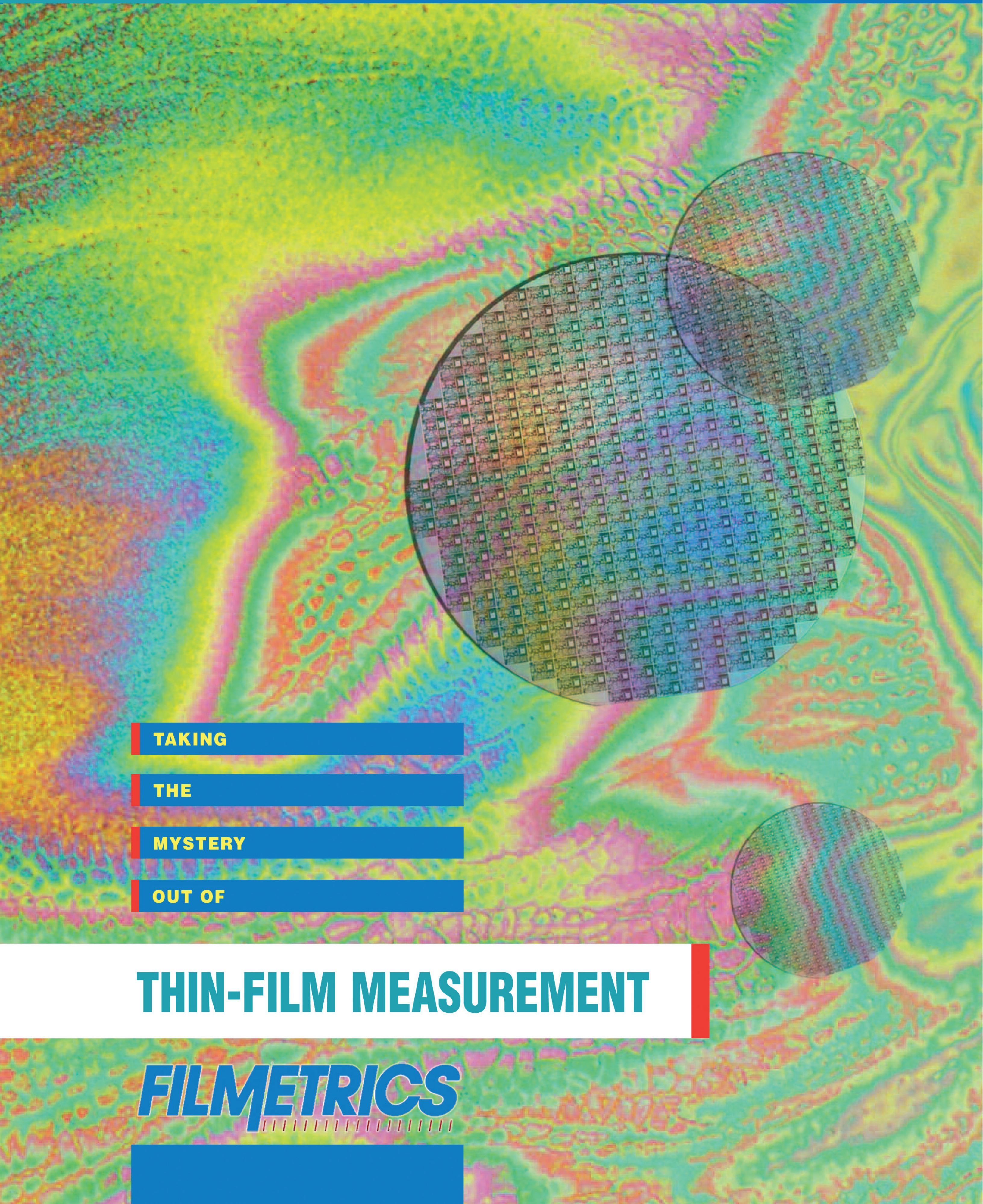
ADVANCED THIN-FILM MEASUREMENT SYSTEMS



TAKING

THE

MYSTERY

OUT OF

THIN-FILM MEASUREMENT

FILMETRICS

THIN-FILM MEASUREMENT

Introduction

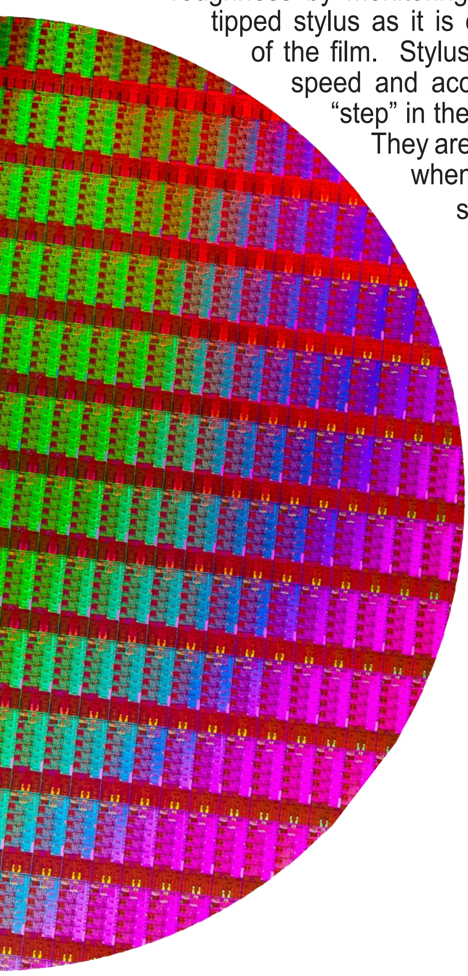
Thin film

Very thin layers of material that are deposited on the surface of another material (thin films) are extremely important to many technology-based industries. Thin films are widely used, for example, to provide passivation, insulating layers between conductors, diffusion barriers, and hardness coatings for scratch and wear resistance. The fabrication of integrated circuits consists primarily of the deposition and selective removal of a series of thin films.

