n&k Analyzers


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.
Fully Automated n&k Analyzers for Wafer Fabrication

~3300 Platform~

n&k 3300 Bridge Tool
For 2" – 12" Wafers

• Semiconductor Wafer Processing Applications (Si, GaAs, InP, etc.)
• Microspot Technology
• Pattern recognition
• Automated X-Y Mapping

n&k 3300
For 12" (300mm) Wafers

• 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
Optical System (n&k Technology)

LIGHT SOURCE

VISIBLE

UV

SLIT

DETECTOR

HOLOGRAPHIC GRATING

PHOTO DIODE ARRAY
190-1000 nm

M1 M2 M3 M4

SAMPLE

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**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
Dispersion Equations

- Forouhi-Bloomer:
  \[ k(E) = \sum_{i} \frac{A_i (E - E_g)^2}{E^2 - B_i E + C_i} \]
  \[ n(E) = n(\infty) + \sum_{i} \frac{B_{oi} E + C_{oi}}{E^2 - B_i E + C_i} \]

- 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:
  \[ \varepsilon_1(\omega) = n^2 - k^2 = 1 + \sum_{i} \frac{\omega_p^2 (\omega_0^2 - \omega^2)}{(\omega_0^2 - \omega^2)^2 + \gamma_i^2 \omega^2} \]
  \[ \varepsilon_2 = 2nk = \sum_{i} \frac{(\gamma_i) \omega \omega_p^2}{(\omega_0^2 - \omega^2)^2 + \gamma_i^2 \omega^2} \]
i-line Photoresist
SiO₂

Reflectance

Wavelength (nm)

Optical Constants

n

k

SiO₂ / Si-sub

Red line: Measured
Green line: Calculated (from F-B)

Red line: Measured
Green line: Calculated (from Oscillator)

Red line: Measured
Green line: Calculated (from Cauchy)

SiO₂ / Si-sub

t = 1066 Å

Green line: Calculated

Red line: Measured

Green line: Calculated

Green line: Calculated
Section III: Improvements For Ultra-thick Film Applications

- Typical Problem of Ultra-thick Film Analysis
- Algorithm Improvements
- Hardware Improvements
Typical Problem of Ultra-thick Film Analysis – Multiple Local Minimia

Wrong solution!
A More Robust Way to Estimate A Film’s Starting Thickness

Phase $\varphi = \frac{2\pi}{\lambda} * \Delta$

$= \frac{2\pi}{\lambda} * (2n*t*cos\theta')$

$\propto n*t / \lambda$

Number of fringes is proportional to $n$ and $t$

- Iline resist in $\lambda$ space
- Iline resist in $1/\lambda$ space

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Tests on Simulated Spectra

Simulated Resist Thickness (Microns)

Calculated Thickness (Microns)

- Method 1
- Method 2

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Higher Resolution Spectrophotometer
Reflectance of 300µm Glass Slide

![Graph of Reflectance vs Wavelength for 820-1020 nm range.]

Reflectance (%)
Wavelength (nm)

![Graph of Reflectance vs Wavelength for 840-845 nm range.]

Reflectance (%)
Wavelength (nm)

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
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 essential. 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 depends 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.
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.
Example of 100 µm Photoresist Spectra

Reflectance from 900 – 1000nm, 100um Resist

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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           | 100 μm          |                 |                 |                 |                 |                 |                 |                 |                 |
| Mean            | 685,099         | 1,040,813       | 685,075         | 1,041,032       | 685,104         | 1,040,715       | 685,059         | 1,040,849       | 685,063         |
| STD             | 30,360          | 47,927          | 30,337          | 48,254          | 30,341          | 48,711          | 30,326          | 48,436          | 48,906          |
| % STD           | 0.004           | 0.025           | 0.004           | 0.050           | 0.004           | 0.010           | 0.004           | 0.005           | 0.009           |

*with 10 trials of 49 points measured per trial
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.