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Determining the effects of backsurface reflections for IR-VASE® data

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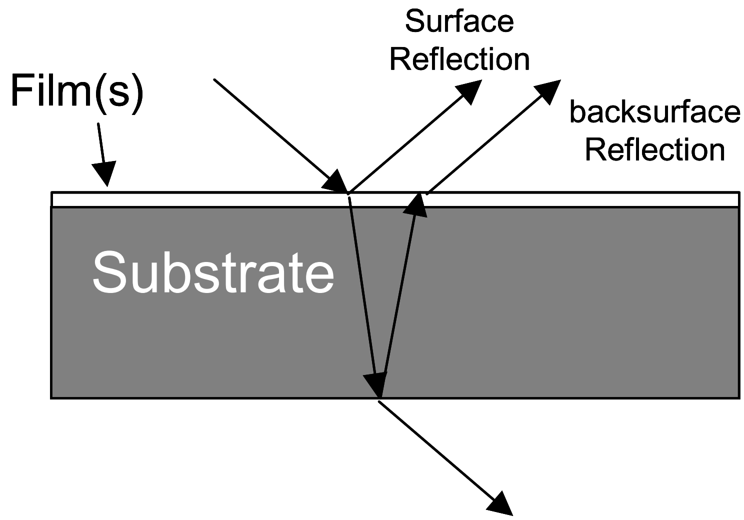
Difficulties with backsurface reflections

PARTIAL COHERENCE:

Reflections from the backside of a substrate can substantially undermine data analysis of Infrared Spectroscopic Ellipsometry (IR-SE) data. This is because the coherence length of blackbody sources is on the order of 10 to 100 wavelengths – approximately 0.1 to 1 mm for mid-IR wavelengths. Since semiconductor wafer substrates are typically 0.2 to 1mm thick, light reflected from the backsurface mixes in a partially coherent manner with light reflected from the front surface.



ANALYSIS DIFFICULTIES:

Ellipsometry analysis software can model either reflected/transmitted light beams that mix in a completely coherent or completely incoherent manner. However, partially coherent mixing cannot be easily analyzed. Even if the front and back surface mixing were completely coherent, strong interference oscillations caused by the relatively thick substrate would dominate the Ψ and Δ spectra, making it very difficult to analyze the properties of surface films. Furthermore, properly resolving these short period oscillations (~ 3 cm^{-1} for a 500 μm silicon substrate) would require the acquisition of very high resolution data.

LESS SCATTERING AT LONGER WAVELENGTHS:

To further complicate matters, the backsurface finish on single-sided polished silicon wafers has roughness features the size of a few microns. Therefore, the backsurface may completely scatter 2 μm wavelengths but only partially scatter 10μm wavelengths, with some light specularly reflected into the detector. Thus the amount of backsurface light reaching the detector can depend strongly on wavelength and surface finish. This wavelength dependence is very difficult to model.

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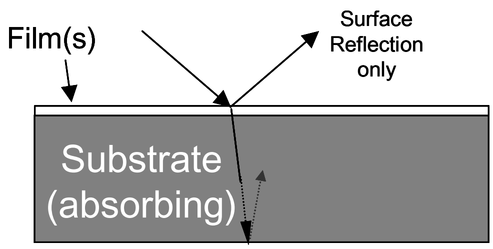
Mitigating backside effects

Several ways to mitigate the problems associated with backsurface-reflections are listed below.

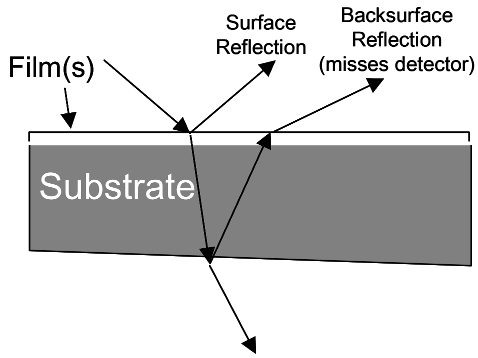
1. USING AN ABSORBING SUBSTRATE:

The substrate or film is sufficiently absorbing such that probe beam either never propagates to the backsurface, or the small amount of light reflected from the substrate backside never exits the sample to reach the detector. Examples would be substrates and films of metal or low-resistivity semiconductors.



