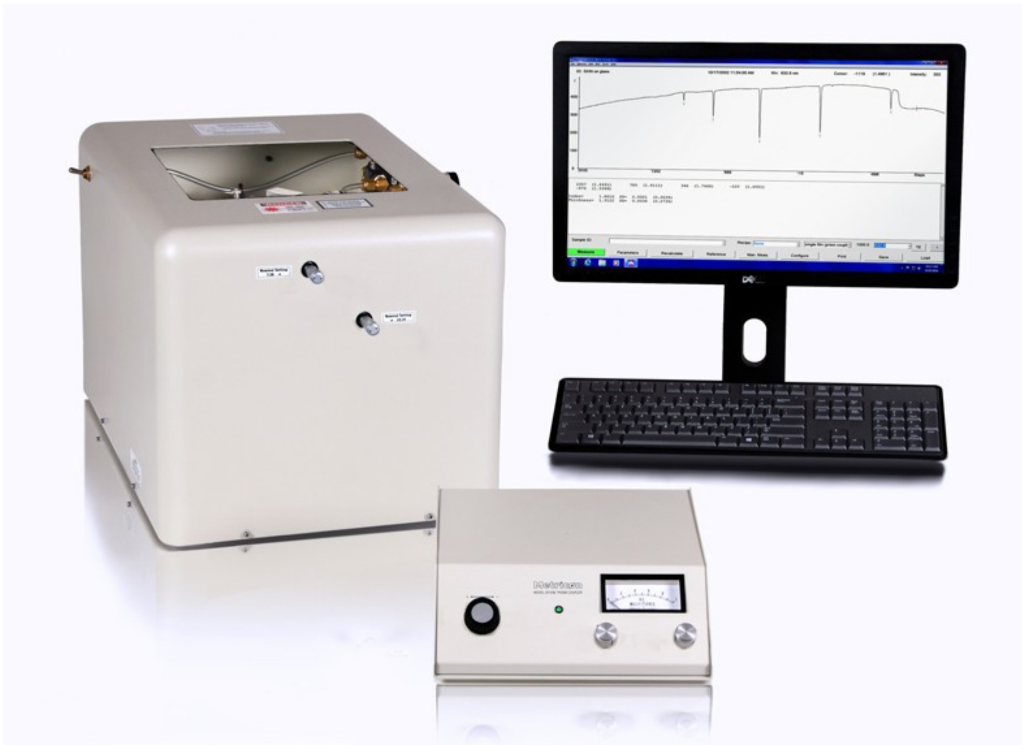
Model 2010/M Overview



NOTE: Click on the colored links below to view related information from this document or from Metricon's website.

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 or spectrophotometry:

a. completely general - no advanced knowledge of optical properties of film/substrate required. Works with rigid or flexible samples of any size or shape.
b. routine index accuracy of ±.0005 (accuracy of up to ±.0001 available for many applications – see specifications)
c. routine index resolution of ±.0003 (resolution of up to ±.00005 available for many applications – see specifications)
d. high accuracy index measurement of bulk, substrate, or liquid materials including birefringence/anisotropy
e. rapid (20-second) characterization of thin film or diffused optical waveguides and SPR sensor structures
f. simple measurement of index vs wavelength
g. options to measure index vs temperature (dn/dT), and waveguide loss
h. 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/7/10, 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, next page) 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 θ, 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:

