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Guidelines For Selecting Multi-Technology Recipes In Multilayer Filmstack Measurements

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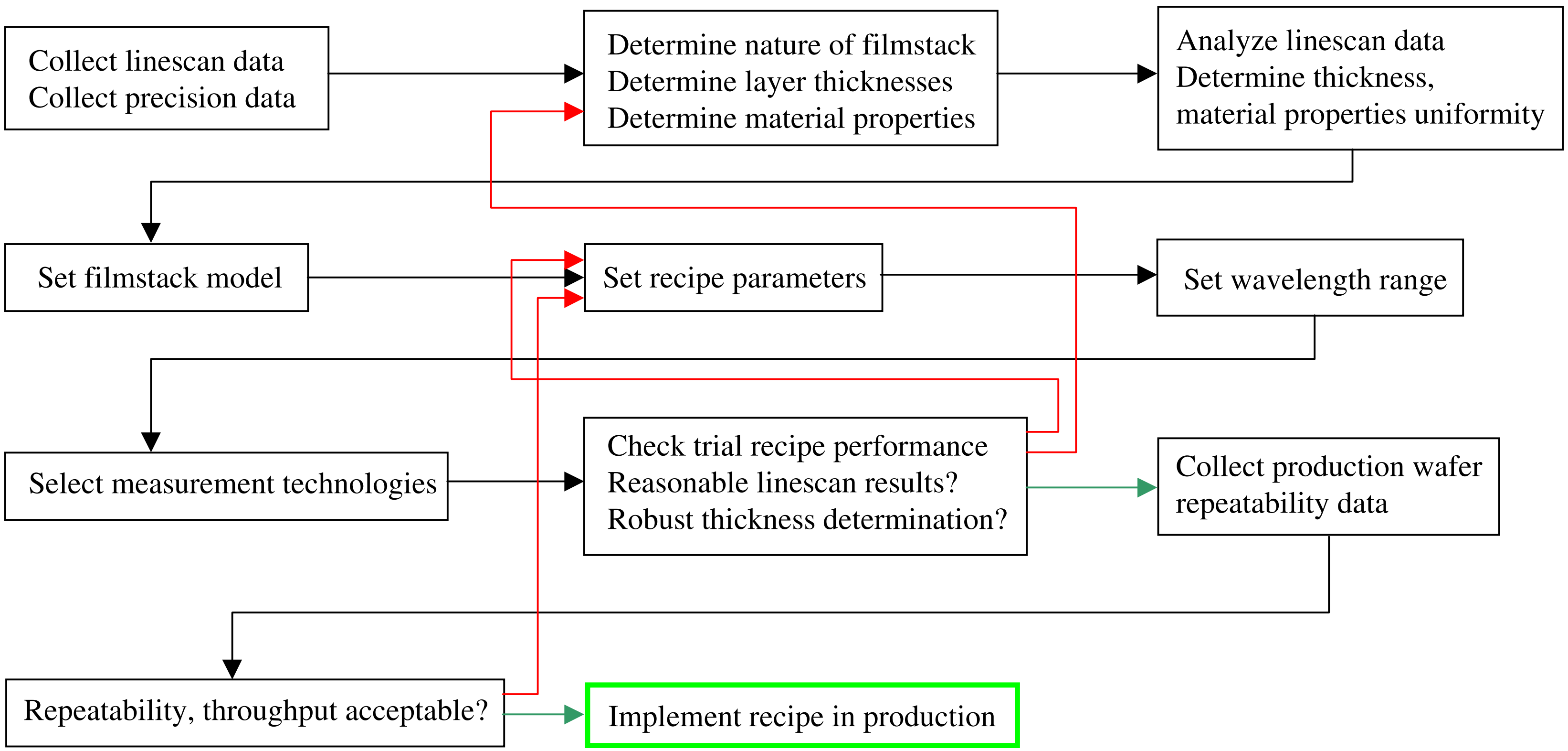
Recipe Development: Background

- recipe development/creation is part of nearly every tool in the fab
- optical film thickness tools
  - optimum parameters to measure
  - optimum technology choice
    - beam profile reflectometry (BPR)
    - normal incidence spectral reflectance (BB)
    - spectroscopic ellipsometry (SE)
    - single wavelength ellipsometry (BPE, AE)
    - multiple angle of incidence single wavelength ellipsometry (MAISWE)
    - variable angle of incidence spectroscopic ellipsometry (VASE)
    - combinations of the above

Recipe Development: Decision Points

- there are several decision points in a typical recipe development project:
  - filmstack model
  - choice of measurement parameters
  - parameter fit ranges
  - choice of measurement technologies and technology weighting
  - wavelength range
  - tradeoff between precision/repeatability/accuracy vs. throughput
  - measure entire stack, or measure substacks
  - when is the result correct?

Recipe Development Flow Chart



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Need For Tools And Metrics

- recipe development time pareto
  - determine layer material properties
  - determine layer thicknesses
  - determine correct filmstack and filmstack model
- in general, all the data and evidence must be collected before a recipe can pass final qualification
- filmstacks are becoming increasingly complex
- measurement demands are increasing
- process engineers want a metrology tool that "just works"
- tools for recipe development, and metrics for recipe performance are needed to simplify and speed the recipe development process

Uncertainty and Correlation

- uncertainty **δa** is related to the confidence interval for the parameter obtained from the fit
- correlation expresses the degree of parameter dependence, measured through the covariance matrix [C]

$$\Delta\chi^2 = \delta\boldsymbol{a}\cdot[\alpha]\cdot\delta\boldsymbol{a} \qquad \alpha_{kl} \equiv \frac{1}{2}\frac{\partial^2\chi^2}{\partial a_k \partial a_l}$$

$$[\boldsymbol{C}] = [\alpha]^{-1}$$

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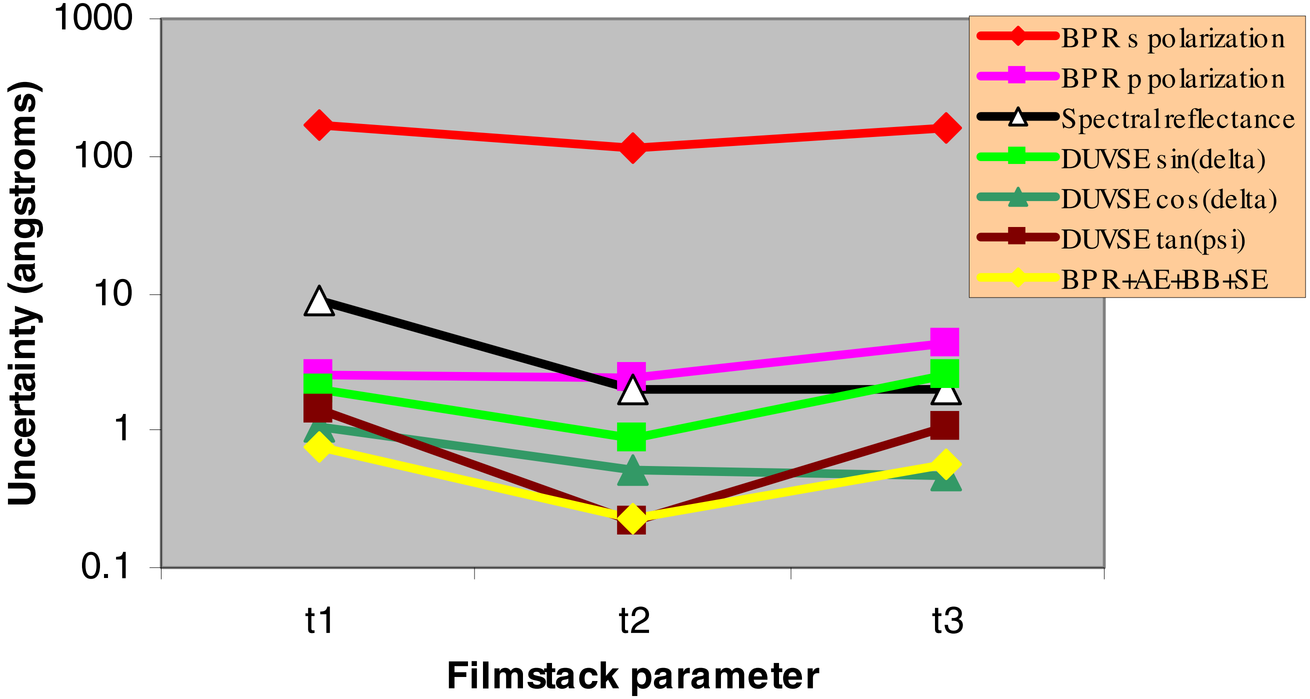
Uncertainty in 3-Thickness ONO Measurement

