n&k Analyzers

Comprehensive Metrology Tools for

Characterization and Measurements of Ultra-Thick Films, Determination of Optical Properties of Materials

n&k Technology, Inc.

Santa Clara, CA

Outline

- Introduction
- *n&k Technology, Inc.*
- Algorithm and Hardware Improvements
- Examples of Ultra-thick Photoresists

Section I: Introduction

- Wafer bumping packaging technology to pack chips more closely together
- Bump bonding technique uses ultra-thick resists to define size and location of bonds
- Resist thickness typically range in 50 to 100 μm, or more, substantially more than resists used in IC manufacturing
- *n&k Technology* provides a solution to address the needs of Advanced Packaging industries

Section II: The Company

- The Company
- Optical Systems
- Products
- Forouhi-Bloomer (FB) Dispersion

The Company: *n&k Technology, Inc.*

- *n&k Technology* designs, manufactures, and sells systems, termed *n&k Analyzers*, for characterization of thin films, and measurements of optical properties and critical dimensions.
- Founded in 1992 by Dr. Rahim Forouhi and Dr. Iris Bloomer.
- Privately held.
- August 1999 - Al Shugart International invested in *n&k Technology*.
- *n&k Technology*'s roots originated in the 1980s with the discovery of the equations for ***n*** and ***k*** by the founders.
- *n&k Technology* offers a broad product portfolio for production and R&D applications in:
  - **Semiconductor industry (Si and GaAs)**
  - **Photomasks industry**
  - **Data storage market (magnetic, optical, and magneto-optical)**
  - **Flat panel displays**
  - **Optical coatings and filters**
- Currently, more than eighty (250) companies, operating in twelve (12) countries, use *n&k Analyzers*, multiple units.

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Fully Automated n&k Analyzers for Wafer Fabrication

~3300 Platform~

n&k 3300 Bridge Tool

For 2" – 12" Wafers

n&k 3300

For 12" (300mm)Wafers

- Semiconductor Wafer Processing Applications (Si, GaAs, InP, etc.)
- Microspot Technology
- Pattern recognition
- Automated X-Y Mapping
- Automated Loading/Unloading
- Automated Z-Direction Stage Movement
- Supporting manual load port, SMIF, and FOUP

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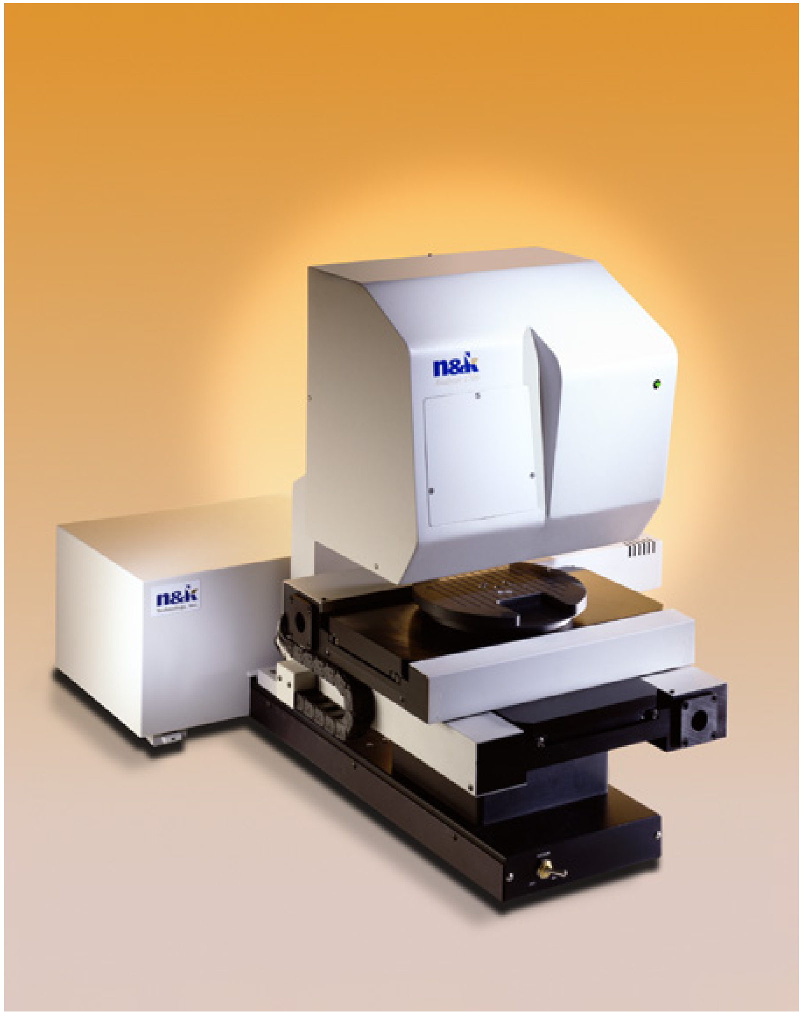
n&k Analyzer 1700



Overview

n&k 1700 Technology

- n&k Patented, all Reflective Optics
  DUV-Visible-NIR, 190 nm - 1000 nm, 1 nm step
- Simultaneous Determination of n, k and thickness
- Agilent Technologies Spectrophotometer Electronics
- Cognex Machine Vision
- 8" x 8" or 12" x 12" Automated Stage
- n&k Technology Thin Film Data Analysis Software
- n&k Technology Patented, Microspot Feature Analysis Software

Application:

- Ultra-High Resolution Thin Film Metrology on Patterned Wafers
- Micro-Feature Film Parameter Mapping