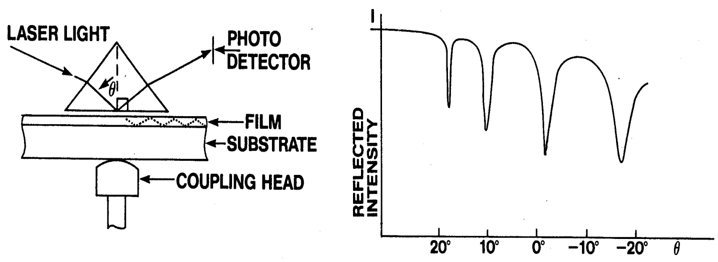


Fig. 1. Measurement principle for thin film

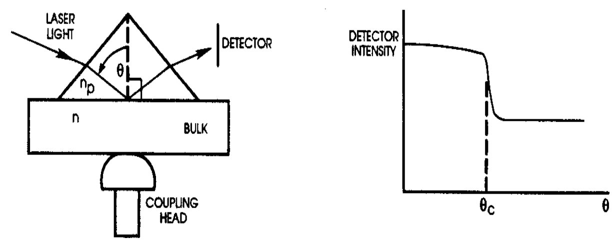


Fig. 2. Measurement principle for bulk material

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.

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 ~100 microns. For thickness above 100 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 ~200 microns with longer wavelength sources

When acting as a refractometer to measure index of bulk materials (Fig. 2 above), the sample is also clamped against the prism and index is determined by measuring the critical angle θ_c 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 six 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 and stability: The prism coupling technique offers greater index accuracy 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 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. Please see Metricon technical note "A Comparison of Prism Coupling and Ellipsometry for Thin Film Measurements".

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 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).

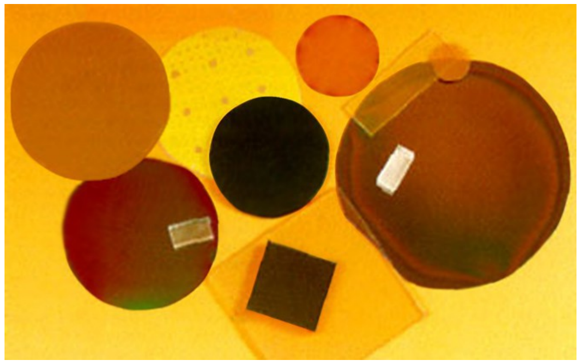
MODEL 2010/M LIMITATIONS

For measurement of both film thickness and index with the Model 2010/M, 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, such as IC fabrication, Model 2010/M measurements are usually made on non-product test samples.

MODEL 2010/M APPLICATIONS



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. Moreover, the 2010/M's routine ±.0003 index resolution (resolution up to ±.00005 available – see specifications) provides a sensitive monitor of film deposition conditions, warning when gas flows, vacuum conditions, or deposition temperatures start to depart from acceptable windows. Compared to conventional techniques, the Model 2010/M offers a number of other unique capabilities for a broad range of specific R&D and production applications:

Optical Waveguides: For organic/inorganic thin film and diffused optical waveguides, the 2010/M provides rapid location of modes and automatic calculation of effective mode indices. The 2010/M is also available with multiple lasers (including a variety of IR sources) or a secondary input port to permit use with user supplied lasers. An inverse WKB calculation of index vs depth for graded index waveguides such as lithium niobate or ion exchanged glass is a standard feature embedded in the 2010/M's control software. An option to measure waveguide loss is also available (see Metricon application notes "Optical Waveguide Characterization" and "Waveguide Loss Measurement")

Index measurement of bulk/substrate materials: The 2010/M can function as a highly accurate refractometer, providing rapid (5-20 second) measurements of the refractive index of bulk glasses, polymers, plastics, garnets and other materials (both rigid and flexible) including liquids with a routine resolution of ±.0003 (±.00005 with a high resolution rotary table). Index in x, y and z directions is easily measured, index measurement range extends from 1.0-3.35, and no matching fluids are required. Measurements can also be made on slightly convex surfaces. Please see Metricon application note "Bulk Material or Thick Film Index/Birefringence Measurement".

Index/birefringence/orientation of film and bulk polymer materials: In-plane and perpendicular plane index for polymer materials, including flexible films, are easily measured by the Model 2010/M without the use of toxic or corrosive index matching fluids. In-plane refractive index can also be measured along any arbitrary in-plane direction by a simple rotation of the sample about the coupling point. Measurement of x, y, and z indices also permits extremely simple and rapid determination of sample crystallinity and orientation. Indices ranging from 1.0 to 3.35 are easily measured and measurements are free of operator subjectivity. Please see Metricon application note "Measuring Index/Birefringence of Bulk Polymers and Flexible Polymer Films".