Calculated from Opti-Probe OP5240 data on an oxide (67 Å)/nitride (77 Å)/oxide (78 Å)/Si filmstack



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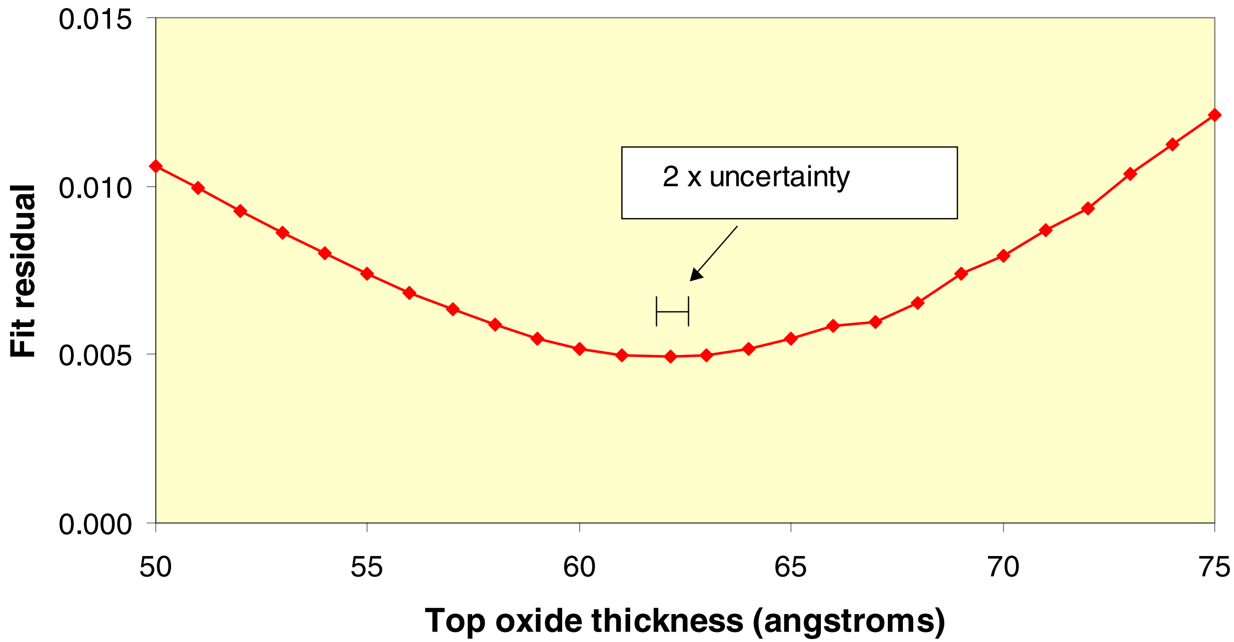
Uncertainty Sampling Range

- uncertainty samples a small range of the fit error vs. fit parameter
- example: top oxide measurement in ONO stacks



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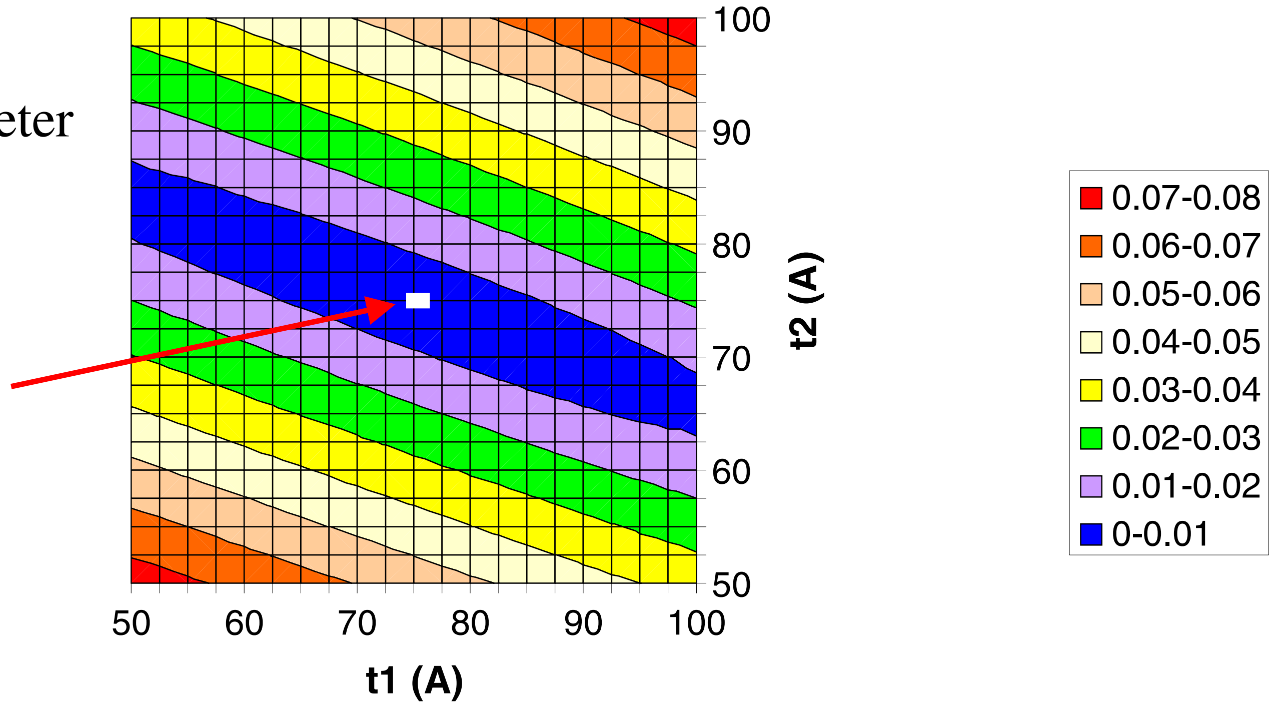
Uncertainty and Parameter Tradeoff

- uncertainty provides little indication of potential parameter tradeoff
- example: nitride and top oxide measurement in ONO stacks

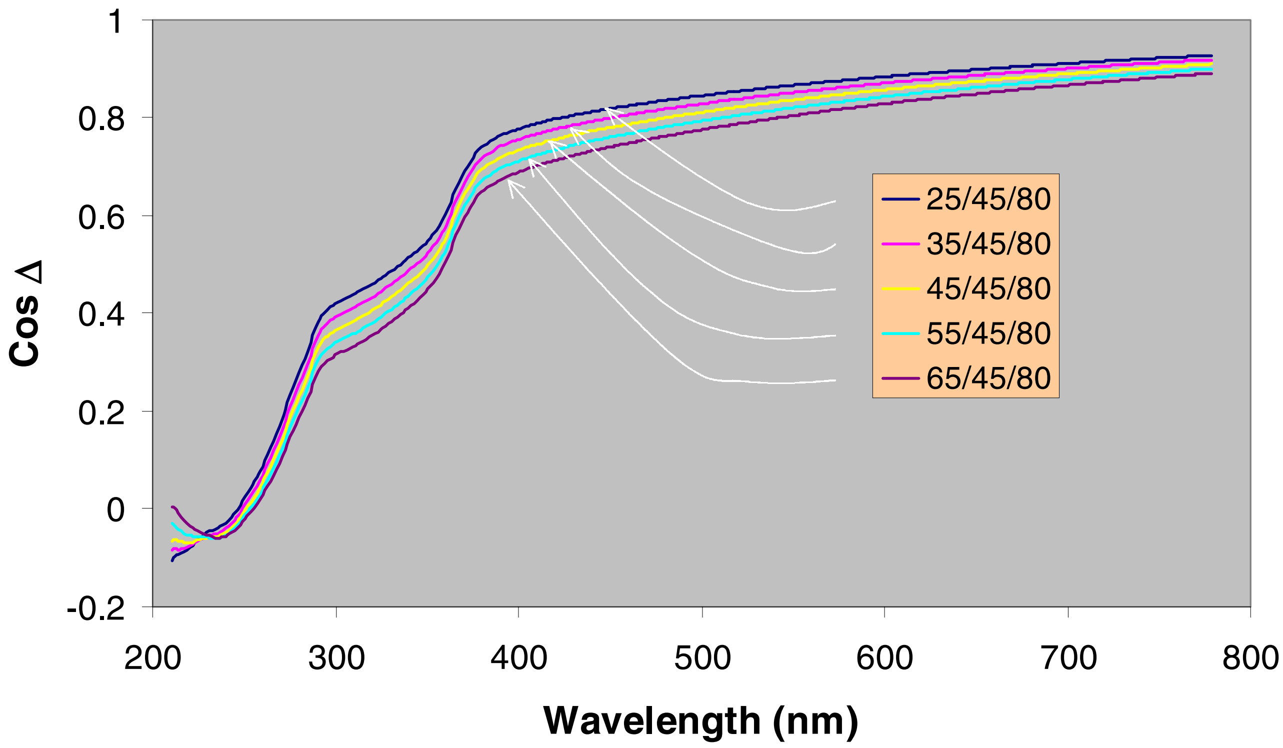
2D fit residual plot, spectrometer recipe

