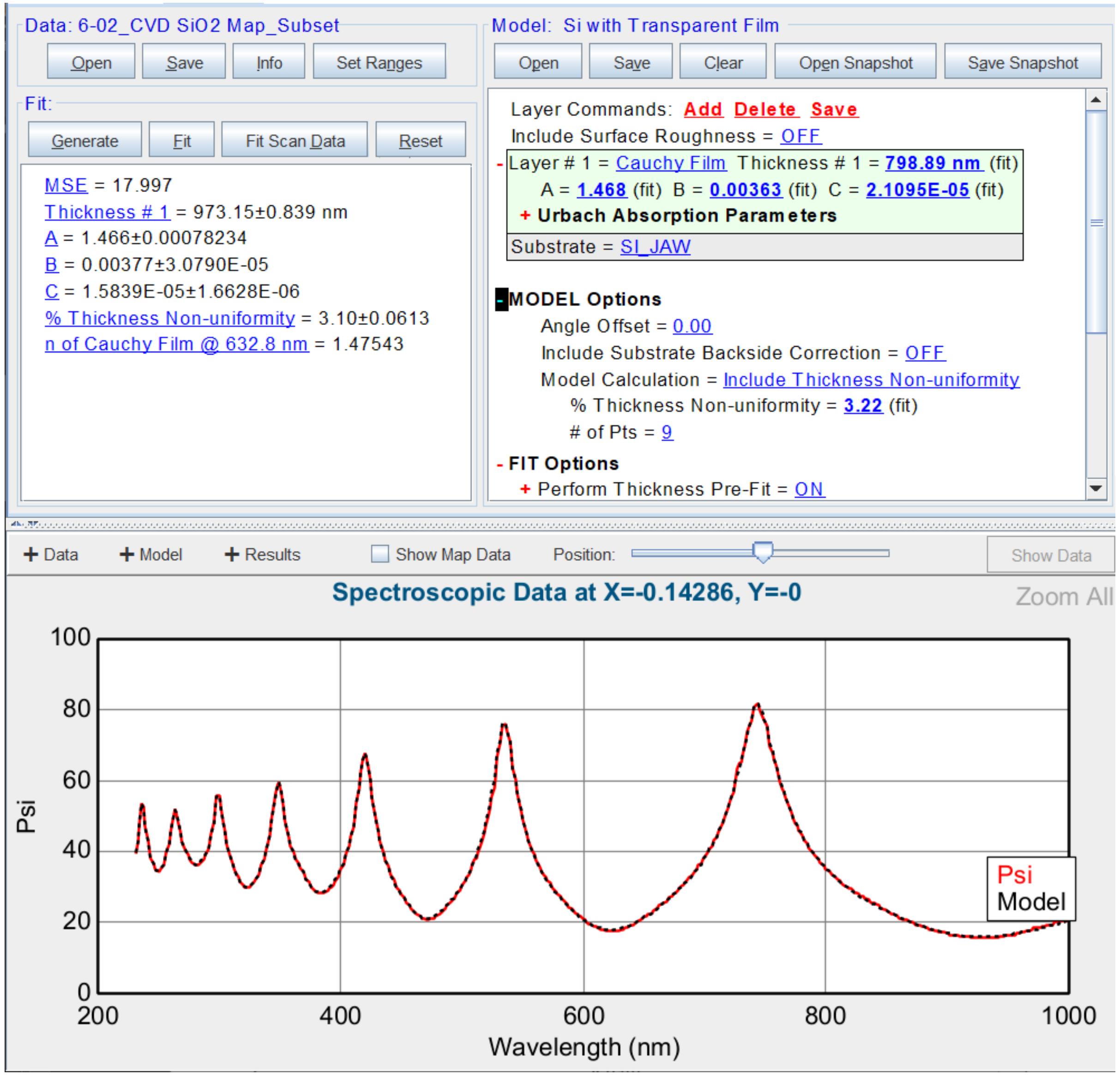
- **Find a model to fit all the data from the map of this non-uniform coating.**

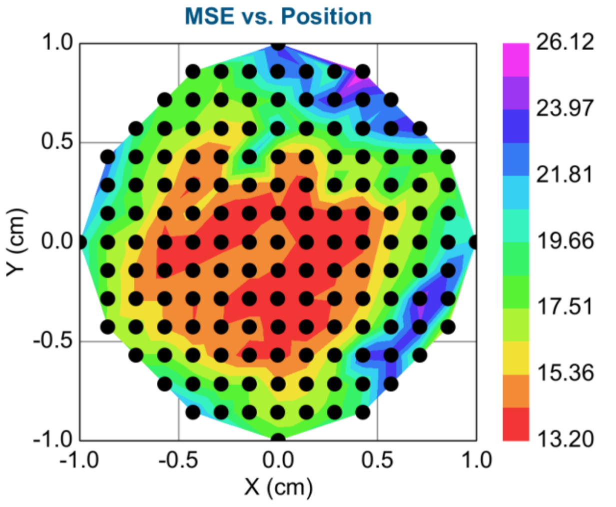
Fit Thickness & Cauchy Parameters

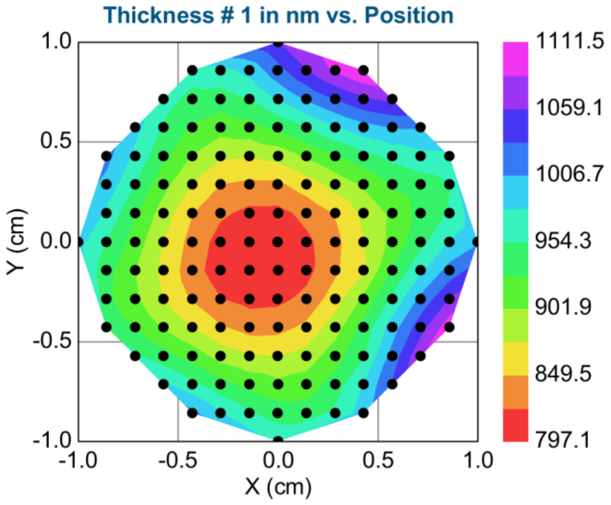
⇩

<u>Add to improve MSE</u>:
Roughness?
Index Grading?
Anisotropy?
Thickness Nonuniformity?

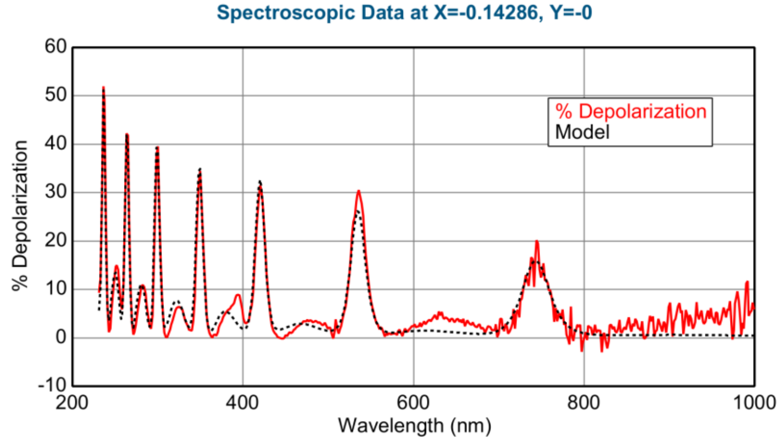
6-02 CVD SIO2 MAP: RESULTS







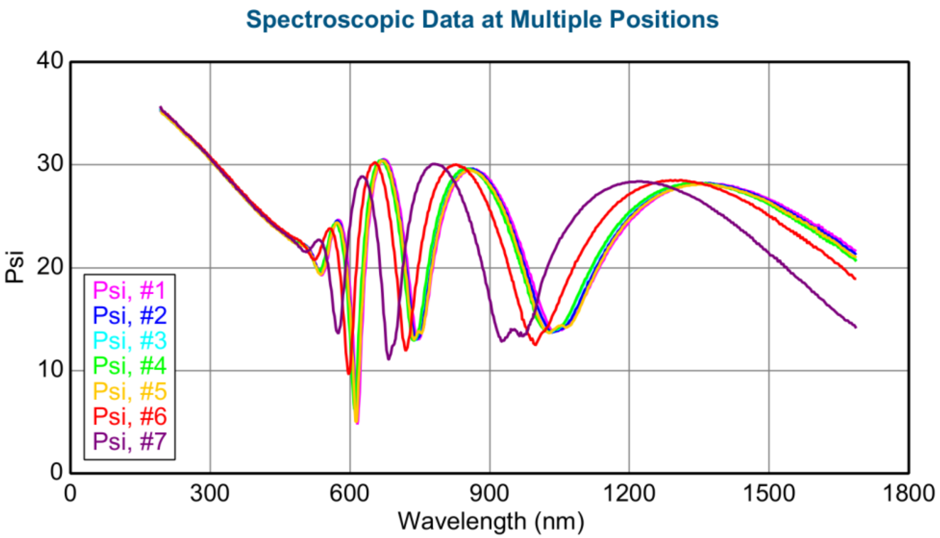
Parameter	Average	Std. Dev.	Slope	Minimum	Maximum	Range
Thickness # 1 in nm vs. Position	927.92	71.21		797.08	1111.55	314.47

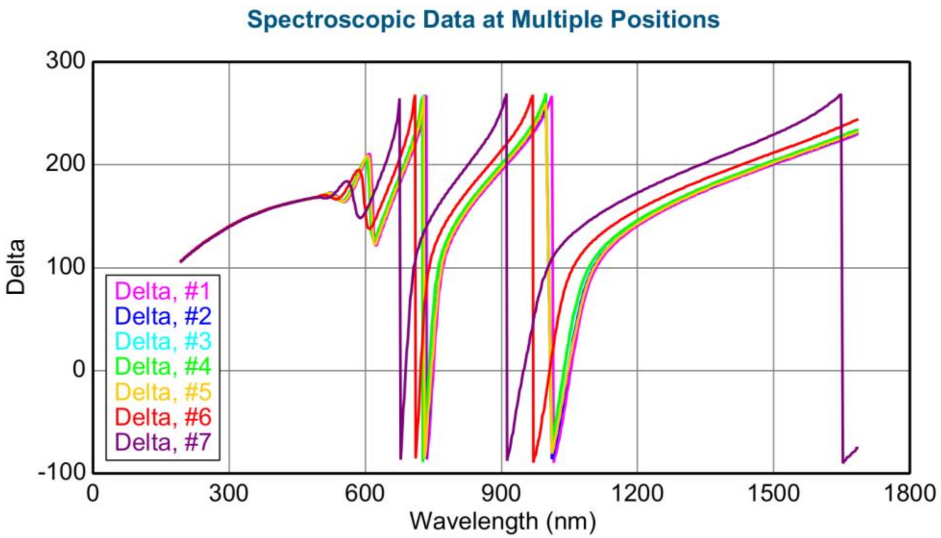


6-03 a-Si on 7059 Glass

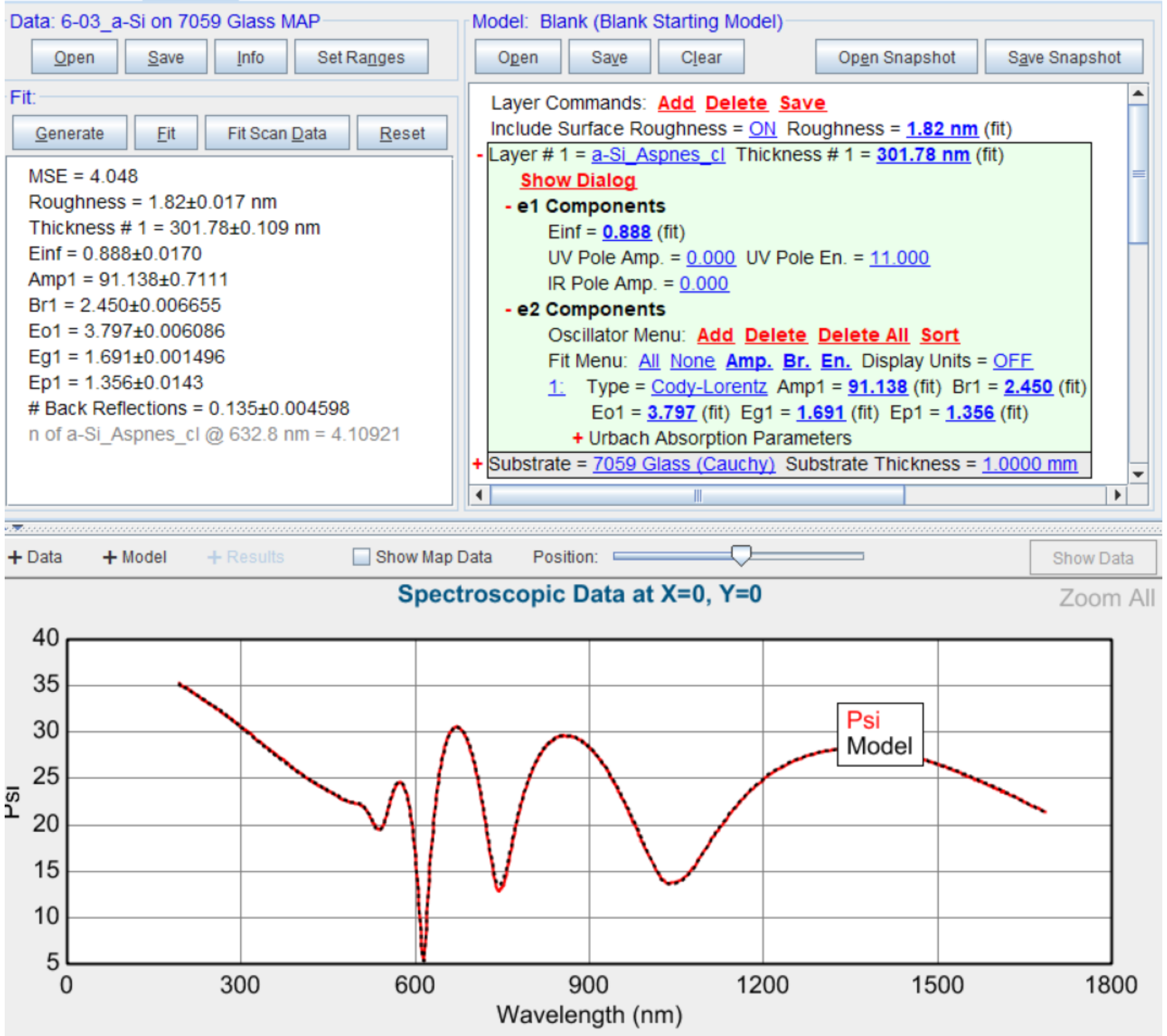
- a-Si is coated over large glass panels for display applications. Thin film uniformity is checked with SE to ensure a great picture.

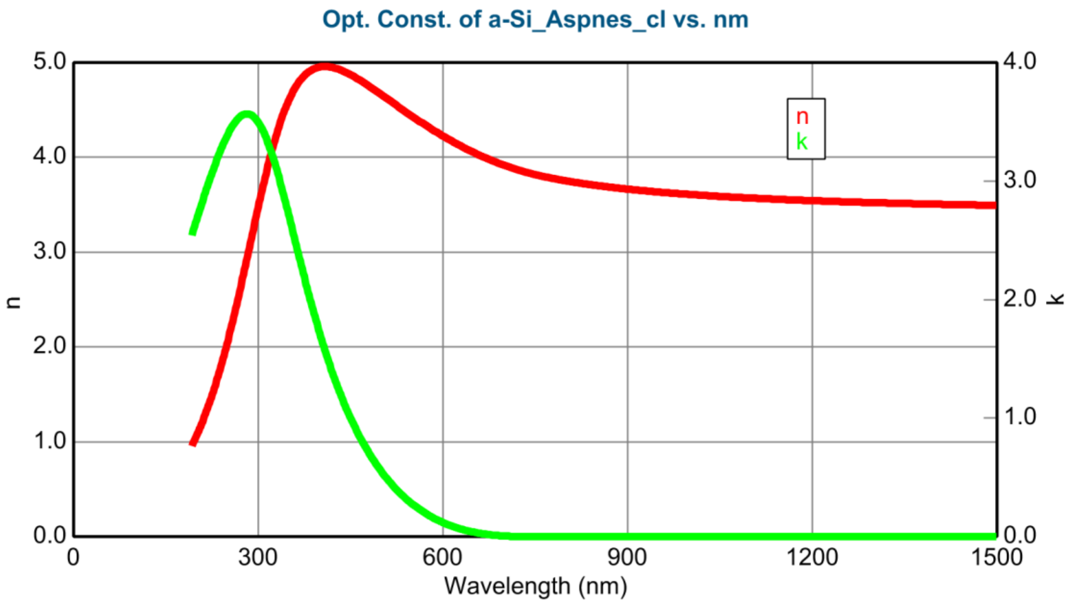
- Observe data variation – How to build a model that fits every data point?



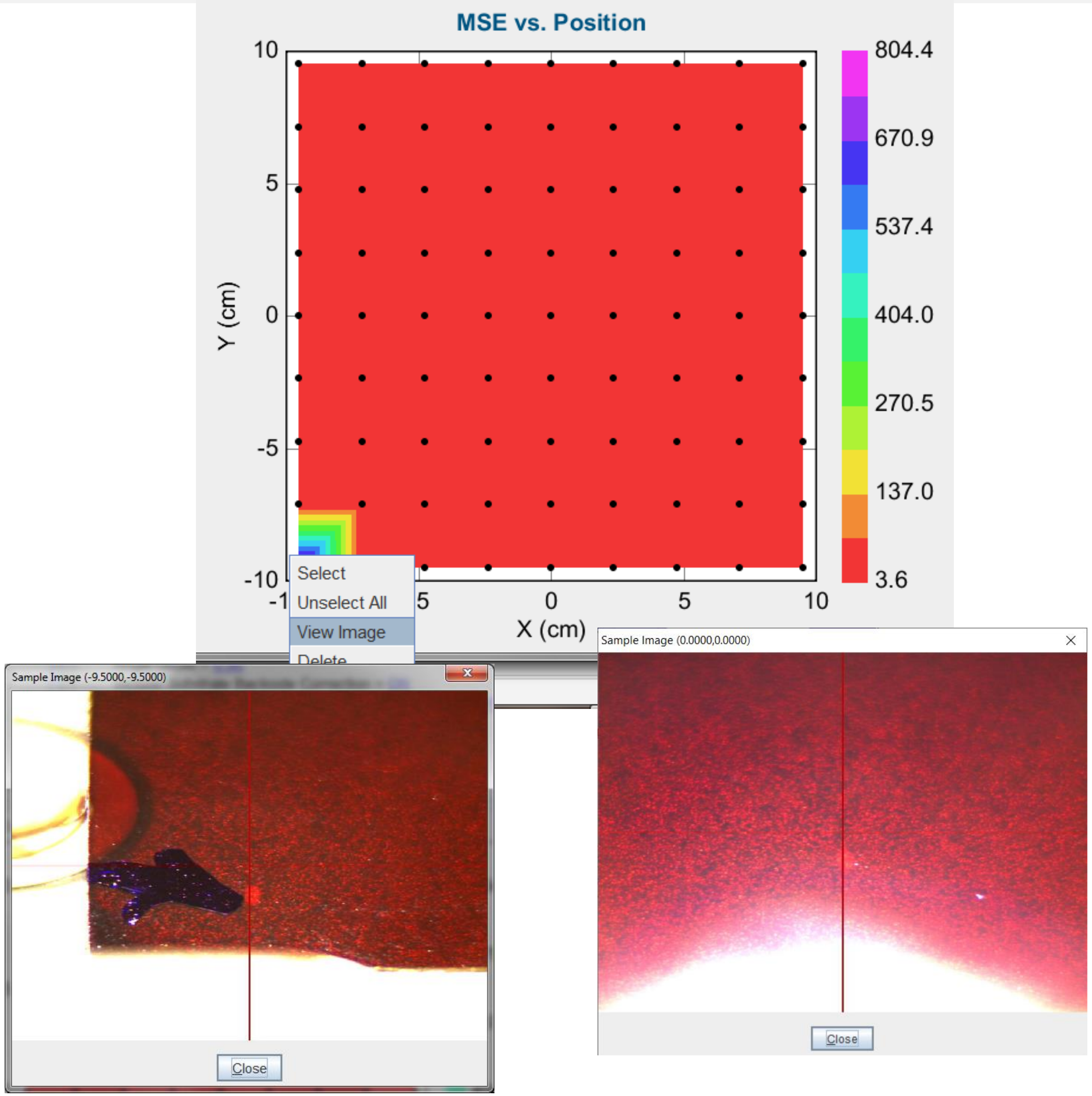


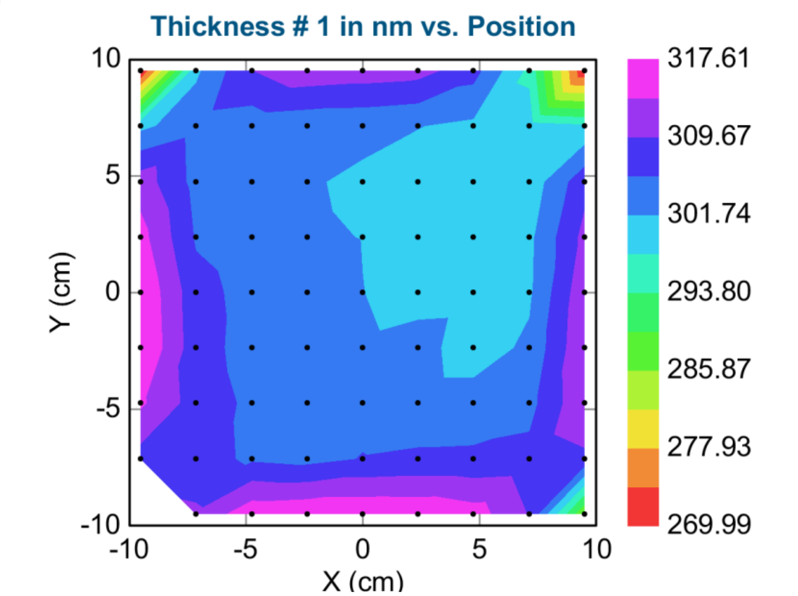
6-03 a-Si on 7059 Glass: Center Results

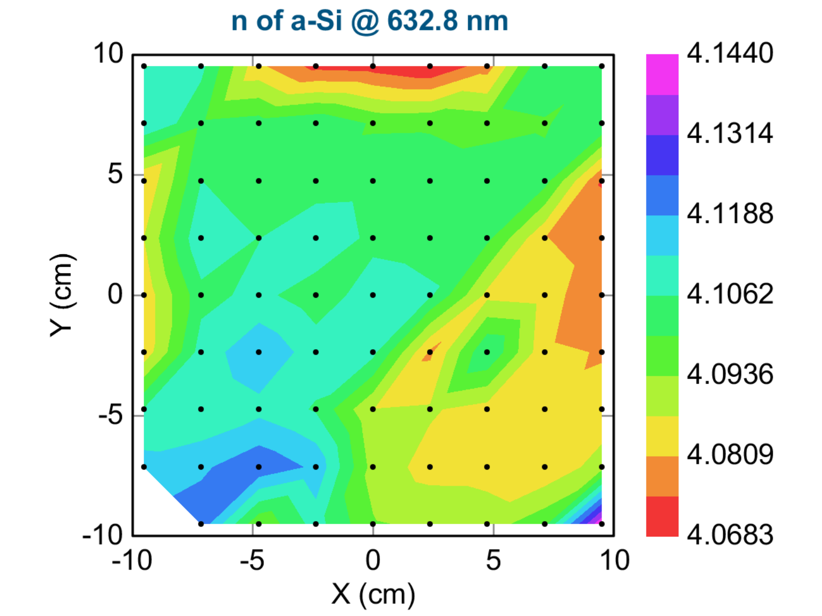




6-03_A-SI ON 7059 GLASS - MAP

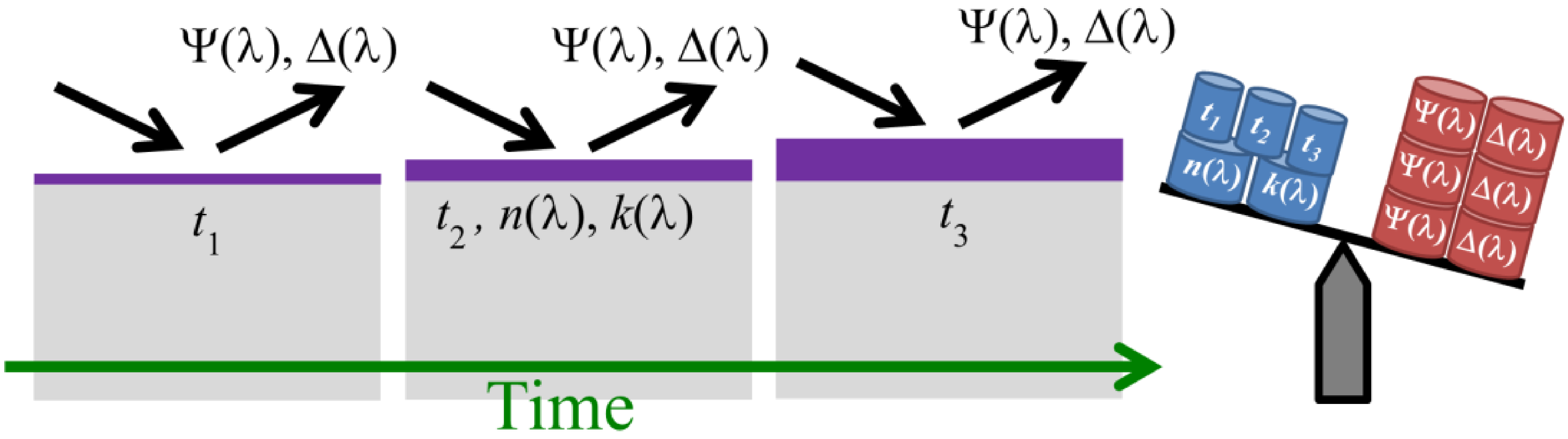






Topic #3: Dynamic Data Analysis

- SE measurements are repeatedly collected during a process, such as film growth.