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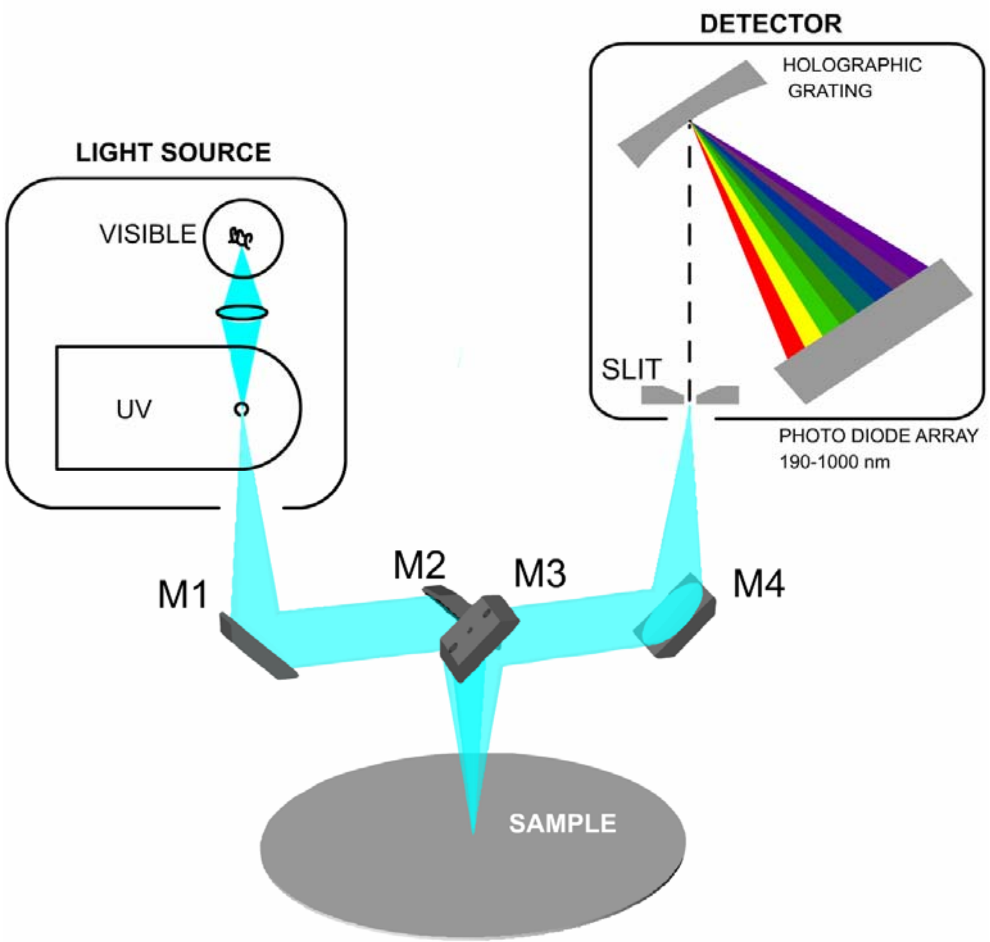
Optical System (*n&k Technology*)



n&k Analyzers Differentiator

- **Wavelength Range**
  - The measured raw data should cover the entire deep UV to near IR wavelength range
- **Signal to Noise**
  - The measured raw data should have a good signal to noise ratio over the entire wavelength range
- **Physical Model**
  - A valid physical model should be used to analyze the measured raw data

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Dispersion Equations

- Forouhi-Bloomer:

$$k(E) = \sum_i^q \frac{A_i(E - E_g)^2}{E^2 - B_i E + C_i}$$

$$n(E) = n(\infty) + \sum_i^q \frac{B_{oi} E + C_{oi}}{E^2 - B_i E + C_i}$$

- Cauchy:

$$n(\lambda) = n_0 + \frac{n_1}{\lambda^2} + \frac{n_2}{\lambda^4}$$

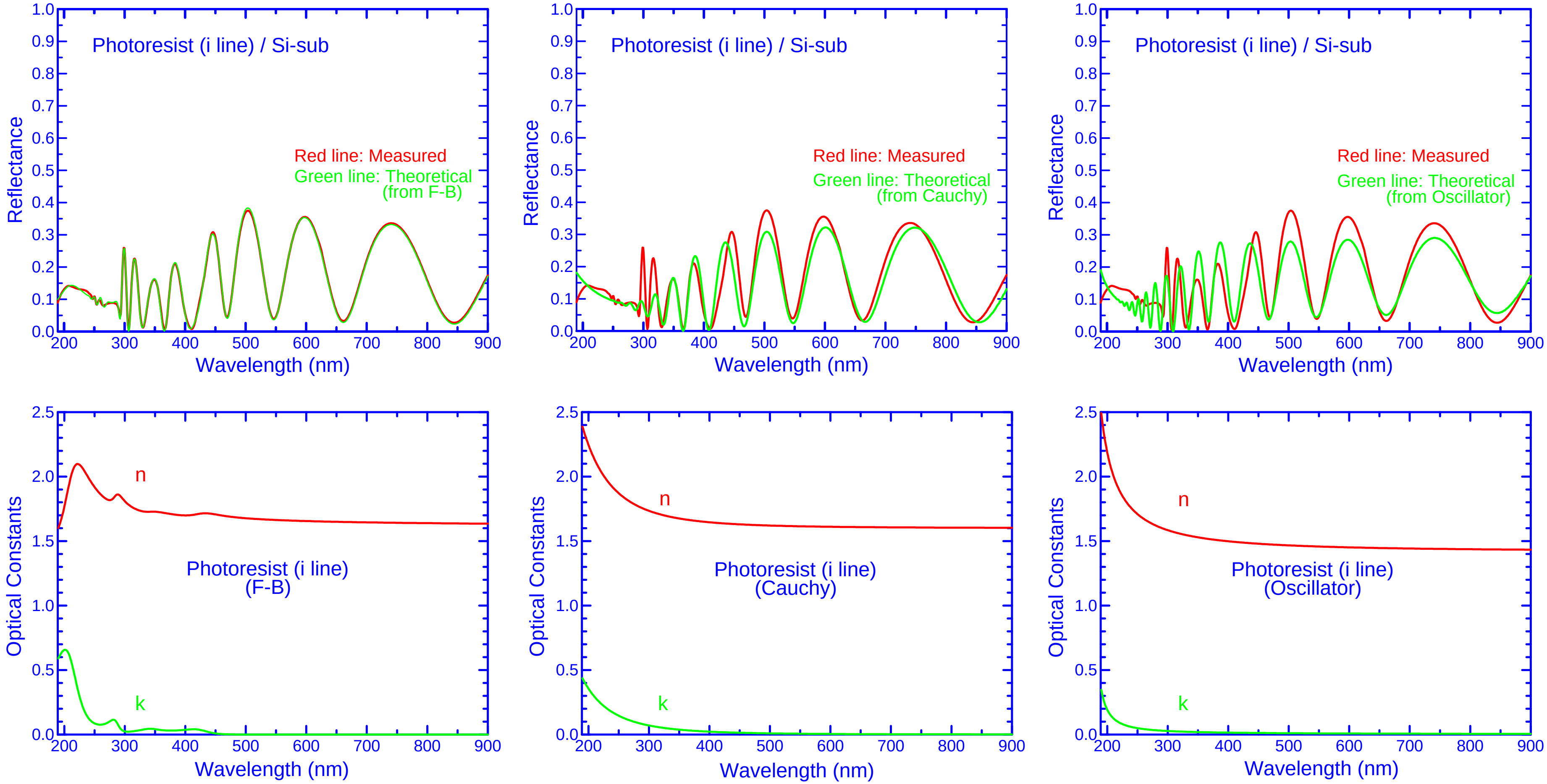
$$k(\lambda) = k_0 + \frac{k_1}{\lambda^2} + \frac{k_2}{\lambda^4}$$