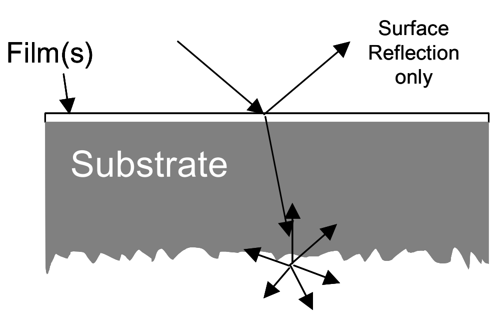
2. USING A WEDGED SUBSTRATE:

Past experience has shown that a 2° or more wedge in substrate thickness is usually sufficient to divert backsurface reflections away from the detector.



3. ROUGHENING THE BACKSURFACE:

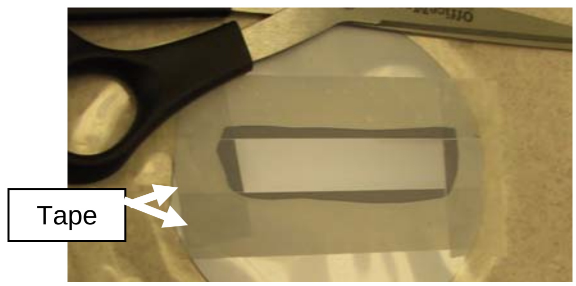
A roughened substrate backsurface will effectively scatter backsurface reflections away from the detector aperture.



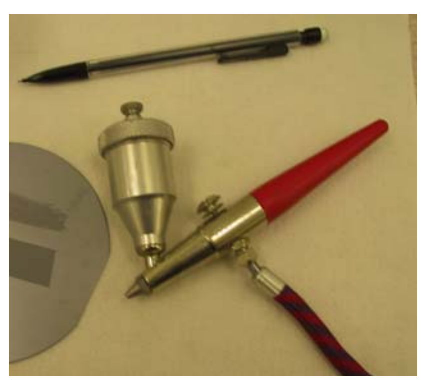
Unfortunately, for single-side polished silicon wafers the typical backsurface finish is insufficiently rough for IR-SE measurements. In contrast, silica glass that has a matte or "frosted" finish on the backsurface can be used. The matte surface is sufficiently scattering for wavelengths less than 5 μm, and silicates are usually opaque at wavelengths greater than 5 μm.

Small "sandblaster" ("bead blaster") tools can be used to roughen backsurfaces. These can be purchased from workshop tool suppliers. They work by bombarding the surface with alumina or other particles at high velocities. A supply of compressed air must be available to operate the tool.

Care must be taken to protect the front surface of the sample. One method is to enclose the sample in a plastic bag, then cut a hole in bag so that the sand particles can roughen the surface. Tape is used to seal the inside of the bag from the outside, as shown in the figure below.



The figure below left shows the sample inside the bench top sandblaster, which is like a glove box. The sample (in its protective plastic bag), particle nozzle, and gloves are shown. One can also purchase an "Etching tool" from art supply stores. One of these is shown below-right (red handle). The particles are held in the cylindrical reservoir located on top, and are gravity-fed into the of the nozzle. Like the bench top sandblaster, a supply of compressed air must be available to operate the tool. Also, the user must supply an enclosure, and care must be taken to protect oneself from the particles.



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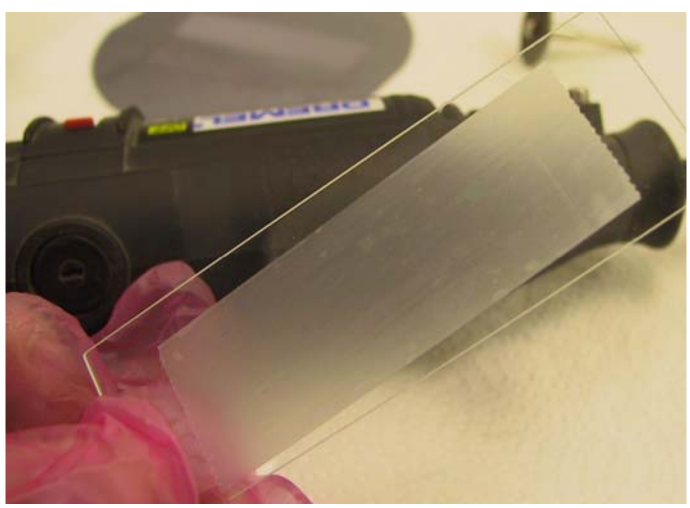
Rotary tools with abrasive heads (such as Dremel tools) can also be effective. However, it can be difficult to sufficiently roughen the backside of silicon and other materials using this method, as small, inadequately-roughened regions sometimes remain. Thus, care must be taken to sufficiently roughen the backside of all parts of the sample that will be illuminated by the beam. The figure below shows the how the rotary tool is used to roughen the backside of a silicon sample. The sample in the figure has also been roughened with the sandblaster. Compare the uniformity of the sandblaster to that of the rotary tool – the sandblaster tends to be much more uniform.