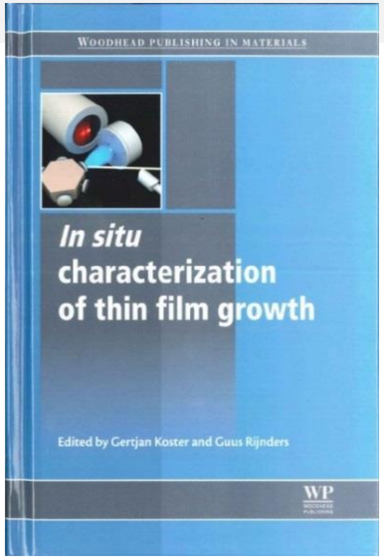


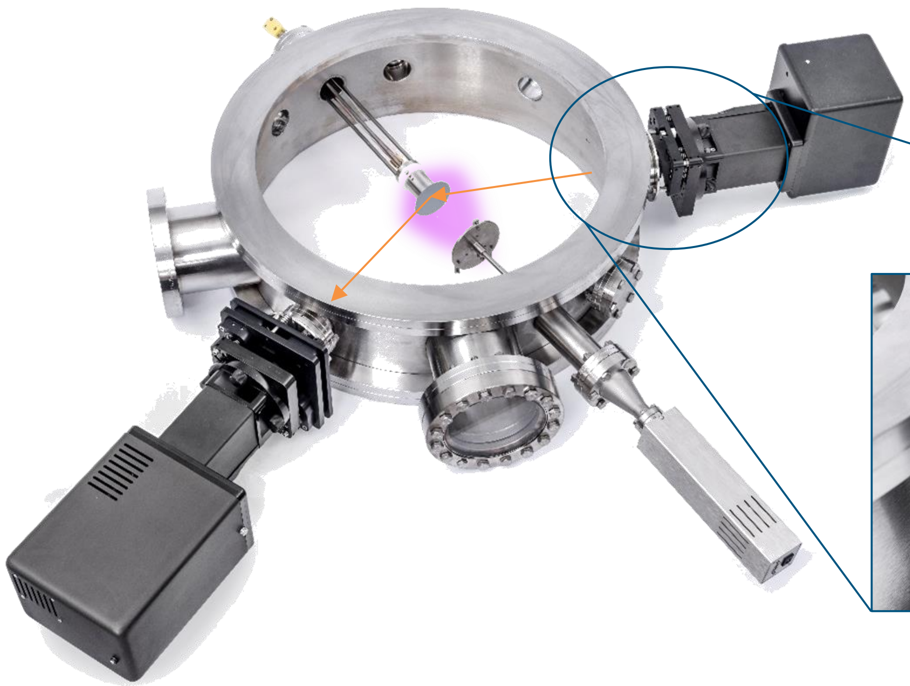
- Analyze all data versus time to characterize the process.

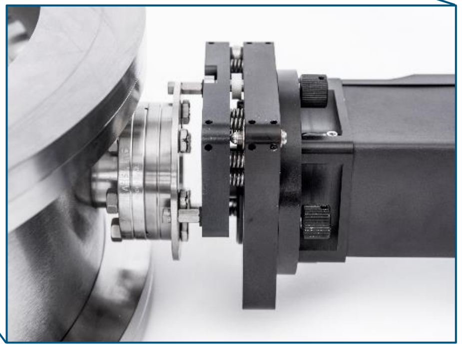
IN SITU ELLIPSOMETRY

- Real-time monitoring and control
- Complete sample history
  - Before, during and after process
- Direct measurement of surfaces & interfaces

J.N. Hilfiker "In situ spectroscopic ellipsometry (SE) for characterization of thin film growth", *chapter in* In situ characterization of thin film growth, G. Koster and G. Rijnders, eds., Woodhead Publishing: Cambridge, UK (2011)



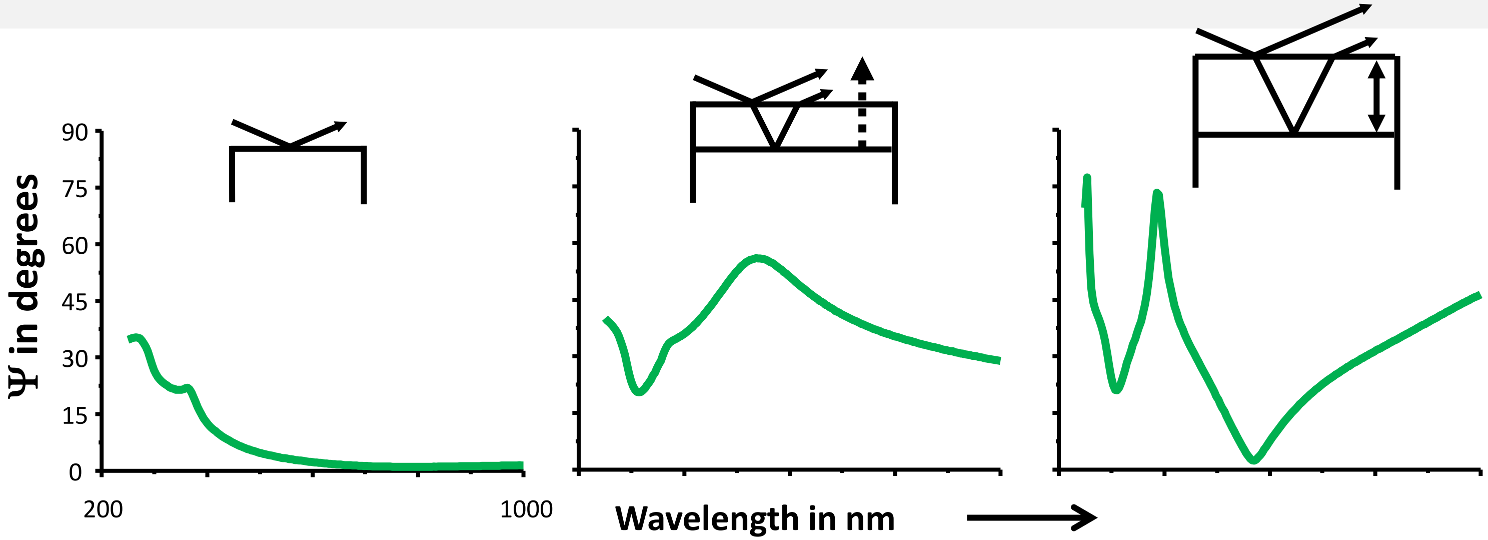




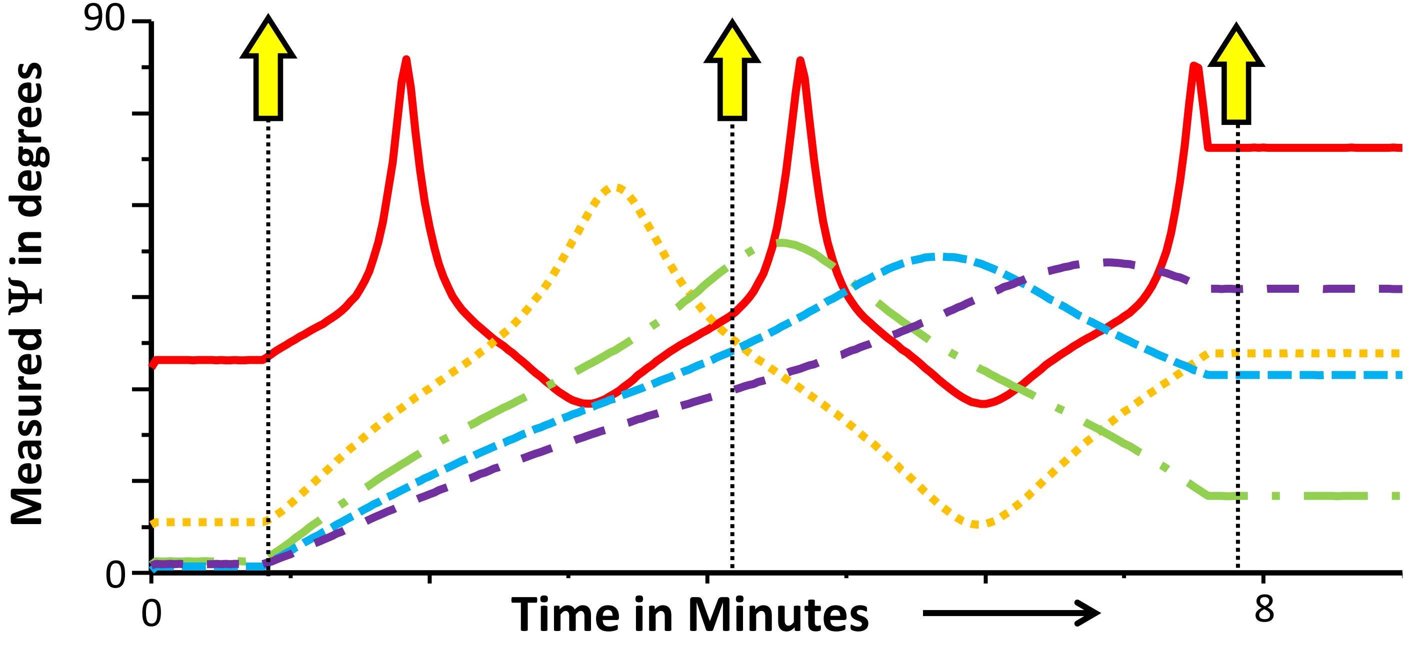
Atomic Layer Deposition

IN-SITU SE DATA

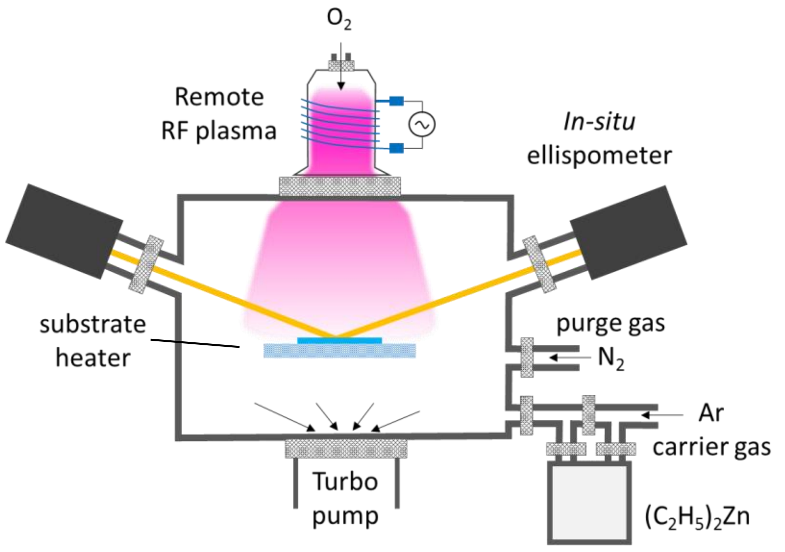
Spectral Data

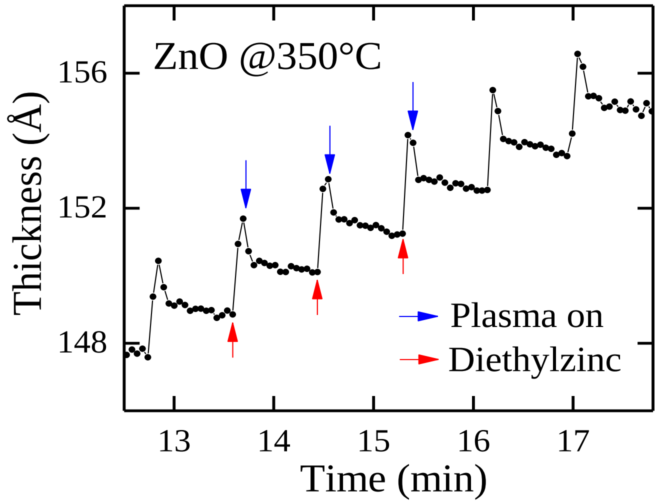


Dynamic Data

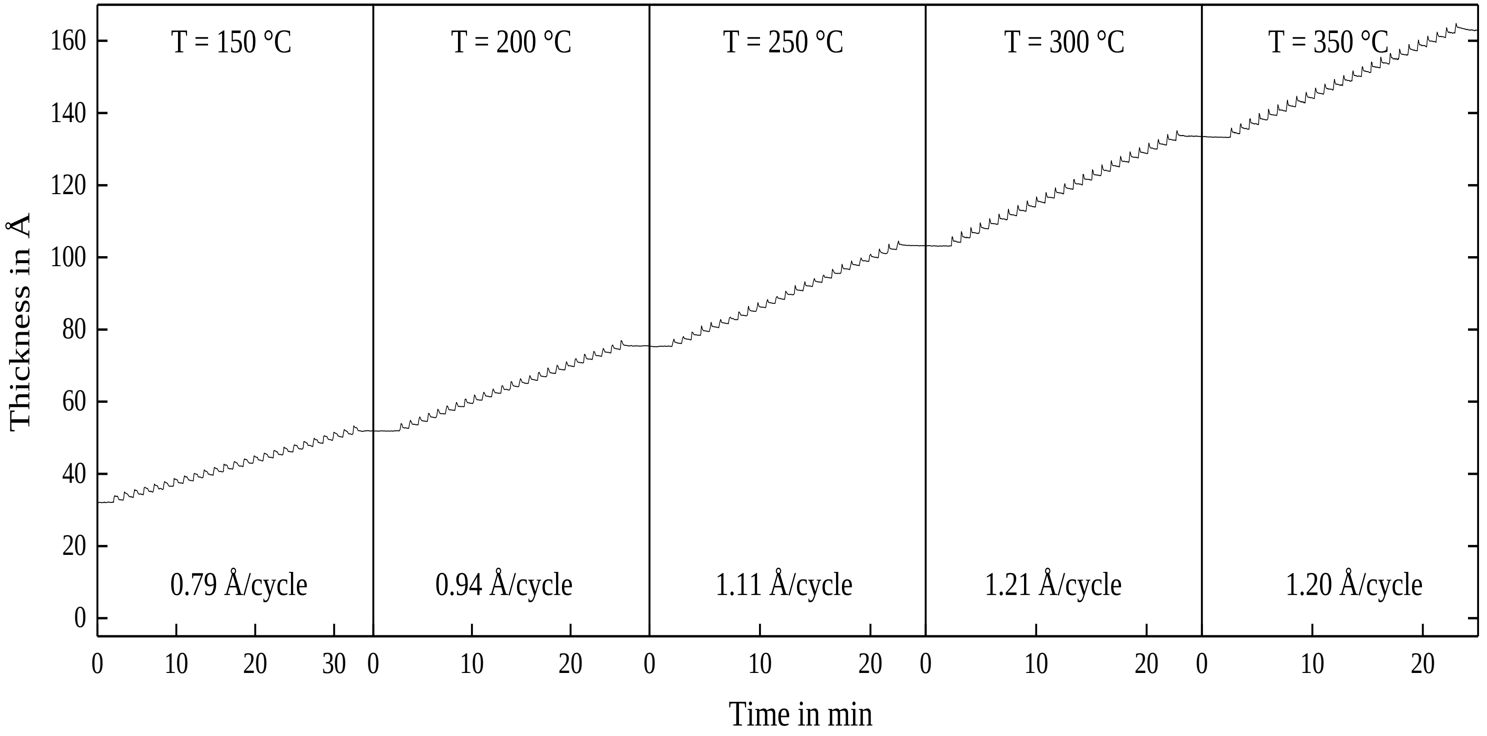


ATOMIC LAYER DEPOSITION





- Process optimization in one single run



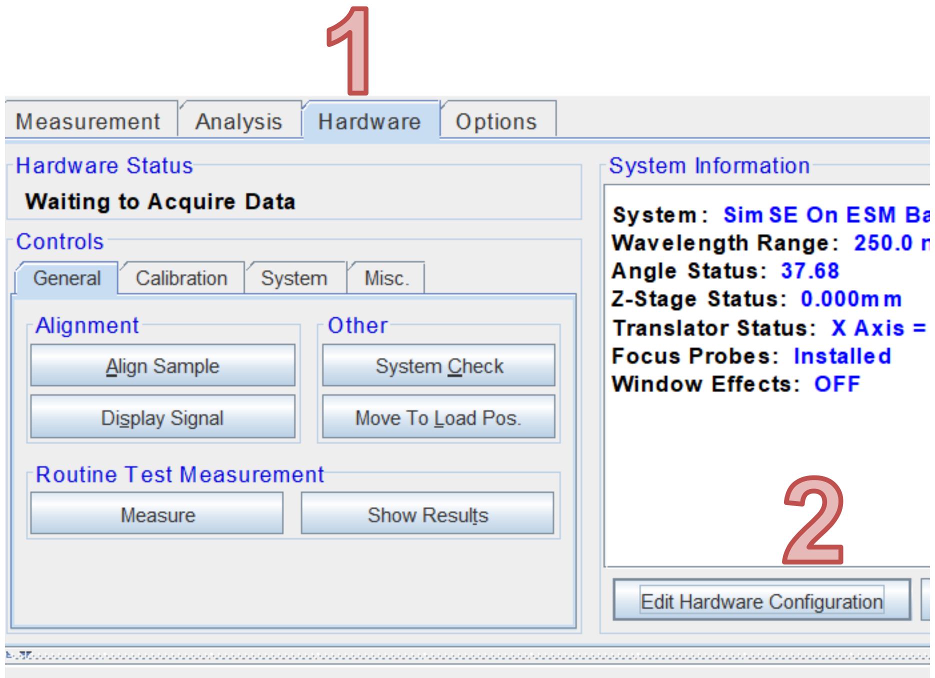
SHORT-CUTS FOR IN SITU DATA

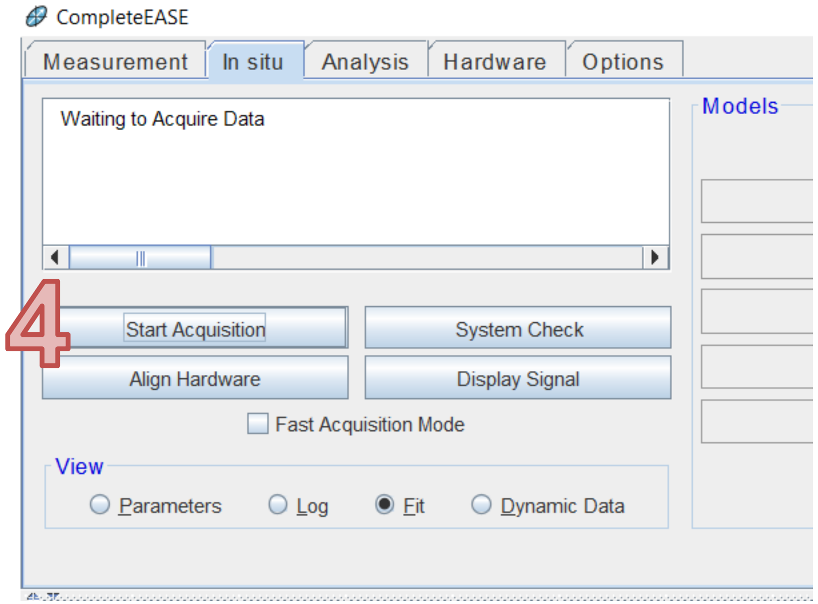
Shortcut	Function
CTRL+Spacebar	Toggle view between single time-slice SE Data & Data vs. Time
ALT- (data set #)	Select specific data set (when multiple data sets selected)
CTRL+'Y'	Toggle double Y-axis
Left-click mouse (Dynamic Data Graph)	Select time-slice
CTRL-Left-click mouse (Dynamic Data Graph)	Add multiple time-slices for multi-time analysis
ALT+Left-click mouse (Dynamic Data Graph)	Set Virtual Interface time-slice (drag mouse to select time range)
CTRL+ALT+SHIFT+'U'	Display the ***In situ*** tab
CTRL+'U'	Select ***In situ*** tab
CTRL+'A'	Select ***Analysis*** tab

BASIC IN SITU DATA ANALYSIS STRATEGY

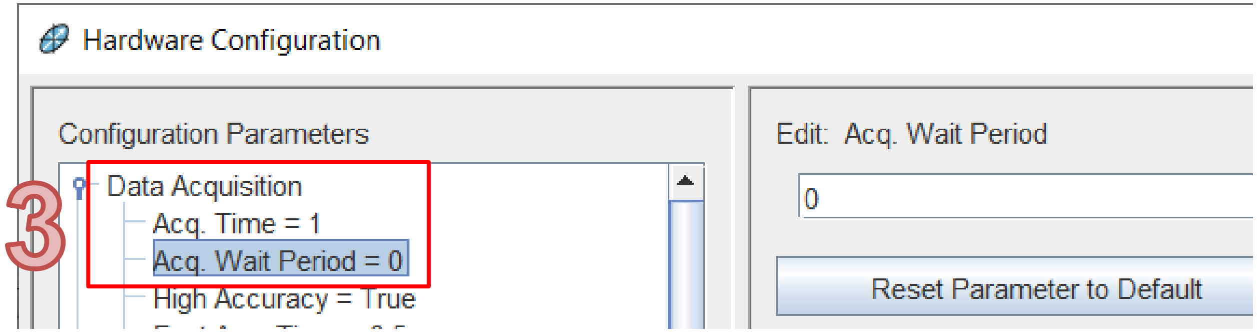
- Select early time-slice to:
  - Fit bare substrate (native oxide thickness, angle offset, temperature)
- Select late time-slice to:
  - Fit thin film optical constants
- Fix parameters except thickness and “Fit Dynamic”
  - Confirm initial model thickness is close prior to “Fit Dynamic”