- Harmonic-Oscillator:

$$\varepsilon_1(\omega) = n^2 - k^2 = 1 + \sum_i \frac{\omega_{pi}^2(\omega_{0i}^2 - \omega^2)}{(\omega_{0i}^2 - \omega^2)^2 + \gamma_i^2 \omega^2}$$

$$\varepsilon_2 = 2nk = \sum_i \frac{(\gamma_i)\omega\omega_{pi}^2}{(\omega_{0i}^2 - \omega^2)^2 + \gamma_i^2 \omega^2}$$

i-line Photoresist



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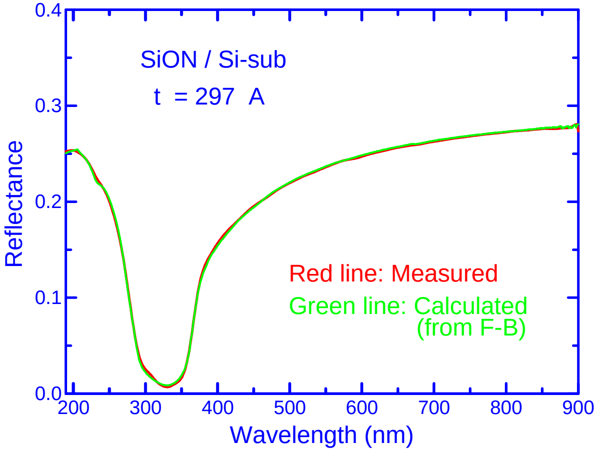
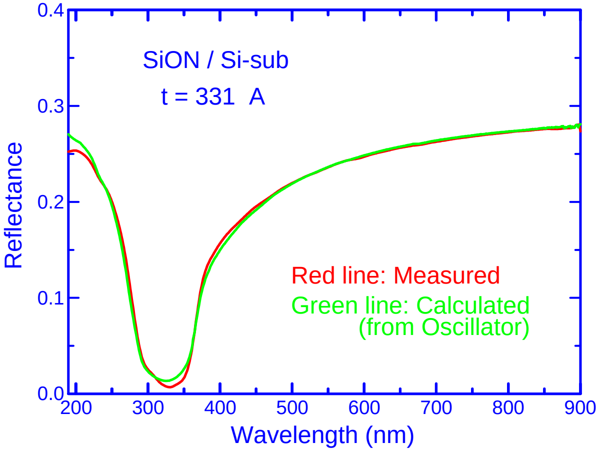
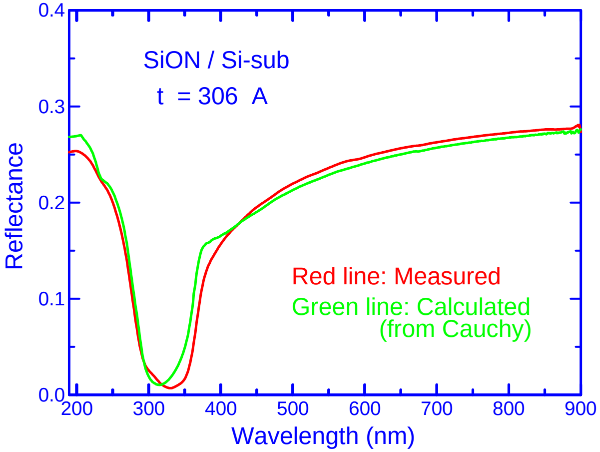
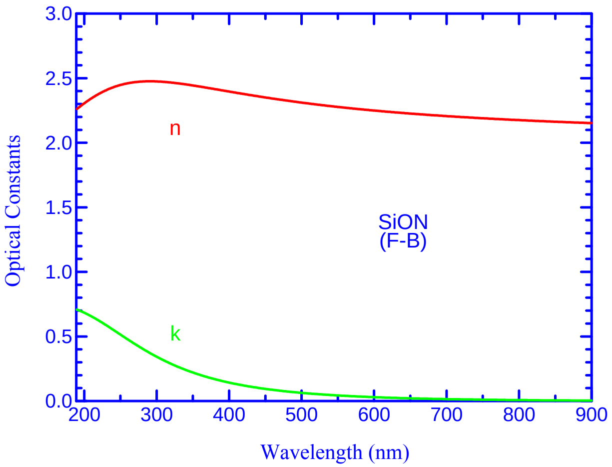
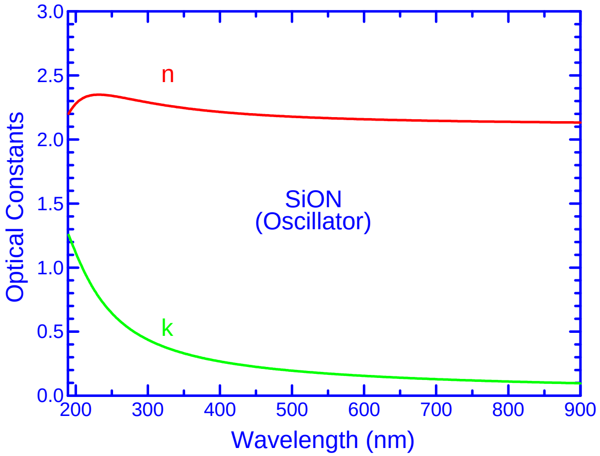
SiON

