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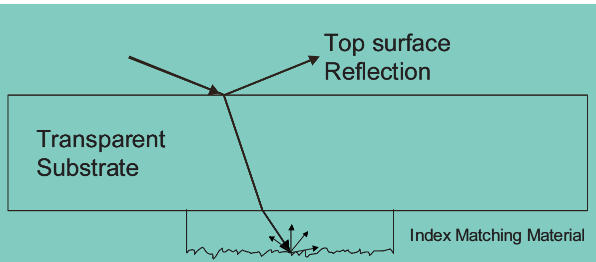

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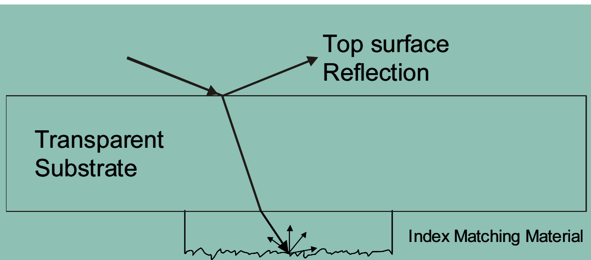

Suppress backside reflections from transparent substrates via index matching with semi-solid materials.

1 Introduction Transparent films and substrates are routinely measured with ellipsometry and other optical techniques [1-3]. Back-surface, or backside reflections occur in transparent substrates which are polished on both sides and thin enough where portions of both the front surface and back surface reflections overlap and enter the detector. These unwanted backside reflections are incoherent with the desired reflection from the front side and must be accounted for in the fit model or suppressed by experimental means such as roughening the back surface [4], focusing the beam small enough to separate the front and back reflections [5], or index matching methods applied to the back side of the sample [6, 7].

1.1 Common backside reflection solutions Reflections from the back surface can be mitigated in a variety of ways including spatial separation, accounting for them in the analysis model, eliminating them via roughening the back surface, and suppressing them via index matching techniques applied to the back surface opposite the measurement beam.

Spatially separating the front and back surface reflections at the detector can be accomplished using a thick substrate or wedged substrate to spatially separate beams reflected from the front and back surfaces. If possible, spatially separating the front and back surface reflections works very well, but does not work if the substrate is thinner than the diameter of the measurement beam spot.

Focusing the incident beam to a small spot is a way of extending spatial separation to thinner samples [5], but introduces an undesired angular spread into the angle of incidence. Focusing also has difficulty on very thin substrates such as microscope cover slips or thin plastic sheets as backside reflections return when the substrate is thinner that the diameter of the focused measurement beam.

Accounting for incoherent backside reflections in the analysis model [4] also works, but introduces additional complexity into the optical model by adding extra fit parameters. Also, modeling backside reflection intensity effects may not be sufficient when modeling reflections from anisotropic substrates as the anisotropic effects on the beam polarization may not be properly accounted for.

A common technique used to eliminate backside reflections is to roughen a small region of the back surface opposite the measurement spot. This can be accomplished via mechanical grinding using sandpaper, pumice stone, or via sandblasting using pressurized air or other gas mixed with sand or abrasive grit. The scale of the roughness created is large enough to scatter almost all reflected light away from the detector. In this technique back-surface reflections are effectively eliminated. Fujiwara [2] has a nice discussion of a successful two-step process to suppress back-surface reflections by first roughening the back surface followed by application of black paint.

Roughening the back surface of a sample has many advantages. It is generally easy to perform, works with materials of any refractive index, works over a wide spectral range, and works at any temperature. These qualities make roughening an excellent reference technique for comparison with other backside reflection suppression treatments. However, roughening is obviously a destructive technique. It can also be difficult to roughen very thin, brittle, or soft samples (e.g. thin plastic wrap) without damaging or destroying them.

1.2 Index matching techniques

Nondestructive techniques for suppressing backside reflections involve index matching to the substrate. The use of liquids or gels for index matching purposes is often used [6]. Generally, these special-purpose liquids and gels are specified to index match to specific substrates at specific wavelengths, or over a limited spectral range.

Recently some very nice and clever work has been presented by Hayton and Jenkins [7] which used a soft, pliable putty to suppress back-surface reflections from a glass substrate. The work of Hayton and Jenkins is also valuable in that it demonstrates using a removable, pliable, nondestructive, semi-solid material to accomplish the index matching. Matching solid or semi-solid materials against a solid substrate with similar index and wavelength variation appears promising for finding index matching materials which can work over the wide spectral range available in modern optical instruments.