Films typically used in thin-film applications range from a few atoms (<1 nm or 0.001 µm) to 100 µm thick (the width of a human hair.) They can be formed by many different processes, including spin coating, vacuum evaporation, sputtering, vapor deposition, and dip coating.

To perform the functions for which they were designed, thin films must have the proper thickness, composition, roughness, and other characteristics important to the particular application. These characteristics must often be measured, both during and after thin-film fabrication. The two main classes of thin-film measurement are optical and stylus based techniques.

Stylus measurements measure thickness and roughness by monitoring the deflections of a fine-tipped stylus as it is dragged along the surface of the film. Stylus instruments are limited in speed and accuracy, and they require a "step" in the film to measure thickness. They are often the preferred method when measuring opaque films, such as metals.



Optical techniques determine thin-film characteristics by measuring how the films interact with light. Optical techniques can measure the thickness, roughness, and optical constants of a film. Optical constants describe how light propagates through and reflects from a material. Once known, optical constants may be related to other material parameters, such as composition and band gap.

Optical techniques are usually the preferred method for measuring thin films because they are accurate, nondestructive, and require little or no sample preparation. The two most common optical measurement types are spectral reflectance and ellipsometry. Spectral reflectance measures the amount of light reflected from a thin film over a range of wavelengths, with the incident light normal (perpendicular) to the sample surface. Ellipsometry is similar, except that it measures reflectance at non-normal incidence and at two different polarizations. In general, spectral reflectance is much simpler and less expensive than ellipsometry, but it is restricted to measuring less complex structures.

n and *k* Definitions

Optical constants (***n*** and ***k***) describe how light propagates through a film. In other words, the electromagnetic field that describes light traveling through a material at a fixed time is given by:

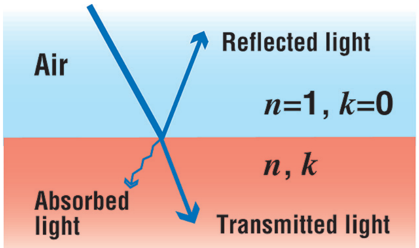
$$A \cdot \cos\left(n \frac{2\pi}{\lambda} x\right) \cdot \exp\left(-k \frac{2\pi}{\lambda} x\right)$$

where ***x*** is distance, λ is the wavelength of light, and ***n*** and ***k*** are the film's refractive index and extinction coefficient, respectively. The refractive index is defined as the ratio of the speed of light in a vacuum to the speed of light in the material. The extinction coefficient is a measure of how much light is absorbed in the material.

Spectral Reflectance Basics

Single Interface

Reflection occurs whenever light crosses the interface between different materials. The fraction of light that is reflected by an interface is determined by the discontinuity in ***n*** and ***k***. For light reflected off of a material in air,

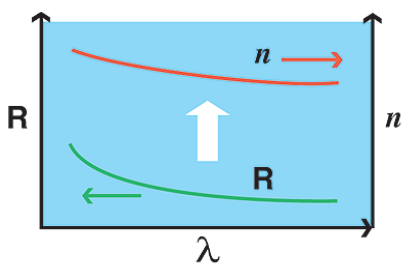


$$R = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2}$$

$$R = \left| \frac{(n-1)}{(n+1)} \right|^2$$

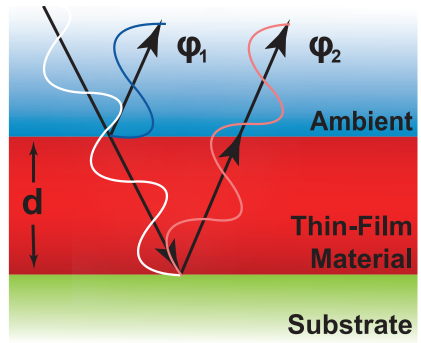
To see how spectral reflectance can be used to measure optical constants, consider the simple case of light reflected by a single nonabsorbing material (***k***=0).

Clearly, ***n*** of the material can be determined from a measurement of ***R***. In real materials, ***n*** varies with wavelength (that is to say, real materials exhibit dispersion), but since the reflectance is known at many wavelengths, ***n*** at each of these wavelengths is also known, as shown here.



Multiple Interfaces

Consider now a thin film on top of another material. In this case both the top and bottom of the film reflect light. The total amount of reflected light is the sum of these two individual reflections.