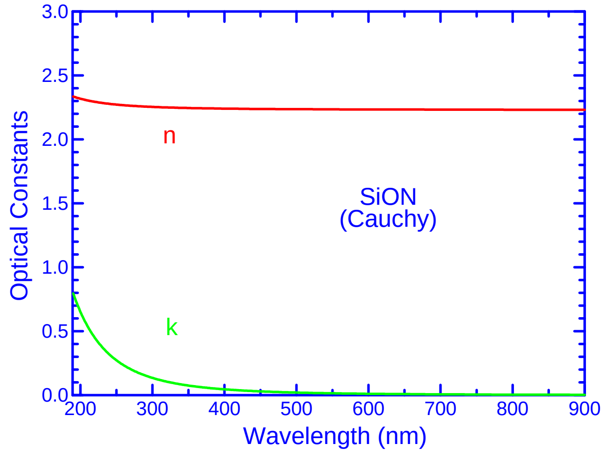












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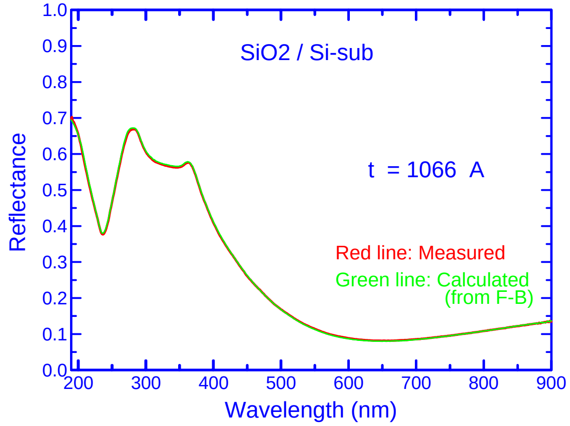
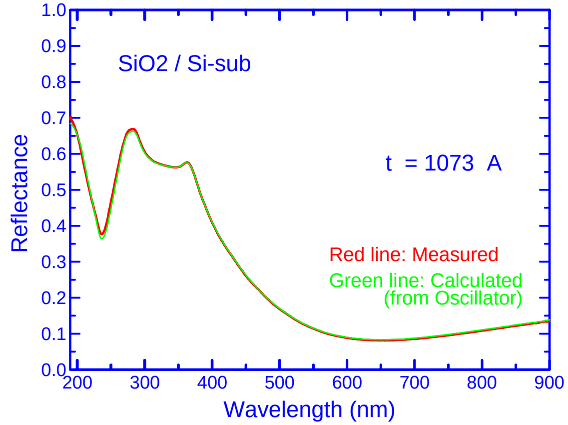
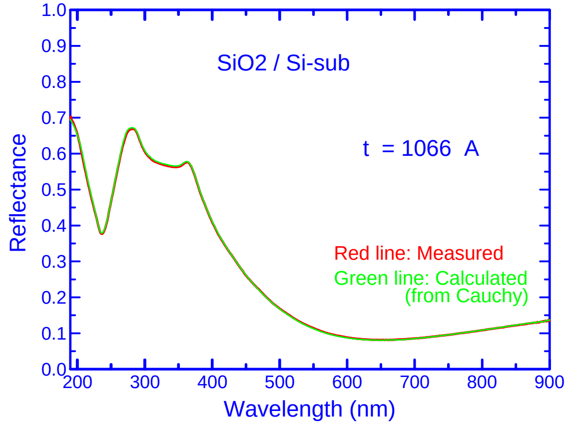
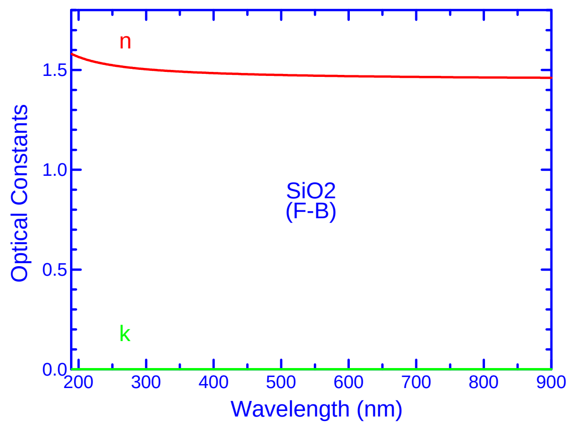
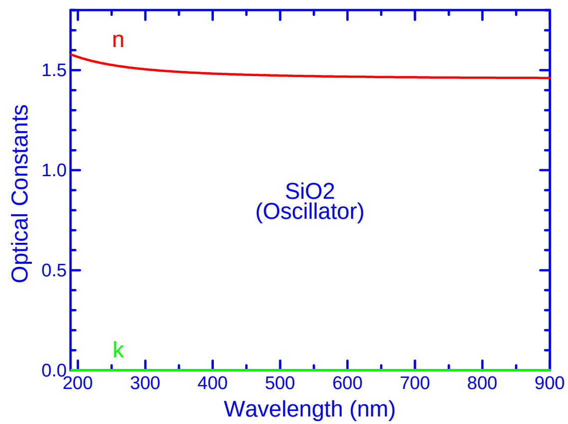
SiO2

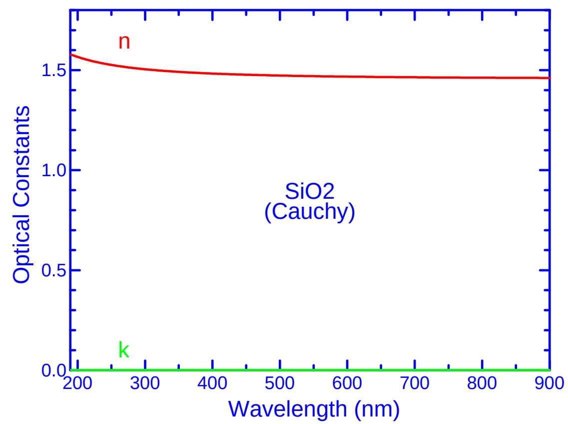

SiO2 / Si-sub
t = 1066 A
Red line: Measured
Green line: Calculated
(from F-B)
Reflectance
Wavelength (nm)


SiO2 / Si-sub
t = 1073 A
Red line: Measured
Green line: Calculated
(from Oscillator)
Reflectance
Wavelength (nm)


SiO2 / Si-sub
t = 1066 A
Red line: Measured
Green line: Calculated
(from Cauchy)
Reflectance
Wavelength (nm)


n
k
SiO2
(F-B)
Optical Constants
Wavelength (nm)


n
k
SiO2
(Oscillator)
Optical Constants
Wavelength (nm)


n
k
SiO2
(Cauchy)
Optical Constants
Wavelength (nm)

Section III: Improvements For Ultra-thick Film Applications

- Typical Problem of Ultra-thick Film Analysis
- Algorithm Improvements
- Hardware Improvements