COLLECTING IN SITU DATA



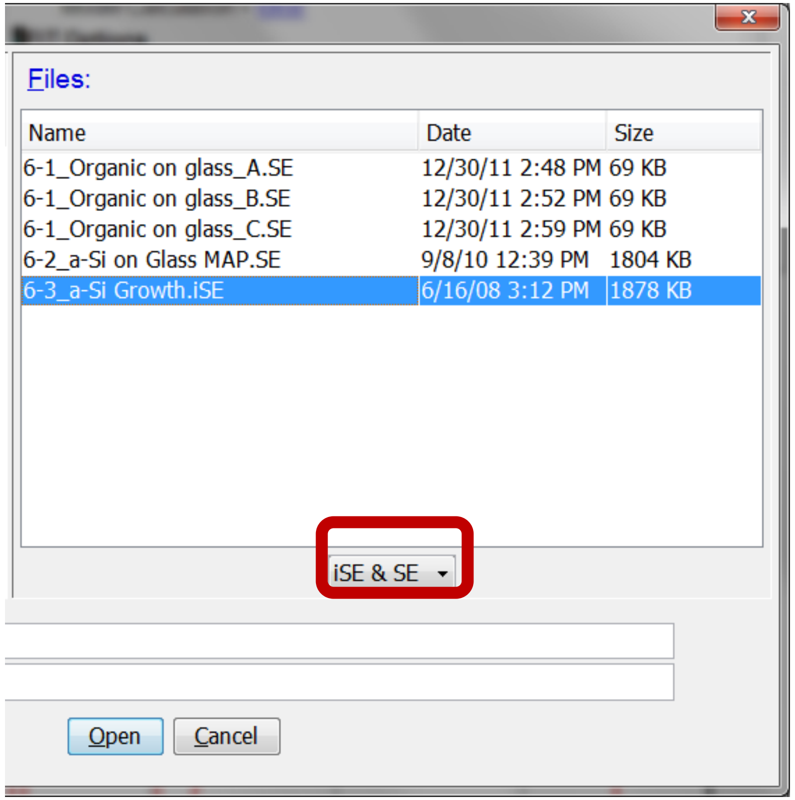


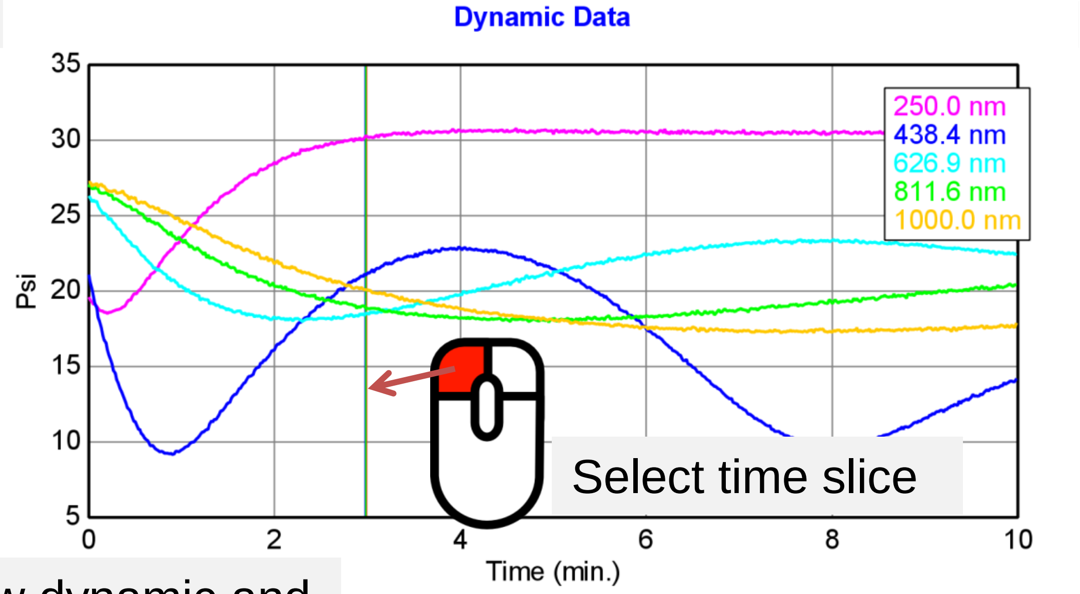
- Preset data acquisition time and intervals



OPEN AND VIEW IN SITU DATA

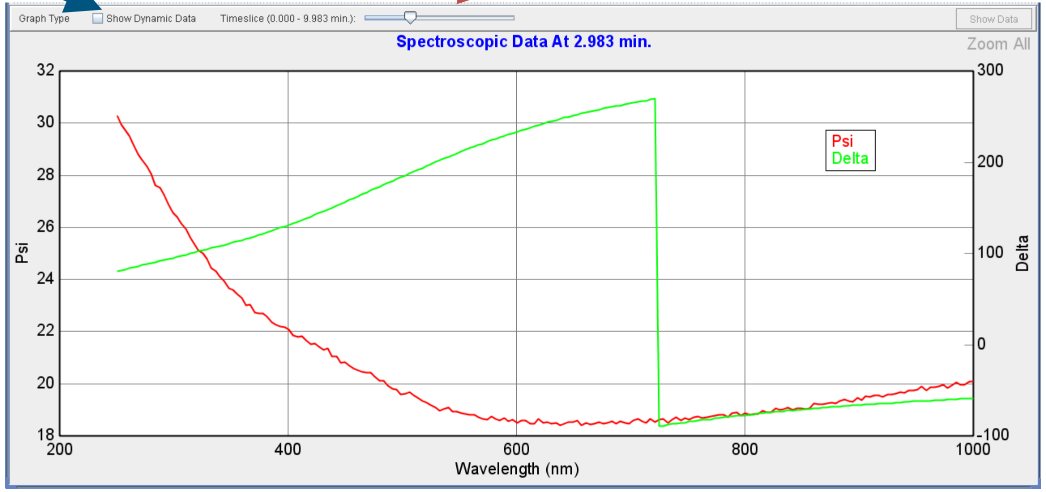
- Dynamic data is saved with “iSE” extension





Toggle bw dynamic and spectroscopic data

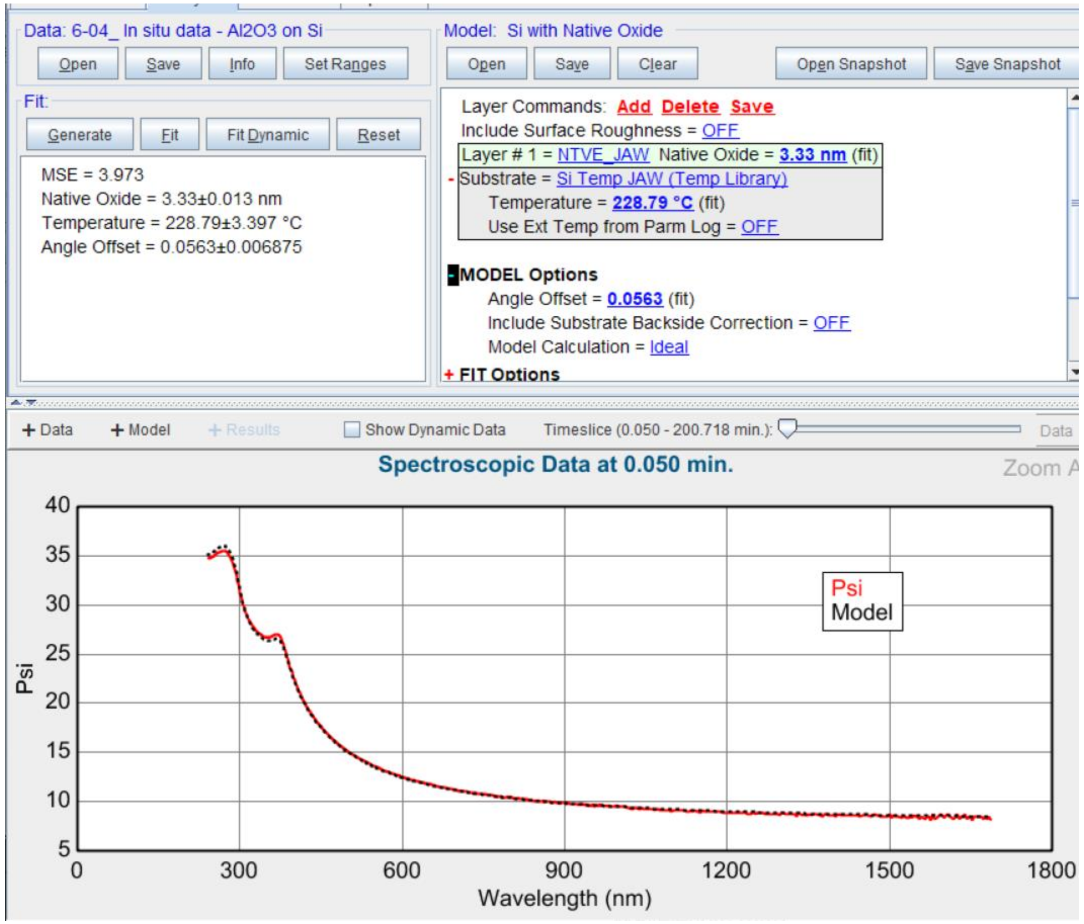
Bar to move through time slices

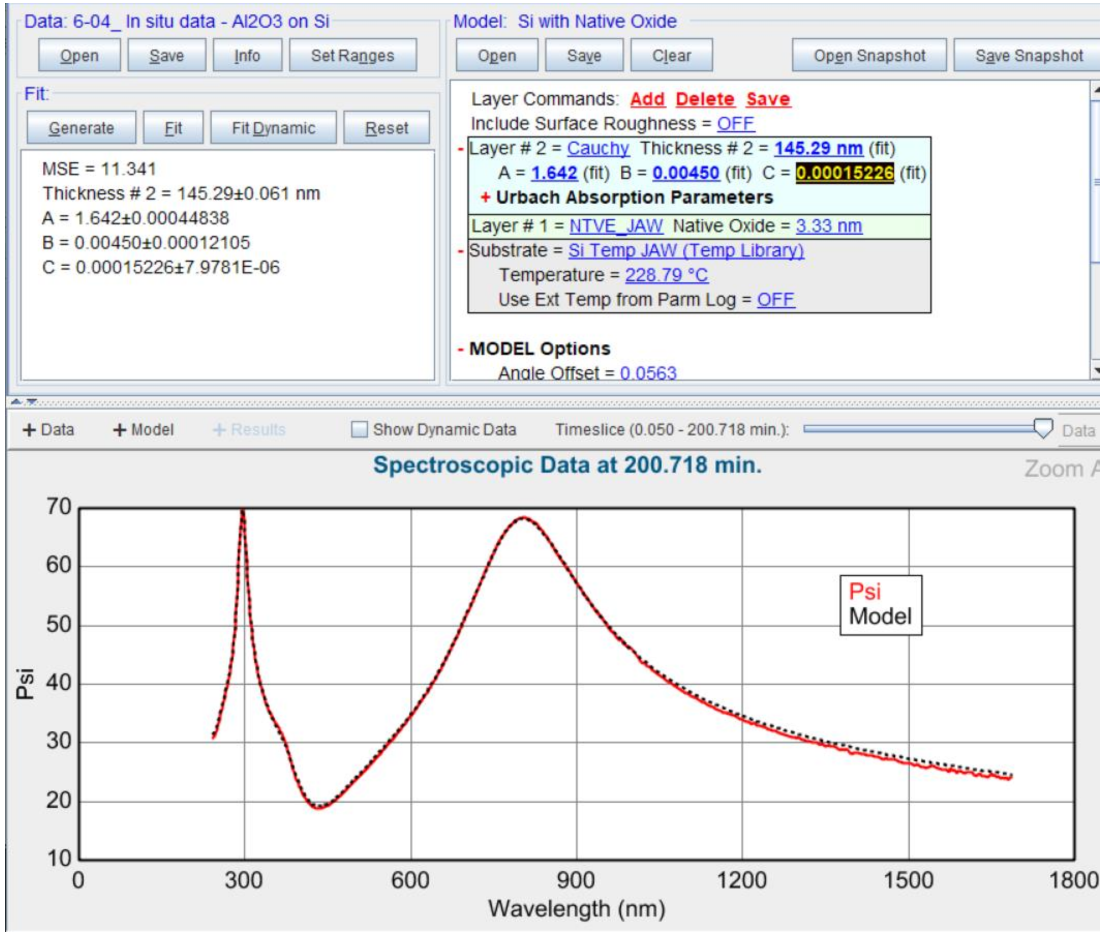


6-04 In situ data – Al_2O_3 on Si

- **Determine Growth Rate from dynamic data of Al_2O_3 on Si.**

FIT STRATEGY



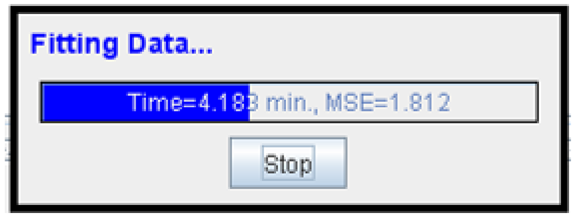


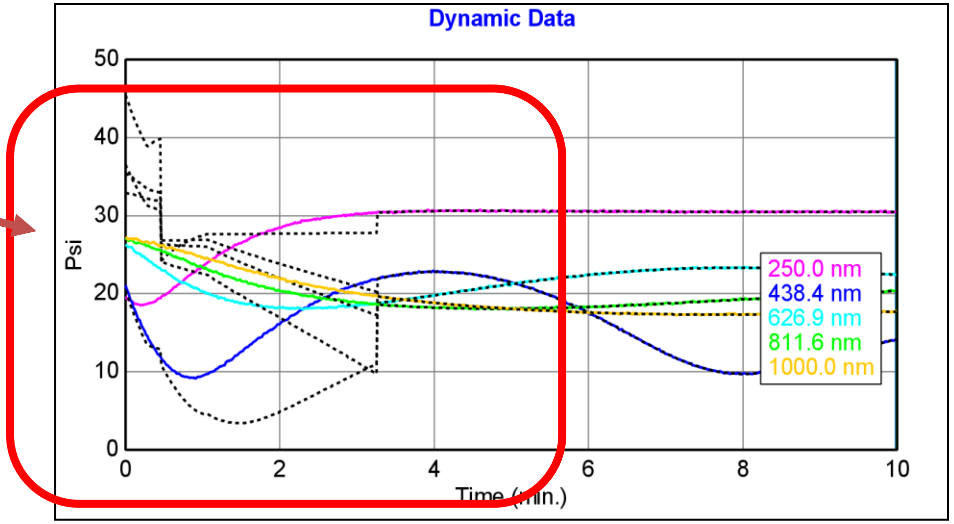
- Determine sample baseline and system condition at the beginning
- Determine ALD layer refractive index when films become thick enough

DYNAMIC FIT

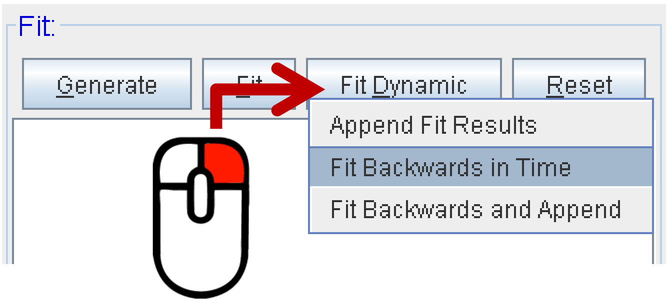
'Fit-Dynamic'

a) Select 'Fit Dynamic'
b) Can also "fit backwards in time" by right-clicking on 'Fit Dynamic'