2x uncertainty zone



Example: Top Oxide Sensitivity In ONO Measurement

DUVSE cos(Δ) simulated data for ONO with various top oxide thickness



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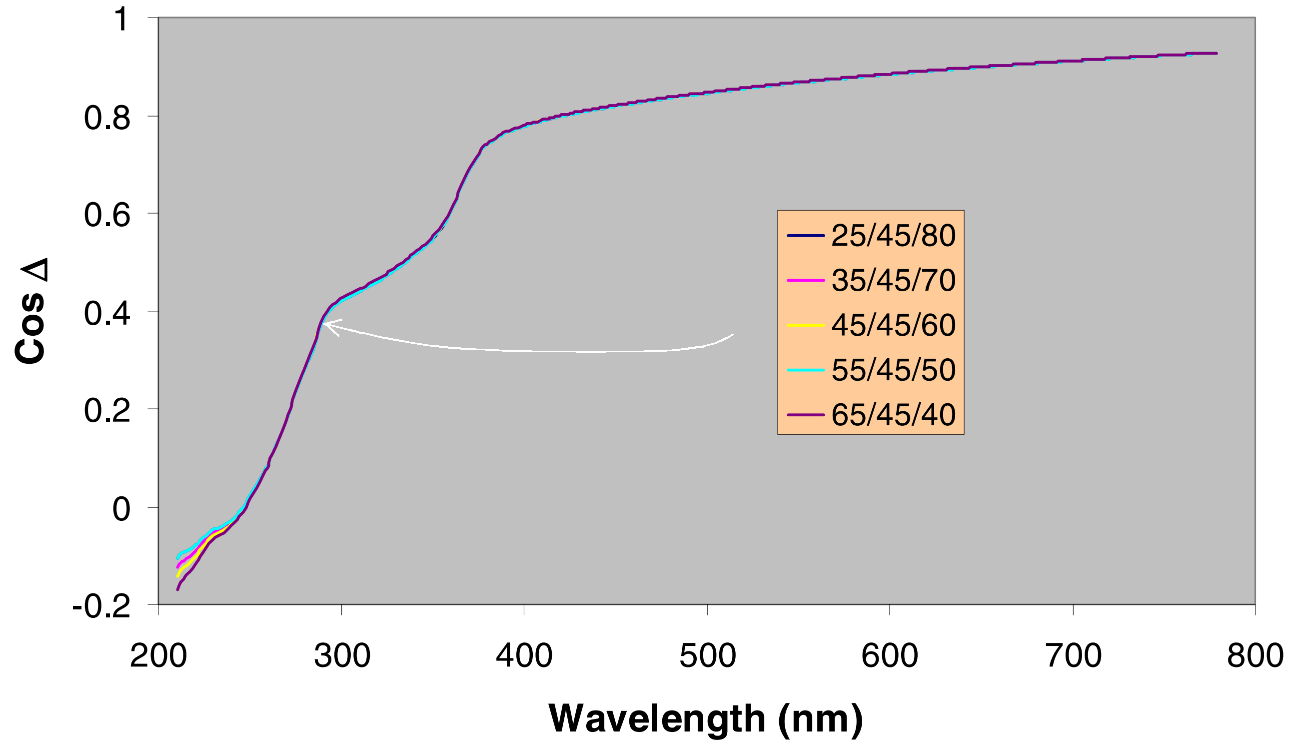
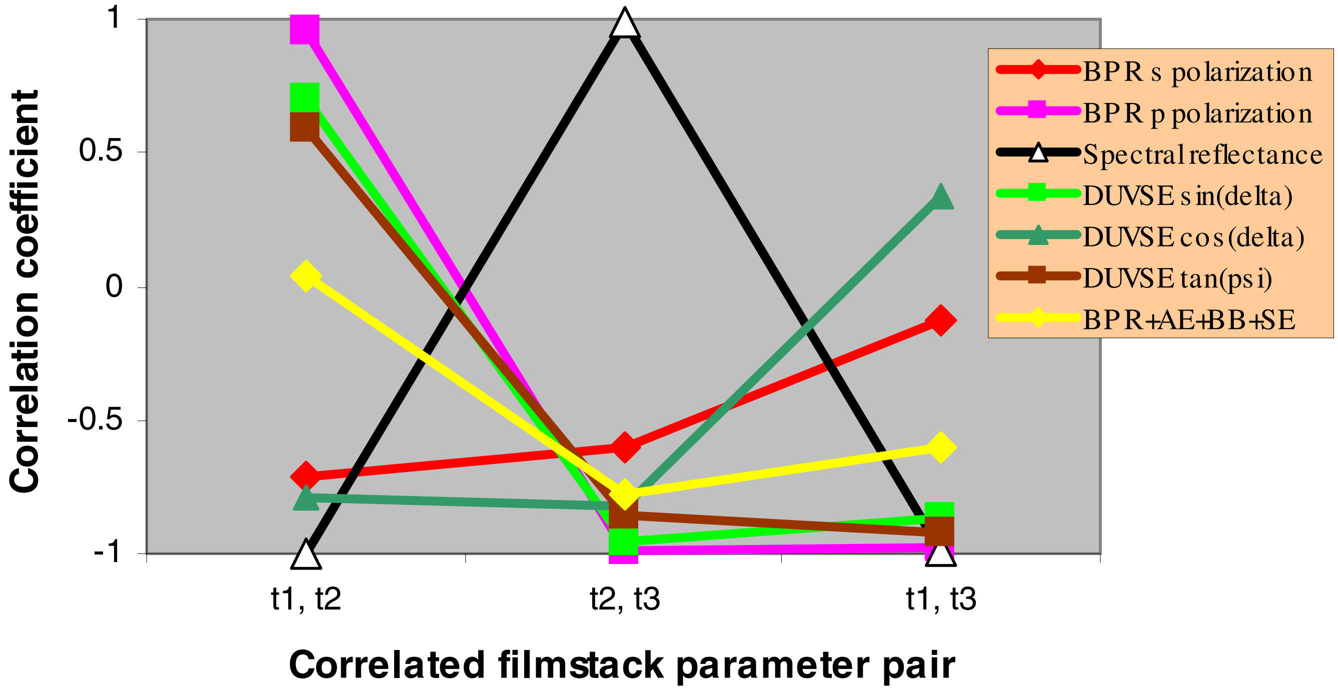
Example: Oxide Thickness Tradeoff in ONO Measurement

DUVSE cos(Δ) simulated data for ONO with fixed total thickness, fixed nitride thickness, and varying top oxide – bottom oxide thickness ratio



Correlation Coefficient

- correlation coefficients provide little information on the utility of individual measurement technologies
- example: 3-thickness ONO recipe, fit to individual technologies



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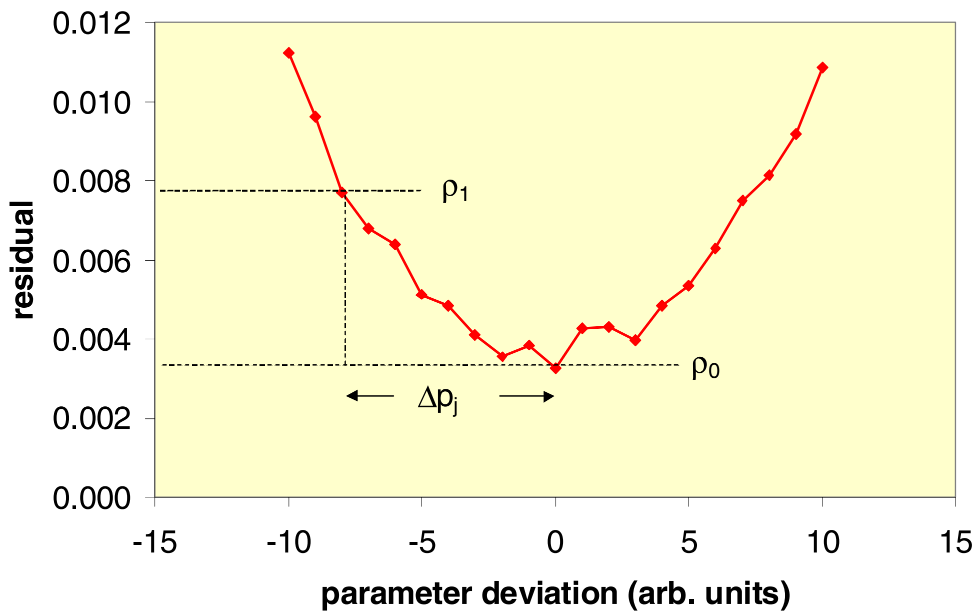
Multiparameter Information Content

$$C_{ij} = \frac{\rho_{i1} / \rho_{i0}}{\left| p_{j1} - p_{j0} \right|}$$

- intrinsic information in measurement i for determining parameter j
- use only measurement i in the recipe
- force parameter j to incorrect value (usu. double the minimum residual)
- allow other parameters to take on any value