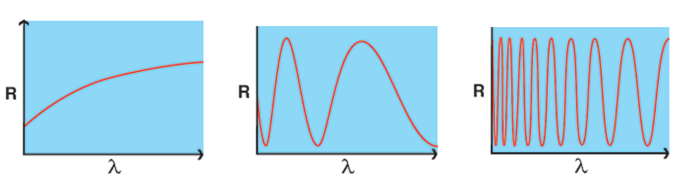


Because of the wavelike nature of light, the reflections from the two interfaces may add together either constructively (intensities add) or destructively (intensities subtract), depending upon their phase relationship. Their phase relationshipis determined by the difference in optical path lengths of the two reflections, which in turn is determined by thickness of the film, its optical constants, and the wavelength of the light. Reflections are in-phase and therefore add constructively when the light path is equal to one integral multiple of the wavelength of light. For light perpendicularly incident on a transparent film, this occurs when $2nd = i\lambda$, where d is the thickness of the film and i is an integer (the factor of two is due to the fact that the light passes through the film twice.) Conversely, reflections are out of phase and add destructively when the light path is one half of a wavelength different from the in-phase condition, or when $2nd = (i+½)\lambda$. The qualitative aspects of these reflections may be combined into a single equation:

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

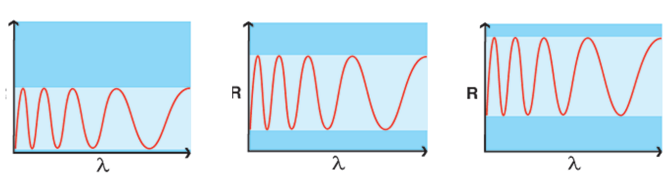
From this, we can see that the reflectance of a thin film will vary periodically with 1/wavelength, which is illustrated below. Also, thicker films will exhibit a greater number of oscillations over a given wavelength range, while thinner films will exhibit fewer oscillations,and oftentimes only part of an oscillation, over the same range.

Determination of thickness (*d*)



d=500 Å d=5000 Å d=20,000 Å

Determination of refractive index (*n*)



n=2 n=3 n=4

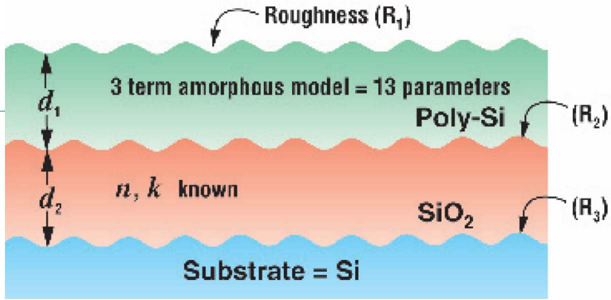
Determining Film Properties from Spectral Reflectance

The amplitude and periodicity of the reflectance of a thin film is determined by the film's thickness, optical constants, and other properties such as interface roughness. In cases where there is more than one interface, it is not possible to solve for film properties in closed form, nor is it possible to solve for ***n*** and ***k*** at each wavelength individually. In practice, mathematical models are used that describe ***n*** and ***k*** over a range of wavelengths using only a few adjustable parameters. A film's properties are determined by calculating reflectance spectra based on trial values of thickness and the ***n*** and ***k*** model parameters, and then adjusting these values until the calculated reflectance matches the measured reflectance.

Models for *n* and *k*

There are many models for describing ***n*** and ***k*** as a function of wavelength. When choosing a model for a particular film, it is important that the model be able to accurately describe ***n*** and ***k*** over the wavelength range of interest using as few parameters as possible. In general, the optical constants of different classes of materials (e.g., dielectrics, semiconductors, metals, and amorphous materials) vary quite differently with wavelength, and require different models to describe them (see below). Models for dielectrics (***k***=0) generally have three parameters, while nondielectrics generally have five or more parameters. Therefore, as an example, to model the two-layer structure shown below, a total of 18 adjustable parameters must be considered in the solution.

Mathematical Models for *n* & *k*



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

$$k(\lambda) = 0$$

Cauchy: Fitting parameters: A, B, C (total of 3)

$$\varepsilon_2(E) = 2nk = \sum_{i=1}^{j=1,2\text{ or }3} \frac{A_i C_i E_{0i}(E-E_{gi})^2}{(E^2-E_{0i}^2)^2 + C_i^2 E^2} \bullet \frac{1}{E} \quad \text{If } E > E_g\text{, or} = 0 \text{ if } E < E_g$$

$$\varepsilon_1(E) = n^2 - k^2 = \varepsilon_1(\infty) + \frac{2P}{\pi}\int_0^\infty \frac{s\varepsilon_2(s)}{s^2-E^2}\,ds \quad \text{(Kramers-Kronig relationship)}$$

Amorphous Semiconductor: Fitting parameters: $\varepsilon_1(\infty)$, A_1, C_1, E_{g1}, E_{01}, … (total of 5, 9 or 13)

$$\varepsilon_2(E) = 2nk = \sum_{i=1}^{j=1,2\text{ or }3} \frac{A_i}{B_i + (E-E_{0i})^2}$$

$$\varepsilon_1(E) = n^2 - k^2 = \varepsilon_1(\infty) + \frac{2P}{\pi}\int_0^\infty \frac{s\varepsilon_2(s)}{s^2-E^2}\,ds \quad \text{(Kramers-Kronig relationship)}$$

Crystalline Semiconductor: Fitting parameters: $\varepsilon_1(\infty)$, A_1, B_1, E_{01}, … (total of 4,7 or 10)

Number of Variables, Limitations of Spectral Reflectance

Spectral reflectance can measure the thickness, roughness, and optical constants of a broad range of thin films. However, if there is less than one reflectance oscillation (i.e. the film is very thin), there is less information available to determine the adjustable model parameters. Therefore, the number of film properties that may be determined decreases for very thin films. If one attempts to solve for too many parameters, a unique solution cannot be found; more than one possible combination of parameter values may result in a calculated reflectance that matches the measured reflectance.