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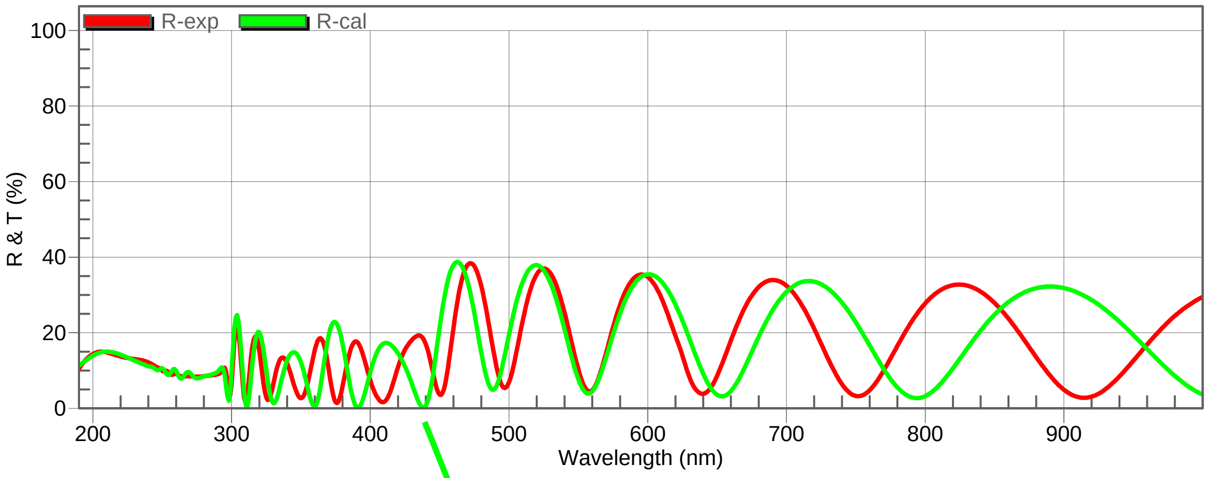
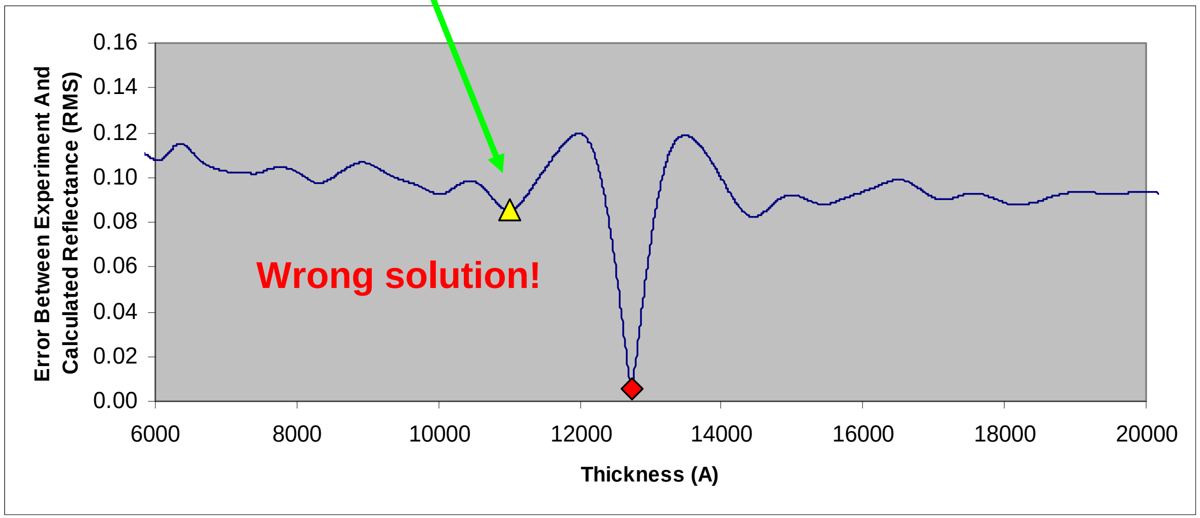
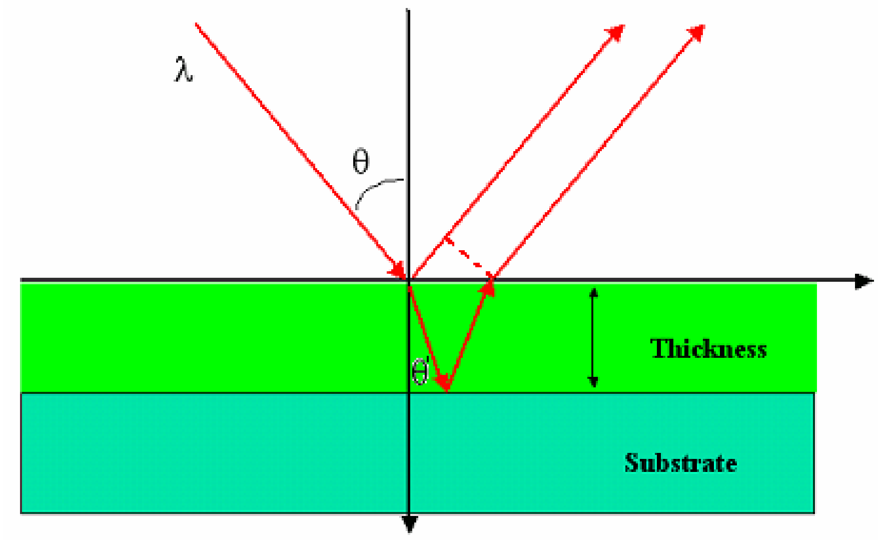
Typical Problem of Ultra-thick Film Analysis – Multiple Local Minima