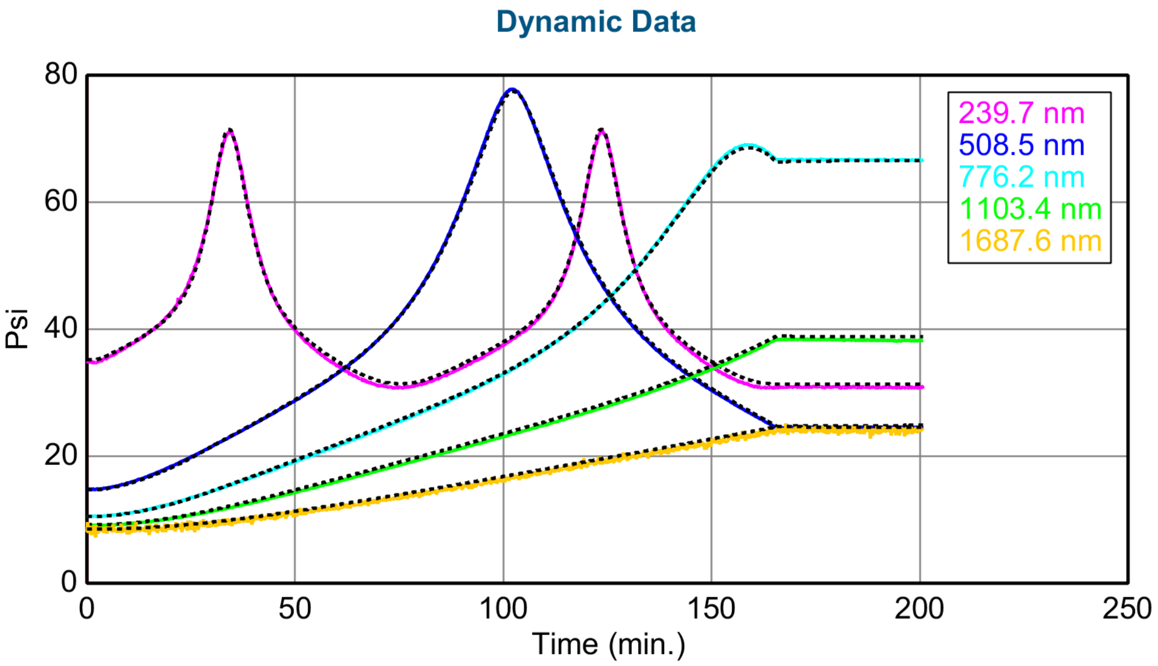


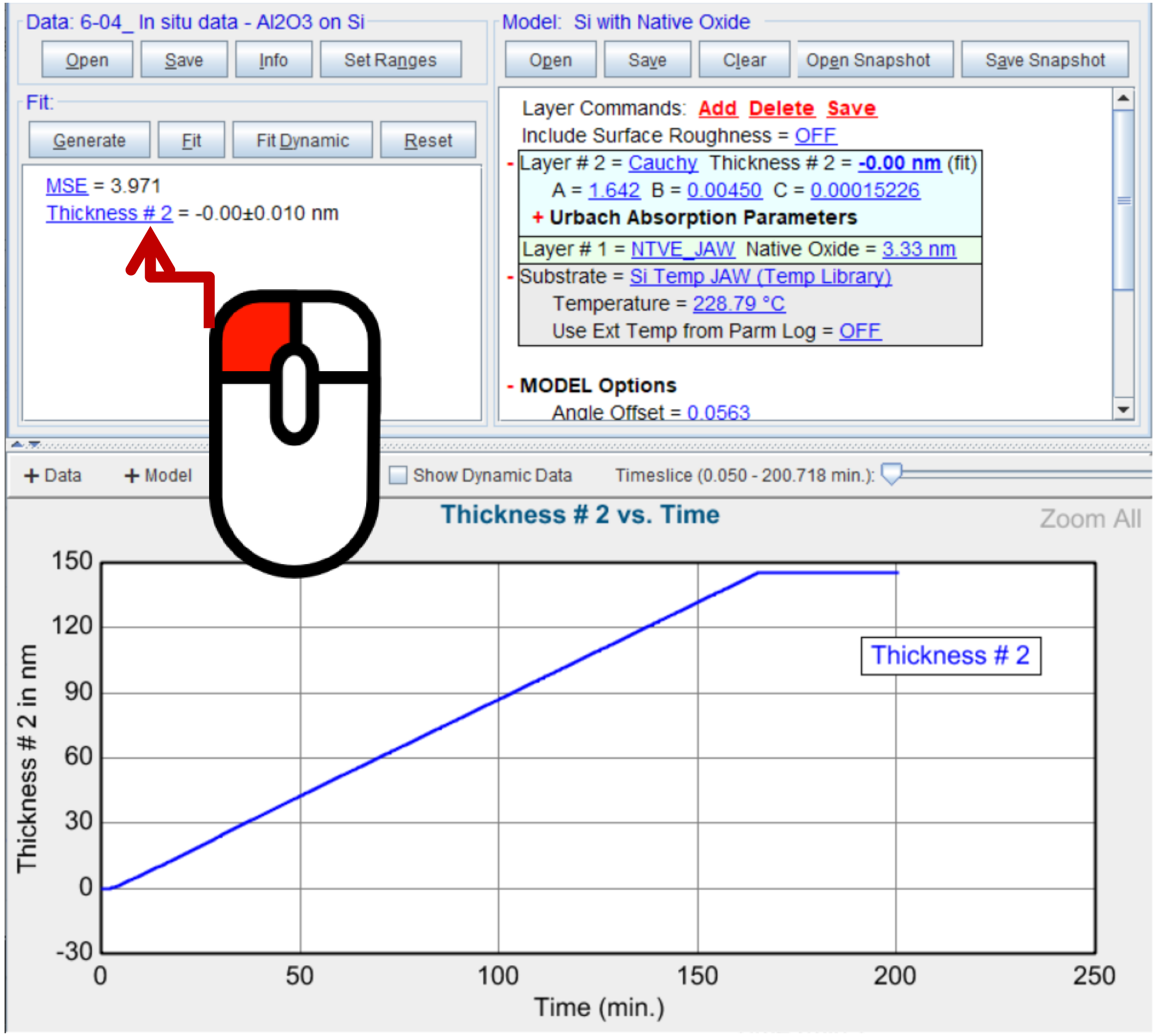


'Seed' fit parameters to good starting values or the Dynamic Fit will get lost

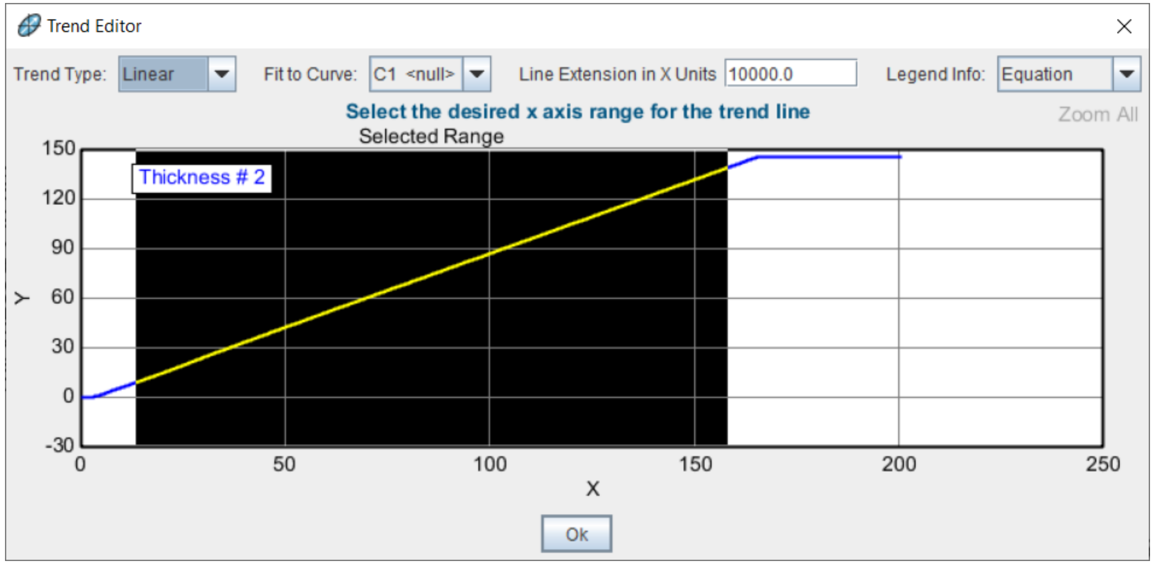


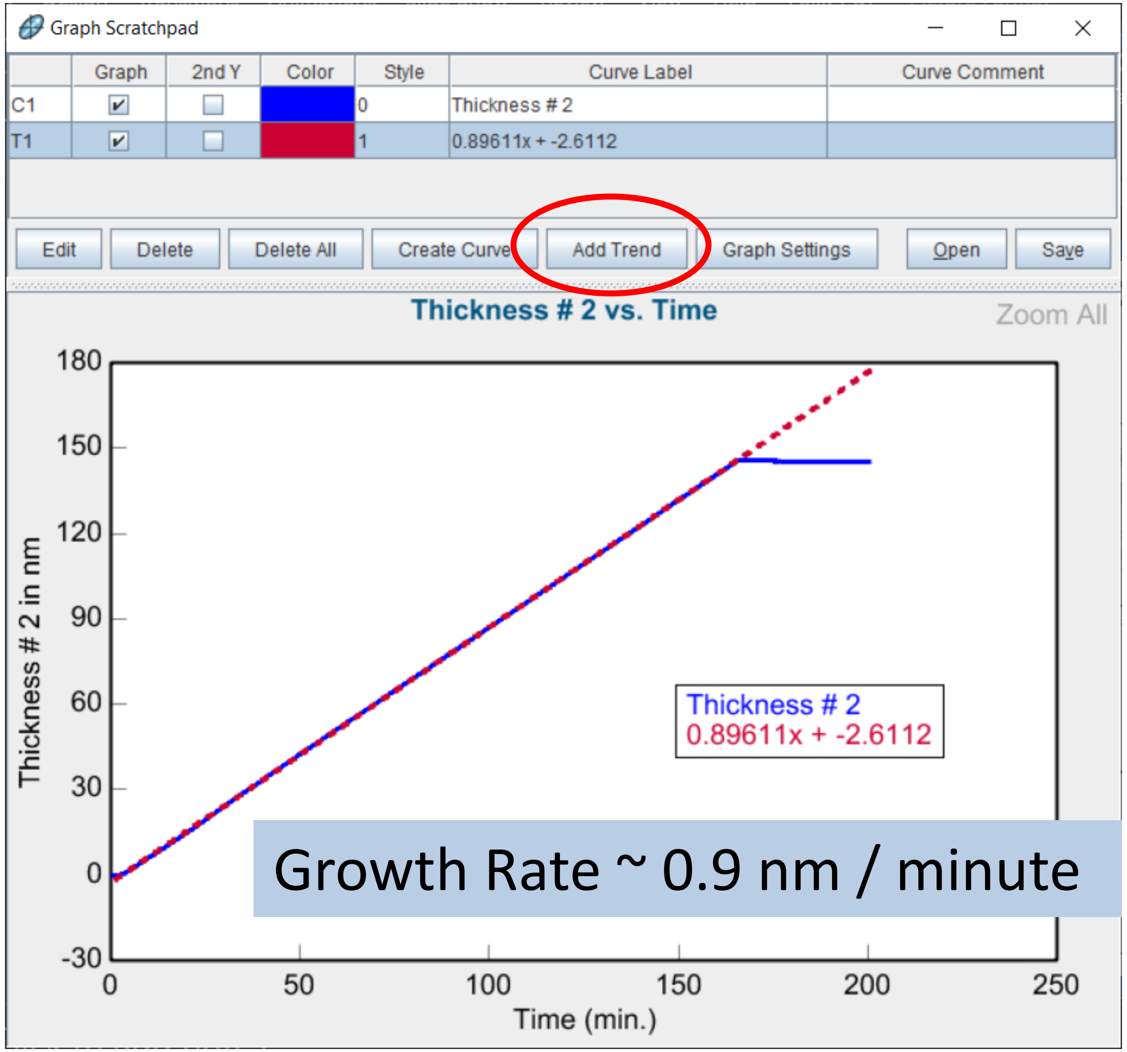
DYNAMIC RESULTS





GROWTH RATE FROM GRAPH SCRATCHPAD

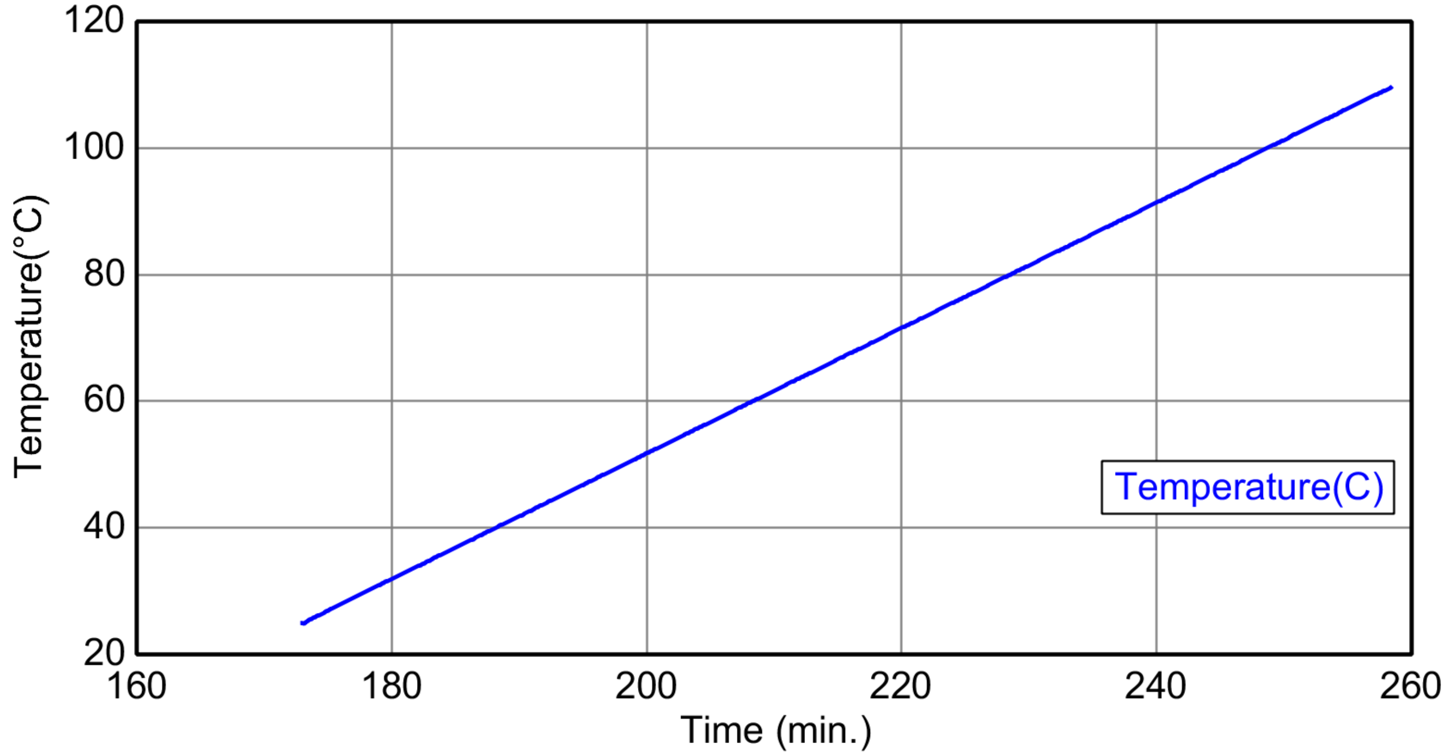




Growth Rate ~ 0.9 nm / minute

Example 6-05: Polymer on Si_Tg

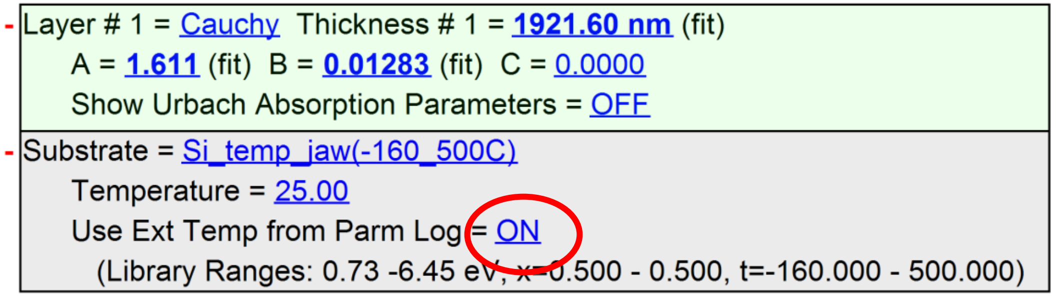
We created a novel polymer mixture and want to study the mechanical properties. We spin coat the polymer onto a Si wafer and use a heat cell to determine the glass transition temperature from the temperature dependence of the layer thickness.



ANALYSIS STRATEGY

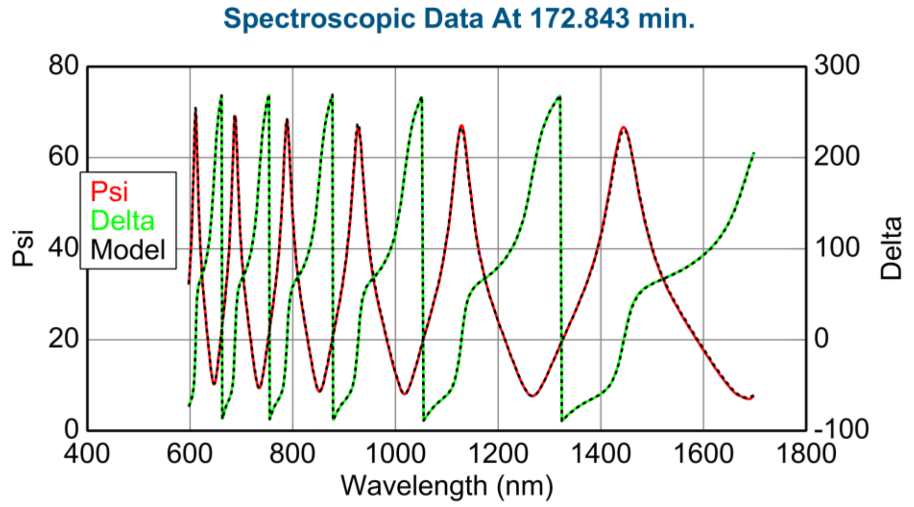
We will do these steps together:

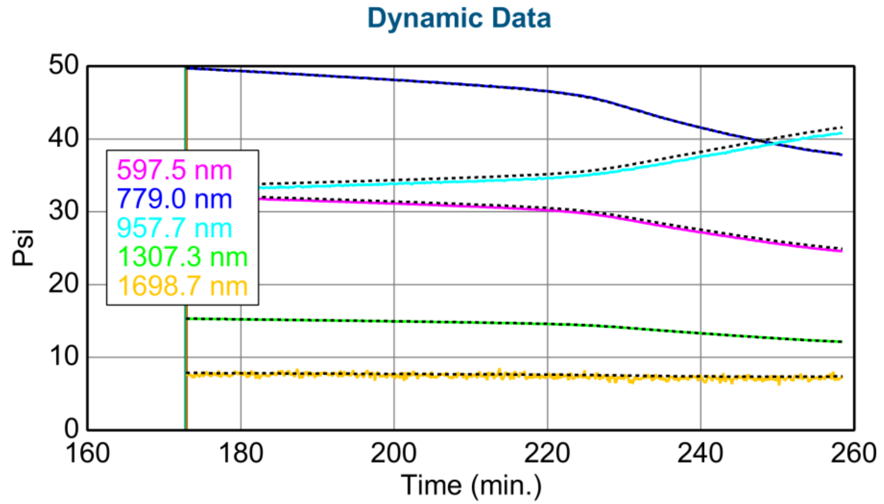
1. Open dynamic data (.iSE extension)
2. Select the first time slice.
3. Build Model: Need to consider temperature effect on substrate
   - Use temperature library material file “Si_Temp_JAW(-160-500C)”
   - Use stored temperature readings

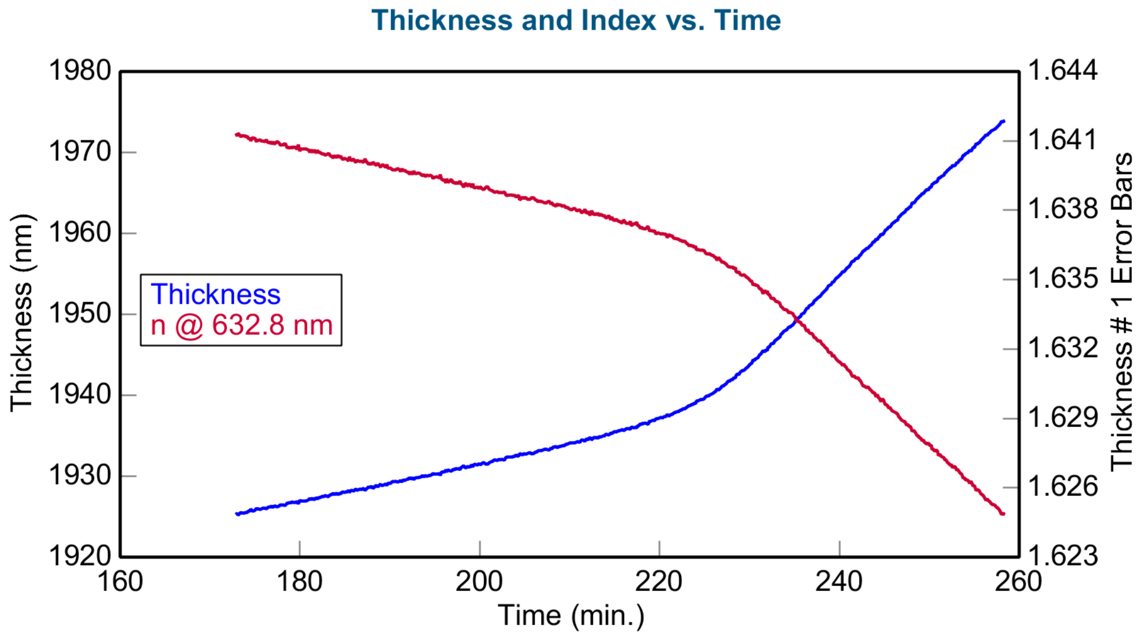


4. Fit Single Time Slice.
5. Fit Dynamic Data.
6. Graph results as function of Temperature using Advanced Graph Options in Fit window.
7. Use the Graph Scratch Pad to determine T_g.

6-05: Polymer on Si_Tg - Results

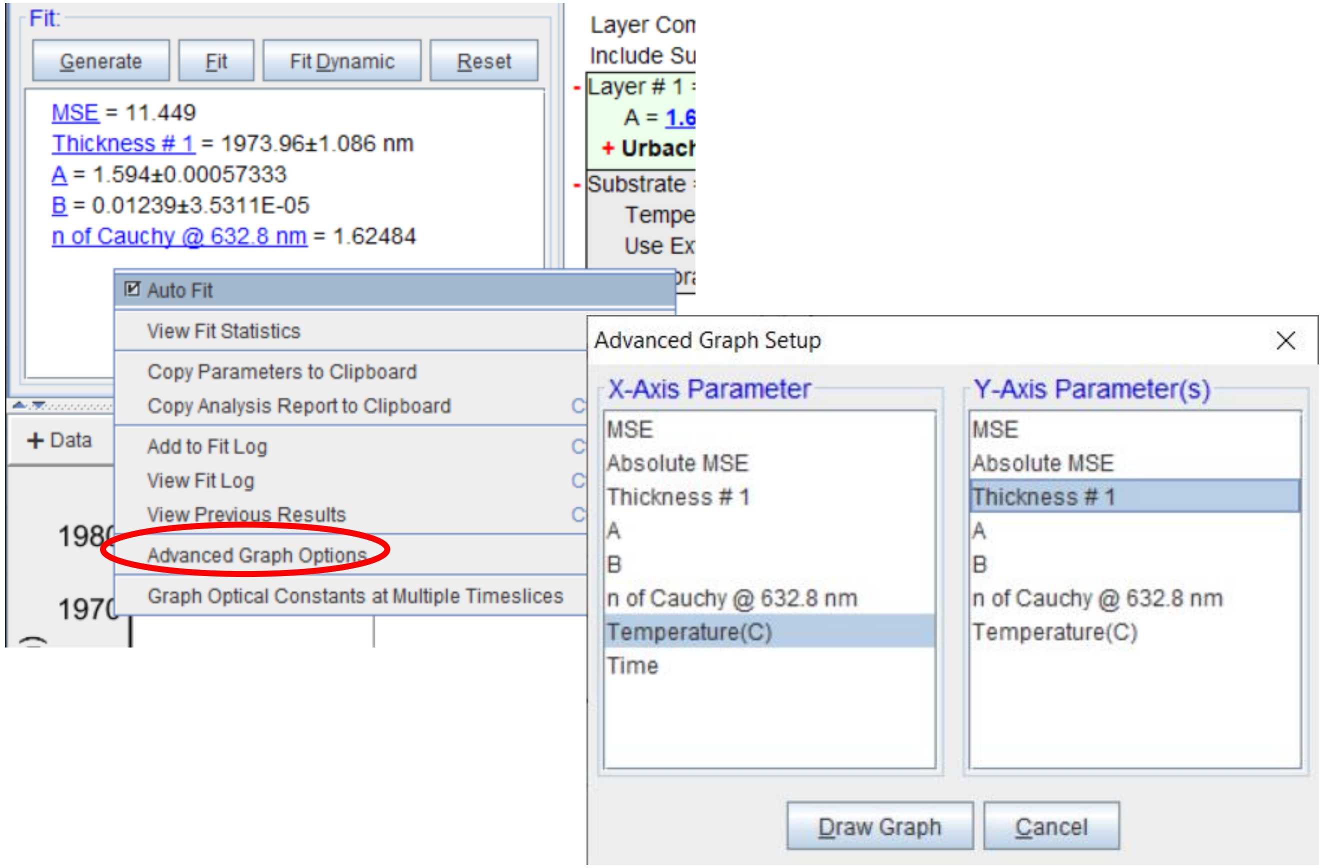


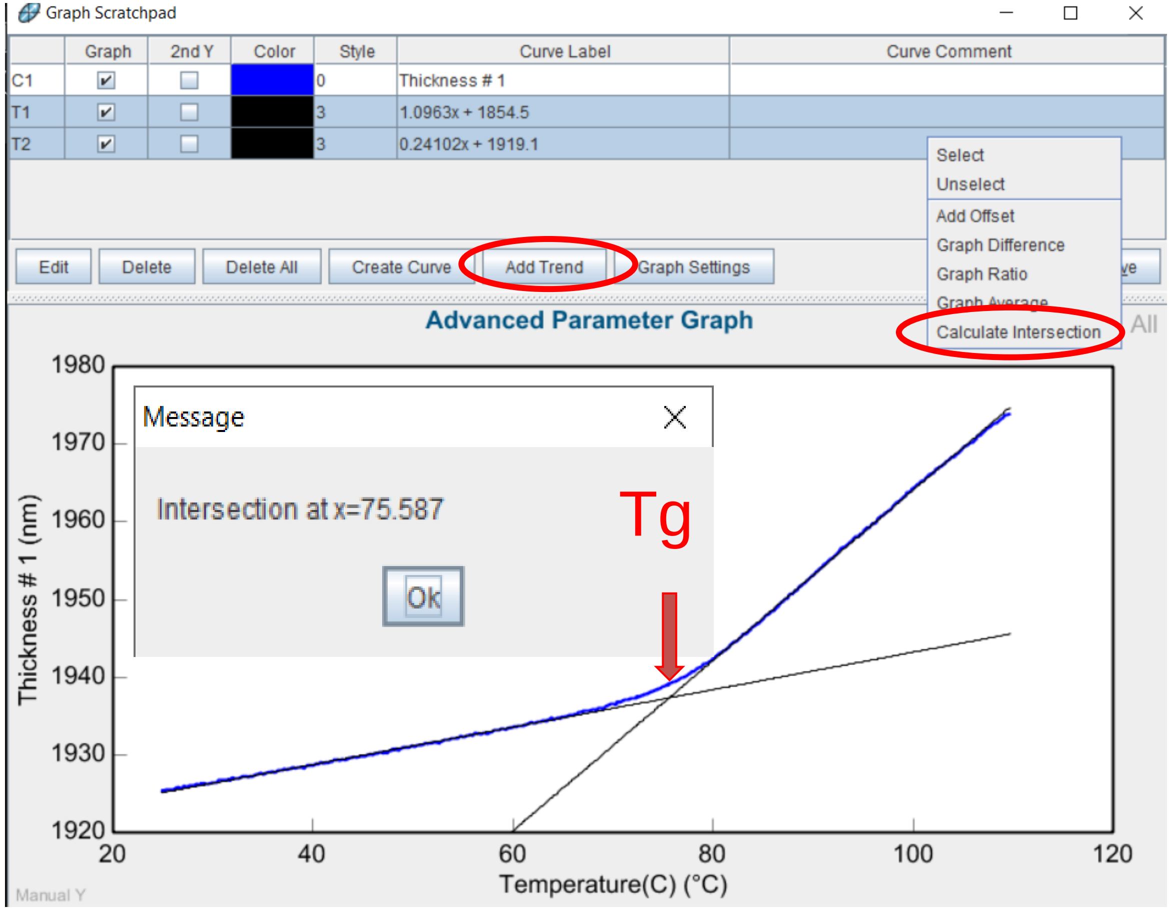




ADVANCED GRAPH CAPABILITIES

- Right Click in Fit Window to open Advanced Graph Options
- Plot thickness vs Temperature in Graphscratchpad
- Add trend lines and calculate Tg



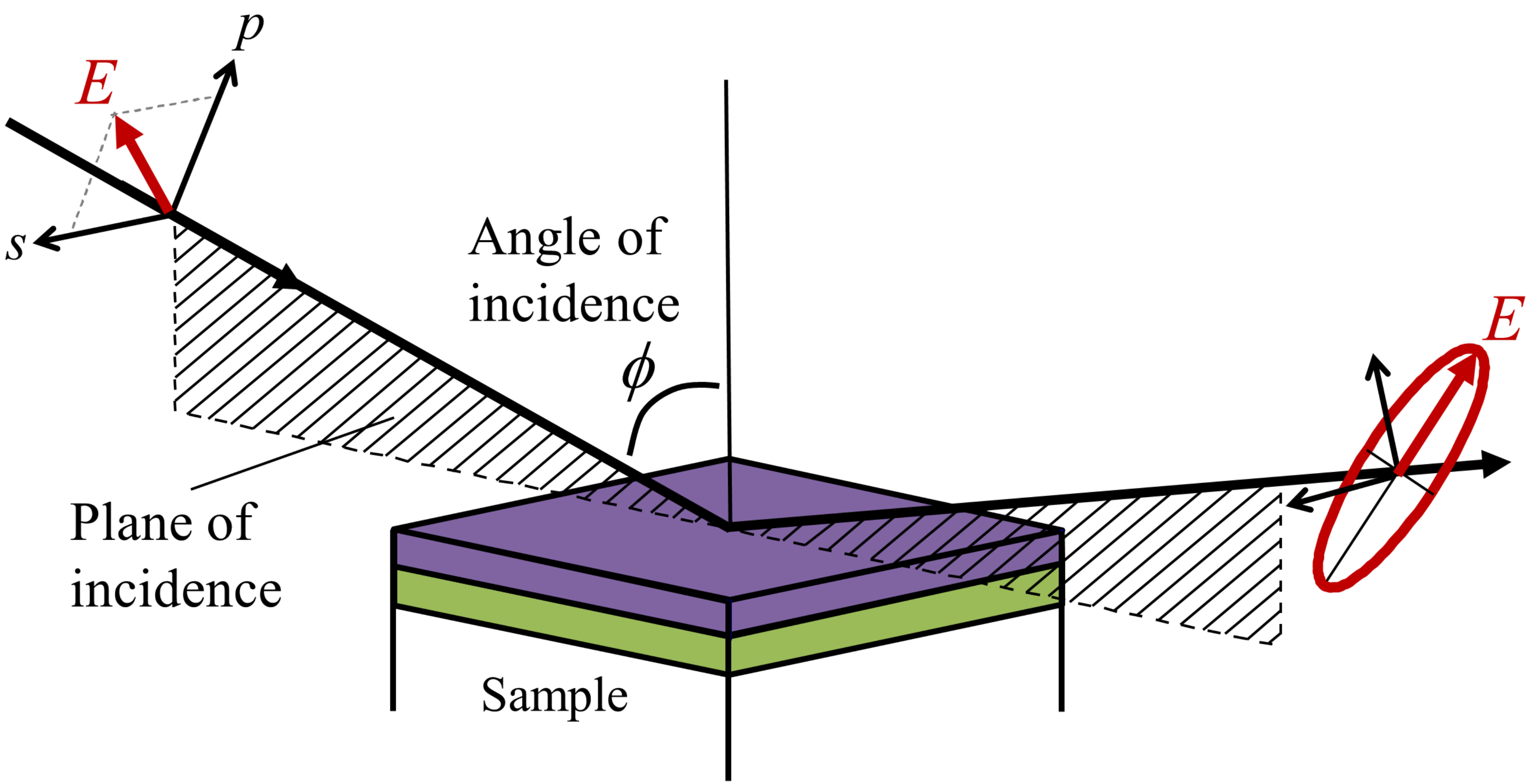


Review

- Consider Key Concepts and how they fit together

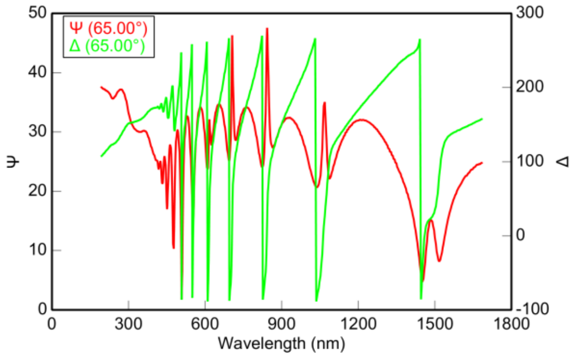
SPECTROSCOPIC ELLIPSOMETRY (SE)

- Measures change in polarization.