Materials for display technologies: Since the prism coupling technique is easily applied to clear substrates, the 2010/M is well suited to measurements of thickness/index/birefringence of films and filters used in the manufacture of LCD's and other display technologies.

Films on silicon, other semiconductors, and metals: Films on higher index substrates (such as silicon, GaAs, or other semiconductors) are not true waveguides, but fully accurate measurements of thickness and index can still be made on the leaky modes which result. Moreover, measurements of films on metallic or metal coated substrates are straightforward and are insensitive to the surface properties of the metal (i.e., smoothness/reflectivity) and thickness limits and performance are virtually indistinguishable from measurements on silicon.

Polyimides/photoresists/polymers: Every step (baking, radiation exposure, etching) in the processing of polymer films causes changes in film thickness and index. With its independent thickness and index measurement and unparalleled index resolution, the 2010/M is an ideal tool to monitor the consistency of polymer processing in production, or, for R&D, to study the fundamental behavior of these films. In addition, since the 2010/M can measure index both parallel and perpendicular to the plane of the film, index anisotropy is easily obtained. Please see Metricon application note "High Accuracy Measurement of Resist, Polyimide, and Polymer Thin Films".

Measurement of electro-optic/NLO coefficients: Index changes of samples while a voltage (electrical field) is being applied across the sample are easily measured on the 2010/M system. Prisms with electrically conductive coupling faces can be supplied to serve as the top electrode, avoiding the need to coat samples with ITO or other conductive layers.

Dispersion (index vs. wavelength) measurements: The Model 2010/M can be equipped with as many as five lasers or supplied with one or more ports for use with user-supplied lasers to permit index measurement of thin films and bulk materials at multiple wavelengths (with 20-second changeover time between wavelengths). After index is measured at three or more wavelengths, a Cauchy fit routine within the Model 2010/M control program displays a continuous curve of index vs wavelength and provides easy calculation of index at intermediate wavelengths.

Thick film measurements: No other film measurement technique comes close to matching the Model 2010/M's performance in measuring films in the thickness range above two microns. And the Model 2010/M now offers as a standard feature the ability to measure thickness and index of films as thick as 100 microns (250 microns with optional longer wavelength lasers). With the VAMFO option, non-contact thickness measurements are possible on thick films ranging from a minimum of 2 microns up to 300 microns.

Surface plasmons and other sensors: For biological and other sensor applications, the 2010/M can used to observe surface plasmon resonances and shifts in SPR or waveguide resonances. Please see application note "Characterization of SPR and Waveguide Structures for Sensor Applications".

dn/dT measurements: An option is available to measure index vs temperature from room temperature up to 200 C. Please request Metricon technical note "Measuring Index vs Temperature (dn/dT)".

Index measurement of epoxies, gels, and other index matching materials: Since measurements are easily made on bulk samples which are cast to give either roughly flat or gently convex surfaces, the 2010/M is an ideal system for measuring these materials.

Rapid measurements of film doping: Since most dopants (e.g., phosphorus in doped oxide) cause small changes in film index, the 2010/M's sensitive ±.0003 index resolution (higher resolution available – see specifications) can provide immediate production feedback on film doping far more rapidly and inexpensively than other techniques. Please see Metricon application note "Monitoring of Phosphorus and Other Dopant Concentrations in SiO2 and other Films".

Measurements of dual film layers: If the upper film index is greater than that of the lower film, in many cases thickness and index may be measured for each film in a dual film structure (or for the first two films in a multilayer stack). Please see Metricon application note "Dual Film Measurements".