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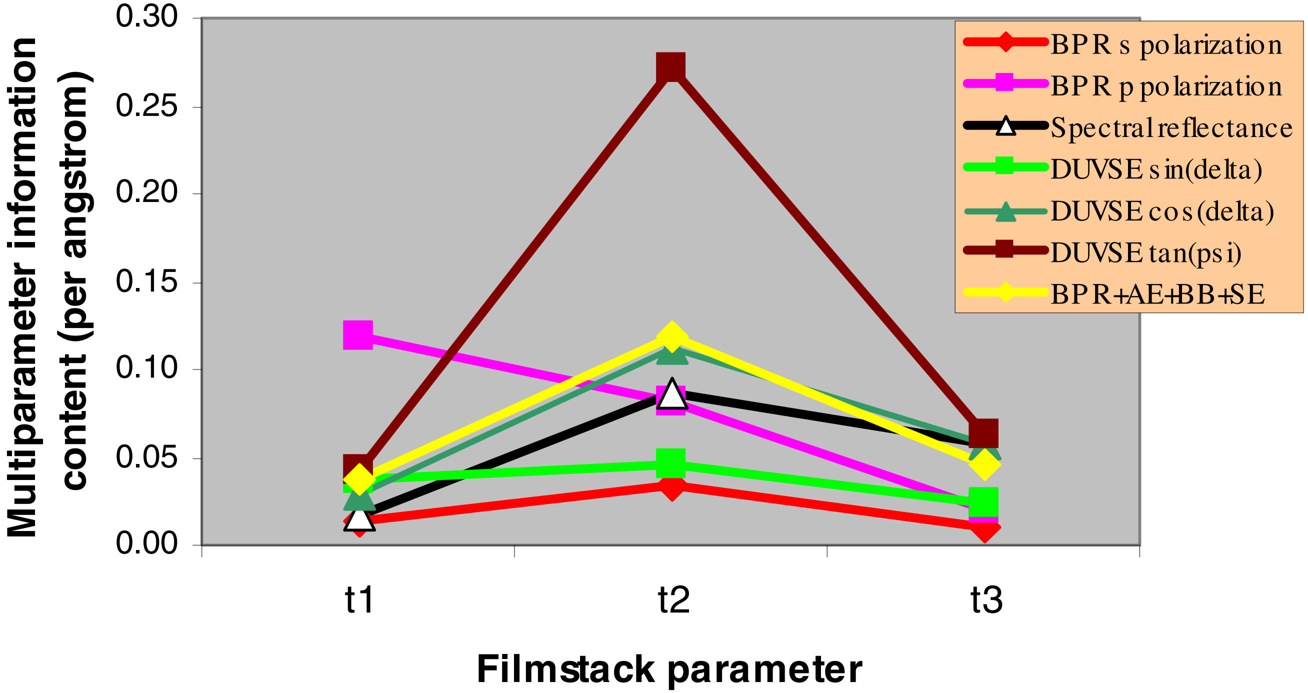
Ultrathin ONO Thickness Information

Information content measured from Opti-Probe OP5240 data on an oxide (67 Å)/nitride (77 Å)/oxide (78 Å)/Si filmstack



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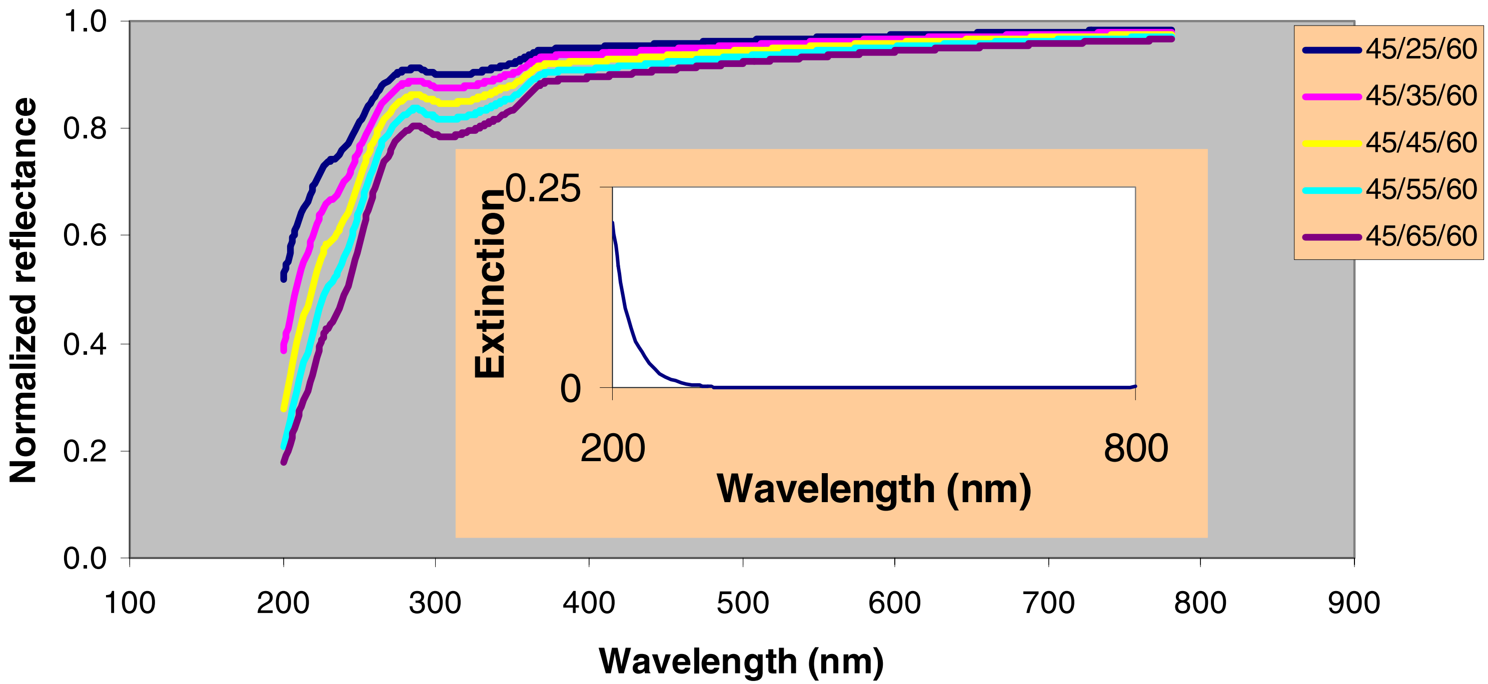
Spectrometer Sensitivity To Nitride Thickness Change