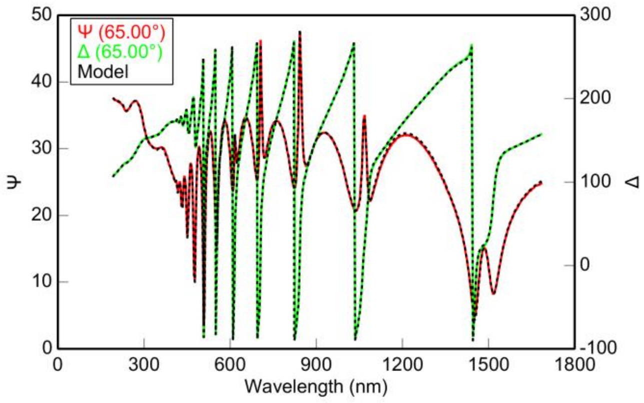


Basics Of Ellipsometry

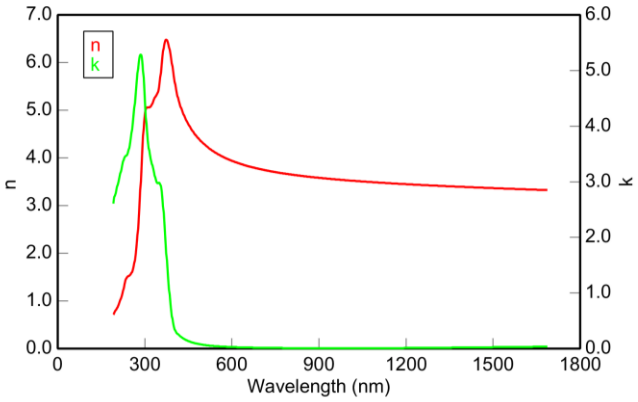
Measurement



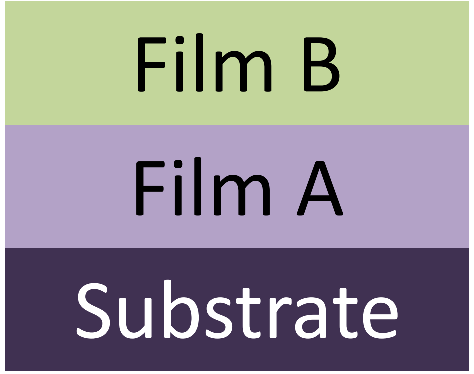
FIT

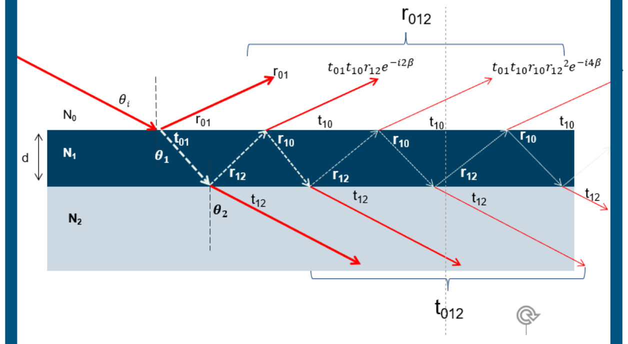


RESULTS



MODEL



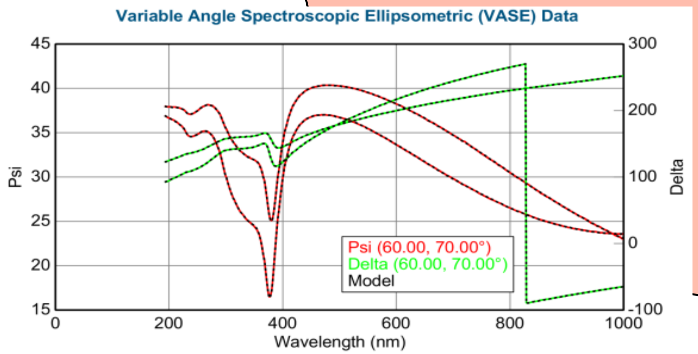


H.G. Tompkins and J.N. Hilfiker "Spectroscopic Ellipsometry: Practical Application to Thin Film Characterization" (2016) Momentum Press.

MODEL EVALUATION

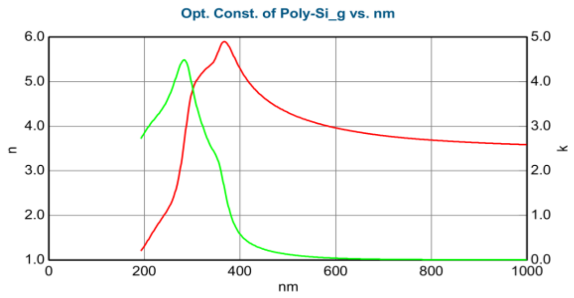
Good Match

- Describes all significant features in the data
- Small MSE



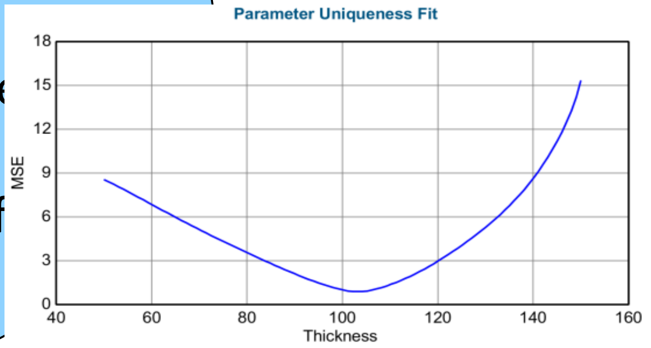
Physical results

- Positive ε_2
- Positive thickness
- KK consistent index



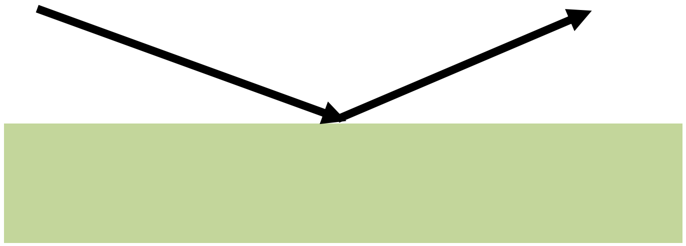
Unique answer

- Good sensitivity to fit parame
- Low error bars
- Simplest model with fewest f parameters

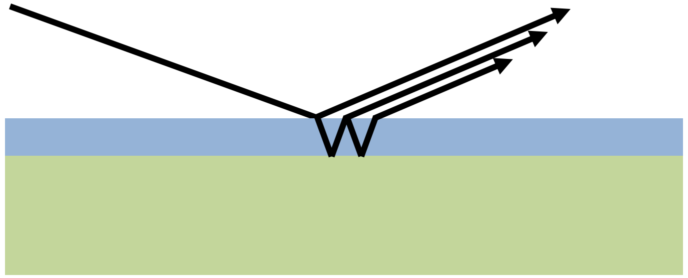


WHAT ARE WE MEASURING?

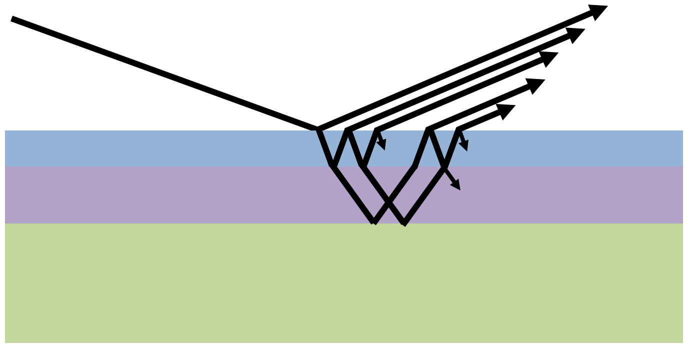
- Substrate
  - Ideal: Single surface reflection.



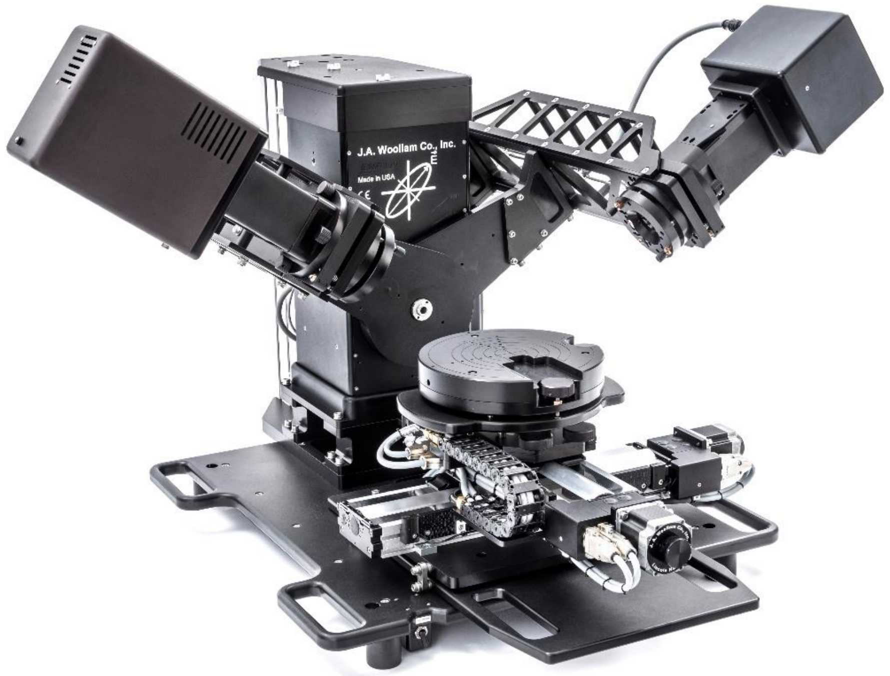
- Single-Layer
  - 1nm to 20 μm of material on substrate

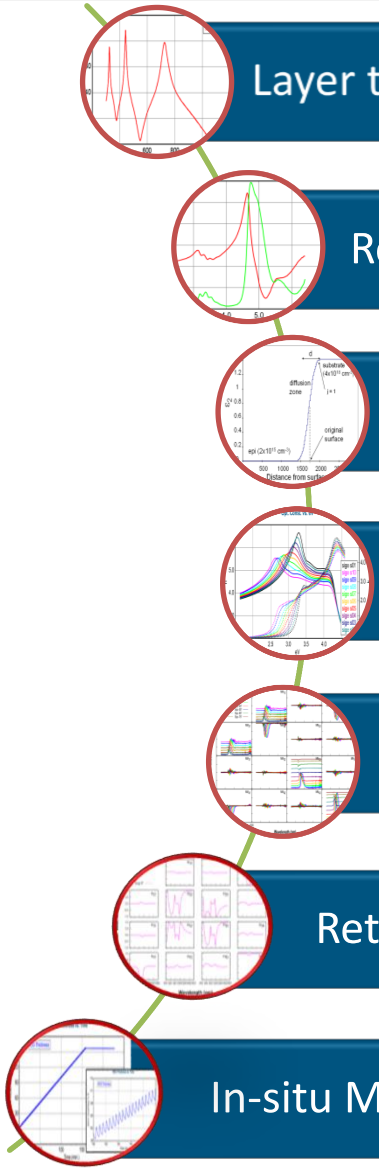


- Multi-Layer
  - More than one film with different *n,k*



WHAT DOES ELLIPSOMETRY DO?





- Layer thickness and Uniformity
- Refractive Index / Optical Constants
- Grading and Roughness
- Composition / Bandgap / Conductivity/ Porosity /Crystallinity
- Anisotropy
- Retardance/ Chirality
- In-situ Monitoring / Dynamic Properties

DATA CONTENT → MATERIAL PROPERTIES

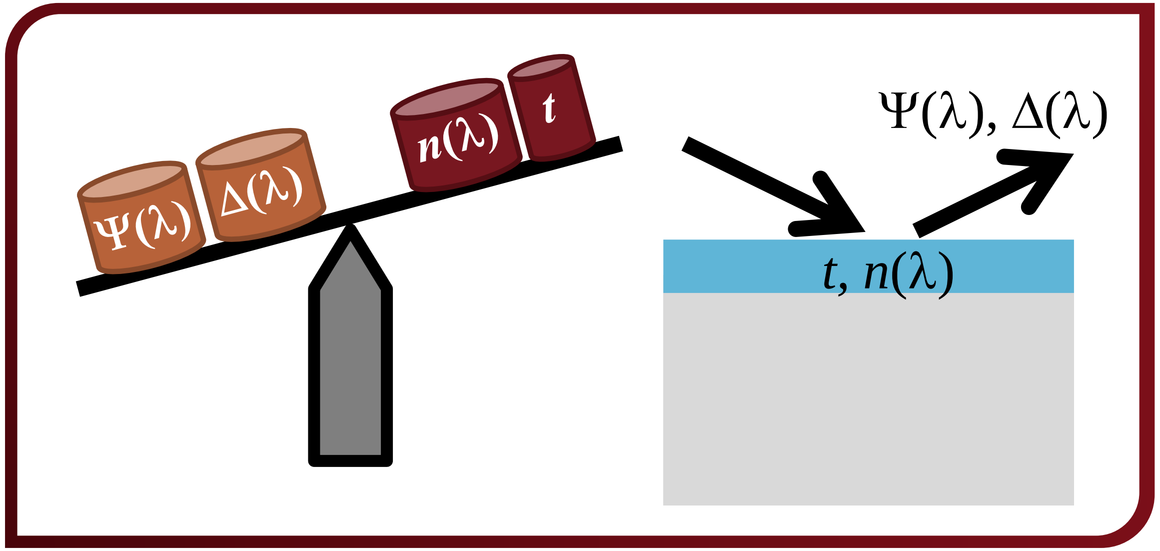
Measurement information

- Total content: **<u>2λ</u>**.
- Multiple angles may add extra information.

Material properties

- Film thickness
- Optical Constants
  - Transparent (*n*): **<u>1λ</u>**
  - Absorbing (*n* & *k*): **<u>2λ</u>**

- Measurement content needs to solve all unknown sample properties



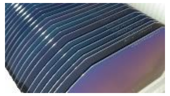
MODELING DIFFERENT MATERIALS

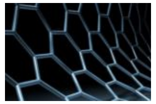
$$\tilde{n} = n - ik$$

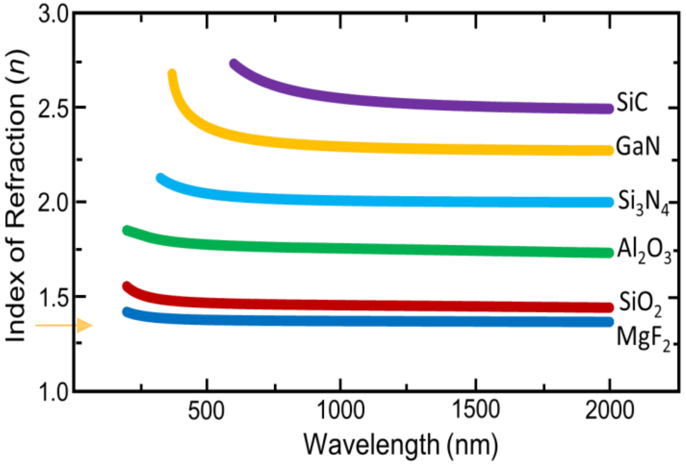
$$\tilde{\varepsilon} = \varepsilon_1 - i\varepsilon_2$$

$$\tilde{\varepsilon} = \tilde{n}^2$$

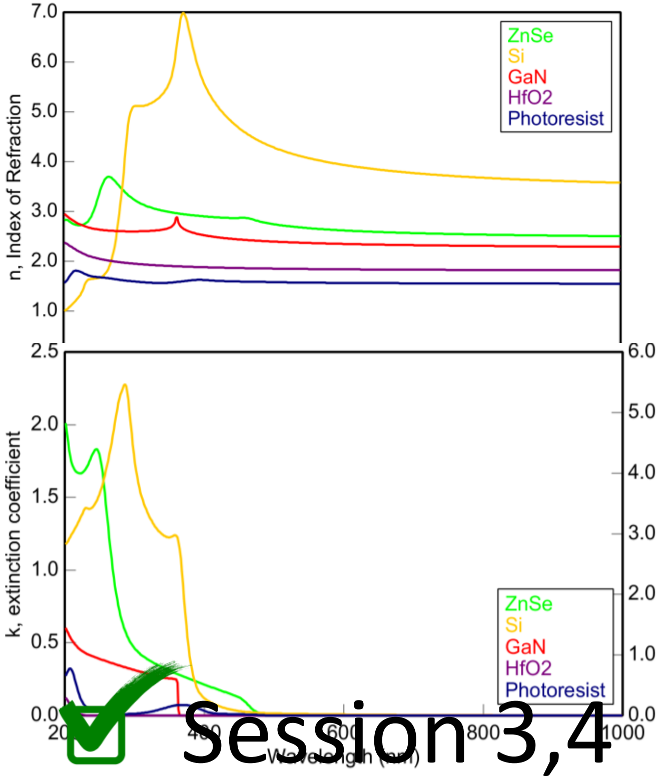
Transparent 

Semi-absorbing 

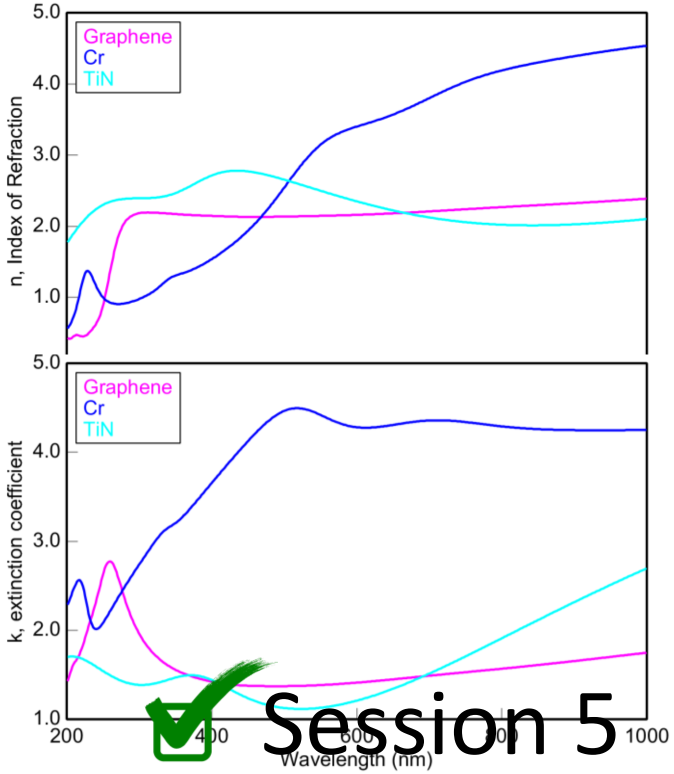
Absorbing 



Session 2



Session 3,4



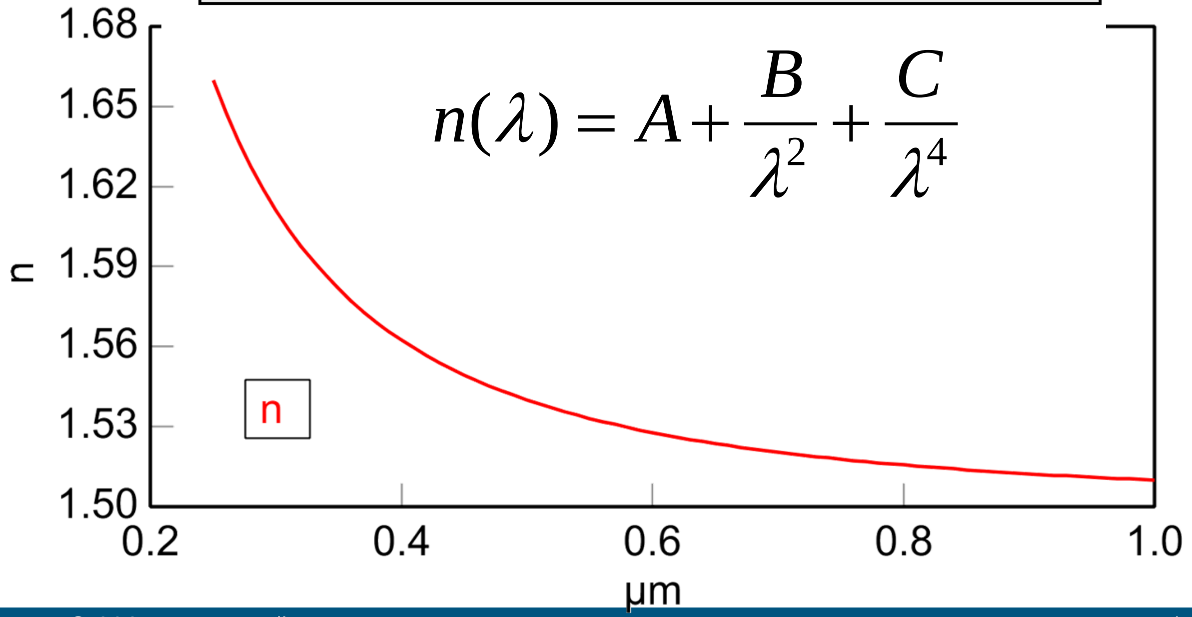
Session 5

TRANSPARENT MATERIALS

Cauchy

- Empirical equations
- Easy to use

- Substrate = Cauchy
  A = 1.450 B = 0.01000 C = 0.0000
  Show Urbach Absorption Parameters = OFF



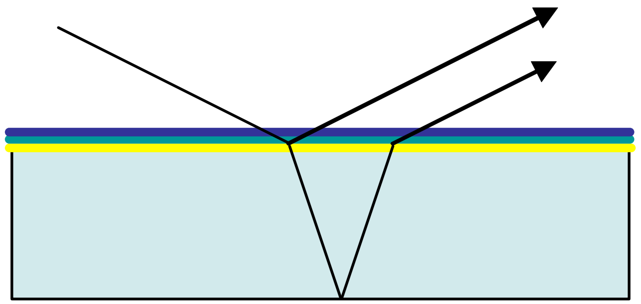
$$n(\lambda) = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}$$

Sellmeier

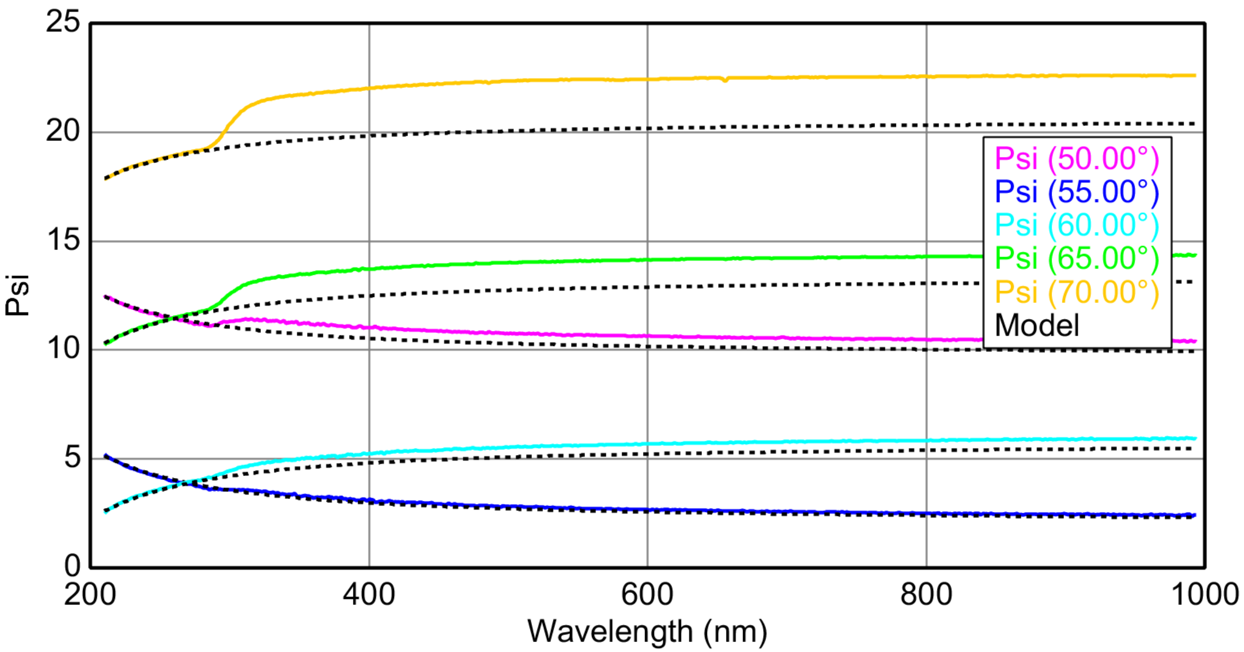
- Embedded in Genosc
- Works better for materials presenting absorptions at longer wavelengths

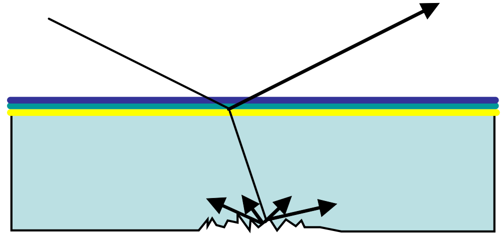
Include Surface Roughness = ON Roughness = **13.44 Å** (fit)
- Substrate = Gen-Osc
  Show Dialog
  - **e1 Components**
    Einf = **1.466** (fit)
    UV Pole Amp. = **92.7823** (fit) UV Pole En. = **10.665** (fit)
    IR Pole Amp. = **0.0200** (fit)
  - **e2 Components**
    Oscillator Menu: **Add** **Delete** **Delete All** **Sort**
    Fit Menu: All None Amp. Br. En. Display Units = OFF
    (There are no oscillators added.)