In this work the method of Hayton and Jenkins is generalized to investigate a variety of commonly available materials for use in suppressing backside reflections from transparent glass and plastic substrates. Ideally, these index matching techniques should be nondestructive, work over a wide spectral range (have similar refractive index variation with wavelength, or dispersion), work for a wide variety of substrates (work over a wide index range), should be easy to apply and remove under normal laboratory conditions, and make use of inexpensive, commonly available materials.

The goal of this work was to investigate and compare various index matching techniques over a wide spectral range on glass and plastic substrates using a variety of semi-solid "glassy" materials with index near 1.5 at visible wavelengths.

2 Experimental

2.1 Samples measured An uncoated glass microscope slide was measured with a variety of back-surface treatments applied. Additional samples measured were various plastics such as a polycarbonate CD-ROM disk, a 4 mil (100 microns) thick polyethylene plastic bag, and a very thin sheet of plastic wrap less than 17 microns thick.

2.2 Backside techniques used Materials investigated here are semi-solid, pliable, removable, and nondestructive. Examples include translucent adhesive tape which consists of a sticky adhesive deposited on a flexible plastic tape backing such as polypropylene. Note this adhesive tape (Scotch Magic® tape, or similar) has a translucent matte finish and appears visually "Cloudy." Black vinyl electrical tape was also successfully used. The glass substrate was also painted using enamel paint. Both black and white paints were used with equal success. Other materials tested include red fingernail polish, ink from a black marker pen, a clear glycerine-based hand lotion, silicone grease, Vaseline® petroleum jelly, Elmer's® white glue, rubber cement, an adhesive-coated paper Post-It® note, etc. Table 1 shows a full list of techniques applied to the back surface of the glass slide.

Translucent tape was also applied to the plastic substrates to test for suppression of anisotropic effects via suppression of backside reflections.

Small areas of the glass and plastic substrates were also roughened on the back surface using a grinding stone on the glass substrate, and fine 600 grit sandpaper on the plastic substrates. Data were acquired opposite these roughened areas. This allows for comparison of the various index matching methods against a proven "reference" technique of roughening. Additional techniques developed in the future can be compared to results from a roughened test sample.

2.3 Instrumentation Data were acquired using a J.A. Woollam Company M-2000® spectroscopic ellipsometer. Different index matching materials were applied one at a time to the back surface of the glass substrate and measured on the ellipsometer. Data were acquired using the M-2000 over the angle range from 50° to 80° in steps of 5° over the spectral range from 192 nm to 1700 nm. The measurements were repeated on the plastic substrates with and without translucent adhesive tape applied to the back surface. All data were acquired at room temperature approximately 25 °C.

3 Results and discussion

3.1 Glass substrate results

The slide was made of soda-lime glass and was transparent at wavelengths 300 nm and longer. Thus it is expected to see effects from back-surface reflections at 300 nm and longer wavelengths, but not below 300 nm since the glass slide itself is absorbing and reflections from the back surface are not present due to absorption in the glass. This is shown in Fig. 1. Data with the backside roughened or taped with translucent plastic tape are effectively identical and demonstrates that translucent tape applied to the back surface is effective for suppressing backside reflections over the full measured spectral range.

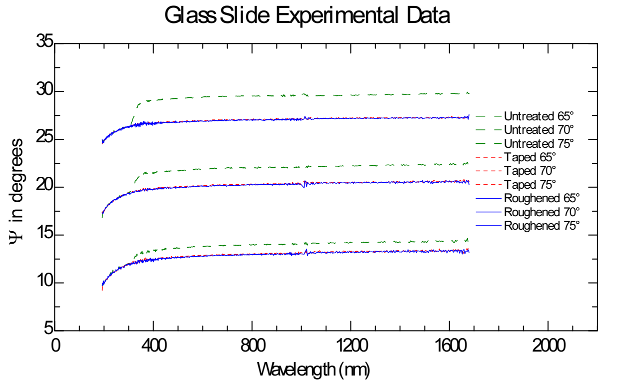

Figure 1 Ellipsometric Ψ data acquired on a glass slide. Note the slide is absorbing below 300 nm so all three data sets are identical Beyond 300 nm the untreated slide data show backside reflection effects. Note the taped and roughened data are effectively identical.

Table 1 below summarizes the index matching techniques used on the glass slide and results obtained. The index results in the table are reported at 633 nm. This wavelength was chosen arbitrarily for easy comparison between techniques.