4. <u>Applying Matte-finish Adhesive tape (silica glass substrates only):</u>

   Perhaps the simplest method to eliminate backsurface reflections is to apply a light-diffusing adhesive tape to the backsurface. These tapes, which are used in many offices and households, consist of a ~50μm plastic backing (see figure below) that has a matte-finish on one side and a contact adhesive coating on the other. One brand sold in the United States is 3-M Corp.'s Scotch Brand™ "Magic Tape".



Glass slide with light-diffusing adhesive tape applied to the backsurface.

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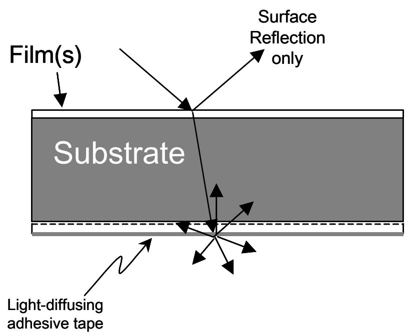
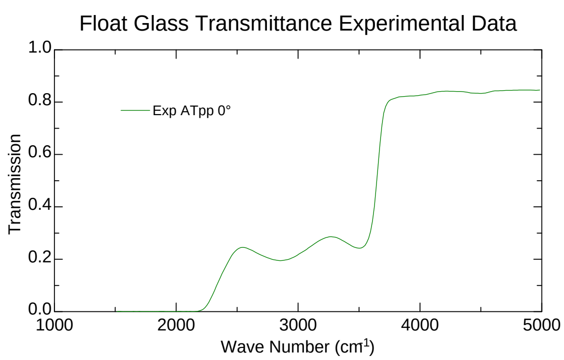
When applying the tape, the experimenter must ensure that there are no air bubbles between the tape and the substrate. With some care, the tape can usually be removed with little or no remaining adhesive residue on the glass substrate.

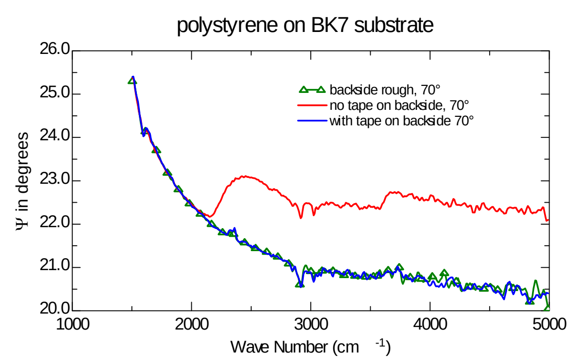
The average refractive index of the adhesive and plastic substrate ~1.5, which is sufficiently close to and index match to most of the silica glasses. The 2nd right-hand figure illustrates the action of the tape when applied to a glass substrate.



Schematic of glass substrate showing scattered backsurface reflections adhesive tape with diffusive plastic backing.

The light-diffusing quality of the tape diminishes for λ > 5μm (or wavenumbers < 2000 cm^{-1}). This is not a problem for silica glasses, which are complete absorbing for wavelengths greater than 5μm (see figure below-left). However this method is less effective for substrates such as PE and PET, which do transmit light at wavelengths greater than 5 μm.





Left: Transmittance spectra for typical 1mm thick silica glass. Right: Ellipsometric Ψ for glass substrate: *green*, backside roughened; *red*, no tape or roughening; and *blue*, light-diffusing adhesive tape applied.

The effectiveness of these treatments is shown in the bottom right-hand figure. The nearly-identical blue and green curves are the taped and backside roughened treatments, respectively. Similar effects are seen in ellipsometric Δ.

The red curve is for no backsurface treatment. Note that the red curve deviates at the same wavelengths where the glass substrate is transparent (see transmittance spectra 3rd right-hand figure).