TRANSPARENT SUBSTRATES

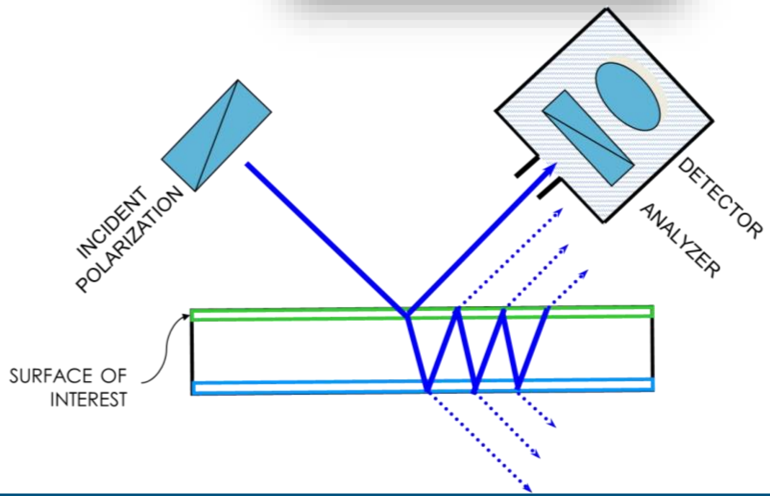


Backside Reflection



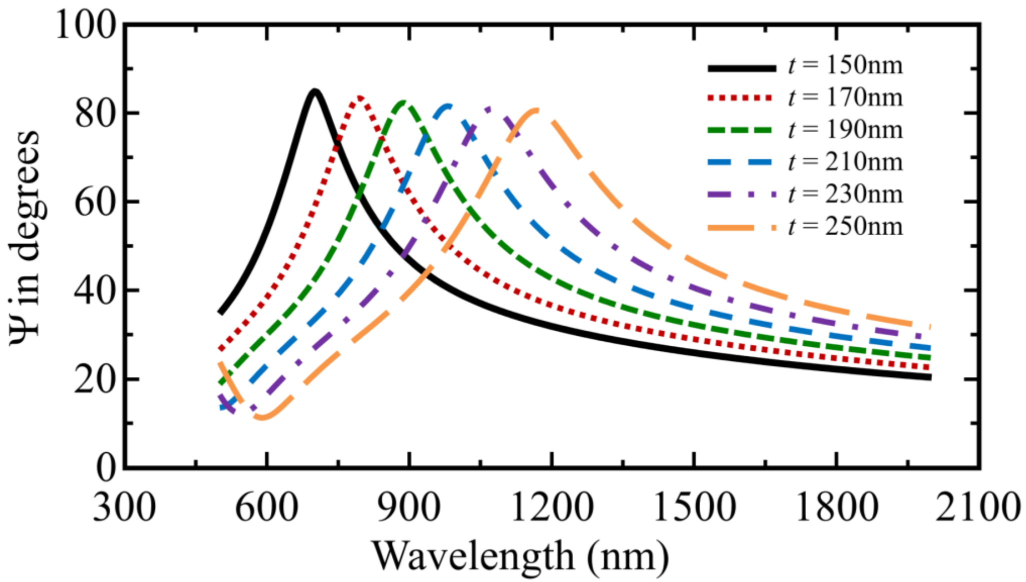


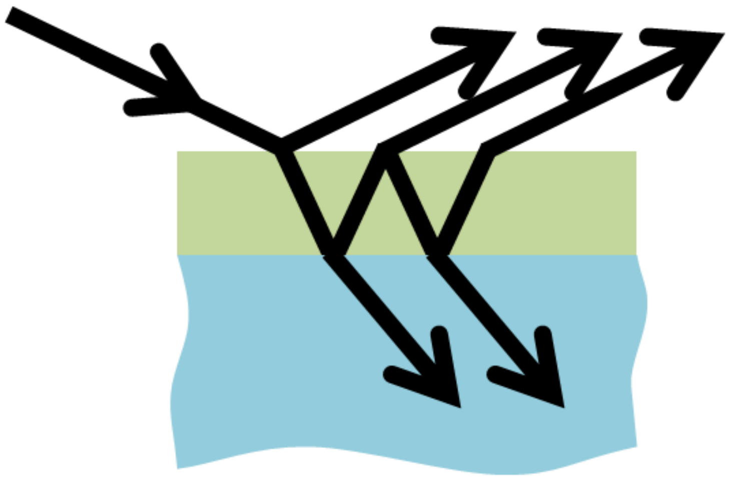
- **MODEL Options**
  - Angle Offset = 0.00
  - Include Substrate Backside Correction = ON
    - Transmission SE Data = OFF Reverse Direction =
    - # Back Reflections = **0.881** (fit)
    - % 1st Reflection = 100.00
  - Model Calculation = Ideal



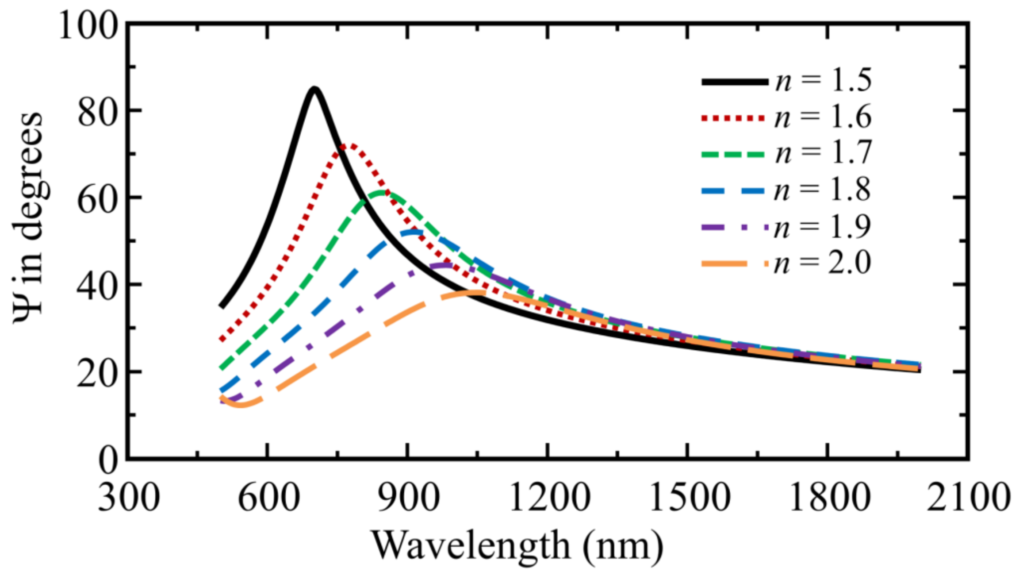
TRANSPARENT THIN FILMS

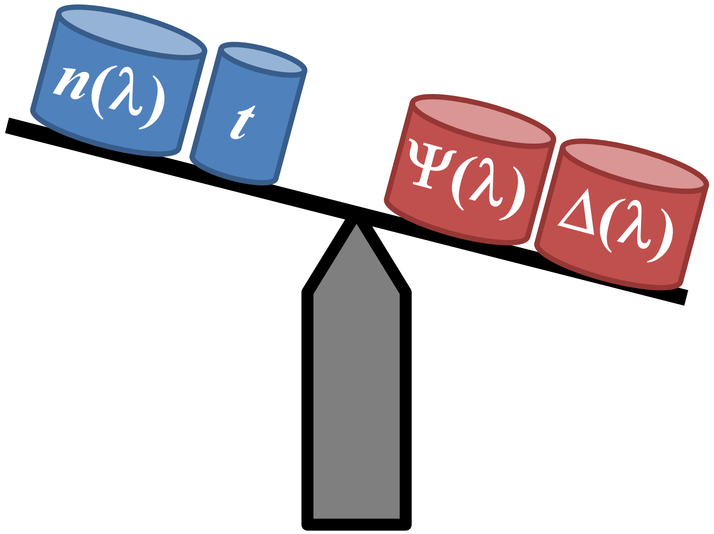
Thickness Shifts interference



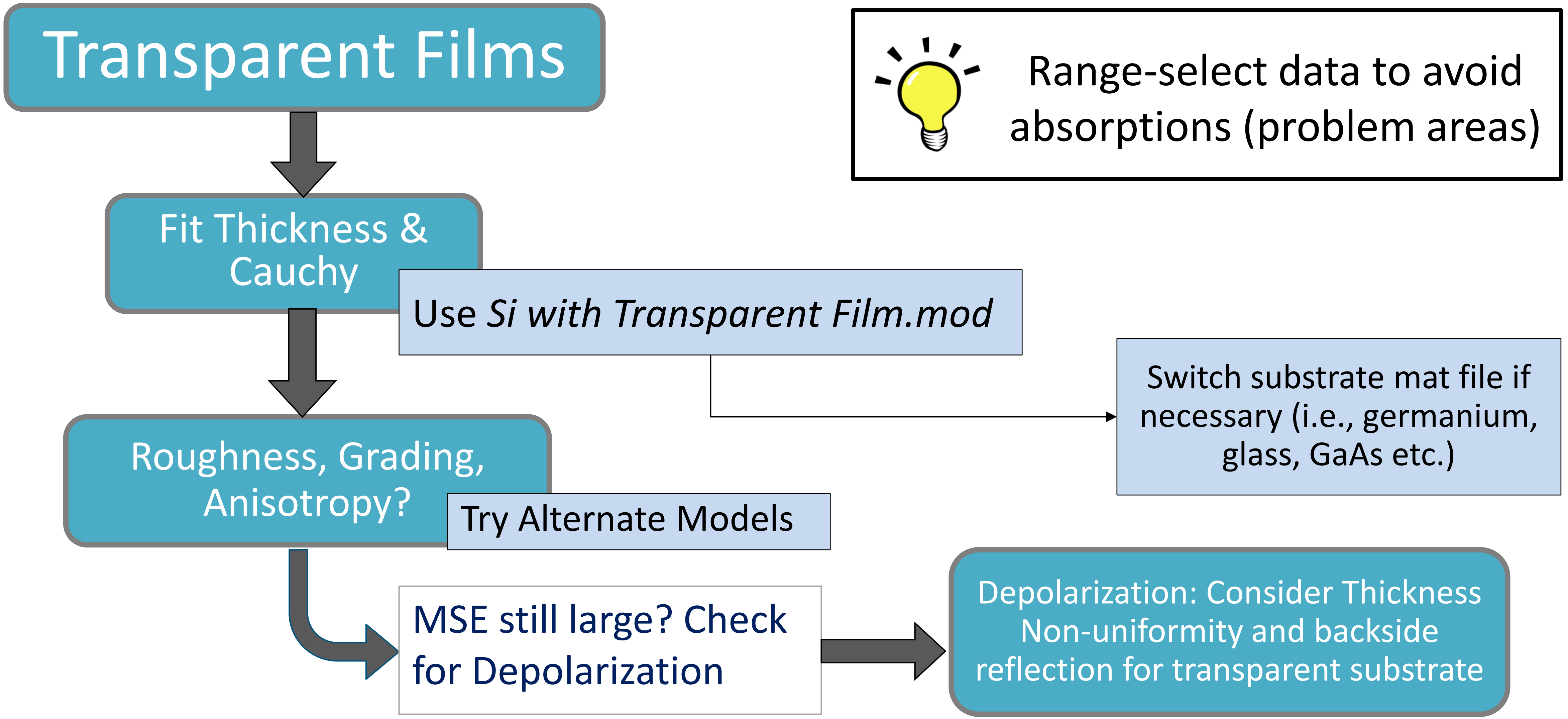


Index of Refraction affects amplitude and shifts peak





TRANSPARENT FILMS



MATERIALS THAT ABSORB

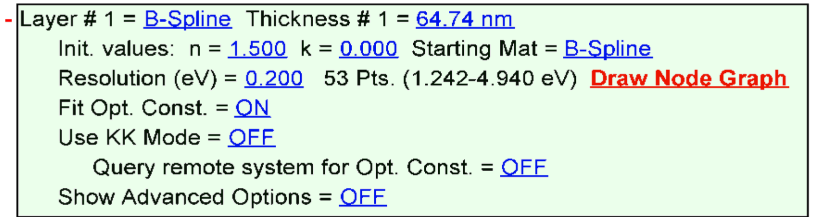
- We will apply the **B-Spline** and **Gen-Osc** layers to describe absorbing materials to fit their optical constants (both n and k).

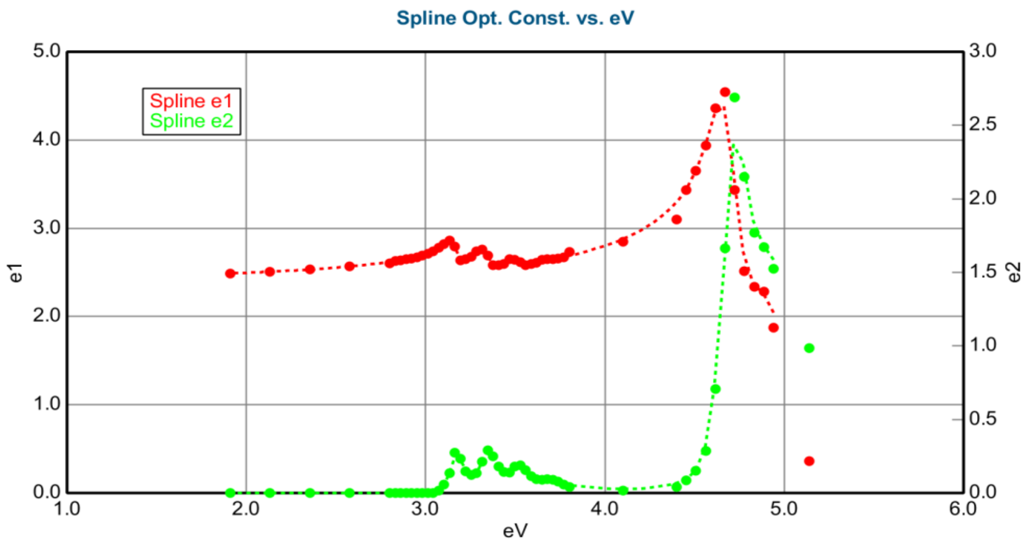
- Benefits:
  - Smooth, continuous functions
  - Can constrain to “physical” shapes

MODELING ABSORPTION

B-spline

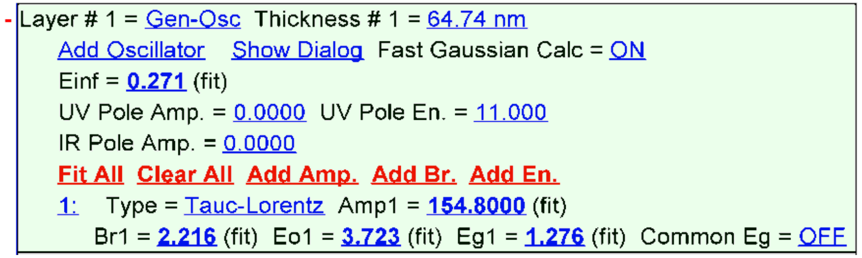
- Interpolation functions to best describe the shape of optical constants

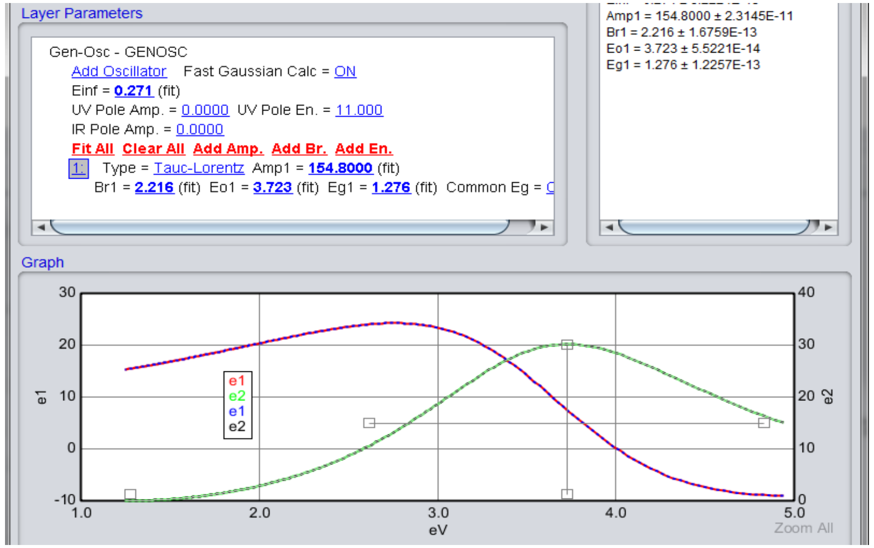




Gen-Osc

- Combine physically motivated Oscillator functions to describe physical nature of optical constants with minimal parameters

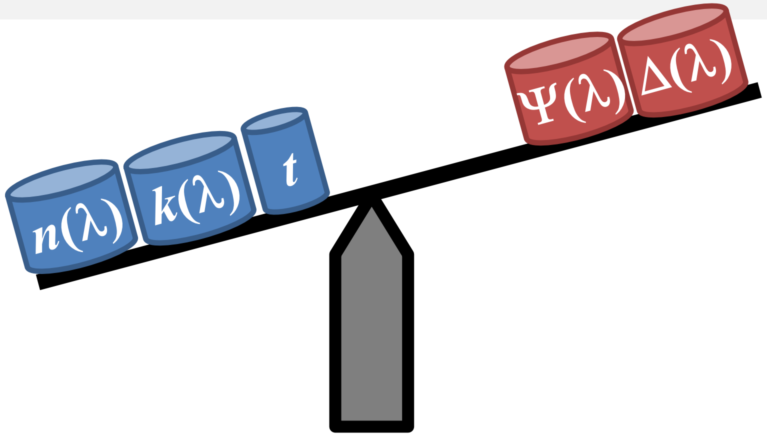


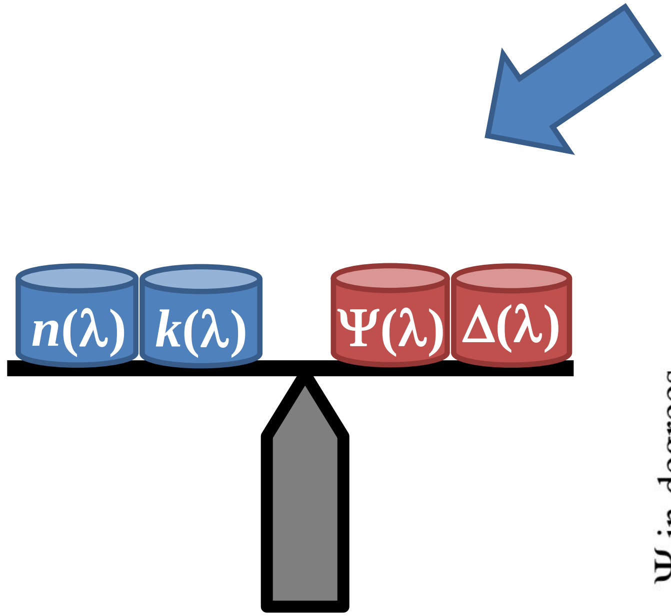


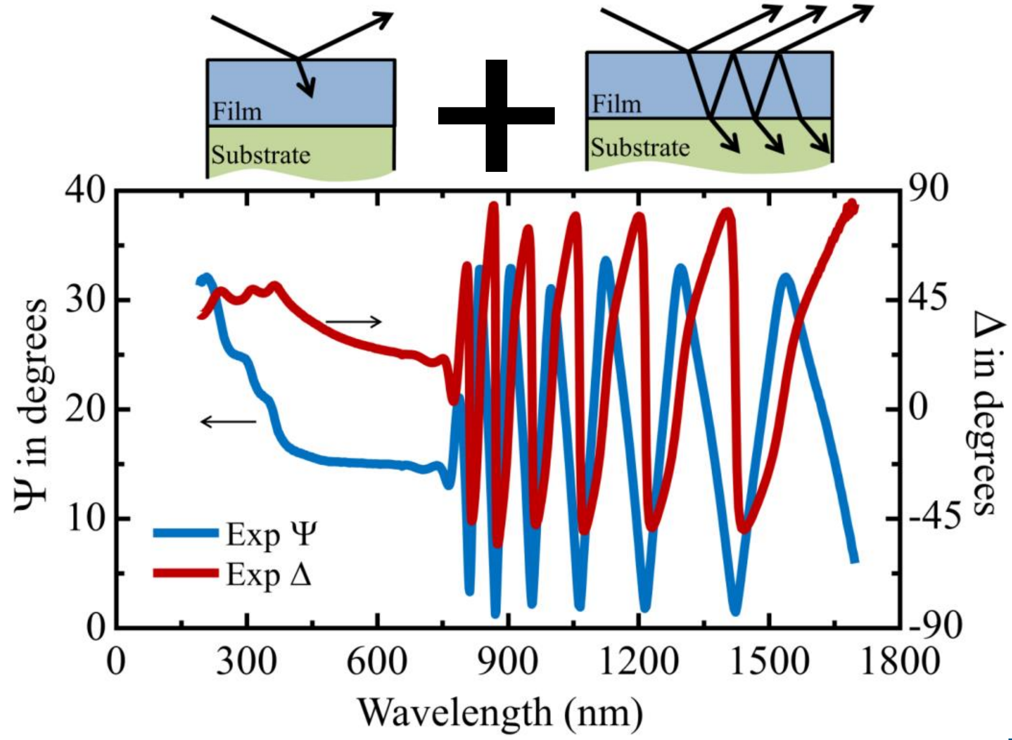
MODEL COMPARISON

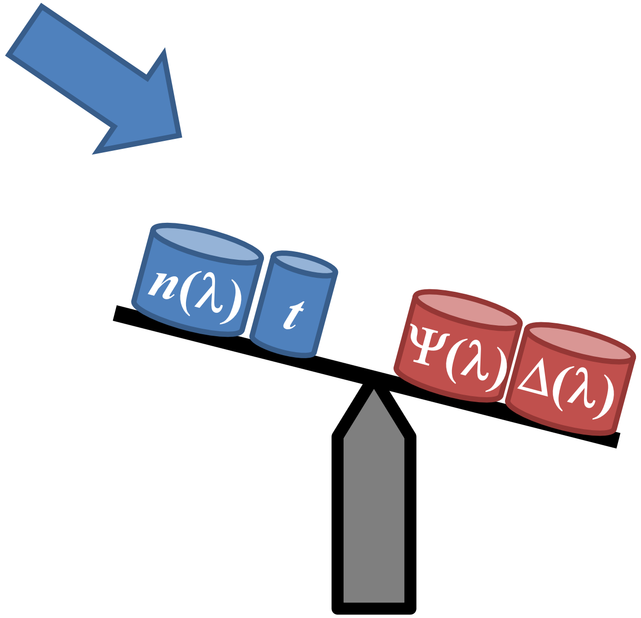
	Model	Advantages	Disadvantages
Metals	**B-Spline**	▪Easy extension of transparent region. ▪Computationally efficient.	▪Most Fit Parameters. ▪No physical basis – just "curve fitting". ▪Can get lost.
Organics Semiconductors	**KK B-Spline**	▪Fewer Fit Parms. than B-Spline ▪May avoid getting lost. ▪Kramers-Kronig consistent.	▪No physical basis for e2 – just "curve fitting". ▪More Fit Parms than Gen-Osc.
Dielectrics Semiconductors	**Gen-Osc**	▪Fewest Fit parameters. ▪Kramers-Kronig consistent	▪Can be tedious. ▪May not capture all features in the data. ▪Oscillators lose physical meaning –become curve fitting.