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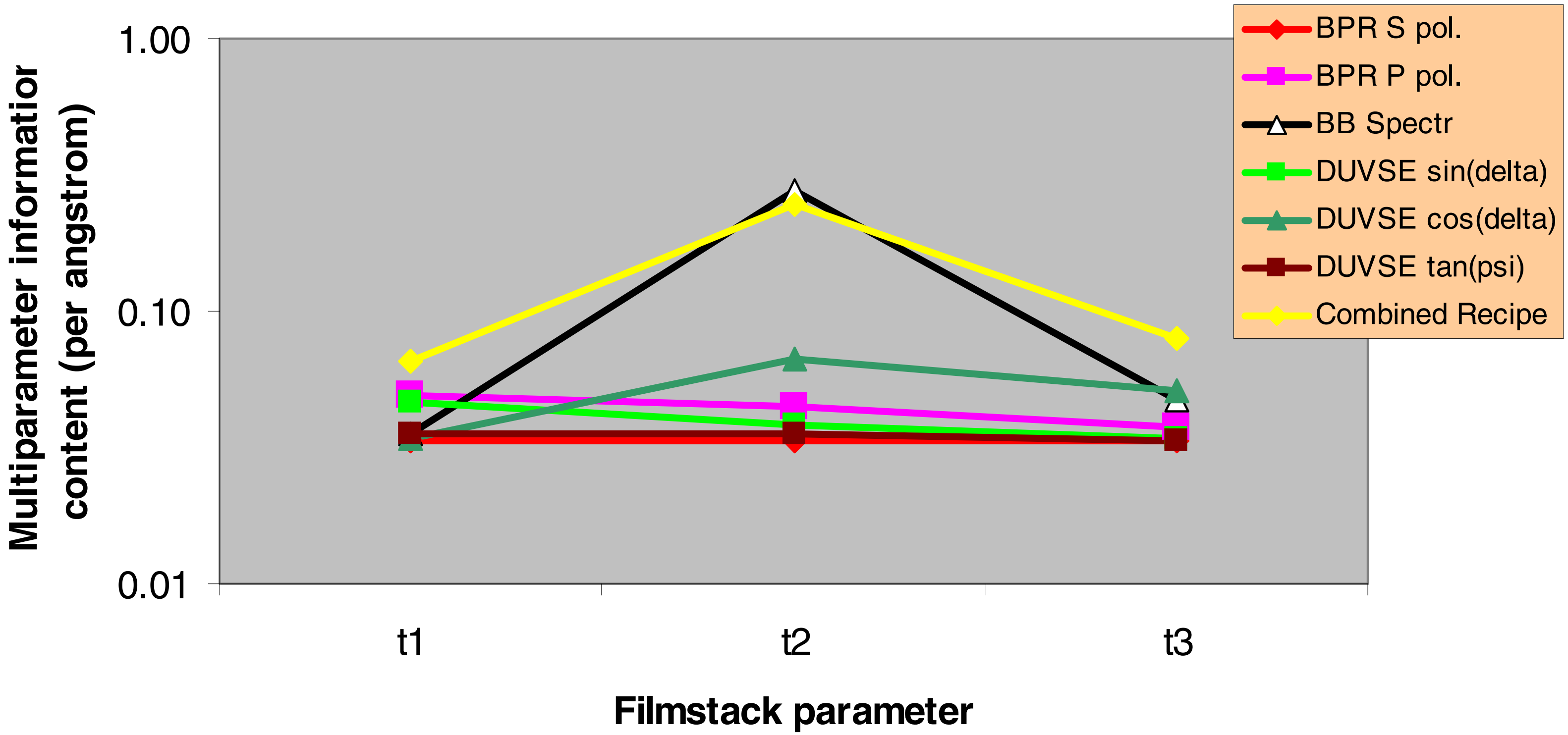
Ultrathin ONO Thickness Information

From simulated data on a 150 Å-thick ONO/Si stack



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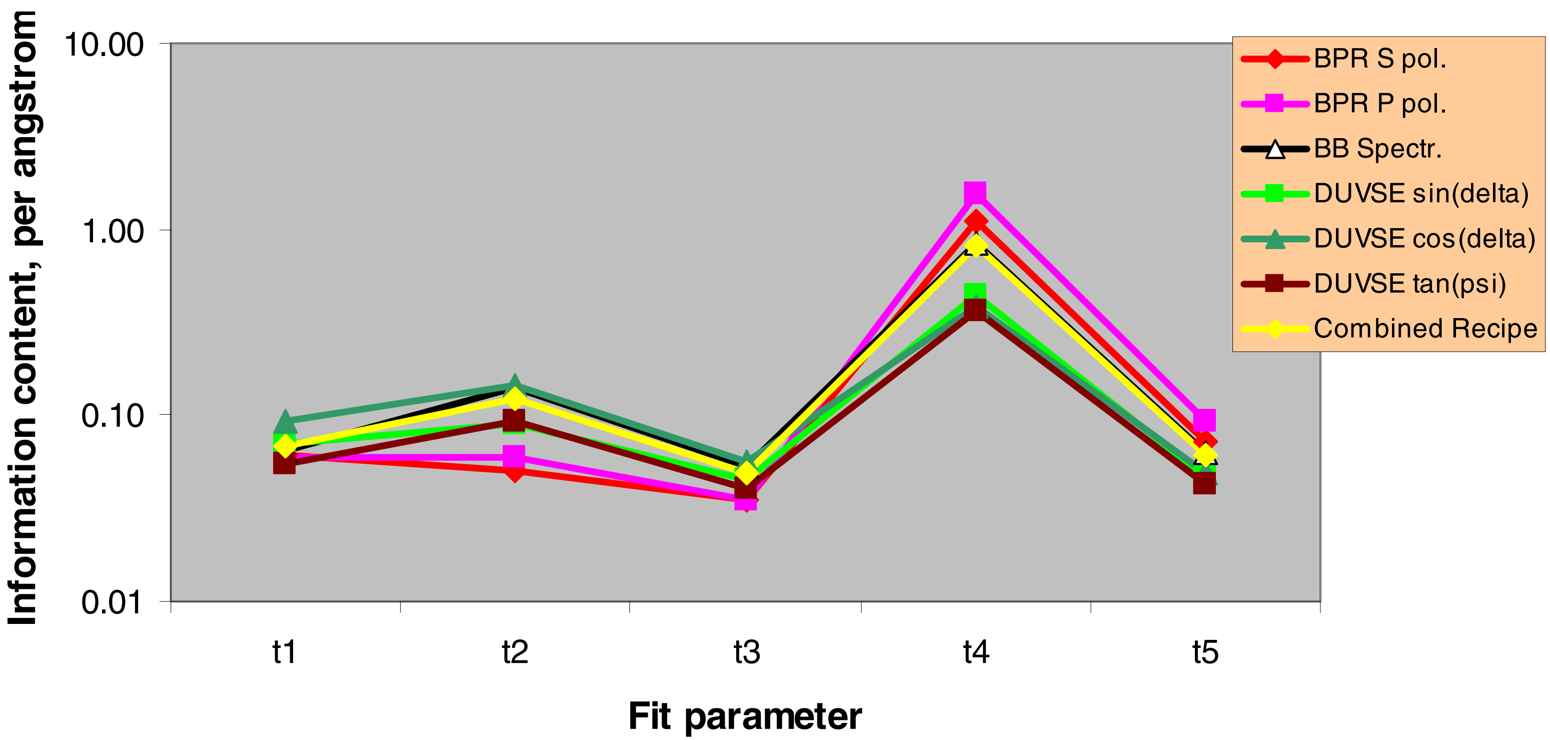
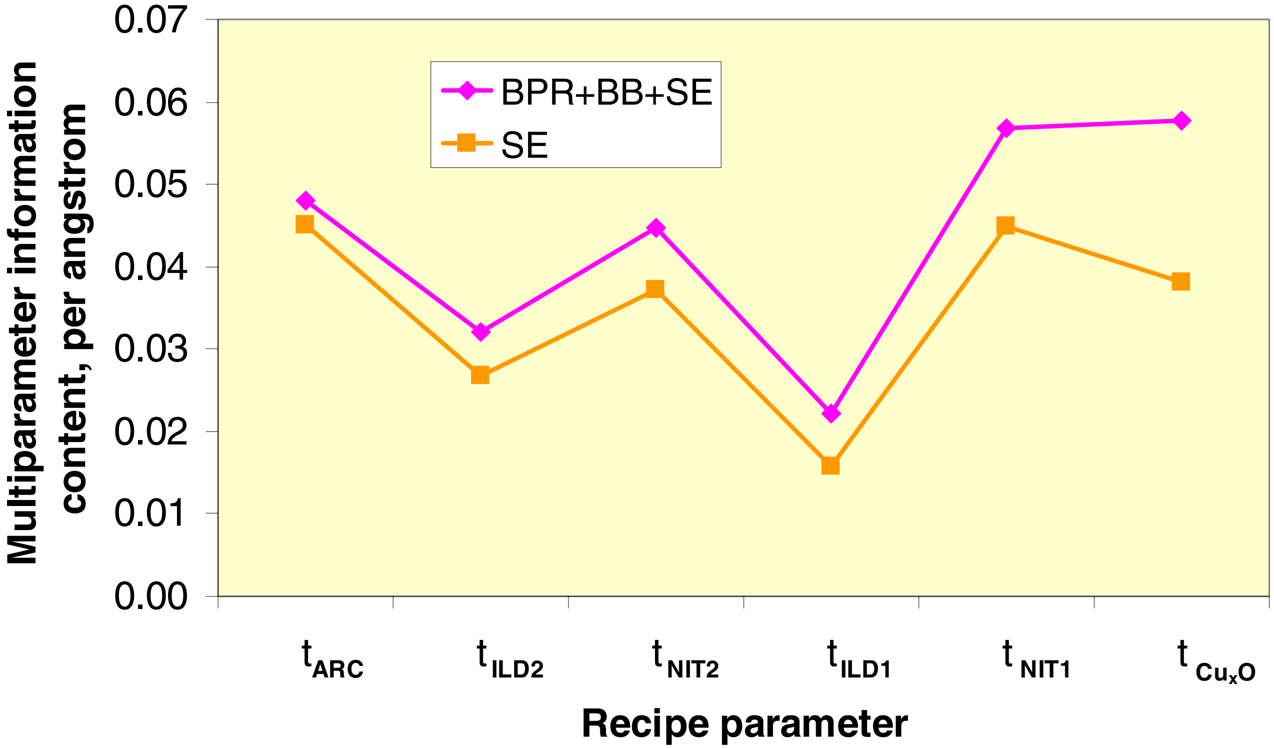
5-Thickness ONOPO Information