Opthalmic/contact lenses, and other lenses: Index of the convex surface of opthalmic (eyeglass) lenses or other lenses, as well as the thickness and index of lens coatings, are easily measured. Contact lenses are also measurable and a cell to measure index of contact lenses while submerged in hydrating solution is available. Multiple wavelength systems are available for determination of Abbe number. Please see application note "Measuring Index of Contact and Intraocular Lenses While Submerged in Hydrating Fluid".

Other applications: The above list is by no means a complete list of the uses of our systems. If your application is not mentioned above, we would be happy to discuss how the Model 2010/M may serve your needs.

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, $BaTiO_3$, GaN, InP, ITO, KTP, MgO, PZT, PLZT, Si, Ta_2O_5, TiO_2,YIG, ZnS, ZnSe, ZnCdSe, ZnMnTe, ZnMgTe.

Bulk materials: Quartz, optical glasses, chalcogenide glasses, sapphire, PET, polycarbonate, polyethylene, polystyrene, $LiNbO_3$, $LiTaO_3$, SiC, ZnS, GaP, GGG, MgO, YAG and other laser crystals.

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.

For materials which fall within the measuring range of the prism coupling technique (films thicker than a few hundred nanometers and bulk materials) many users report that Metricon measurements of refractive index are the standard against which they assess the validity of 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.

SPECIFICATIONS

Index accuracy: ±.0005 (worst case). Absolute index accuracy is limited primarily by uncertainties in determining the angle and refractive index of the measuring prism. For samples of reasonable optical quality, if a high resolution table is used and if the user is willing to perform a simple calibration procedure with each prism, absolute index accuracy of ± .0001-.0002 can be achieved. NIST, fused silica, and other standards are available for index calibration.

Index resolution: ±.0003 (worst case). For samples of reasonable optical quality, index resolution can be improved up to ±.00005 by use of a high resolution rotary table, a no-cost option (see below).

Thickness accuracy: ±(0.5% + 5 nm)

Thickness resolution: ±0.3%

Operating wavelength: Low power 635 nm diode laser, Class 3R/IIIa. Optional shorter wavelengths (405, 450, 473, 488, 520, 532, 594 nm) for measurement of thinner films and near-IR (850, 980, 1064, 1310, 1550 nm) wavelengths for fiber/integrated optics applications are available. Some optional sources change laser safety class to 3B/IIIb.

Typical measurement time: 10-25 seconds with standard table, 20-75 seconds with high resolution table.

Measurement area: While the film and measuring prism are in contact over an area roughly 8 mm square, film area actually measured is only 1 mm diameter.

Refractive index measuring range: With standard prisms, films and bulk materials with refractive index 2.65 and below are measurable. Specialized prisms are available to permit index measurements up to 3.35 (consult Metricon for details).

Film types/thickness ranges measurable: The Model 2010/M can measure virtually any film type which is not metallic or very highly absorbing at the operating wavelength. In many cases, thickness and index of one or both films of dual film layers are measurable*, provided the top film has higher refractive index. Thickness must exceed a minimum threshold which depends on film and substrate (or underlying film) index. Examples of thickness ranges measurable for common single or upper film types at the standard (635 nm) operating wavelength (for other film types, interpolate between example films with closest index):

Film type/index	Thickness and index **	Thickness or index only (assume other parameter)
Silicon dioxide (n = 1.46) or PMMA (n ~1.5) over Si	0.48-100 μ**	0.20-0.48 μ
Photoresist (n=l.63) over Si	0.42-100 μ**	0.18-0.42 μ
Photoresist (n=l.63) over SiO_2 or glass*	0.70-100 μ**	0.30-0.70 μ
Alumina or polyimide (n=l.70) over Si	0.38-100 μ**	0.15-0.38 μ
Alumina or polyimide (n=l.70) over SiO_2 or glass*	0.50-100 μ**	0.16-0.50 μ
Si oxynitride (n=l.80) over Si	0.35-100 μ**	0.14-0.35 μ
Si oxynitride (n=l.80) over SiO_2 or glass*	0.45-100 μ**	0.13-0.45 μ
Ta_2O_5 or Si nitride (n=2.05) over Si	0.32-100 μ**	0.12-0.32 μ
Ta_2O_5 or Si nitride (n=2.05) over SiO_2 or glass*	0.30-100 μ**	0.15-0.30 μ

*High-index films over substrates or underlying films of lower index other than silicon dioxide are sometimes measurable at thicknesses up to half as thin as the above limits. Optional shorter wavelengths are also available to extend the measuring range to thinner films. Please consult Metricon for details.