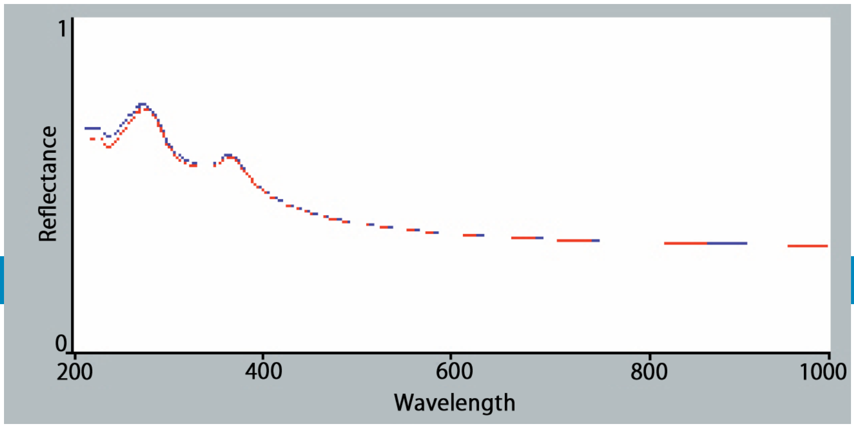
An example of the reflectance from a very thin film, 5 nm of SiO_2 on silicon is shown below, where it is compared to the reflectance from a bare silicon substrate. In this case, measuring the thickness, roughness, and n of the SiO_2 requires five parameters to be determined. Clearly, the change in the spectra caused by adding 5 nm of SiO_2 does not require five parameters to describe, and a unique solution cannot be found unless some additional assumptions are made.

Depending upon the film and the wavelength range of the measurement, the minimum single-film thickness that can be measured using spectral reflectance is in the 1 nm to 30 nm range. If one is trying to measure optical constants as well, the minimum thickness increases to between 10 nm and 200 nm, unless minimal parameterization models can used. When solving for the optical properties of more than one film, the minimum thicknesses are increased even further.

Spectral Reflectance versus Ellipsometry

Given the restrictions listed above, spectral reflectance can be used to measure a large percentage of technologically important films. However, when films are too thin, too numerous, or too complicated to be measured with spectral reflectance, oftentimes they can be measured with the generally more powerful technique of spectroscopic ellipsometry. By measuring reflectance at non-normal incidence (typically around 75° from normal), ellipsometry is more sensitive to very thin layers and the two different polarization measurements provide twice as much information for analysis. To carry the idea even further, variable-angle ellipsometry can be used to take reflectance measurements at many different incidence angles, thereby increasing the amount of information available for analysis.

The following pages of this brochure describe spectral reflectance systems available from Filmetrics. If you are uncertain whether spectral reflectance or ellipsometry is appropriate for your film measurements, please call us to discuss your application. If spectral reflectance cannot satisfy your needs, we will be happy to refer you to a reputable source for ellipsometry.



Thin-Film Measurements on Your Bench Top

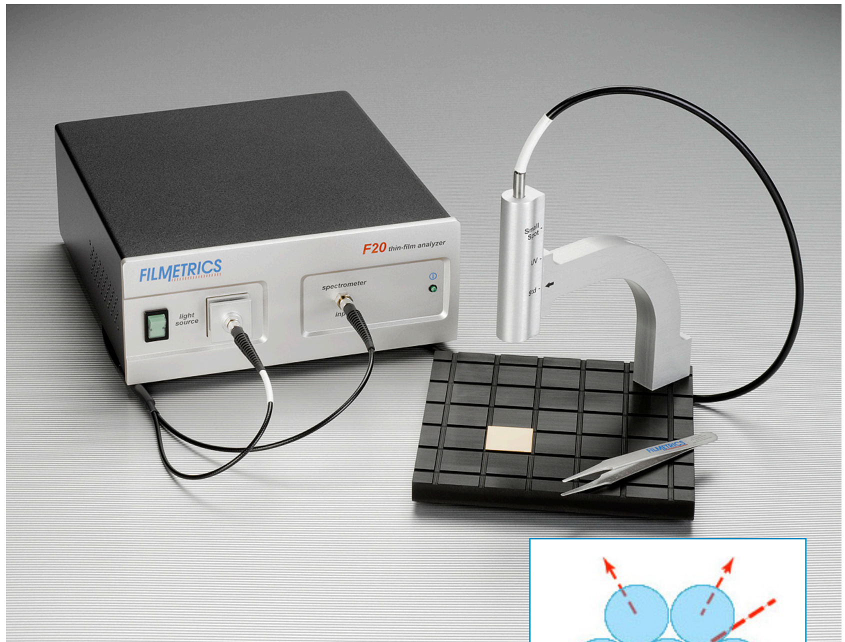
Thickness, refractive index, and extinction coefficients are measured quickly and easily with Filmetrics' advanced spectrometry systems. Simply plug the Filmetrics system into your computer's USB port and start making measurements. The entire system sets up in minutes and measurements can be made requiring little more than basic computer skills. This simple hardware and intuitive software provides thin-film knowledge to a whole new group of users.

