Model 2010/M Overview

The Metricon Model 2010/M Prism Coupler utilizes advanced optical waveguiding techniques to rapidly and accurately measure both the thickness and the refractive index/birefringence of dielectric and polymer films as well as refractive index of bulk materials. The 2010/M offers unique advantages over conventional refractometers and instruments based on ellipsometry (/ellips) or spectrophotometry:

- Completely General – no advanced knowledge of optical properties of film/substrate required
- Routine index resolution of ±.0005 (accuracy of up to ±.0001 available for many applications – see specifications (/specifications))
- Routine index resolution of ±.0003 (resolution of up to ±.00005 available for many applications – see specifications (/specifications))
- High accuracy index measurement of bulk, substrate, or liquid materials including birefringence/anisotropy
- Rapid (20-second) characterization of thin film or diffused optical waveguides (/app1) or SPR (/app8) sensor structures
- Simple measurement of index vs wavelength
- Options to measure index vs temperature (dn/dT (/app4)), and waveguide loss (/app2)
- Wide index measurement range (1.0-3.35)

The Model 2010/M represents a significant improvement over its predecessor, the Model 2010, offering compatibility with Windows XP/Vista/Seven, a greatly improved and user-friendly Windows based control program, and new measurement features such as the ability to make accurate thickness and index measurements of very thick films as well as an option to measure index vs. temperature (dn/dT). It also eliminates the need for the now–obsolete ISA interface card required by the 2010.

Metricon Corporation has pioneered the practical application of prism coupling technology to problems of thin film, bulk material, and optical waveguide characterization since introducing the world's first commercial prism coupling instrument, the PC-200, in 1980. Over the years, more than a thousand Metricon systems have been delivered to top universities, research institutes, and corporations in more than 40 countries and Metricon prism coupling systems have been referenced in hundreds of articles in scientific journals.

Theory of Measurement

The sample to be measured (Fig. 1, below) is brought into contact with the base of a prism by means of a pneumatically-operated coupling head, creating a small air gap between the film and the prism. A laser beam strikes the base of the prism and is normally totally reflected at the prism base onto a photodetector. At certain discrete values of the incident angle , called mode angles, photons can tunnel across the air gap into the film and enter into a guided optical propagation mode, causing a sharp drop in the intensity of light reaching the detector:

To a rough approximation, the angular location of the first mode (dip) determines film index, while the angular difference between the modes determines the thickness, allowing thickness and index to be measured completely independently.

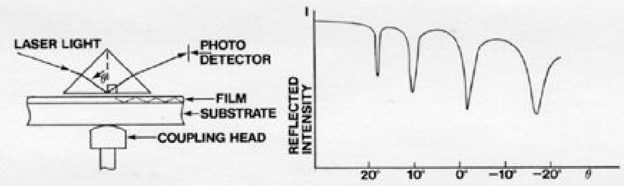


FIG. I. MEASUREMENT PRINCIPLE FOR THIN FILM

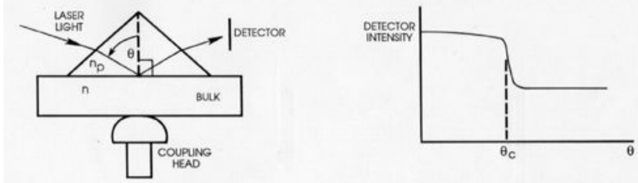


FIG. 2. MEASUREMENT PRINCIPLE FOR BULK MATERIAL

Measurements are made using a computer-driven rotary table which varies the incident angle, and locates each of the film propagation modes automatically. As soon as two of the mode angles are found, film thickness and index can be calculated. The entire measurement process is fully automated and requires approximately twenty seconds.

The number of modes supported by a film of given index increases with film thickness. For most film/substrate combinations, a thickness of 100-200 nm is required to support the first mode, while films in the one-micron range can support as many as four or five modes. If the film is thick enough to support two or more propagation modes (typically 300- 500 nm), the Model 2010/M calculates thickness and index for each pair of modes, and displays the average and standard deviation of these multiple estimates.

The standard deviation calculation, unique to the prism coupling technique, is an indication of measurement self-consistency and a powerful means of confirming the validity of the measurement.

Measurements of thickness and index can be made on most samples with thickness up to 10-15 microns. For thickness above 15 microns, index is still measurable using the bulk measurement technique (see below) although thickness and index for many samples is often measurable at thicknesses up to 150-200 microns.