STRATEGY: FILMS WITH ABSORBING REGION









SIMPLIFIED AND AUTOMATED B-SPLINE PROCEDURE

III

CAUCHY ▶
Convert to
Transparent B-Spline

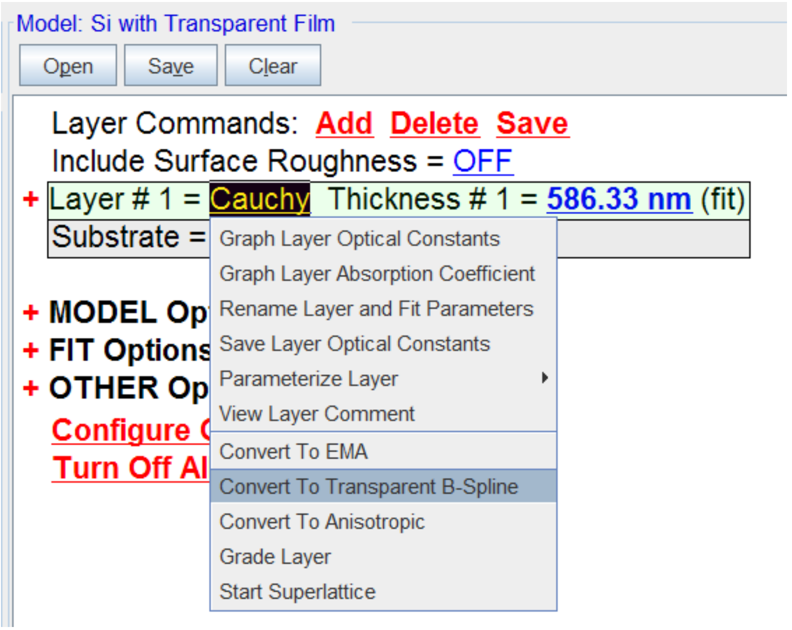
Fit Transparent Region with Cauchy

⇩

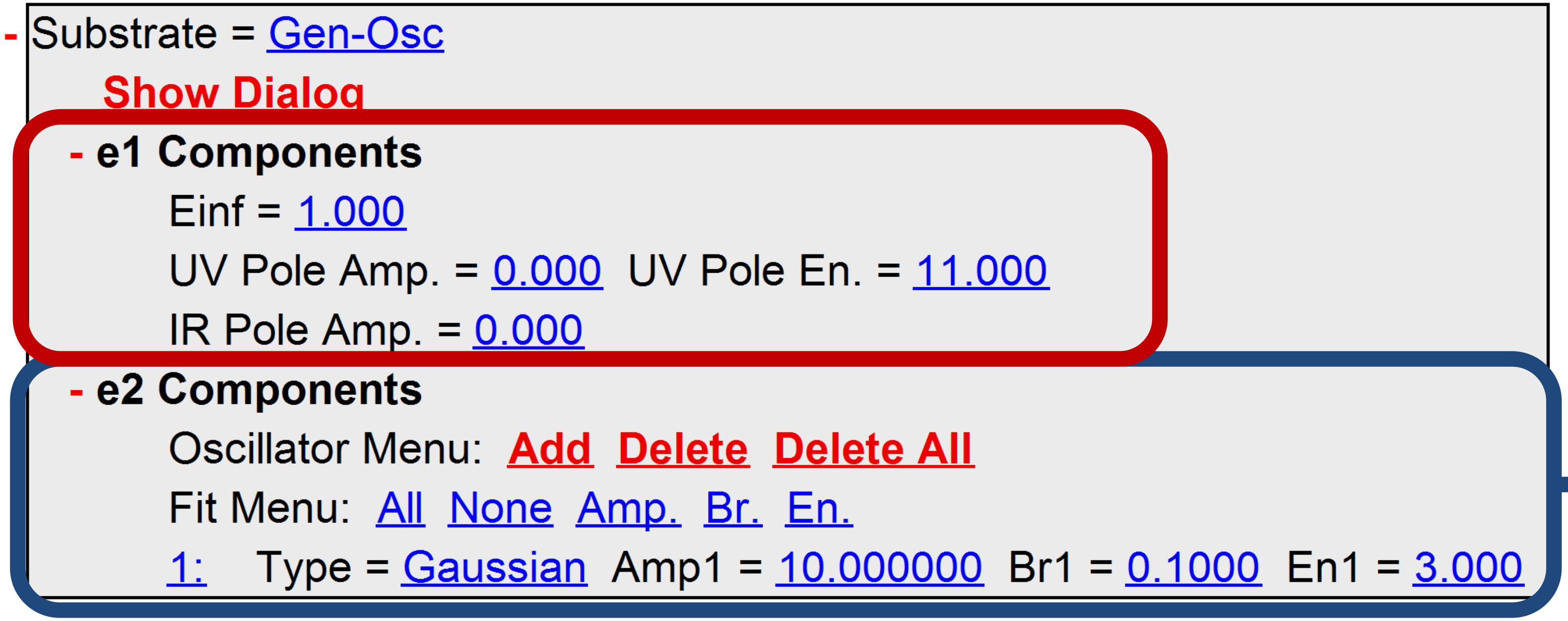
**Right-Click on Cauchy ▶
"Convert to Transparent B-Spline"**

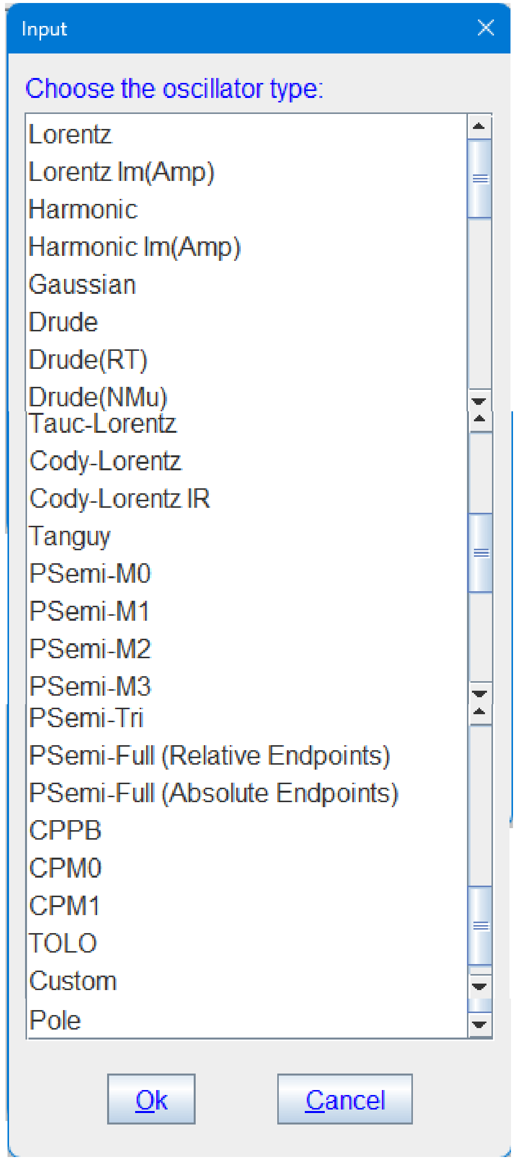
⇩

Optimize Node Resolution, Roughness, Grading,…



Gen-Osc Layer





e1 - Einf & Poles:

Describes the effect on ε1 from out-of-range absorptions

e2 - Oscillator List:

Describe absorptions within the analysis range, affecting ε_2 and KK transformed ε_1 shape

CHOOSING THE BEST APPROACH

III

Cauchy ▶ B-Spline

Build Gen-Osc from B-Spline n,k

II

Build Gen-Osc from Tabulated Reference

I

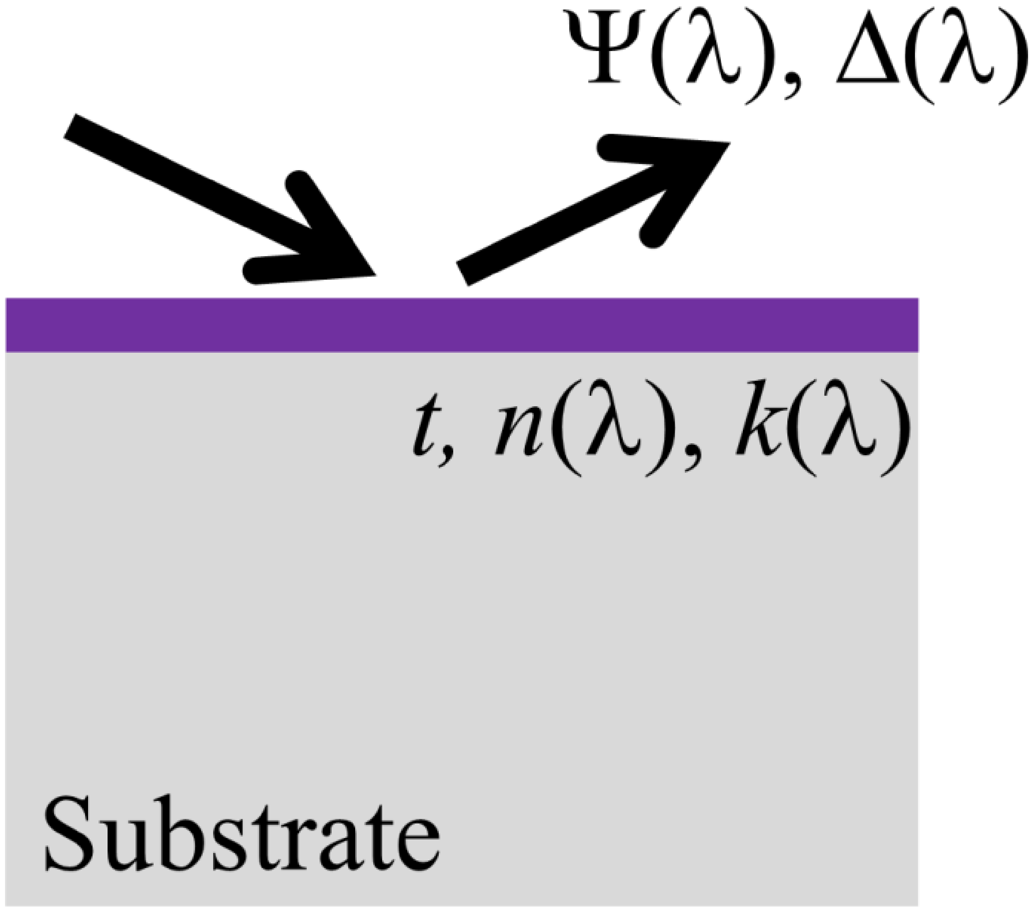
Fit Data with Pre-built Gen-Osc

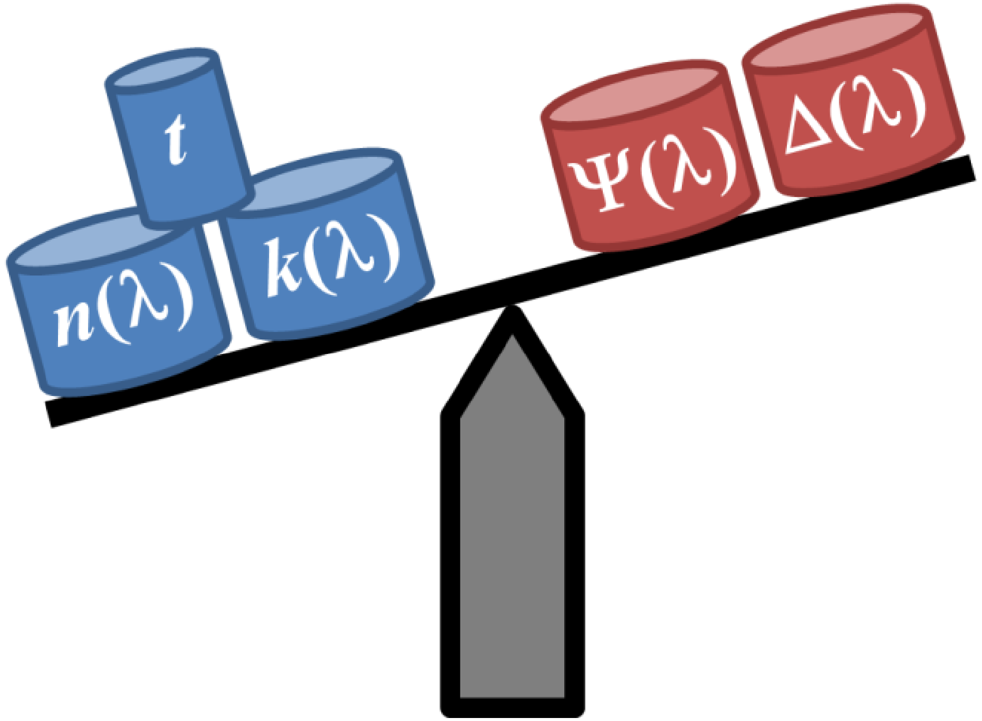
Fit Data with Gen-Osc

Fit Data with Gen-Osc

ABSORBING MATERIAL CHALLENGE

- Need to determine thickness, *n* and *k*!





STRATEGIES

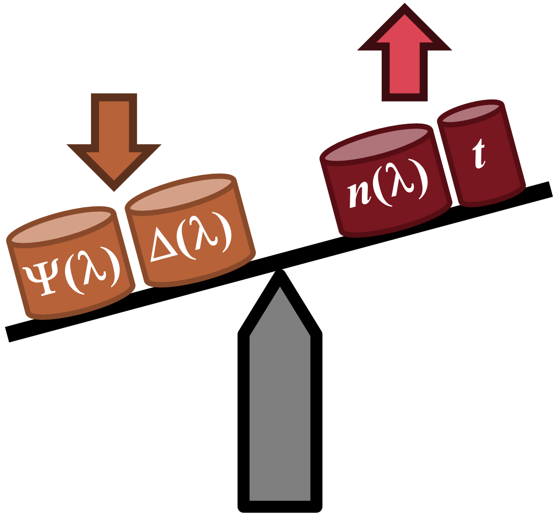
Increase measurement content

- Multi-angle interference enhancement
- SE + Transmission
- Multi-sample
- In situ (Real-Time)

- OTHER TECHNIQUES

Reduce sample unknowns

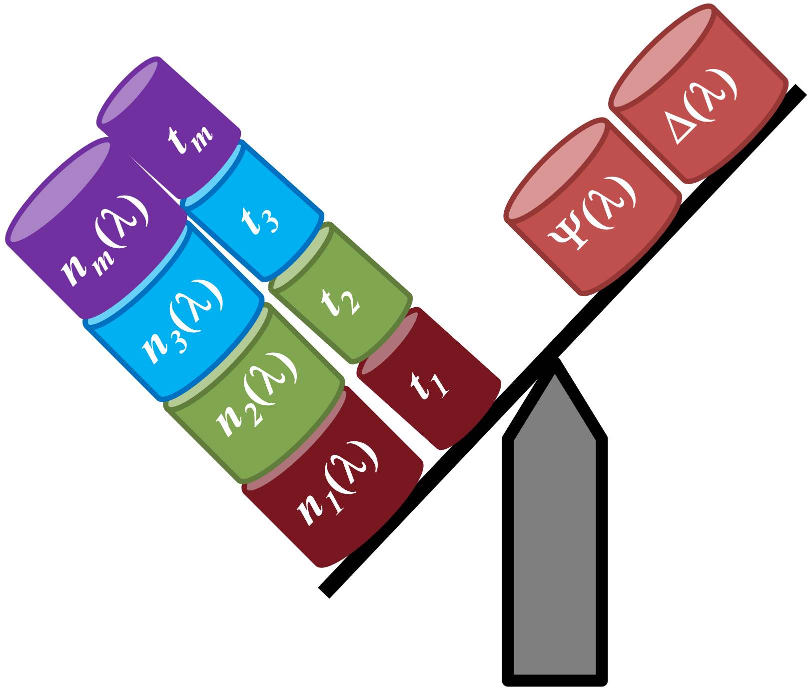
- Opaque materials
- Transparent wavelengths
- Dispersion equation

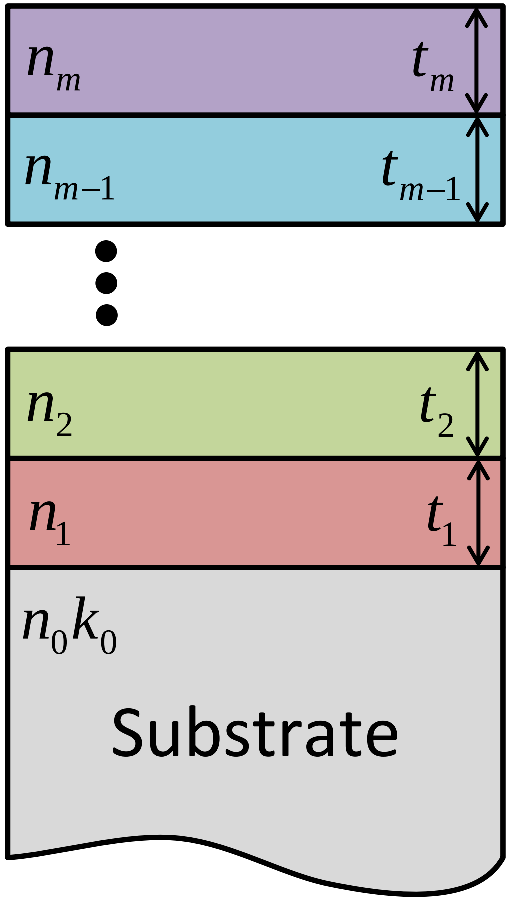


J.N. Hilfiker, et al. "Survey of methods to characterize thin absorbing films with spectroscopic ellipsometry" *Thin Solid Films* **516** (2008) 7979-7989.

MULTILAYER STACK CHALLENGE

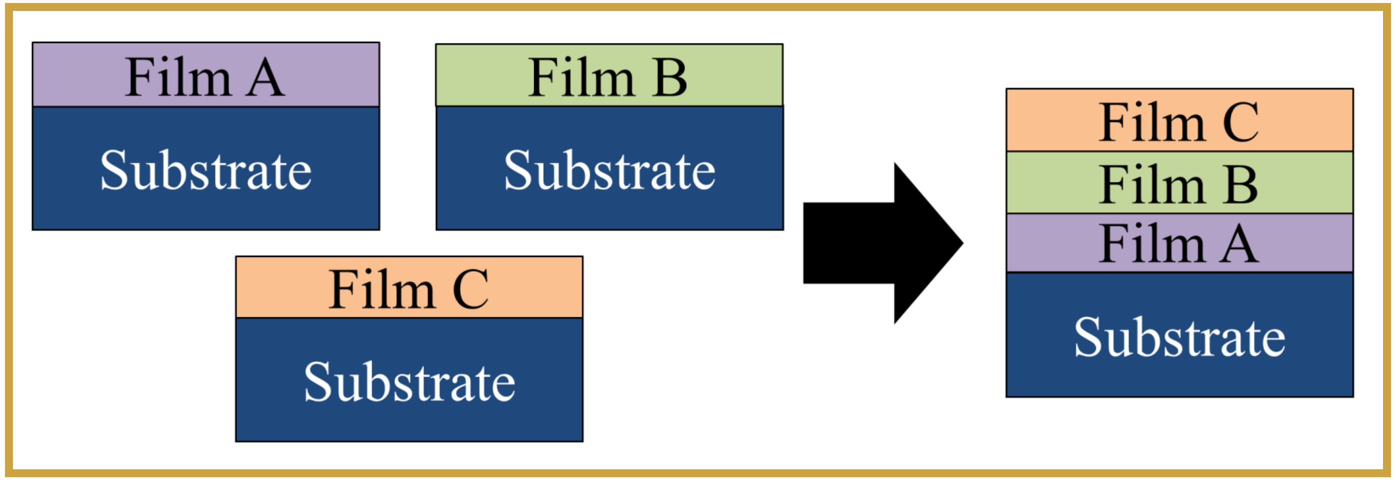
- Multilayer applications lead to excessive unknowns!