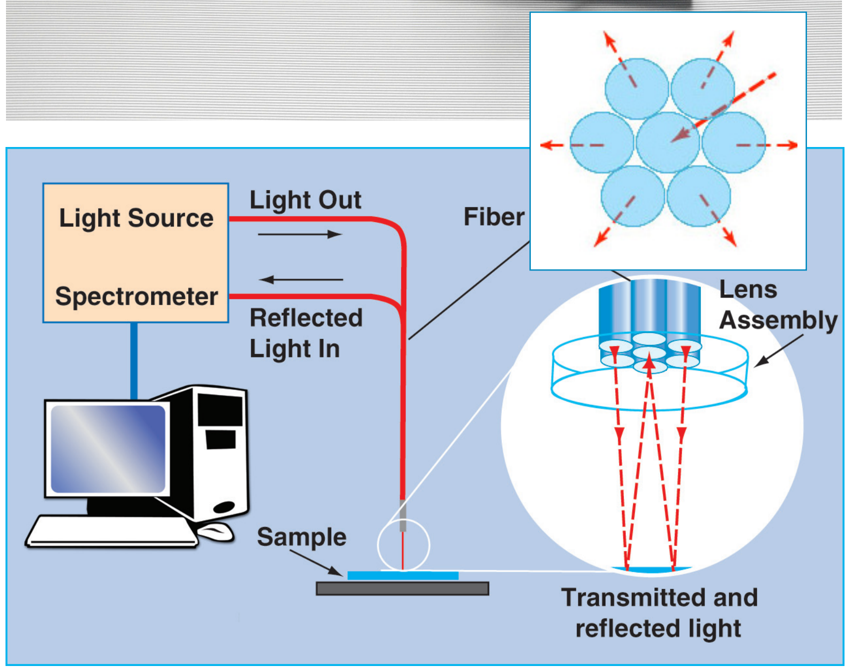
From near infrared to ultraviolet

Systems are available with wavelengths from 200 nm to 1700 nm enabling thickness measurements of films 1 nm to 13 mm. The Filmetrics systems measure transparent thin films made from virtually all common materials.

Easy to use software

The familiar and user friendly interface provided by Filmetrics software is quickly mastered. Measurements are made at about one per second. Measured data, along with meaurement details, are easily saved and exported with standard Windows file saving and clipboard methods. Plus, a public .NET Assembly allows for easy integration with other programs.





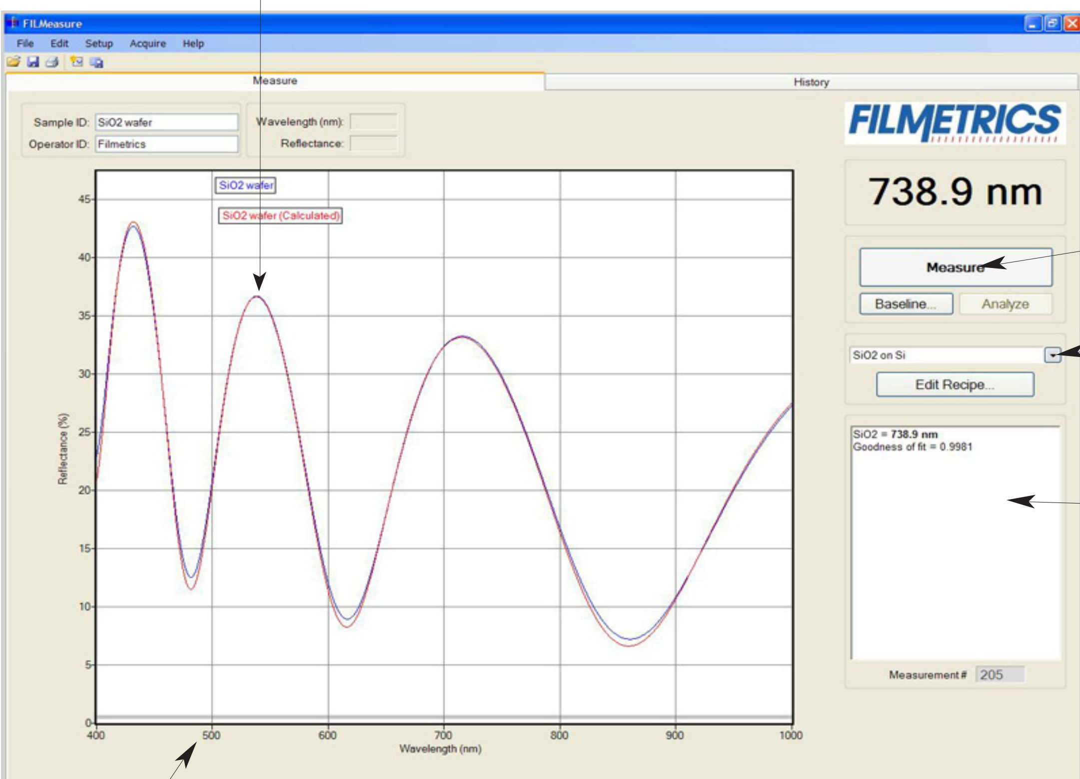
AWARD WINNING PRODUCTS

R&D 100 Award

The Filmetrics in-situ system, Model F30, was selected as one of the 100 most technologically significant new products by R&D Magazine.

COMPLEX MEASUREMENTS MADE SIMPLE

Both the measured and calculated reflectance spectra are displayed so that the integrity of the measurement may easily be judged. The measured n and k curves may also be plotted.