Table 1 A variety of index matching materials applied to a glass substrate.

Backside Treatment	Glass Index n(633 nm)	Roughness, Angstroms	Comments:
Roughened	1.520	27.8	Used mechanical grinder. Reference value.
Translucent Adhesive Tape	1.521	24.1	Excellent adhesive bond. Translucent surface scatters.
Clear Adhesive Tape (Sanded)	1.522	17.6	Good. Sanding creates scattering surface.
Double-Side Adhesive Tape	1.518	16.7	Good, but sticks to stage.
Black Enamel Paint	1.520	24.4	Good.
Red Nail Polish	1.517	40.7	Good.
Silicone Grease	1.521	33.0	Good.
Vaseline	1.521	24.9	Good.
White Hand Lotion	1.517	36.2	Good.
Toothpaste	1.520	41.4	Good, but messy. Very easy to remove.
Elmer's White Glue	1.519	48.1	Good! Water soluble white glue.
Weldbond White Glue	1.519	46.0	Good! Water soluble white glue.
Super Glue (Cyanoacrylate)	1.516	38.2	Smeared to be translucent.
Rubber Cement	1.516	37.7	Smeared to be translucent. Very easy to remove
Modeling Clay	1.518	26.5	Good.
Stick Tack Putty	1.522	28.6	Good.
Water	1.537	18.9	Bad. Water index too low.
Clear Glycerin Lotion	1.531	31.9	Bad. Lotion index too low.
Gel-Pak Adhesive	-	-	Bad. Caused anisotropic effects.
Adhesive Paper Post-It Note	-	-	Bad. Incomplete Adhesive coverage.
Black Ink Marker Pen	-	-	Bad. Semitransparent ink. BacksideReflections still present.

Figure 2 shows the refractive index of the glass slide versus wavelength using seven different index matching treatments. These are compared with results obtained from a roughened area of the slide. Note the results for water and the glycerin-based lotion (dashed lines) show index values which are too high. This is attributed to the index of these more liquid materials being too low for a good index match, and not completely suppressing the backside reflections. Note the semi-solid materials have a nearly identical index to the roughened glass.

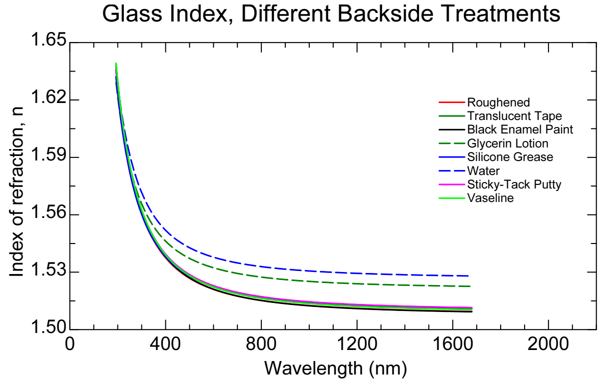

Figure 2 Glass slide index versus wavelength. The semi-solid materials have a nearly identical index to the roughened glass. Note these techniques work over the full UV, visible, and infrared wavelength range measured.

Examination of Table 1 and Figs. 1 and 2 show several simple techniques were found to work very well over a wide spectral range. These techniques included translucent plastic tape, white glue, silicone grease, petroleum jelly, enamel paint, rubber cement, modeling clay and putty. These simple techniques work well for substrate materials with refractive indices in the range of 1.35 to 1.60, including materials such as fused silica, float glass, display glass, microscope slides, plastic sheets, etc.

Results were compared to data acquired on the same samples where the back surface had been roughened by mechanical grinding. These simple techniques were found to work as well as mechanical grinding or sanding for glass substrates with index *n* approximately 1.5 in the visible.

3.2 Discussion

In addition to a close index match between the substrate and the matching material it was found that two experimental conditions were required for adequate suppression of back-surface reflections. The first is good, firm, optical contact between the substrate and the index matching medium (e.g. no air bubbles present). Good optical contact ensures a good index match everywhere under the measurement beam, which allows light to enter the index-matched medium rather than reflect from the interface at the back surface. The second criterion is light which enters the index-matched medium must then become scattered and/or absorbed before exiting the medium. Scattering surfaces can include a rough surface such as the backing on translucent tape or via scattering or absorption by large particles in glues or paints.

A surprising result is how well these techniques work over a wide spectral range (Figs. 1 and 2). Also surprising is a close, but not perfect index match is all that is required for the techniques to work over a wide spectral range.