When acting as a refractometer to measure index of bulk materials (/app3) (Fig. 2 above), the sample is also clamped against the prism and index is determined by measuring the critical angle θc for the sample/prism interface. Films thicker than 10-15 microns usually show a clear critical angle knee and can be measured as bulk materials. Flexible materials are easily measured and a cell is available for liquid measurements. Unlike most conventional refractometers, which are single-wavelength (typically 589 nm), the 2010/M can be equipped with as many as five lasers, allowing easy measurement of dispersion across a wide wavelength range.

By changing the polarization state of the laser, index anisotropy (birefringence) can be measured in x, y, and z directions for both thin films and bulk materials.

Model 2010/M Advantages

The Model 2010/M, utilizing the prism coupling technique, offers several other advantages compared to existing methods of film characterization:

- **Generality:** The Model 2010/M data analysis software is completely general, permitting measurements of virtually any film without knowing anything about the optical properties of the film or substrate.
- **Index accuracy, resolution and stability:** The prism coupling technique offers greater index accuracy and resolution for thin film measurements than any other film measurement technique. In addition, since index measurements are sensitive only to the coupling angle and index of the prism (which do not change with time), prism coupling measurements are extremely stable over time and periodic calibrations of the 2010/M are unnecessary.
- **Insensitivity to errors caused by index variation with wavelength:** The refractive index of every film varies with wavelength. In techniques which rely on spectrophotometry (interference vs. wavelength), if the refractive index variation of the film over the full wavelength range is not accurately known, substantial errors will result. Moreover, the index vs. wavelength curves of many films are highly dependent on film deposition conditions. For such films, the monochromatic measurement of the Model 2010/M offers a clear advantage. If index at a variety of wavelengths must be determined, the Model 2010/M may be configured with as many five lasers and a continuous index vs wavelength curve can be generated in less than five seconds from the individual index measurements.
- **Advantages over ellipsometry:** Since ellipsometer (/ellips) data is periodic with film thickness, single wavelength ellipsometry requires advance knowledge of film thickness to an accuracy of ±75 to ±125 nm, depending on film

index. The Model 2010/M, which makes direct thickness measurements, does not require advance knowledge of film thickness. Moreover, at certain periodic thickness ranges, index measurements with single wavelength ellipsometry are impossible. With the 2010/M, full-accuracy index measurements are obtained once film thickness exceeds a certain minimum threshold value (typically 300-500 nm, depending on film/substrate type). Multiple wavelength ellipsometry offers the potential for accurate film measurements, but data analysis is extraordinarily complex and good results are usually obtainable only with extensive advance knowledge of the optical parameters of the sample.

- **Simple "spectroscopic" measurement of material dispersion:** The Model 2010/M measures index at discrete laser wavelengths and is typically equipped with 1-5 lasers. For systems with three lasers, Metricon has developed proprietary software using novel fitting techniques which calculates (in just a few seconds) extremely accurate index vs wavelength (/app7) curves over an extended wavelength range (for example 400-700 nm or 633-1550 nm). Four or five laser systems provide accurate dispersion curves over the 400-1064 and 400-1550 nm ranges, respectively. In most cases, index values calculated at intermediate wavelengths provide virtually the same accuracy as if index had been measured by a laser at that wavelength.

- **Measurements on transparent substrates:** The Model 2010/M can be used to measure films on transparent substrates, even when the refractive index match between film and substrate is relatively close. Moreover the prism coupling technique is insensitive to reflections from the back surface of the substrate which are often troublesome with ellipsometry and other film measurement techniques.

- **Internal self-consistency check:** If film thickness exceeds 500-750 nm, multiple independent estimates of film thickness and index are made, and the standard deviation of these multiple estimates is displayed. As long as measurement standard deviation is low (typically 0.3% for thickness and .01% for index), there is little chance that an appreciable error has been made. No other technique provides a similar "confidence check" on the validity of each measurement.

- **Greater ease and accuracy in measuring index of bulk materials:** The 2010/M can measure index from 1.0 to 3.35 in x, y, and z directions and measurements are fully automatic and free of the operator subjectivity common to conventional refractometers. The 2010/M does not require use of messy, toxic, or corrosives matching fluids and can handle samples with relatively poor optical flatness or polish (gently rounded cast "blobs" are even measurable).

Model 2010/M Limitations

Thickness must be sufficient to support two or more propagation modes. At a measurement wavelength of 633 nm, this establishes a lower thickness limit of 300 to 500 nm for films on high index substrates (e.g., silicon or GaAs). For films on lower index substrates, minimum thickness limits can be lower by as much as a factor of two and if film index is assumed, thickness-only measurements can often be made on single mode films as thin as 100-200 nm. Accurate measurement of films which are single mode at longer wavelengths (e.g., 1310 or 1550 nm) can be made by first measuring thickness and index at a shorter wavelength such as 633 nm. The thickness measured at the shorter wavelength can then be used with the single mode measured at the longer wavelength to provide an accurate index measurement.