One measurement – One mouse click

Choose from a list of common film types or define your own

Measurement results are displayed in an easy-to-read format

A wide range of reflectance wavelengths are available, from 200 nm to 1700 nm

Photonics Spectra Circle of Excellence

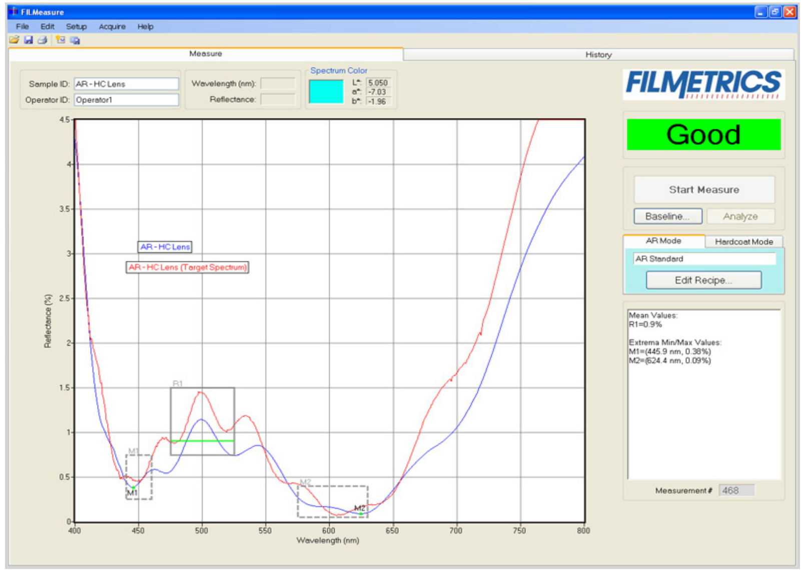
The Filmetrics F20 was chosen as one of the 25 most significant new products by Photonics Spectra Magazine.

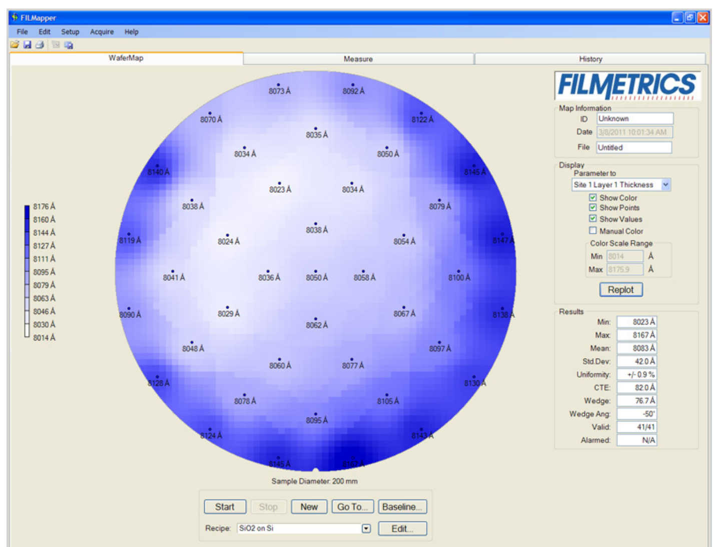
REAL WORLD APPLICATIONS

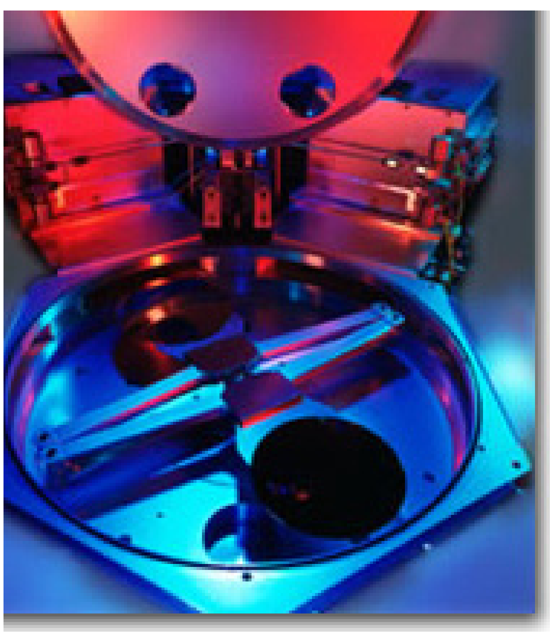
Semiconductor Process Films

Lab / Process

Filmetrics measurement systems are routinely used to measure the thickness, roughness, and optical constants of oxides, SiN_X, photoresist, and other semiconductor process films. In addition to these single layer applications, many two- and three-layer film measurements are also possible. An example is polysilicon/SiO_2 on silicon, which is used in SOI applications. The screen to the right shows a typical measurement result for the structure modeled on page 4.





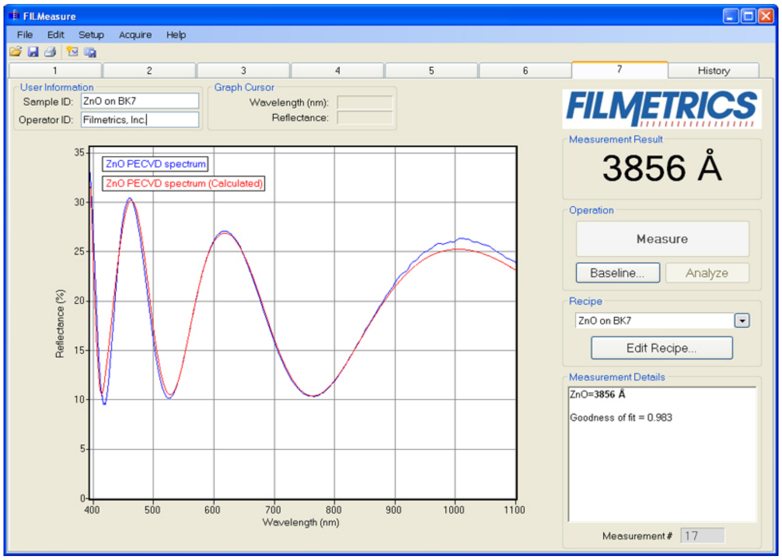


In-Situ Measurements

The flexible optical probe assembly makes on-line and in-situ thickness measurements possible. All that is required is optical access for normal incidence reflectance measurements. Call us for more details about interfacing with your production equipment.