**For films which exceed maximum thickness limit, index is still measurable using bulk measurement. In some cases, thicknesses up to 200 μ are measurable - please consult Metricon for details. With VAMFO option, non contact thickness-only measurements may be made on films as thick as 150 μ.

Index-only measurement of bulk materials/thick films: Materials must be transparent or semi-transparent. Maximum index measurable with standard prisms is 2.65 (3.35 with high index prisms). Accuracy and resolution are same as for thin film measurement (see above). Typical measurement time for bulk measurement is 10-20 seconds.

Substrate materials/sizes: Film measurements may be made on virtually any polished substrate material including silicon, GaAs, glass, quartz, sapphire, GGG, and lithium niobate and the sample can be virtually any size or shape. Substrates may be rigid or flexible and measurements of rigid and flexible freestanding samples (no substrate) are also measurable. The standard unit accepts samples up to a maximum of 8" (200 mm) square - contact Metricon for larger sample sizes.

Prism types: Three standard prism types are available for measurement of films in various index ranges. Prisms are easily interchangeable in approximately one minute to permit use of more than one prism type with a single system:

Prism type	Index range	Comments
200-P-1	<1.80	low wear, optimum for low index (<1.80) films.
200-P-2	1.70-2.45	best for films with index >2.0. Optional 200-P-2-60 prism measures index from 2.0-2.65.
200-P-4	<2.0	useful over a wide index range (1.4-2.0).

200-P-2 and 200-P-4 prisms eventually become abraded with use and must be replaced after a typical life of 8,000-10,000 measurements. Ten additional specialized prism types are available including high index prisms to permit index measurements as high as 3.35 (consult Metricon for details).

Rotary table step size: 3.0 or 1.5 minutes, keyboard selectable. Higher resolution tables (0.9/0.45 or 0.6/0.3 minutes) are also available as a no-charge option. Higher resolution tables are recommended when film thickness exceeds 5-7 microns, or when improved index resolution and accuracy are required.

Major options: Options to permit measurement of waveguide loss and determination of index vs temperature (up to 200º C) are available. VAMFO option allows non-contact measurement of thickness only.

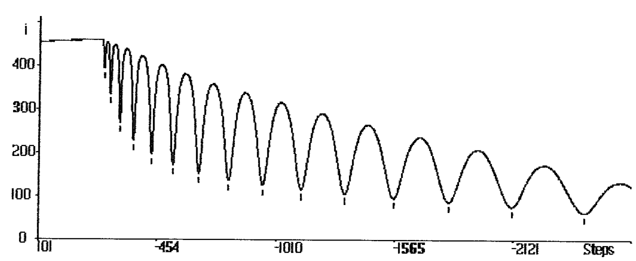
PC requirements: operates with Windows 98, 2000, XP, Vista, or Seven. RS232 serial (COM1) port must be available and cannot be accessed by other applications.

Services required: 85-260 VAC 50/60 Hz outlets for each laser power supply, interface module, and printer (0.5 amp each) and PC (2.0 amps). 60 psi air (.01 cfm). Unit can be mounted on ordinary bench top -- vibration isolation not required.

Dimensions: Overall system installation requires an area of 45 in (108 cm) wide, 27 in (61 cm) deep, 15 in (38 cm) tall. Total system weight, including computer is 92 lbs (41 kg). Individual dimensions/weights:

- Optical module: 15 in (38 cm) wide, 22 in (56 cm) deep, 12 in (30 cm) tall/40 lbs (18 kg).
- Computer/monitor: 16 in (40 cm) wide, 15 in (38 cm) deep, 15 in (38 cm) tall/50 lbs (22 kg).
- Interface/printer: 10 in (25 cm) wide, 7 in (18 cm) deep, 3 in (8 cm) tall/2 lbs (1kg).