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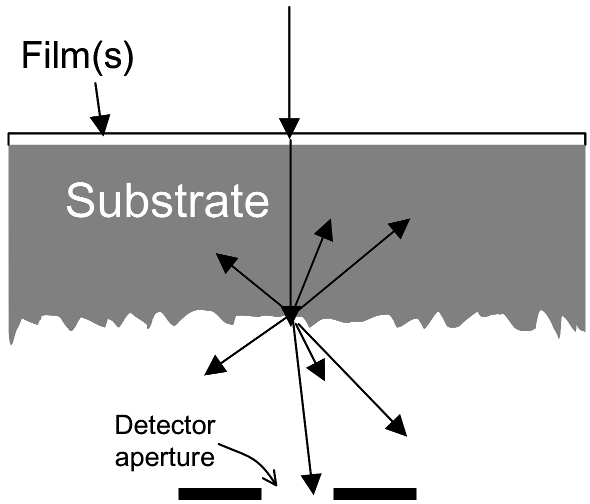
Using transmission measurements to estimate the effects of backsurface reflections on IR-VASE® data

The user can estimate the effects of backsurface reflections by performing an IR-VASE® transmission intensity scan at normal incidence.

A transmission intensity measurement will indicate how much light is transmitted through the sample and exits the backside without scattering. This is because the ~1 cm diameter detector aperture of the IR-VASE® blocks all light that is scattered outside of a relatively small acceptance angle (see figure below).



Another reasonable assumption is that transmission intensity is of the same order of magnitude as the backsurface reflection that reaches the detector during IR-SE data acquisition. Typical transparent substrates transmit anywhere between ~50% of the light for high index materials (Si or Ge), to ~90% of the light for low index materials (glasses, polymers). The remaining light is reflected from the substrate's front and back surfaces. Thus, to ratio of reflected to transmitted light is generally between 1:1 for high index materials and 1:10 for low index materials.

Measuring transmission intensity with the System Alignment mode

For the purposes of estimating backsurface effects, a user can perform a standard transmission scan[1] using the R/T procedure. However, the measurement can be easily accomplished using the System Alignment mode found in the WVASE-IR® software. This section describes the System Alignment mode procedure in some detail.

The procedure has two steps: first, the user must align the sample and detector stages so a normal-incidence transmission measurement can be made; second, the user opens the System Alignment dialog box and performs a quick relative intensity measurement. Those two steps are described next.

[1] The Transmission Intensity measurement procedure is described in chapters 2 and 6 in WVASE-IR® software manual.

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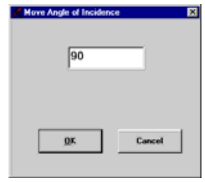
Aligning sample & detector stages for normal-incidence transmission measurement

We must first align the sample and detector stages using the incidence angle selection feature found in chapter 9 of the WVASE-IR® software manual.

1. **Select Motors|Incidence Angle and enter an incident angle of 90°**. This aligns the detector stage in the straight-through position.



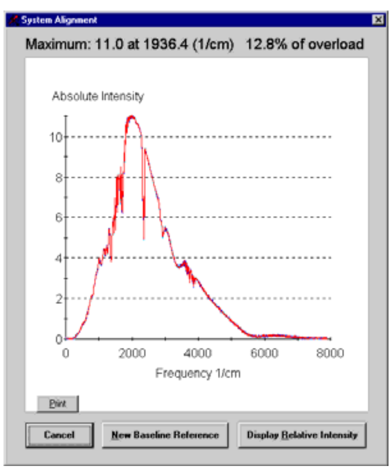
2. **Select Motors|Incidence Angle 0°**. This aligns the sample stage to the normal incidence position. *You must align the detector stage by selecting Incidence angle = 90° first – see part 1 above.*

Using system alignment to determine unscattered transmitted intensity

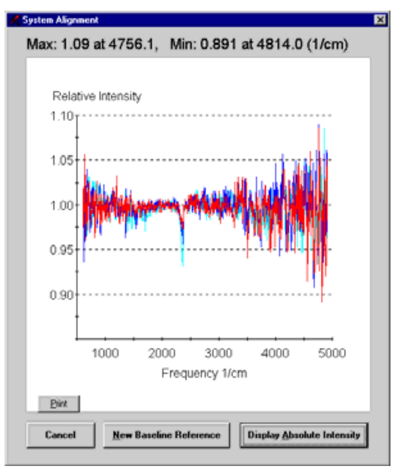
After the detector and sample stages have been aligned, we can use the System Alignment screen to approximately determine the unscattered transmitted intensity. The procedure is as follows:

1. Without mounting the sample on the sample stage, select the System | System Alignment menu item. After a few seconds, you will see the absolute intensity spectrum (figure below left).
2. Select "New Baseline Reference". This updates the Baseline intensity values.
3. Select "Display Relative Intensity". After a few seconds, you will see the Relative intensity spectrum. The Relative Intensity should be approximately equal to 1 across all wavelengths (see next figure, middle). If you block the light beam completely, you should see a "noise floor" of approximately 1 – 3 % across the spectrum (see next figure, right side).