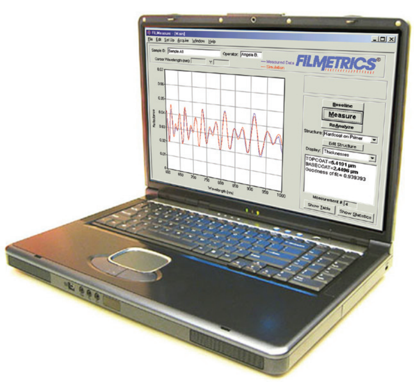
Optical Coatings

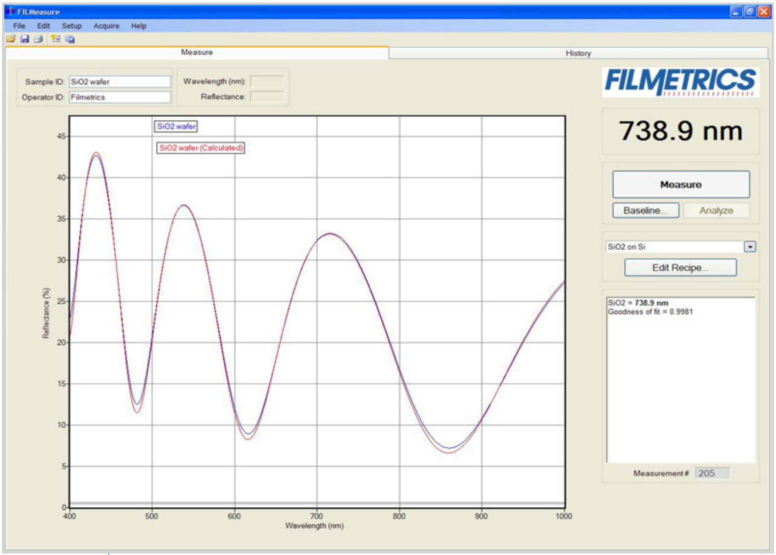
Thin films are used for scratch resistance and/or antireflection coatings in many industries. Automotive plastics, eyeglass lenses, and many plastics packaging applications use thin films. For hardcoats, a primer layer is often applied first for improved film adhesion. Filmetrics systems are capable of measuring the thickness of these layers individually or simultaneously, regardless of the presence of coatings on the backside of the sample.



Flat Panel Display Applications

Proper polyimide and resist thicknesses are critical to yield in flat panel display manufacturing. Besides measuring these materials, Filmetrics systems can also measure cell gap spacing, for both empty and filled cells.





F20

Thin-Film Measurements in Seconds

Bench top measurements of thickness, optical constants (n and k), and transmittance are made quickly and easily by the Model F20. This versatile hardware can be configured to measure transparent or translucent films that are 1 nm to 1 mm in thickness. Typical accuracy is within a few angstroms. Spot size is adjustable over a wide range.

Accessories

A wide variety of stages, chucks, and special measurement heads are available to fixture most sample geometries.

Surprisingly Low Price

Filmetrics is pleased to offer a breakthrough low price. The difficult and expensive task of thin-film measurement is now simple and inexpensive.

Wafer chucks make sample handling easy

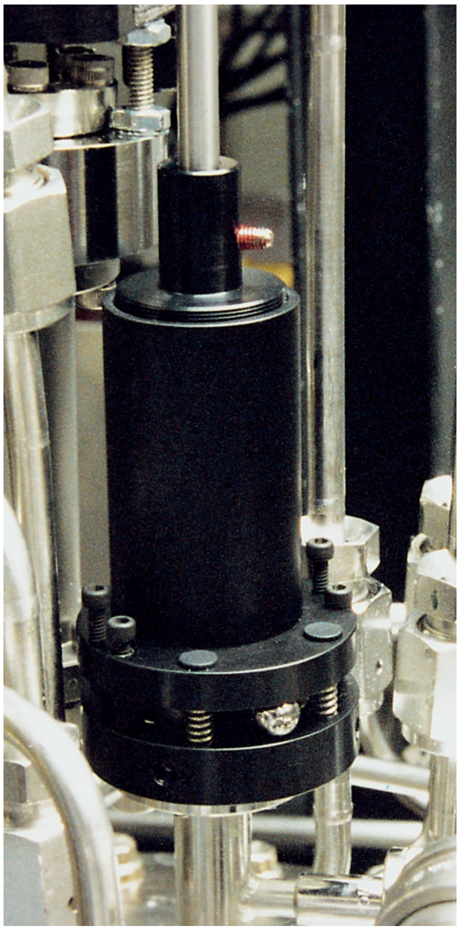
Accessories are available for measuring nonstandard samples

Transmittance may be measured with a simple stage modification

F30

In-Situ Measurements

For process applications, Filmetrics offers systems that need only optical access. Interfaces to a wide range of control systems are available.