Sample Measurements




```
ID=Thick SiO2 on silicon               11/20/06 4:55:00 PM     v1.81.79m
Prism= 977.2          Substrate N= 3.85   Data= 101 to -2676
Wavelength= 632.8     Prism N= 1.9648
                                        Polarization= TE
   -201  (1.4656)     -230  (1.4605)     -276  (1.4524)     -341  (1.4409)
   -424  (1.4261)     -527  (1.4076)     -647  (1.3856)     -786  (1.3599)
   -946  (1.3300)    -1127  (1.2957)    -1330  (1.2569)    -1559  (1.2127)
  -1818  (1.1627)    -2114  (1.1058)    -2453  (1.0417)
Index=       1.4672  SD=  0.0000  (0.001%)
Thickness=   4.4823  SD=  0.0223  (0.499%)
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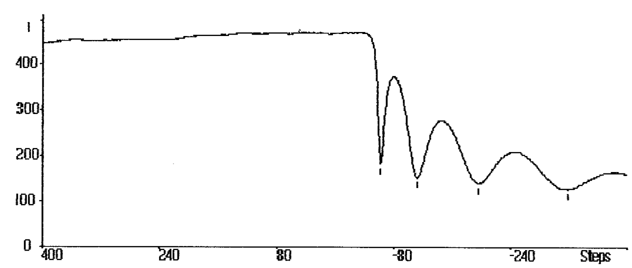


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ID=Coating on flexible PET plastic sheet     11/20/06 4:16:00 PM     v1.81.79m
Prism= 988.0            Substrate N= 1.6774 Data= 400 to -400
Wavelength= 632.8       Prism N= 1.9648
                                         Polarization= TE
    -62  (1.4670)      -112  (1.4377)      -196  (1.3871)      -318  (1.3112)
Index=       1.4768  SD=  0.0001  (0.006%)
Thickness=   1.7738  SD=  0.0089  (0.501%)
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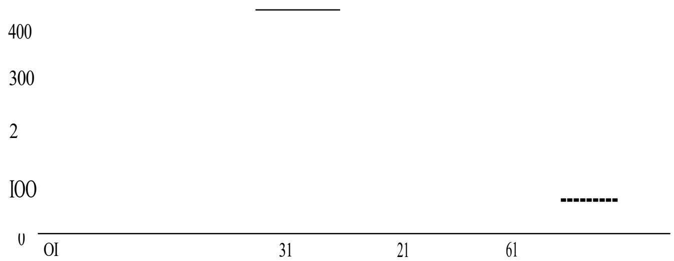
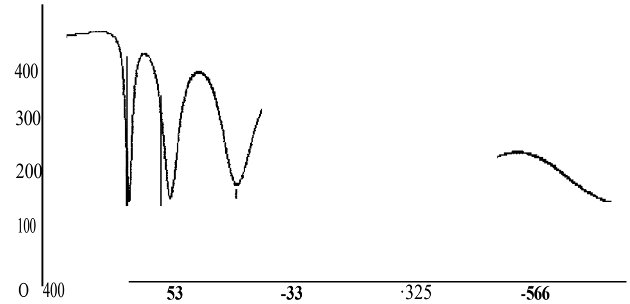
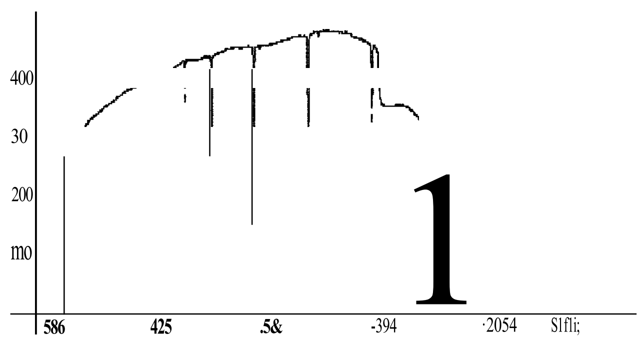


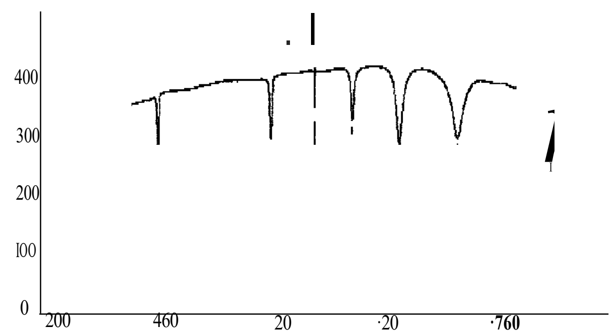
lD=lndex of convex side of eyeglass lens   l1120/06 4:24:00 PM   vl.81.nm
Prism= 988.0   Dala= 701 lo -99
l.lil11>length= 594   Prisn N= 1.%93