A More Robust Way to Estimate A Film's Starting Thickness

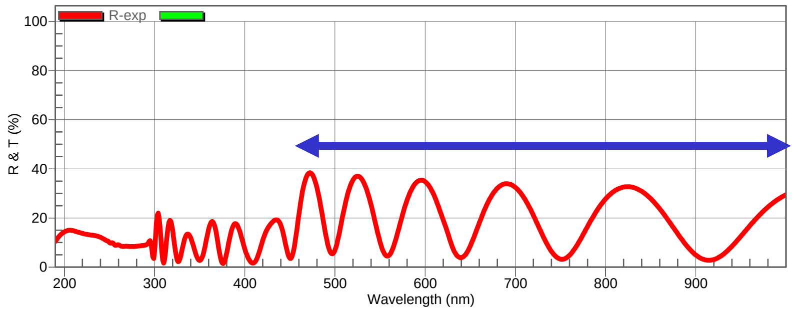


Phase $\varphi = 2\pi/\lambda * \Delta$

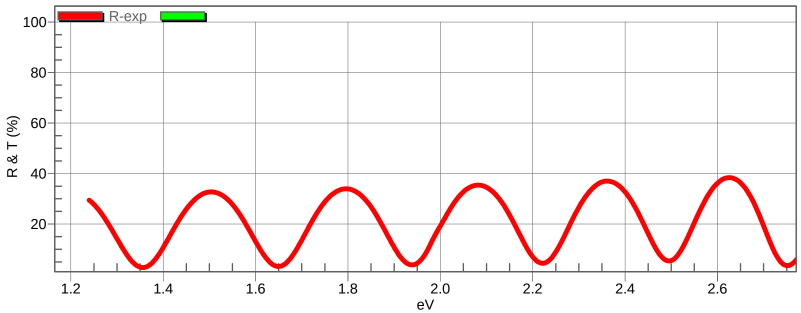
$= 2\pi/\lambda * (2*n*t*\cos\theta')$

$\propto n*t / \lambda$

Number of fringes is proportional to n and t

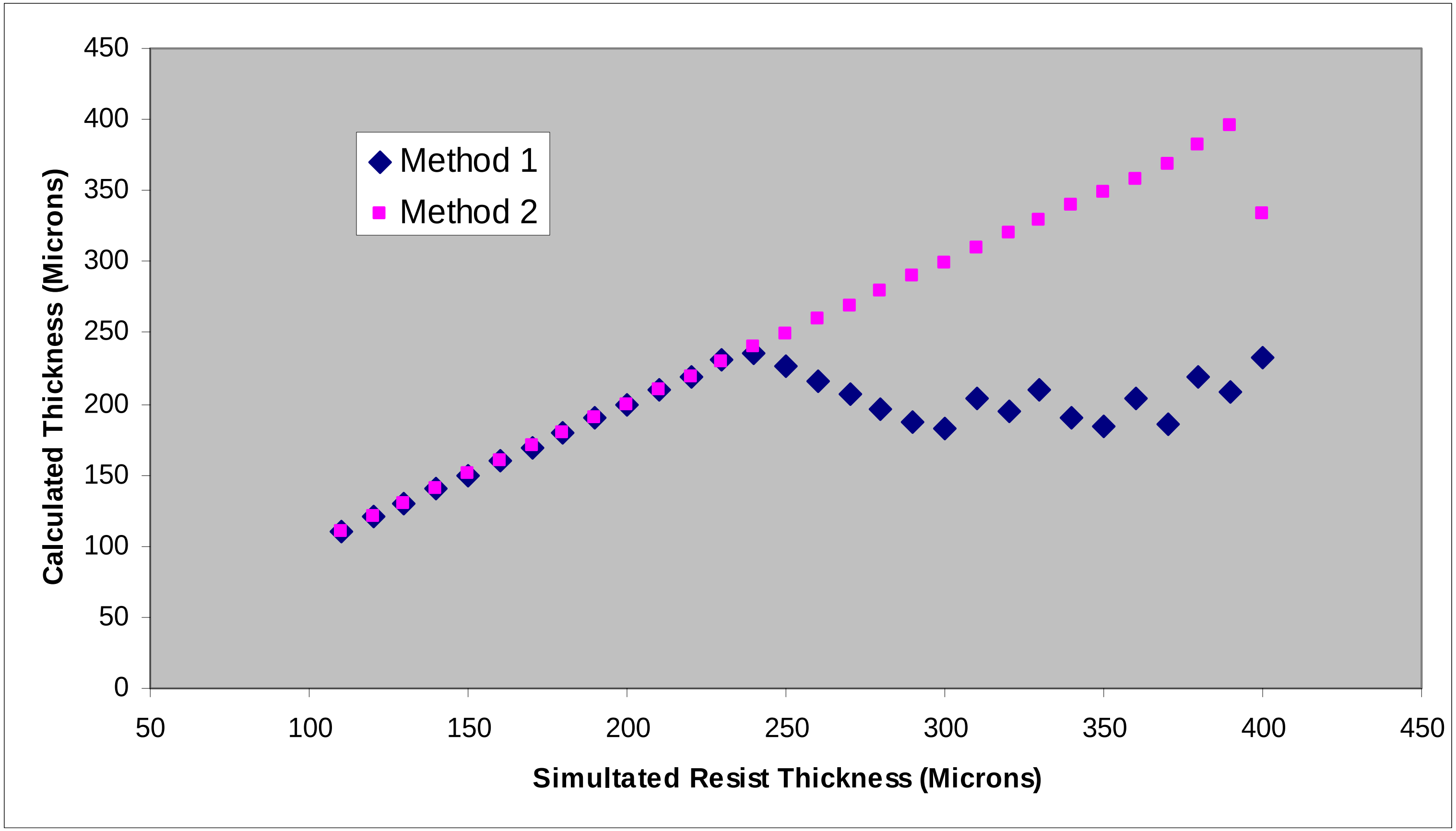


iline resist in λ space

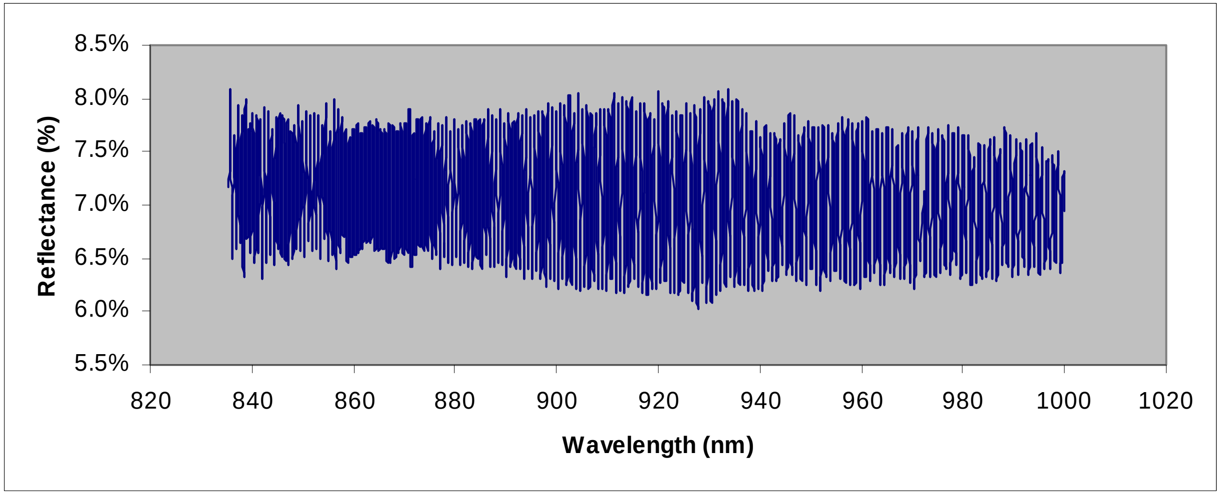


iline resist in 1/λ space

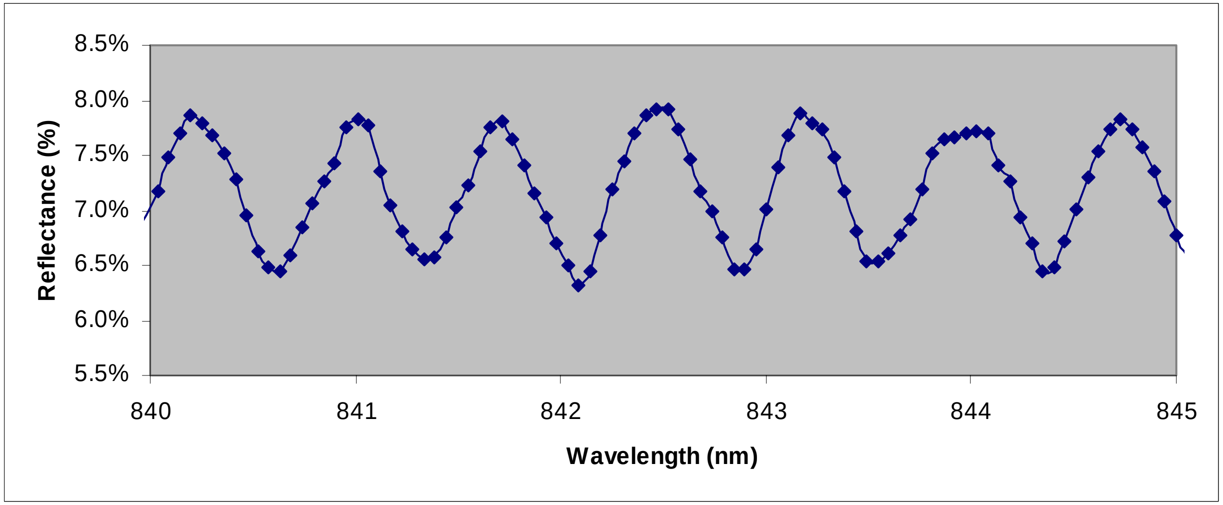
Tests on Simulated Spectra



Higher Resolution Spectrophotometer Reflectance of 300μm Glass Slide



Full Spectral Range



Same Data, Zoomed Range

20x Improvement!