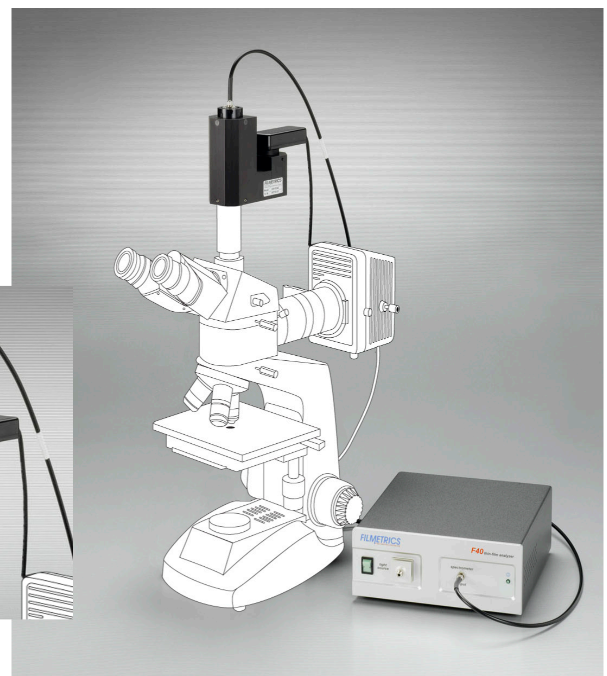


F40

Turns Your Microscope into a Film Thickness Measurement Tool

For thickness measurements on patterned surfaces and other applications that require a spot size as small as 10 microns.

For most common microscopes, the F40 is a simple bolt-on attachment. Standard C-MOUNT adapter provided for CCD camera viewing of measurement location.

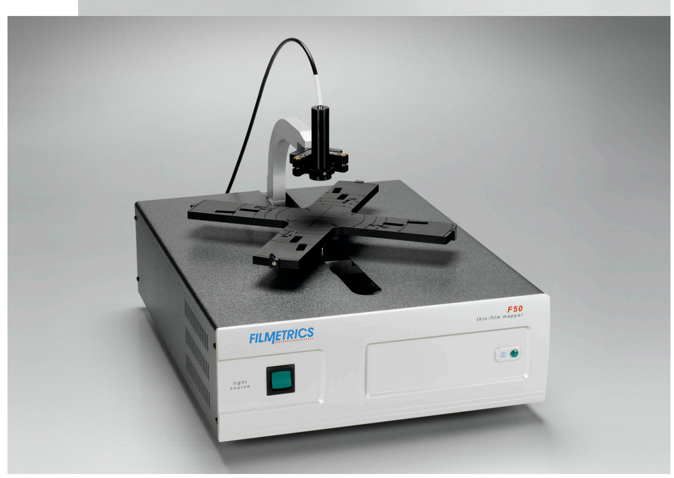


F50

Thickness Mapping System

Extends F20 thickness measurement functionality and intuitive operation to automated mapping of large area samples.

Map sample uniformity in minutes. Five points to hundreds of points as fast as one second per point. Standard chucks available for up to 12" diameter wafers. Custom chucks also available.



Models - for complete specifications, visit www.filmetrics.com

	F20-UV	F20-UVX	F20	F20-EXR	F20-NIR	F20-XT
Thickness Measurement Range*:	1 nm - 40 µm	1 nm - 250 µm	15 nm - 70 m	15 nm - 250 µm	100 nm - 250 µm	0.2 µm - 450 µm
Min. Thickness to Measure n& k:	50 nm	50 nm	100 nm	100 nm	500 nm	2 µm
Accuracy* The Greater of:	1 nm or 0.2%		2 nm or 0.2%		3 nm or 0.4%	5 nm or 0.4%
Precision[1]:	0.02 nm				0.1 nm	1 nm
Stability[2]:	0.05 nm				0.12 nm	1 nm
Spot Size:	Standard 1.5 mm, Optional down to 20 µm					600 µm
Sample Size:	From 1 mm to 300 mm diameter and up					
Light Source:	External, D2 + Halogen		Internal, Halogen			
Spectrometer						
Wavelength Range:	190 - 1100 nm	190 - 1700 nm	380 - 1050 nm	380 - 1700 nm	950 - 1700 nm	1440 - 1650 nm

Custom wavelength combinations available
* Material dependent.
1 Standard deviation of 100 thickness readings of 500 nm SiO_2 film on silicon substrate. Value is average of standard deviations measured over twenty successive days.
2 Two sigma based on daily average of 100 readings of 500 nm SiO_2 film on silicon, measuring over twenty successive days.

General:	
Power Requirements:	100-240 VAC, 50-60 Hz, 0.3-0.1 A
Computer Requirements:	
Operating System:	Windows XP(SP2) - Windows 8(64-bit)
System Memory:	50 MB min
Hard Disk Space:	60 MB min
Interface:	USB 2.0
Internet Access:	Recommended for online support
Certifications:	CE EMC and safety directives

Questions?

Please call us if you would like more information about measuring your thin films, or to arrange for a free trial measurement.
International customers: Please visit our website to get information on local agents.

Filmetrics, Inc.,
10655 Roselle St., Ste. 200, San Diego, CA 92121
Tel: (858) 573-9300 Fax: (858) 573-9400
Website: www.filmetrics.com