Polarizallon= TE
Knee localed al 296
lndex= 1.6578



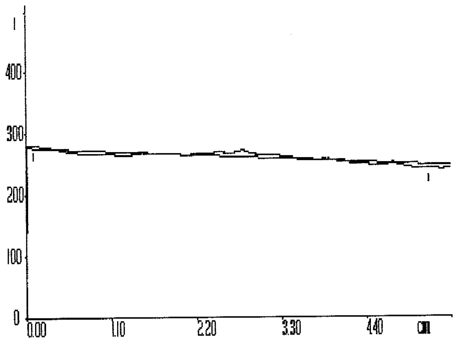
ID=Pol \Iller on s ii icon   11120/06 5:07:00 PM   vl.81.7%
Pri"IIF 988.0   Subslrale N= 3.85   Dala= 400 lo -808
l.livelen•lh= 632.8   Prism N= 1.9648
Polarization= TE
227 (1.6218)   144 (1.5802)   10 (1.5081)   -176 (1.3993)
-419 (1.2469)
Index= 1.6356 SD= 0.0001 (0.00)
Thickness= 1.4134 SD= 0.0076 <0.536¾)



IO=Silicon OXYnilride waveguide on gJass   10117102 11:54:00   vl.81.7'.ln
Pri5111= 6631.0   Subslrale N= 1.51   Dala= 2586 lo -3214
Wavelength= 632.B   PriSIII N= 2.1674
Polarization= TE
1057 (I.84'31)   780 (I.8111)   346 (1.146B)   -220 (1.6551)
-878 (1.5399)
Inci!x= 1.8616 SD= 0.0001 <0.003¾)
Thickness= 1.3122 SD= 0.0036 <0.273¾)

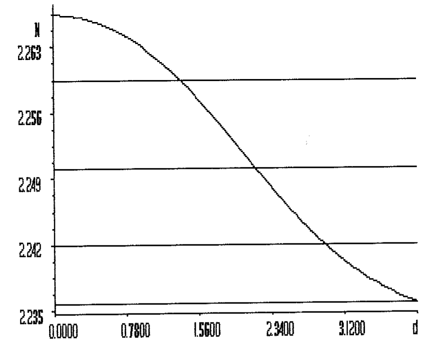


ID=Si OxYnilride guide on ll\ller index OXYnil ll/20/06 4:56:00 Pl'I vl.81.7'.ln
Prism= 985.0   Subslrale N= 3.85   Data= 2200 lo -1500
Wavelength= 632.8   Prism N= 1.%48
Ass111ed LF Index= 1.5700   Dead zone 111idlh= .004
Polarizalion= TE
l988 (1.7736)   1442 (I. 7129)   701 (1.6130)   168 (1.5298)
-140 (1.4779)   -520 (1.4107)   -1131 (1.2970)
llPPer Film Inci!x= 1.7937 SD= 0.0000 (0.003%)
Thickness= 0.9994 SD= 0.0013 (0.129")
wier Film Index= 1.5564 SD= 0.0001 (0.004%)
Thickness= 1.0110 SD= 0.0014 <0.139")



ID=doped oxide guide 2/19/03 2:56:00 PM v1.81.79m
Prism= 917.7 Data= 0 to -1083
Wavelength= 632.8 Prism N= 1.9648
Temp= 0 TempCo= 0
Polarization= TE
Fit: ln(I) = 5.617 -0.022XX ChiSq= 0.02
X: -18 to -1024 (5.12 cm)
Loss= 0.10 dB/cm at table location 618 (1.5872)