Section IV: Ultra-thick Film Applications

- Correlation with Profilometry
- 70 and 100μm Photoresist Measurements
- Repeatability and Reproducibility of Results

Applications: Ultra Thick Films

Characterization of ultra-thick

Photoresists

Advanced Packaging

BROADBAND SPECTROPHOTOMETRY FOR WAFER-LEVEL PACKAGING

BY JOHN C. LAM

A growing number of semiconductor manufacturers use wafer bumping packaging technology to pack chips more closely together for such applications as cell phones, where space is at a premium. The bump bonding technique requires ultra-thick photoresists to define bond size and location. These photoresist layers typically are in the range of 50 to 100 µm (or more) thick, which is substantially thicker than resists used in IC manufacturing.

Because of the high costs associated with defects and subsequent rework, accurate characterization of photoresist layers is depend on the wavelength of light used to make the measurement. The index of refraction describes how the path of a beam of light deviates (refracts) as it passes through a material — the greater the value of *n*, the greater the refraction. The extinction coefficient relates to the absorption of light — the value of *k* increases as more light is absorbed by a material. Transparent materials have an extinction coefficient of zero in the visible wavelength spectrum. The film's energy band gap, E_g, is another useful parameter: it

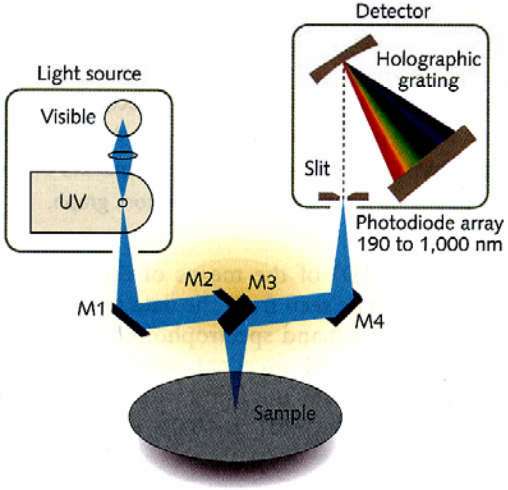


Figure 1. Configurations of the light source and detector used in broadband spectrophotometry.

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Applications: Ultra Thick Films Correlation with Profilometry

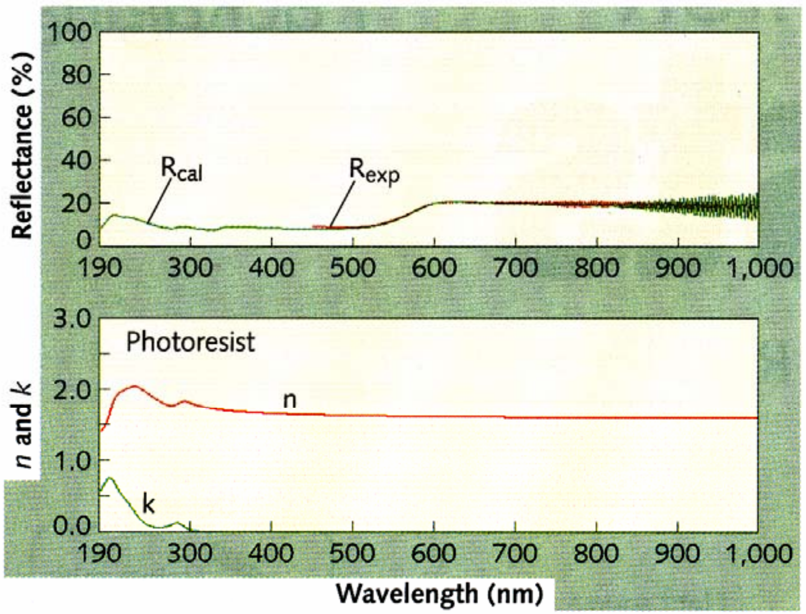

Figure 2. Measured and calculated reflectance spectra from the 70 μm photoresist sample are shown in the top graph. Optical properties (*n* and *k* spectra) of the photoresist film are shown in the bottom graph.

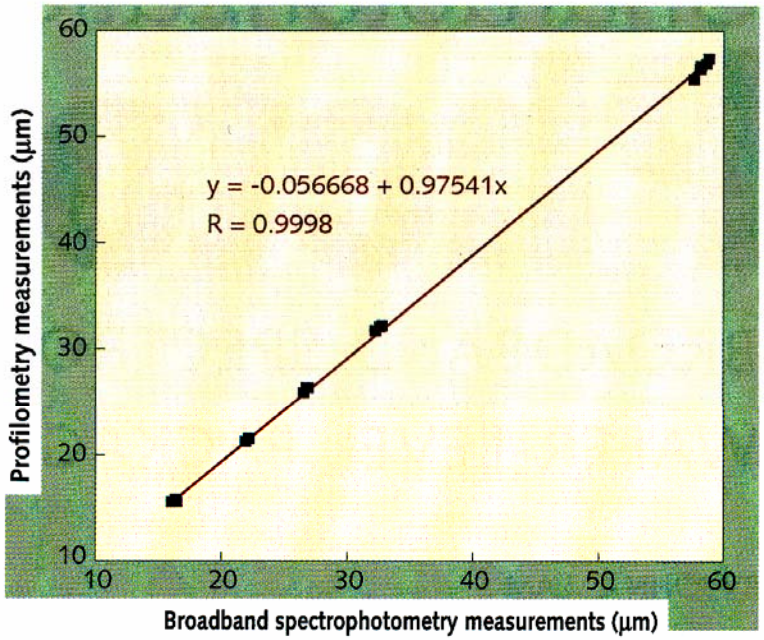

Figure 4. Broadband spectrophotometry and profilometry measurements for photoresists up to 60 μm thick show good agreement.