This work covers the UV-VIS-NIR spectral range between 192 nm to 1700 nm. The translucent tape technique was also tested on glass substrates into the mid infrared and worked well out to approximately 9 microns where the substrate became opaque, but has potential to be extended to longer or shorter wavelengths.

It should be noted that both white paint and black paint worked equally well, suggesting that the color is less important for suppressing backside reflections than the scattering which occurs from the pigment particles. This makes scattering more important than absorption and may explain why these techniques work so well over a wide spectral range without introducing artifacts into different portions of the spectral range due to different colored pigments.

3.3 Anisotropic plastics The translucent tape technique was also useful in suppressing anisotropic effects in substrates such as plastic sheets, CD-ROM disks, etc. It is expected that many of the other techniques in Table 1 tested on glass should work equally well on plastics. Anisotropic effects are usually encountered by light passing through the substrate and back out to the detector. Suppressing back-surface reflections via index-matching techniques makes the sample appear isotropic and thus much easier to analyze. This is shown in Fig. 3 below for a polycarbonate CD-ROM disk.

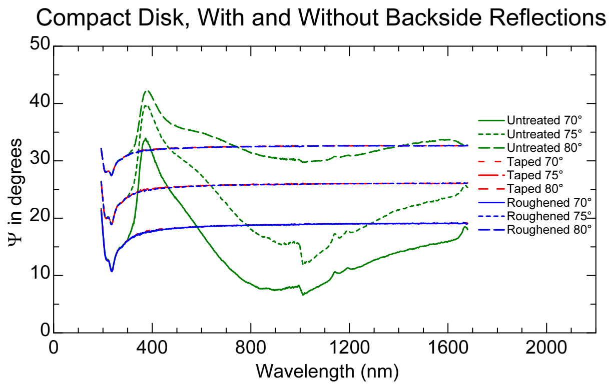

Figure 3 Ellipsometric Ψ data acquired on a plastic CD-ROM disk. The untreated data show strong anisotropic effects. Translucent tape or roughening removes the anisotropic effects.

Figure 4 shows data acquired from an extremely thin substrate of plastic wrap used for food storage. This plastic wrap was measured with a caliper and found to be less than 17 microns thick. Measuring this sample untreated shows both thickness effects (oscillations in the data) as well as anisotropic effects. Translucent tape was applied to the back side of this very soft, flexible film. The index matching tape suppressed both the thickness and anisotropic effects. Applying the tape also made the sample more rigid, making it easier to align and measure on the ellipsometer.

Note without application of back-surface index matching data from the plastic substrates were unusable due to anisotropic effects present. With translucent tape applied to the back surface both look like bulk, isotropic dielectric materials, and the ellipsometric data were easy to analyze.

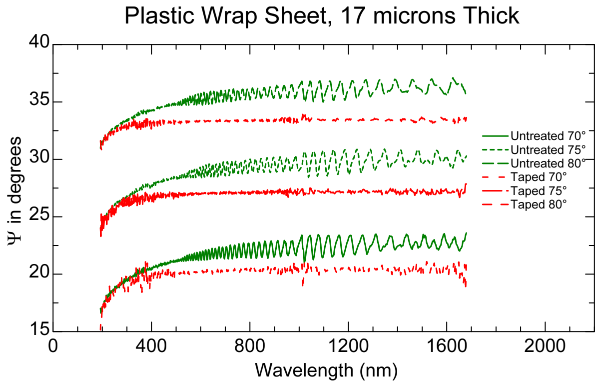

Figure 4 Ellipsometric Ψ data acquired on a thin plastic wrap 17 microns thick. The untreated data show both anisotropic effects and oscillations due to the thickness. Translucent tape applied to the back surface removes both effects.

4 Conclusion A variety of simple index matching techniques were investigated and found to suppress unwanted backside reflections from transparent glass and plastic substrates. These techniques involve application of semi-solid materials such as translucent adhesive tape, electrical tape, white glue, enamel paint, grease, etc. to the uncoated back surface of the substrate. These materials form a close contact with the back surface and have a refractive index close enough to the substrate to suppress backside reflections. These techniques are nondestructive, work over a wide spectral range, make use commonly available materials in a typical office or household, are simple to apply and remove, and work well for transparent glass and polymer substrates with refractive indices in the range from n = 1.35 to n = 1.6. These techniques have been successfully used on both coated and uncoated samples.

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