From simulated data on a 45/45/60/2500/100 stack, also measuring poly k



Dual Damascene Copper Thickness Information

SR-SiON (500)/oxide (5000)/SRN (500)/oxide (5000)/SRN (500)/CuO (50)/Cu



Simulated recipe

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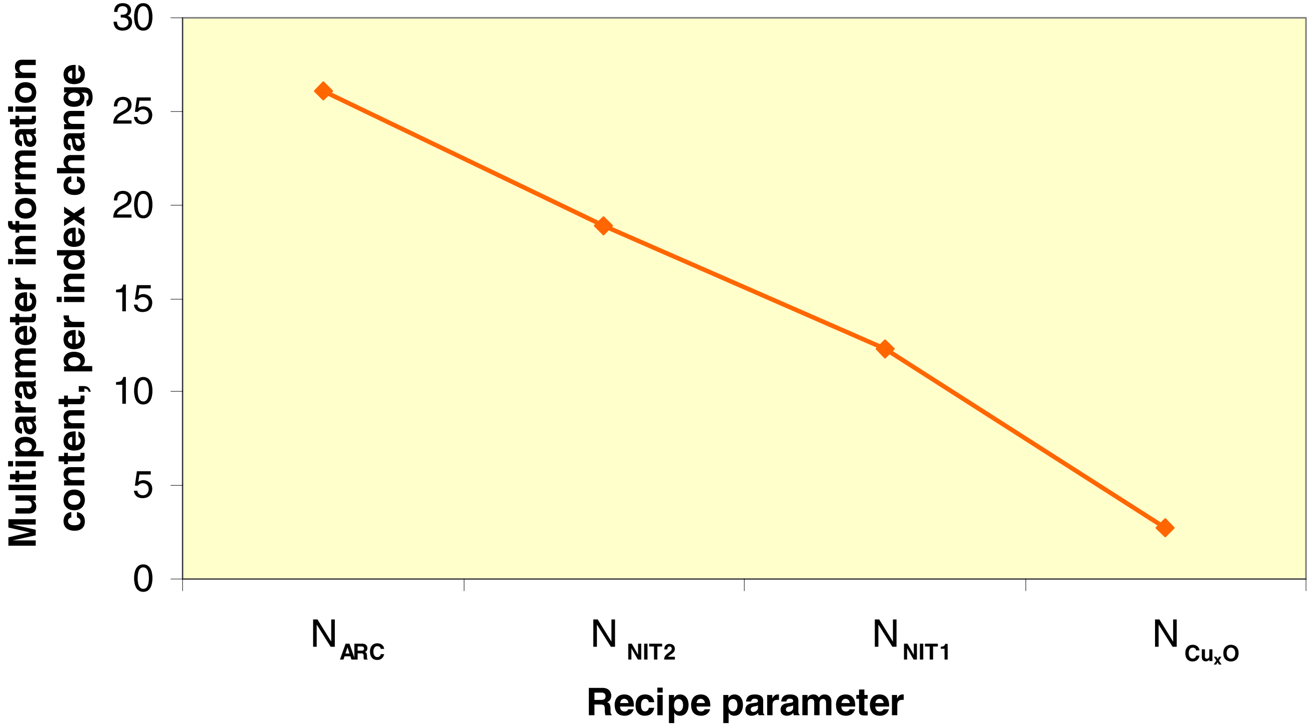
Dual Damascene Copper Composition Information

SR-SiON (500)/oxide (5000)/SRN (500)/oxide (5000)/SRN (500)/CuO (50)/Cu

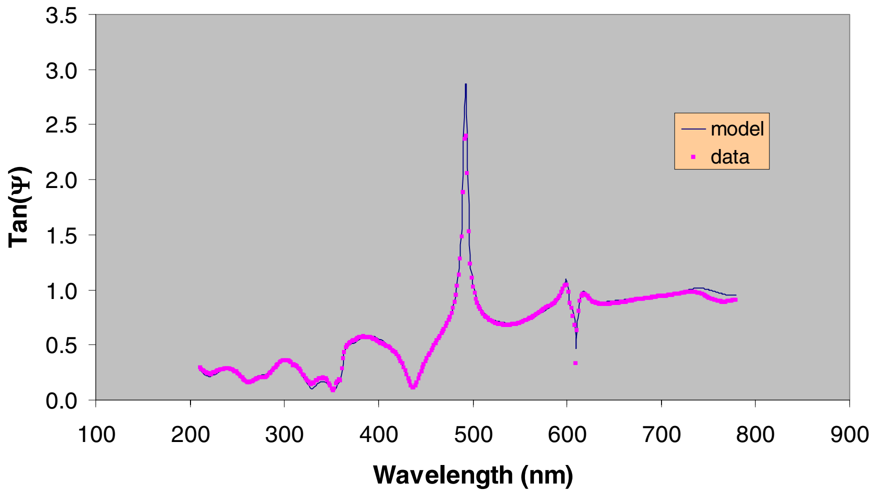


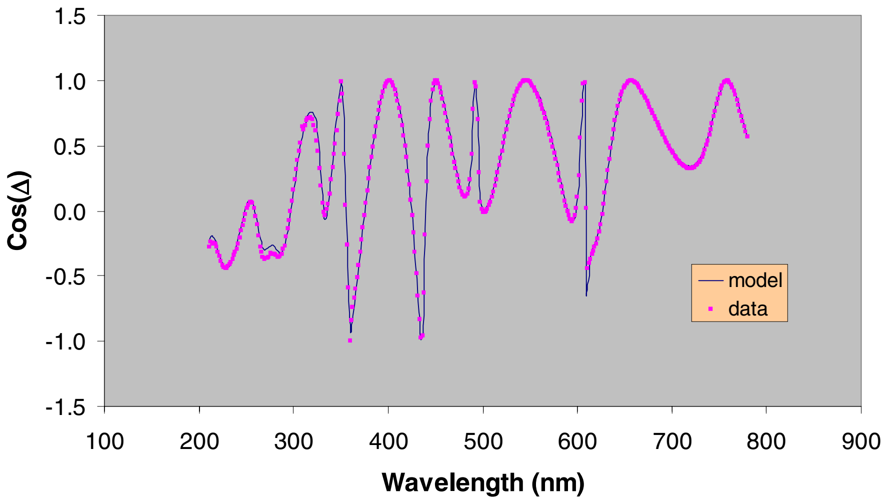
Simulated DUVSE recipe

Damascene Composition Information: Dispersion Test

- consider a 6-layer-thickness + 1-material-dispersion recipe (DUVSE only recipe as an example)
- determine best fit solution
- alter dispersion parameters of layer of choice
- start with different nominal values of layer thicknesses (generated randomly in range +/- 20% from t_{best}): mimics actual situation in which the true thicknesses are unknown and may not be equal to the expected thicknesses
- fit thicknesses, material dispersion; thickness ranges: +/- 20% of expected thicknesses
- compare results from multiple trials

