

Infrared Ellipsometry – bulk and thin film characterization beyond standard FTIR spectroscopy

Q&A

Question Asked

When comparing k as a function of wavenumber with a standard FTIR spectrum, would you expect exactly the same result?

Answer Given

Because k is a property of the material, both results should give the same result. You may see shifts in the "absorption" versus wavenumber that is related to how the data are collected (and the angle of incidence that is used), but if both tools are used to extract the underlying optical functions (n and k), then they should produce the same result

Because of the longer wavelength, is there a minimum film thickness that can be analyzed? in UV-Vis SE, this is not something we'd worry about

If you want to determine n & k as well as thickness, 20nm is approximately the minimum (although I have managed with three films in a multisample analysis, where the films ranged from 10 to 14 nm). The measurement will pickup thinner films than that, but your ability to determine n & k are limited.

If you routinely use UV-Vis SE + high-sensitivity FTIR methods (like IRRAS), what are the applications where IR-VASE can offer most added value?

IR-VASE analysis can unambiguously determine not only thickness but the real and imaginary parts of the optical function (n & k , or the dielectric function) across the measured wavelengths.

on slide 28, we see sharp transition in delta. What is the reason for that?

The delta measurement is a "relative" phase difference between the p- and s- oriented light. Since it is not an "absolute" phase, we can only determine the phase within a 360° range. When we graph the Delta curve, it will appear to have "sharp" features where Delta goes off the top of the range and reappears at the bottom of the range. In reality, the Delta curve is smoothly varying - but the sharp "jump" is artificial because of the limited range where Delta is graphed over.

What is the reason for the difference in sensitivity between gold, glass and silicon? The data show that you are close to the Brewster angle on silicon, so I would expect good sensitivity.

When light illuminates a metal surface such as gold, strong electric fields are generated near the metal surface. High electric fields increase the probability of photon absorption from vibrational modes in any film that is deposited on that surface.

Do you model the depletion region just as a dielectric layer?

Thanks for your question, The depletion layer is modeled using optical constants of the substrate material, except it doesn't have the free carrier absorption term (Drude function = 0).

How do you manage backside reflections? I see 1mm substrates in your model, so I expect coherent backside reflections. Roughening would probably not help much at these wavelengths. Do you use wedged substrates?

A sandblaster actually roughens the backside enough to avoid the backside reflections, otherwise we use Dremel grinders on materials that are too hard for our alumina particles used in the sandblaster; of course, wedges are also an option.

Can you elaborate a bit on instrumentation. Do you use a FTIR, what kind of polarising optics, how much time does a measurement take?

We use wire grid polarizers. Measurement times vary quite a bit. Typical measurement times are 10 minutes per angle to many hours, depending on the complexity of the measurement and the wavenumber resolution used for the measurement.

Thank you for the nice webinar. What can you recommend modelling of multi layers such as InGaN/GaN/sapphire. In fact, the InGaN has two layers with different doping concentrations and indium fractions. (it is a whole stack, there is no chance to measure the layers one by one)

If possible break the analysis down in sublayers or at least sequentially add films. There is sensitivity to multilayer coating properties in a single measurement, but it is relatively hard to get them all figured out in one measurement. Also, all of these layers are anisotropic meaning the phonon modes along the c axis will be different compared to the perpendicular direction. I recommend you look up papers by M. Schubert and A. Kasic for some really nice papers that will be a very good starting point, or get in touch with us

In the IR spectra of PSI and DELTA, to determine vibrational modes should we take all maxima, minima and the inflection points ?

You generally can't extract vibrational mode information directly from the Psi and Delta data - for most samples, absorption features in Psi and Delta will be shifted and/or distorted depending upon the strength of the absorption and the refractive index (after all, Psi and Delta are related absorption only because absorption changes the polarization response of the surface). For films, interference effects will also shift and/or distort the absorption features. The best way to obtain absorption features is to fit the data with a model, and then extract the dielectric function (or n & k) from the model.

To determine the vibrational modes from PSI and Delta spectra is enough accurate, or is better to determine them from $\text{Im}(-\epsilon_{-1})$?

If you are measuring a substrate, it is better to transform Psi & Delta into Pseudo optical functions $\langle n \rangle$ & $\langle k \rangle$ (or $\langle \epsilon_1 \rangle$ & $\langle \epsilon_2 \rangle$). If it is a film, you really need to fit the data with a model in order to eliminate the distortion and shifting caused by interference effects.

Can the instrument deliver the 12 MM elements?

Yes, the IR-VASE can measure 12 MM elements.

When working on Si substrates, what is your preferred method of avoiding the backside reflection effect? Roughening is not as good / easy as in the vis. How about attaching a wedge?

I personally use our sandblaster and it gets the surface rough enough to scatter even the longer wavelength light. I have worked with wedged substrates that work really well at spatially separating the front and back beams, but they came that way. I have never tried to put flat wafer against a wedge and I worry that it would cause reflections at this interface.

What are the advantages/limitations of FTIR ellipso vs standard absorption transmission or reflection FTIR?

FTIR measures transmission or reflection intensity, which may provide information such as absorption, based on which sometimes bonding structure/vibrational mode can be quickly identified or compared. IR Ellipsometry provides the fundamental material properties nk or dielectric functions, in addition to film thickness. With the fundamental information, optical properties, such as reflection, transmission and absorption can be calculated.

How exactly do you model the depletion region? EMA of Drude and non-Drude phases?

Thanks for your question, The depletion layer is modeled using optical constants of the substrate material, except it doesn't have the free carrier absorption term (Drude function = 0).

Si being flat in IR wavelengths, if you delete the Drude you are left with basic a Cauchy? Could Tom share a link to one of his publications?

Yes, you are left with a Cauchy-like term (increasing index at shorter wavelengths). I will have Tom reply directly to your question by e-mail. Thanks for the question.

That last part was very interesting. Does Woollam provide ZnSe prisms and with the configuration of IR-VASE how do you mount it?

We offer a dedicated attachment for the standard sample holder for these measurement, different prism materials are available. Please contact us at sales@jwoollam.com for more details

What is your common practice in finding the right acquisition parameters with IR VASE?

I make "short" measurements at one angle in order to determine the best wavenumber resolution and averaging time. I choose a low number of scans per spectra, but a high number of cycles. I watch the data as it comes in to see how long I need to acquire data to obtain good low noise data set. I note how many cycles were required, and multiply that by the number of scans/spectra to obtain the consolidated scans/spectra. When I set up my final run, I use 1 cycle and the consolidated value for the scans/spectra (it is better to use one cycle and many scans/spectra, rather than few scans/spectra and more cycles).

Why is sensitivity higher when film is deposited on gold compared to glass?

When light illuminates a metal surface such as gold, strong electric fields are generated near the metal surface. High electric fields increase the probability of photon absorption from vibrational modes in any film that is deposited on that surface.

Is the IR-VASE mark II faster than mark I?

It is faster for samples that are smaller than ~ 3 cm long.

Is there a reason to prefer DTGS over MCT detectors (linearity) ?

Linearity is exactly why the DTGS is preferable.

What is coating thickness limit for VASE in general. is it applicable for industrial coatings those are in 10's micron in thickness with sub-micron roughness?

10s of microns are definitely possible; when the film becomes too thick, say a few hundred microns, i.e. on the order of the coherence length of the global light source, the model approaches might start to fail to describe the partial coherence correctly