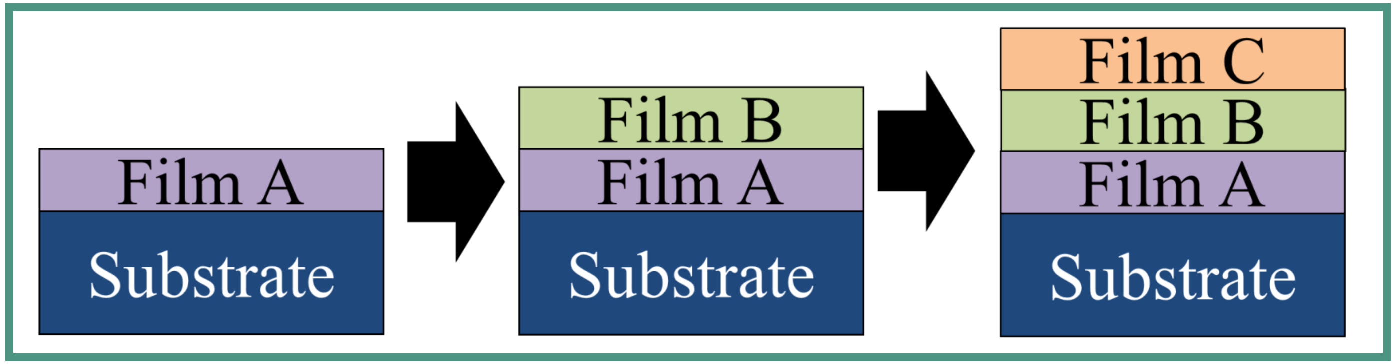




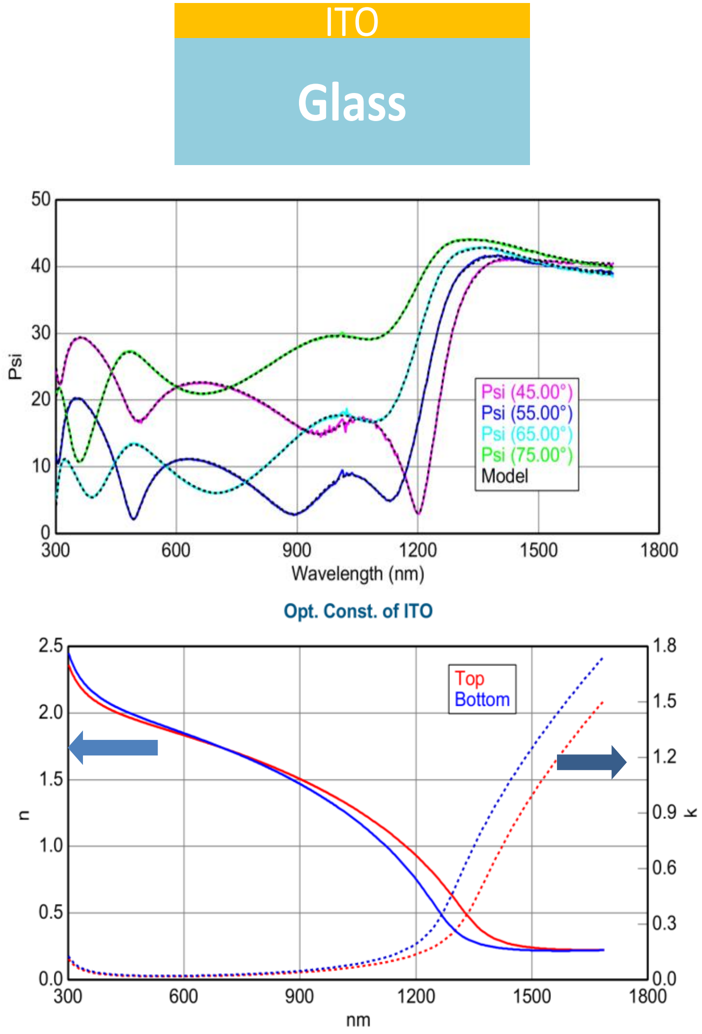
MULTILAYER STACKS

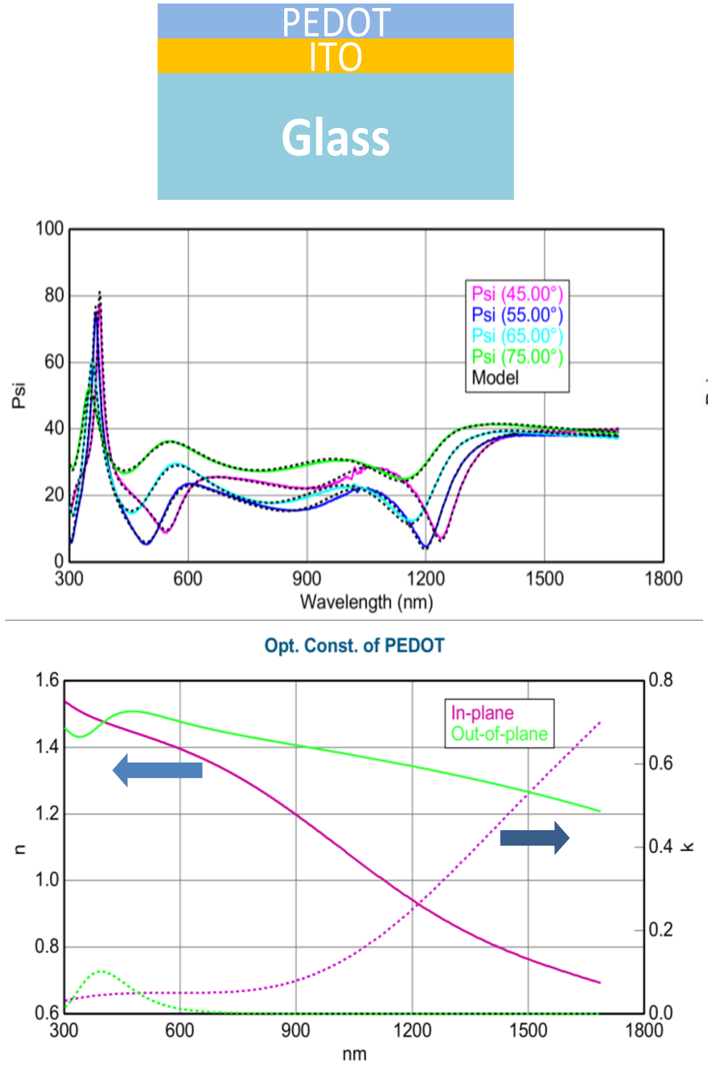
- Solution: Determine optical constants from single layers.

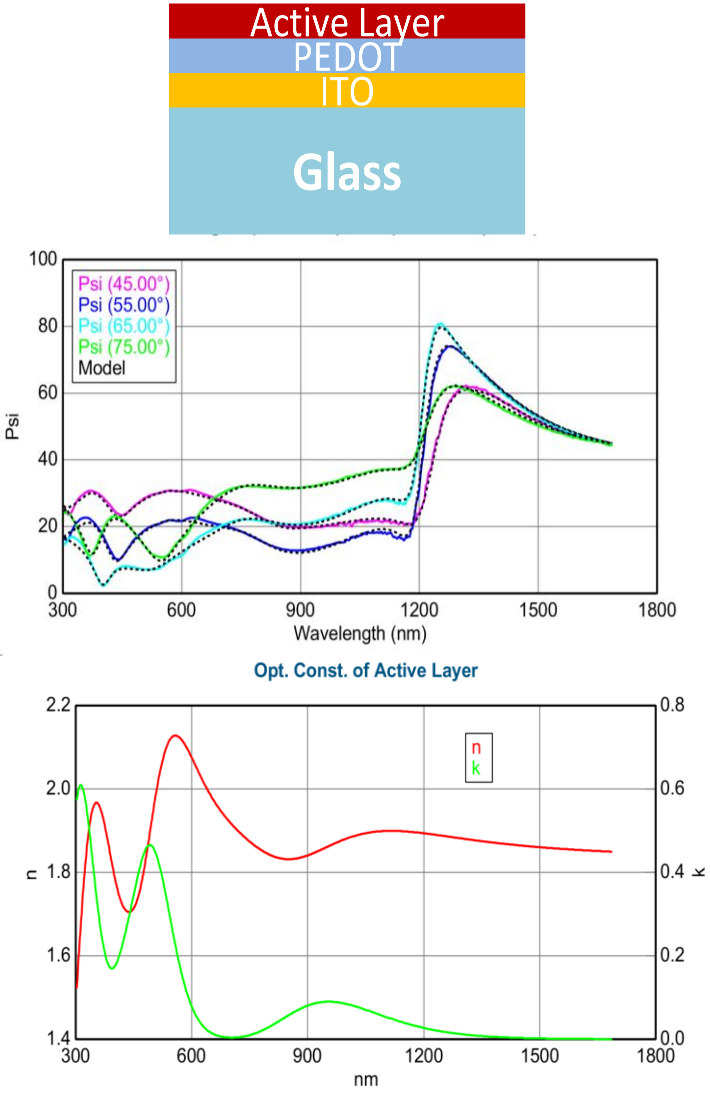




MULTILAYERS - OLED







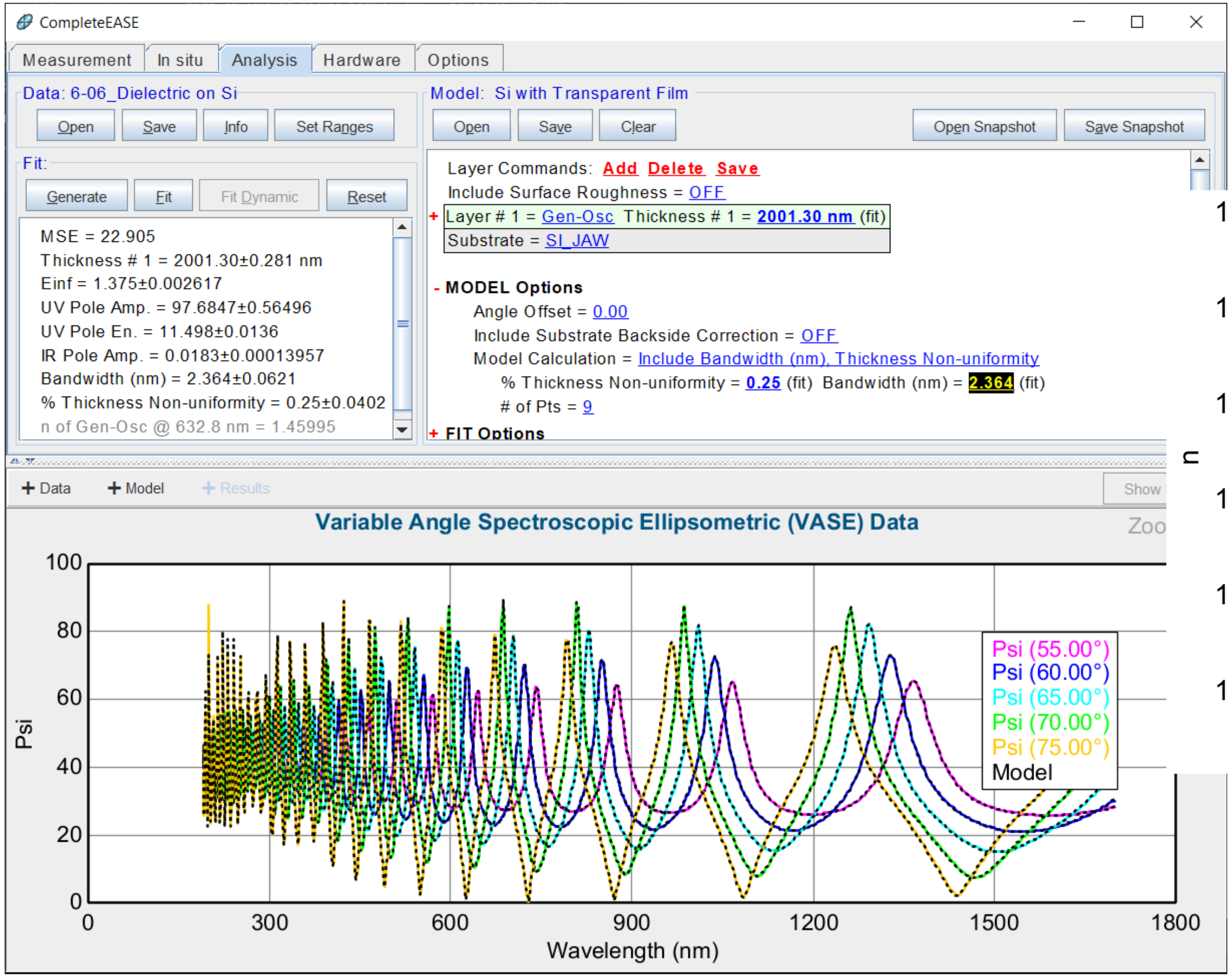
FINAL PRACTICE SET

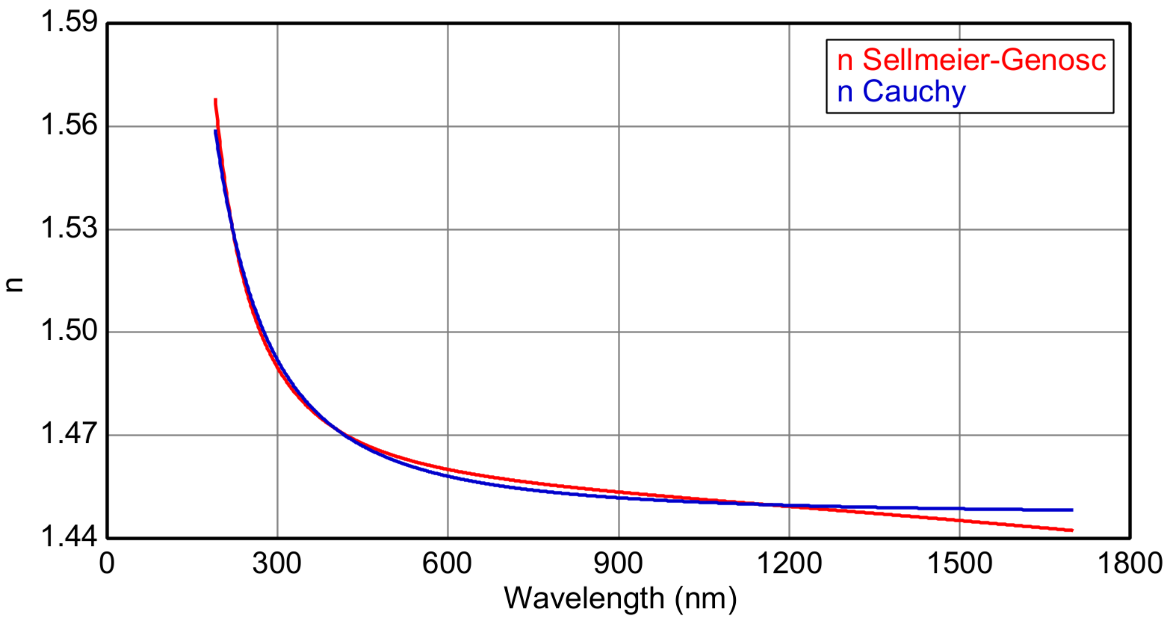
6-06 Quiz: Dielectric on Si

- **Determine thickness and optical constants over full wavelength range.**

What Model Approaches to use?

6-06 Dielectric on Si: Results



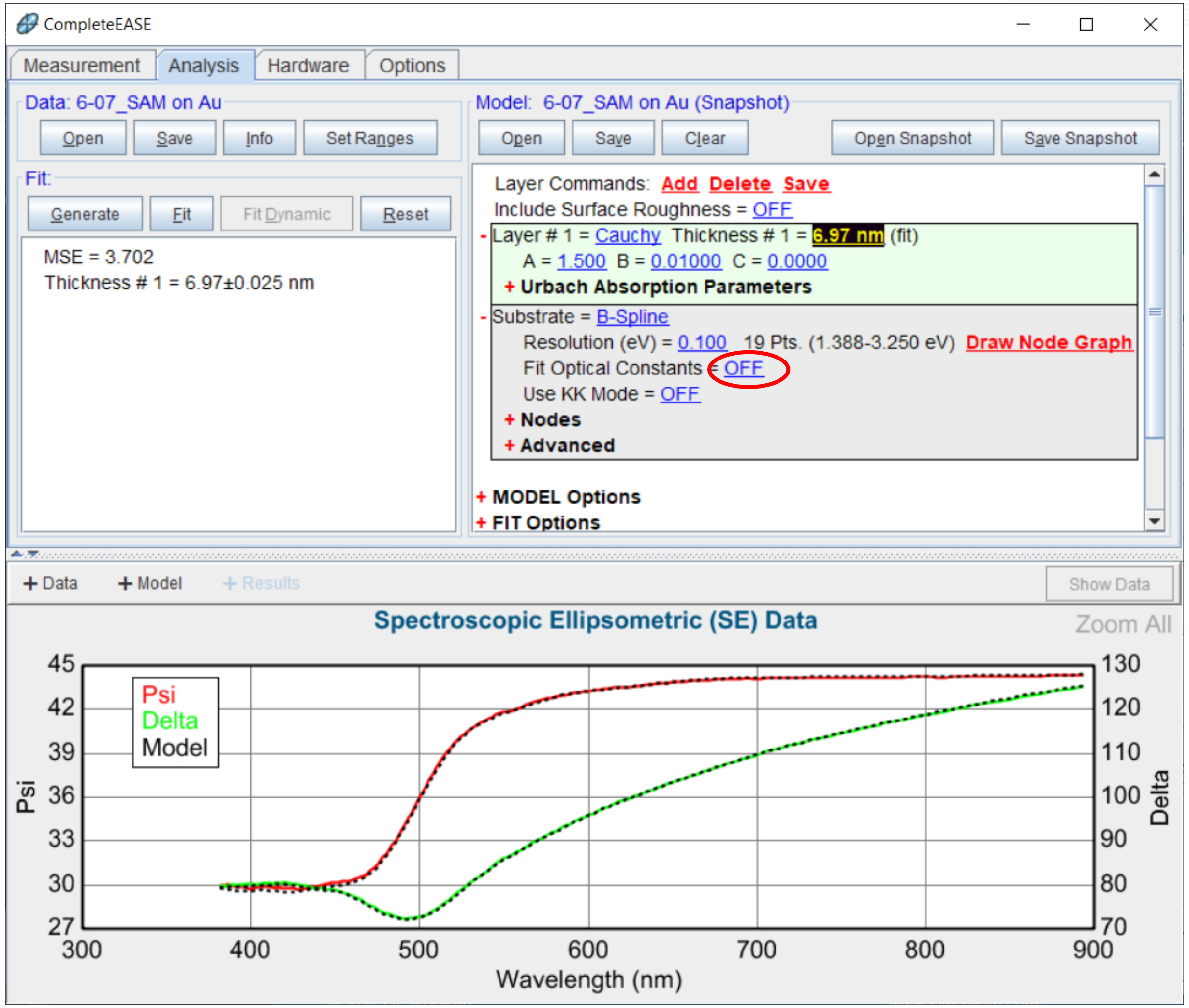


6-07 Quiz: Self-Assembled monolayer on Au

- **Determine thickness of SAM layer.**

What Model Approaches to use?

6-07 SAM on Au: Results

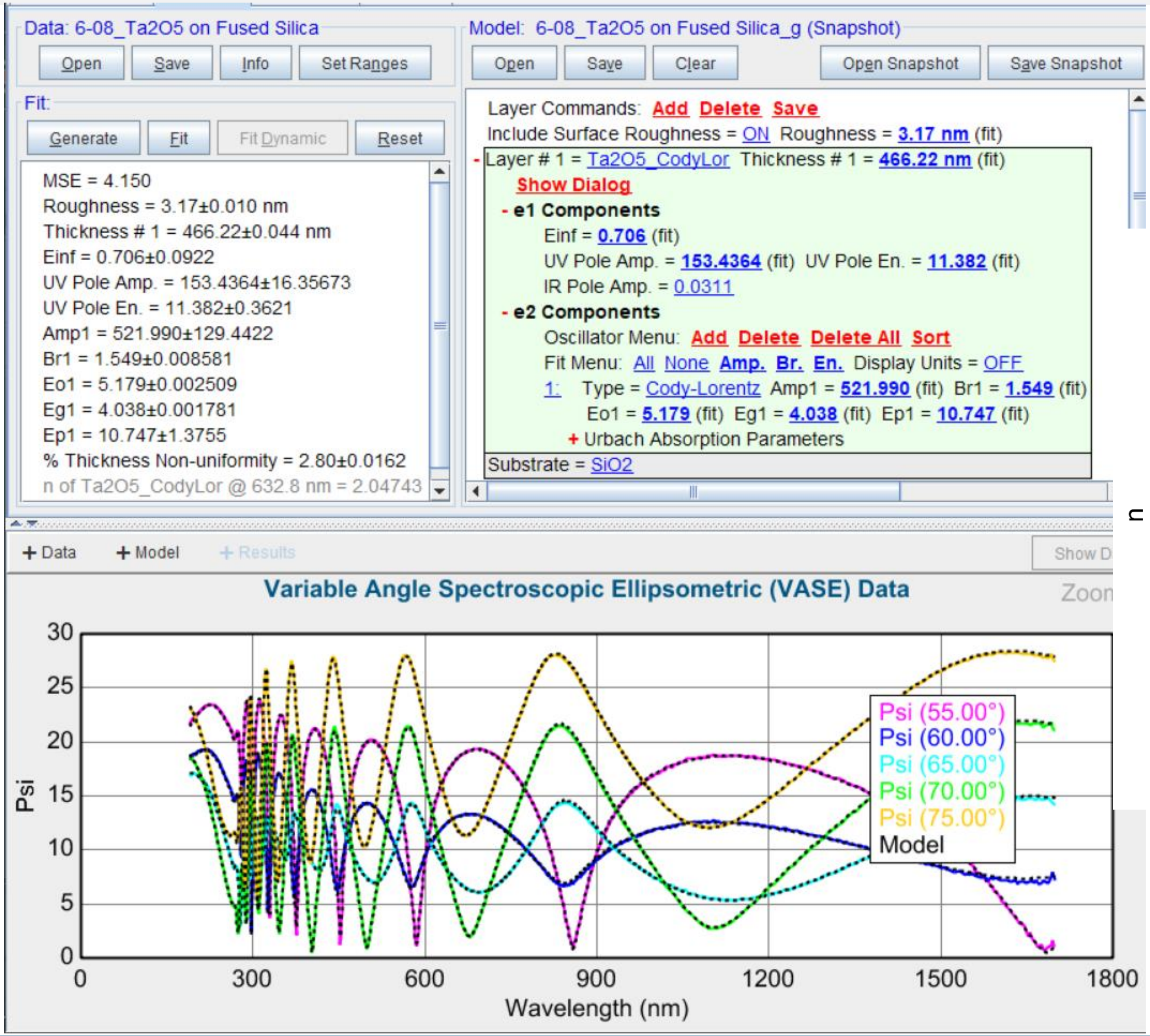


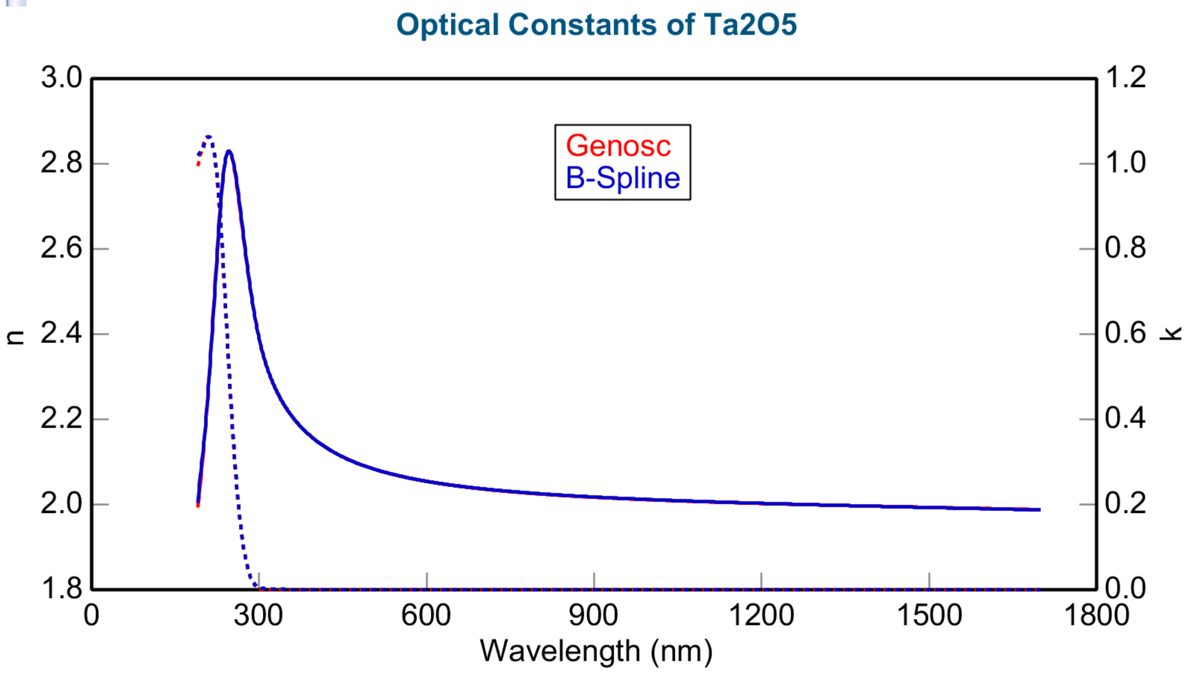
6-08 Quiz: Ta_2O_5 on Fused Silica

- **Use “SiO2.mat” for substrate**
- **Determine optical constants for Ta_2O_5 film**

What Model Approaches to use?

6-08 Ta_2O_5 on FS: Results






Thank
You
köszönöm
Suksama
Asante
Shukria
Vinaka
Maake
Dhanyavadagalu
Dankscheen
спасибо
Kiitos
اشكرا
Manana
Dankon
Suksama
Mauruuru
Biyan
Diolch i Chi
Gratias Tibi
Terima Kasih
Dank Je
Taiku
நன்றி
Dziekuje
Chokrane
Grazie
Juspaxar
Arigato
Najis Tuke
Gracias
Khap
Paldies
Matur Nuwun
감사합니다
धन्यवाद
cảm ơn bạn
Bedankt
Dakujem
Grazas
Ua Tsaug Rau Koj
Mèsi
Tack
Khun
Obrigado
Nirringrazzjak
Děkuji
Di Ou
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Danke
Merci
Go Raibh Maith Agat
Tingki
ขอขอบคุณคุณ
Salamat