Damascene Dispersion Test: Fit to DUVSE Data





Opti-Probe OP5240 data and model fit for a

Si-rich SiON
Oxide
Si-rich nitride
Oxide
Si-rich nitride
CuO
Cu

sample

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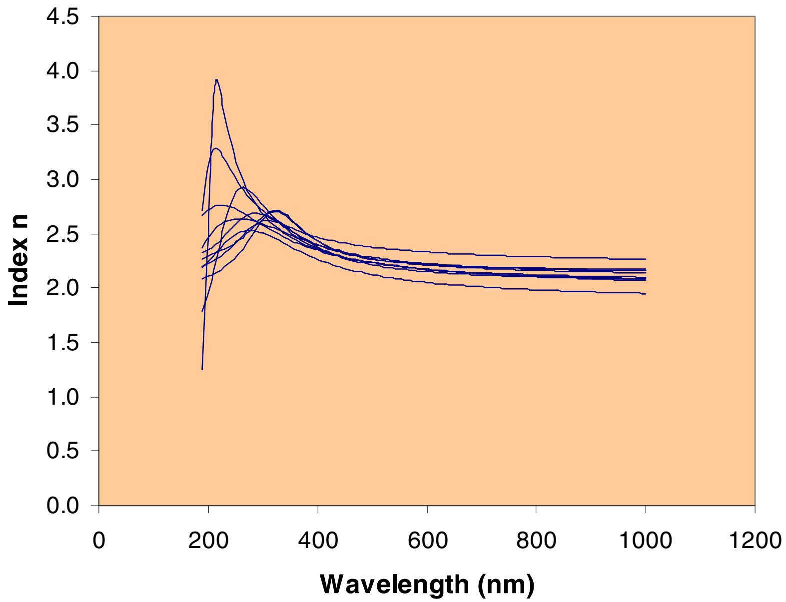
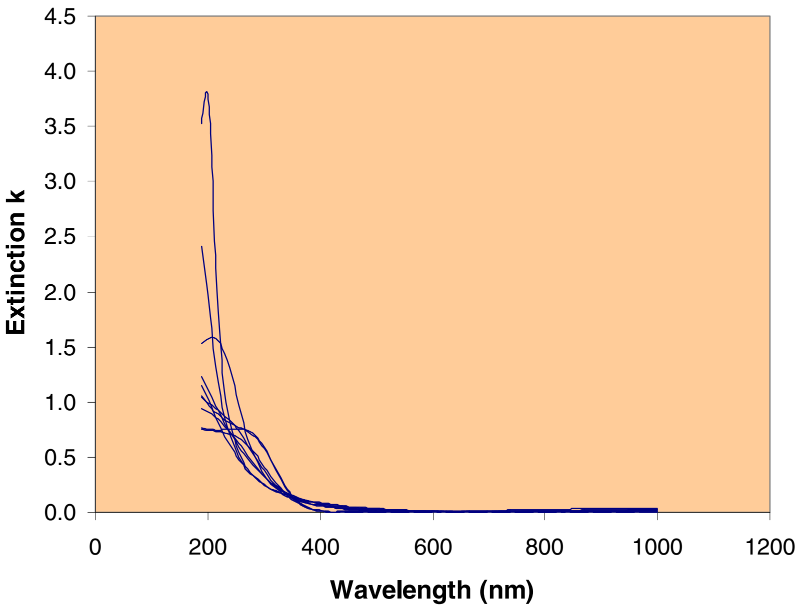
Barrier Nitride Composition Measurement

10 repeated trials, measuring 6 thicknesses and NIT1 dispersion for a DUVSE recipe for a Si-rich SiON/oxide/Si-rich nitride/oxide/Si-rich nitride/CuO/Cu stack





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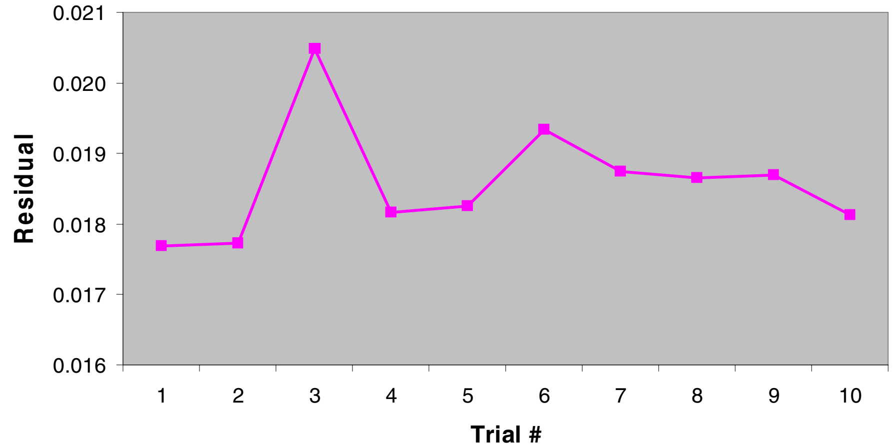
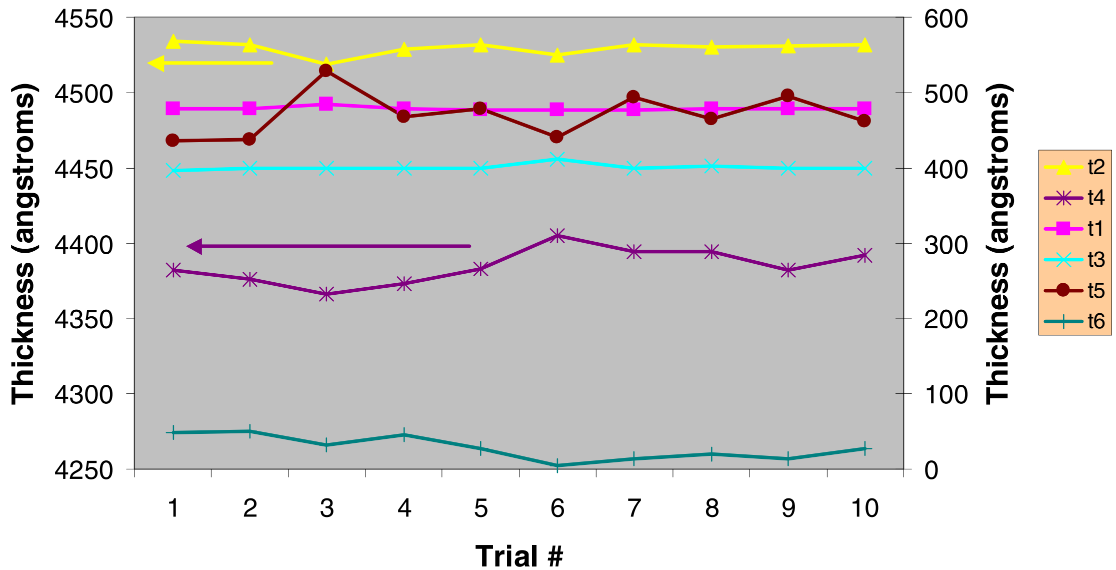
Barrier Nitride Composition Measurement



10 repeated trials, measuring 6 thicknesses and NIT1 dispersion for a DUVSE recipe for a Si-rich SiON/oxide/Si-rich nitride/oxide/Si-rich nitride/CuO/Cu stack



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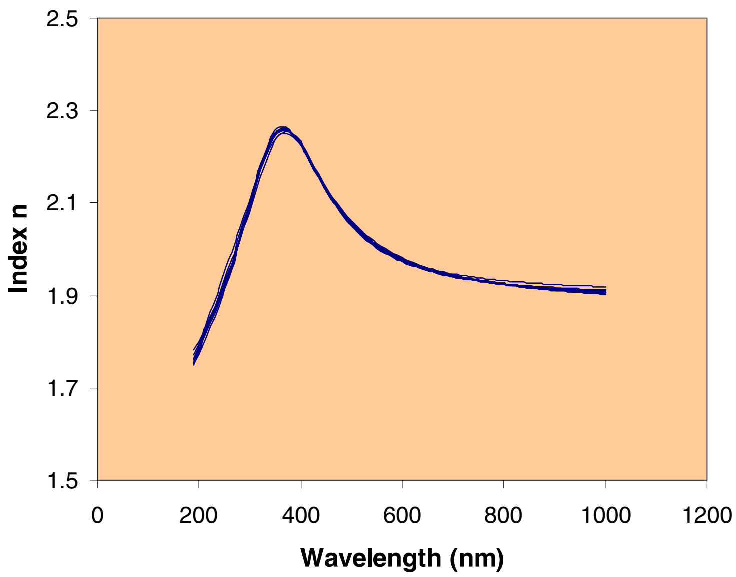
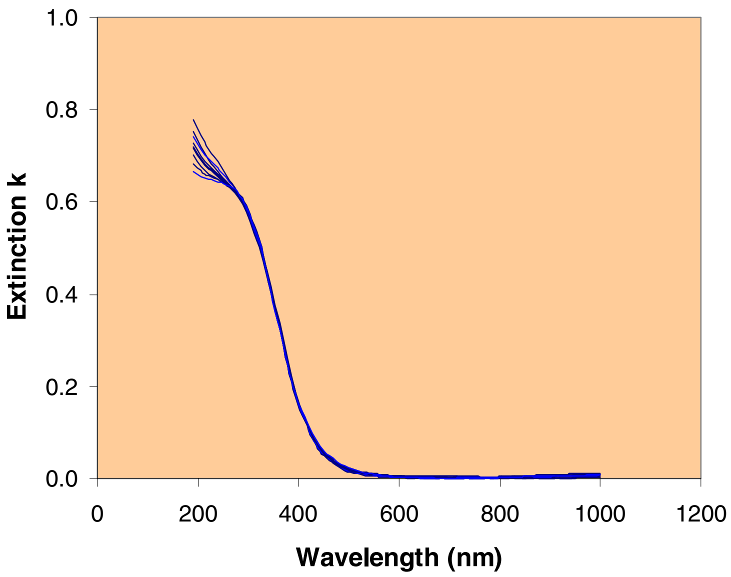
SiON ARC Composition Measurement