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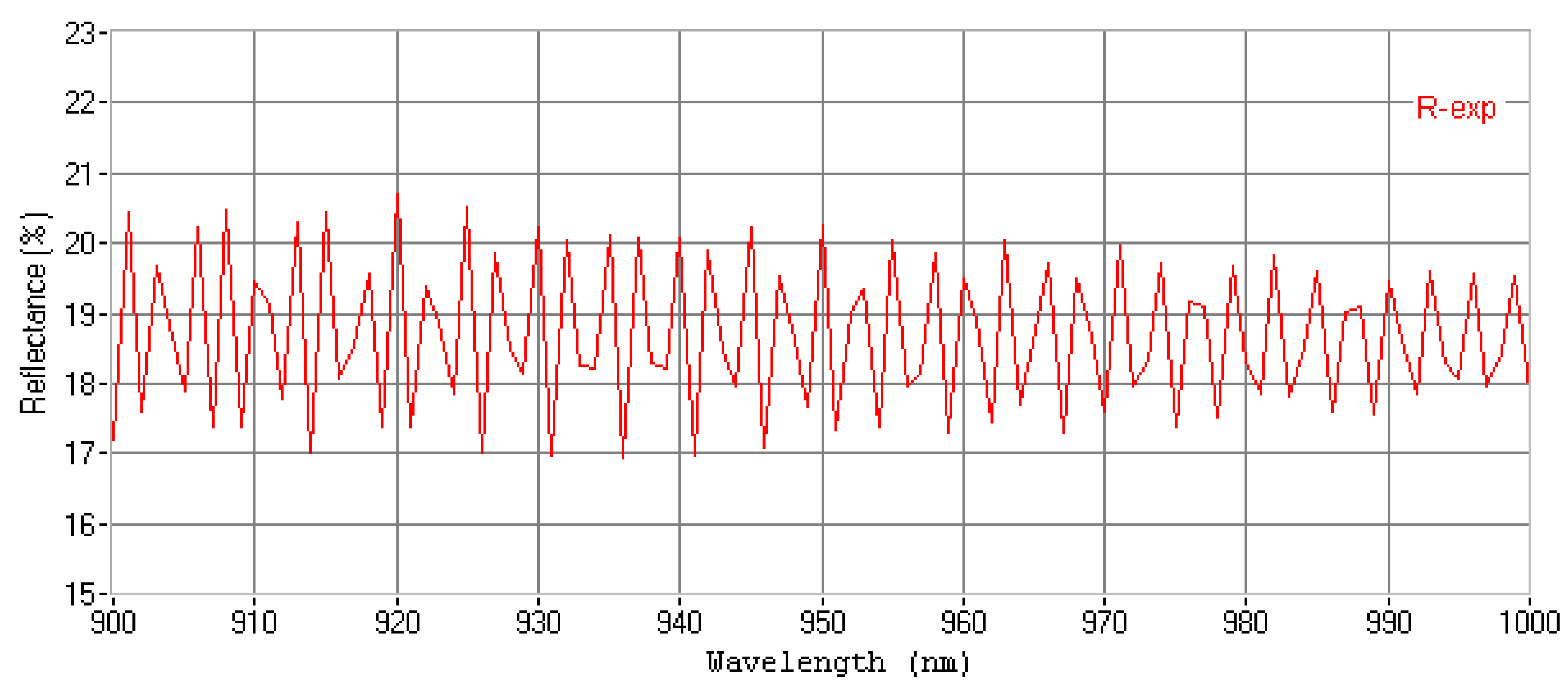
Example of 100 µm Photoresist Spectra

Reflectance from 900 – 1000nm, 100um Resist



Applications: Ultra Thick Films
Repeatability and Reproducibility Studies

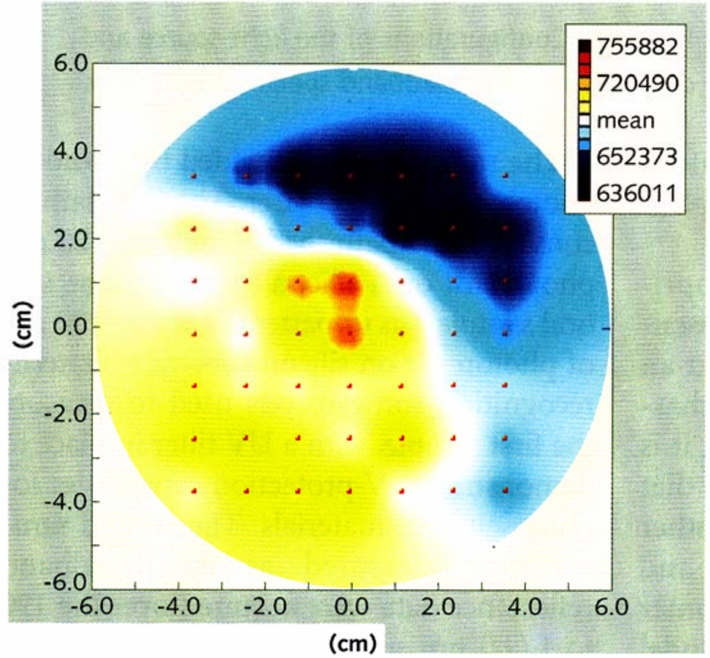


Figure 3. A map of 49-point thickness measurements from the ~70 μm-thick photoresist sample.

Mean measured thickness of nominally 70 and 100 μm photoresist films*

70 μm	Trial #1	Trial #2	Trial #3	Trial #4	Trial #5	Trial #6	Trial #7	Trial #8	Trial #9	Trial #10	% STD
Mean	685,099	685,075	685,075	685,104	685,093	685,063	685,059	685,119	685,030	685,025	0.004
STD	30,360	30,330	30,304	30,337	30,337	30,341	30,326	30,360	30,315	30,323	
100 μm	**Trial #1**	**Trial #2**	**Trial #3**	**Trial #4**	**Trial #5**	**Trial #6**	**Trial #7**	**Trial #8**	**Trial #9**	**Trial #10**	**% STD**
Mean	1,040,813	1,041,032	1,040,715	1,040,606	1,040,849	1,040,184	1,040,769	1,040,330	1,040,909	1,040,722	0.025
STD	47,927	48,254	49,434	48,711	48,436	49,285	48,906	49,925	48,539	48,658	

*with 10 trials of 49 points measured per trial

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Conclusions

- Demonstrated ultra-thick resists capability provides manufacturers with a fast, accurate, repeatable, and non-destructive characterization tool for process monitoring.
- No blindspots in the entire thickness range – due to innovative analysis algorithm.
- Measured 300 µm film (eg, glass slide). High resolution detector allows comfortable measurement up to 600 µm, and more. Ultimate thickness not known – limited only by the quality of film.
- Non-destructive, fast measurements – less than 3 seconds per site.
- Excellent repeatability and reproducibility compared to traditional methods.