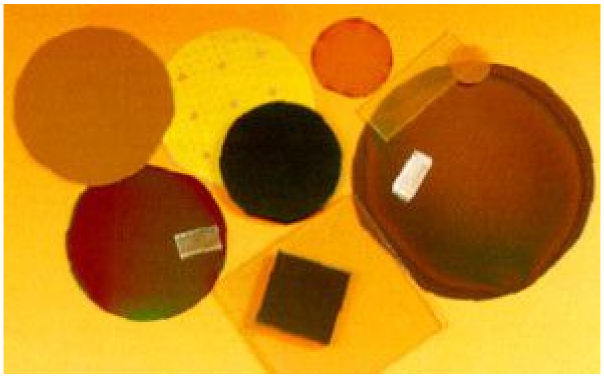
If film thickness falls below the minimum measurable threshold, erroneous measurements are not made, and the 2010/M simply informs the user that the measurement cannot be made. The minimum thickness limits described above are only approximate, and depend in detail on the refractive index of the film and substrate, and on the measuring wavelength. If your application falls close to any of the above limits, please consult Metricon.

An additional limitation is based on the fact that the prism coupling technique involves contact to the surface being measured. As a result, for applications requiring extreme cleanliness Model 2010/M measurements are usually made on non-product test samples.

Measurable Films/Substrates

Most Model 2010/M applications revolve around the need to rapidly and accurately measure variable index films which are deposited by plasma, low temperature, or other deposition methods or to measure novel or unusual films or bulk materials for which little data exists in the scientific literature. For these applications, the Model 2010/M offers a thickness measurement fully corrected for any refractive index variation.

Virtually any film which is not strongly absorbing at the measurement wavelength can be measured, providing the film is thick enough to support at least two optical propagation modes (for typical minimum thickness, see Specifications). Films are measurable on almost any substrate, including high index or absorbing substrates such as silicon or metals. Virtually any bulk material which is not strongly absorbing at the measuring wavelength is also measurable. The following is a representative, but by no means inclusive, list of films and substrate or bulk materials types which have been measured by Metricon systems (free-standing films or bulk samples of any of the below film materials are also measurable):



- **Films:** SiO2 (doped and undoped), silicon nitride, plasma SiN, silicon oxynitride, photoresists, polyimides, polyanyline, liquid crystals, PMMA, holographic gels, sol gels, silicon, SiC, diamond, epi garnets, electro-optic polymers, AlGaAs, BaTiO3, GaN, InP, ITO, KTP, MgO, PZT, PLZT, Si, Ta2O5, TiO2,YIG, ZnS, ZnSe, ZnCdSe, ZnMnTe, ZnMgTe.
- **Bulk or substrate materials:** Quartz, optical glasses, chalcogenide glasses, sapphire, PET, polycarbonate, polyethylene, polystyrene, LiNbO3, LiTaO3, SiC, ZnS, GaP, GGG, MgO, YAG and other laser crystals.

Please see "Applications Overview (/applications-overview)" for additional information on uses of the Model 2010/M.

State-of-the-Art Accuracy with Convenience

In summary, the Model 2010/M is an instrument which combines state of the art accuracy with the speed, convenience, and versatility of a production tool. Without any advance knowledge of film parameters, in an automated 20-second measurement, the 2010/M offers a routine index accuracy and resolution which have, at best, been approached only by the most costly and cumbersome research instruments.

The 2010/M independently measures thickness and index, so that the thickness measurement is fully corrected for index variation. Moreover, the thickness measured is direct (not incremental), so there is never a need to predetermine approximate thickness or interference order of the film. The 2010/M also offers clear advantages in measurements of thicker films, films on transparent substrates, and there are no periodic thickness ranges where index measurement cannot be made. All these advantages are completely general, applying to both ordinary materials as well as to novel materials which have never been characterized before.

Most users report that for materials which fall within the measuring range of the prism coupling technique (films thicker than a few hundred nanometers and bulk materials) Metricon measurements are the standard against which they assess the validity of all other measurement tools.

New Capabilities

Since 1980, Metricon Corporation has pioneered the practical application of prism coupling technology to problems of thin film, bulk material, and integrated optics characterization. The Model 2010/M represents a major improvement in power and user-friendliness over its predecessor, the Model 2010, and we are committed to continue expanding the range of usefulness for the 2010/M system. If your application falls outside any of our current capabilities, please call to discuss modifications or enhancements that might be available to fit your needs.