10 repeated trials, measuring 6 thicknesses and SION dispersion for a DUVSE recipe for a Si-rich SiON/oxide/Si-rich nitride/oxide/Si-rich nitride/CuO/Cu stack





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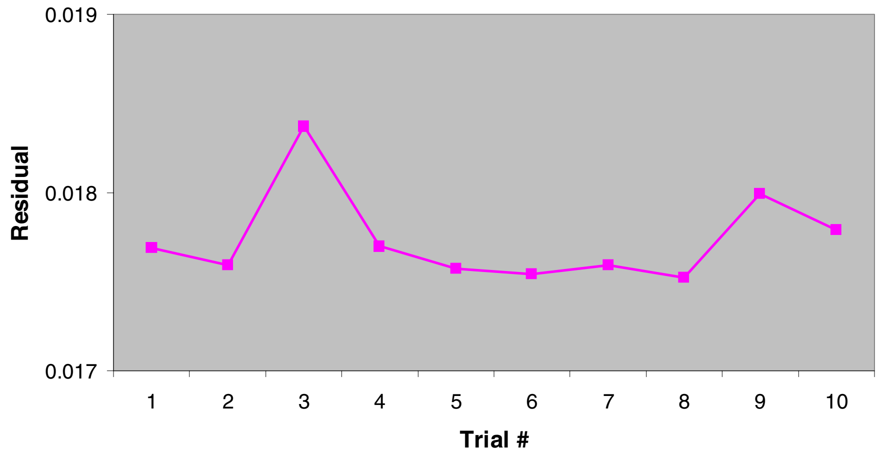
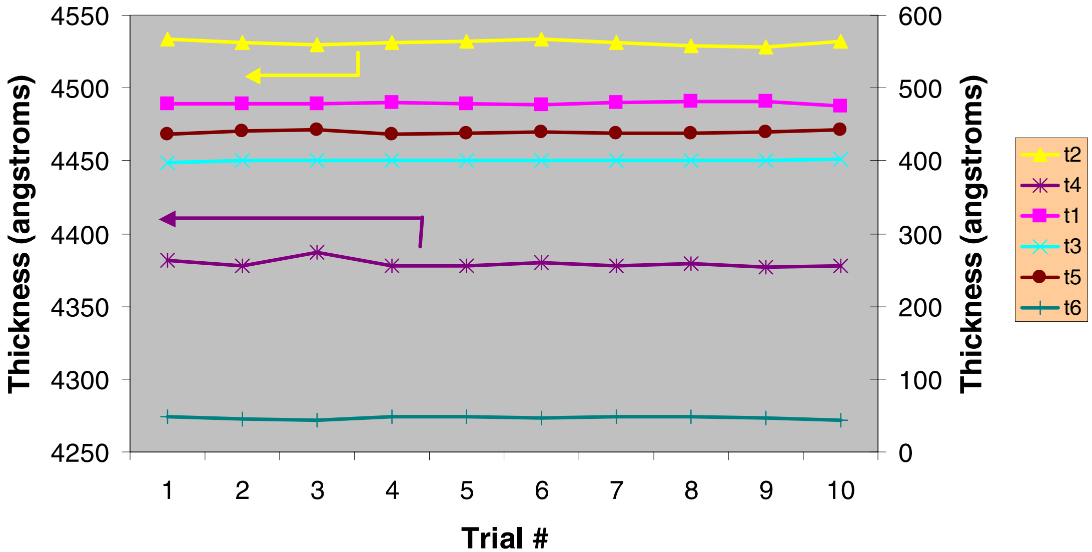
SiON ARC Composition Measurement





10 repeated trials, measuring 6 thicknesses and SION dispersion for a DUVSE recipe for a Si-rich SiON/oxide/Si-rich nitride/oxide/Si-rich nitride/CuO/Cu stack

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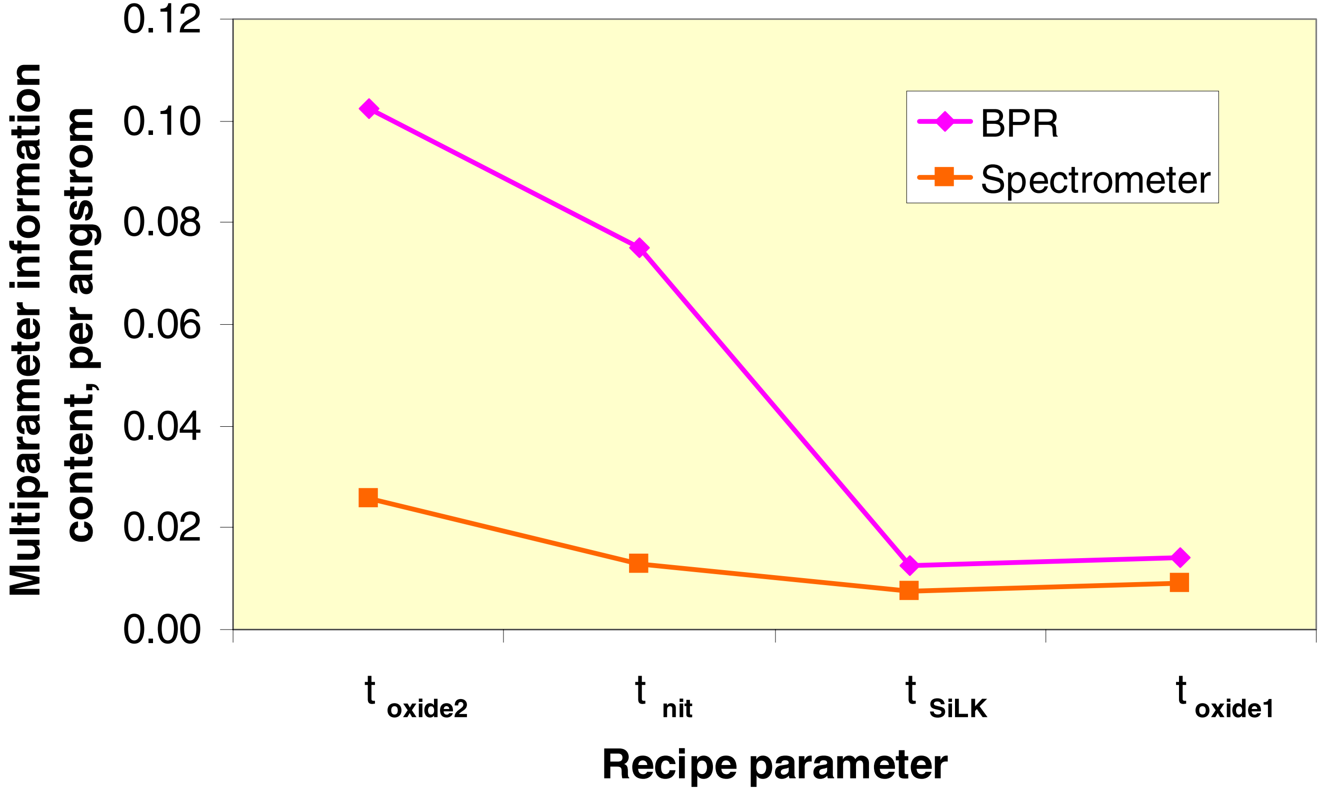
Uncertainty For Composition Measurement

Parameter	NIT1	SION
t_1	1.91	2.28
t_2	3.23	3.21
t_3	3.19	3.65
t_4	6.31	4.67
t_5	6.17	1.83
t_6	3.66	1.46
residual	0.01875	0.01808

Low-k Stack Information Content

oxide (870)/SRN (475)/SiLK (4180)/oxide (8500)/Si stack



From Opti-Probe OP5240 data

Summary

- proposed a new, simple metric for determining the information in a given optical measurement for determining a given filmstack parameter
- samples the fit residual (error) over a wider range
- accounts for potential parameter tradeoff
- measures the intrinsic measurement performance under stringent conditions
- combines the estimates of performance from uncertainty, correlation calculations
- can examine ONO measurement performance as a function of total stack thickness, for various recipes
- revealed ability to measure layer thickness and material composition in dual damascene copper and low-k stacks