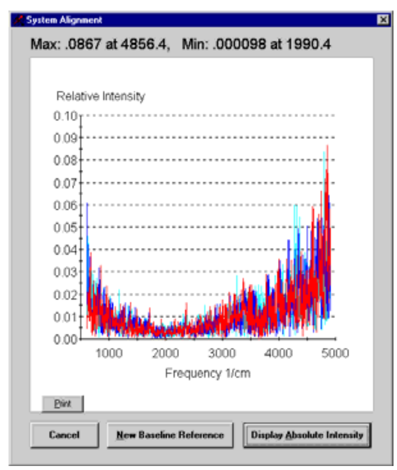
Absolute Intensity (no sample)



Relative Transmitted Intensity (no sample)



Relative Transmitted Intensity for completely blocked light path, showing "noise floor".



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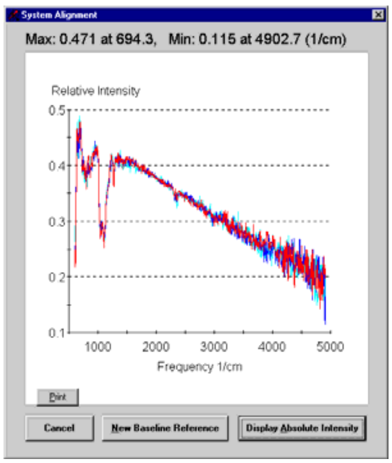
4. Mount sample on sample stage (or simply hold it in path of IR beam).

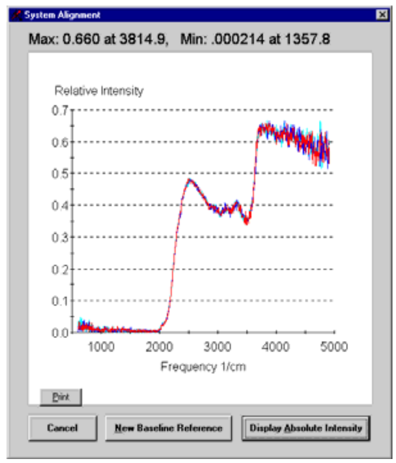
Examples of Relative Transmitted Intensity measurements

Several examples of Relative Transmitted Intensities are shown below. Examples A and B will experience backside reflection effects during IR-SE, while the backsides of samples C and D are sufficiently rough to effectively scatter backsurface reflections. Sample E may not have sufficient roughening to prevent backsurface reflection effects.

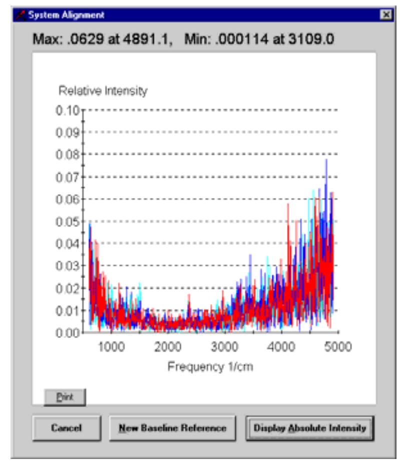
A. Single-side polished silicon wafer, no additional roughening.



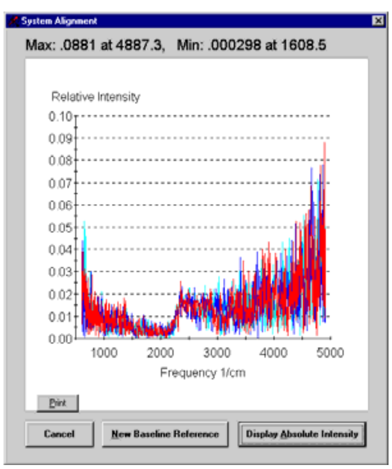
B. Film on slide glass substrate, no backside roughening.



C. Single-side polished silicon wafer, with sufficient additional roughening to prevent backsurface reflections.



D. Relative Transmitted Intensity for backside roughened glass substrate.



E. Glass substrate partially roughened with a Dremel rotary tool. Roughening is probably insufficient scatter backside reflection effects.