ID=LN Waveguide 11/25/02 10:50:00 AM v1.81.79m
Prism= 4373.7 Substrate N= 2.2347 Data= 1236 to 786
Wavelength= 532 Prism N= 2.9664
Polarization= TE
1178 (2.2594) 1121 (2.2501) 1071 (2.2419) 1034 (2.2357)
Index= 2.2618 SD= 0.0006 (0.027%)
Thickness= 2.3466 SD= 0.3372 (14.370%)
Standard deviation(s) exceed normal levels.



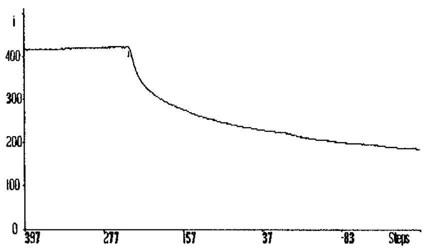
10/27/2006 9:22:02 PM

ID: LN Waveguide
Wavelength: 532 nm TE
Points on Graph: 100
Substrate Index: 2.2347

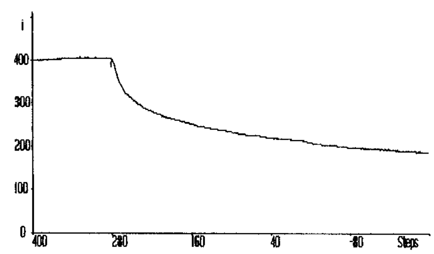
m	beta	depth
	2.2666	0.0000
0	2.2594	1.3693
1	2.2501	2.1683
2	2.2419	2.9200
3	2.2357	3.9085

Loss of doped oxide waveguide

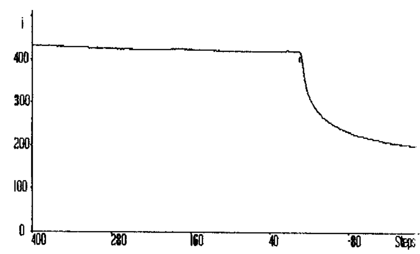
Mode pattern for lithium niobate waveguide and resulting index gradient calculation



ID=2 liter PET axial (x) 8/6/04 9:06:00 AM v1.81.53m
Prism= 988.0 Data= 397 to -203
Wavelength= 632.8 Prism N= 1.9650
Temp= 25 TempCo= 10
Polarization= TE
Knee located at 239
Substrate index= 1.6277



ID=2 liter PET circumferential (y) 8/6/04 9:08:00 AM v1.81.53m
Prism= 988.0 Data= 400 to -200
Wavelength= 632.8 Prism N= 1.9650
Temp= 25 TempCo= 10
Polarization= TE
Knee located at 281
Substrate index= 1.6476



ID=2 liter PET perpendicular (z) 8/6/04 9:09:00 AM v1.81.53m
Prism= 988.0 Data= 400 to -200
Wavelength= 632.8 Prism N= 1.9650
Temp= 25 TempCo= 20
Polarization= TM
Knee located at -5
Substrate index= 1.4998 (TM)

Measurement of index in x, y and z directions index for PET plastic beverage bottle

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