Angle-Dependent Reflection Analysis of Smart Phone Privacy Screens

Introduction

From smart technology to solar cells, a variety of materials are analyzed as solid film samples. For some applications, analysis of these substances through UV-Visible spectroscopic techniques can be highly beneficial. Unlike liquid samples, solid samples are known to reflect a non-negligible amount of incident light. As such, it can be important to collect the reflection spectrum of a given sample for further materials characterization. These reflections can be either specular (mirror-like) or diffuse in nature (Figure 1). For film samples which do not appear opaque or cloudy, the reflection spectrum will be primarily specular while hazy films will mostly reflect light diffusely. For films which are clear to the naked eye, it is also possible to reliably measure the transmission spectrum as well, which can provide further insights into the behaviour of a given substance.

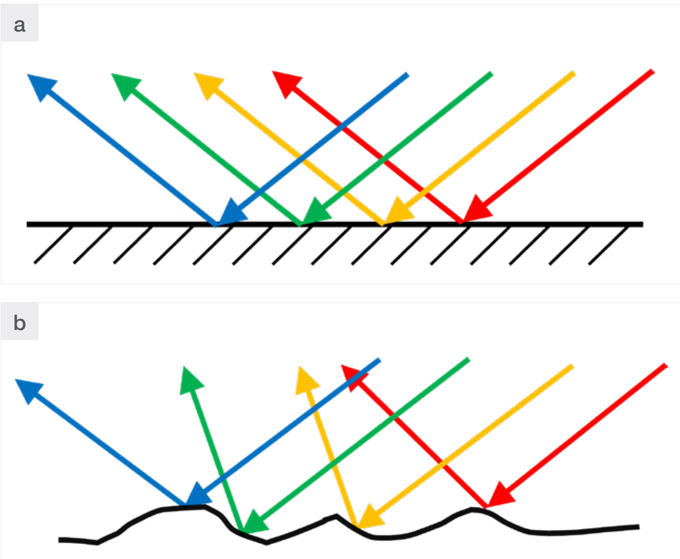

Figure 1. Diagrams depicting (a) specular and (b) diffuse reflections.

As an example, privacy screens for smart devices are films which protect the user's privacy by blocking light transmission when viewed from wide angles of incidence. These films typically utilize a micro-louvre design involving an array of "shades" which allows for transmission of light directed at a 0° angle of incidence.[1,2] At greater angles of incidence, the amount of light transmitted is limited. Similar methods have also been used for solar energy applications, like solar thermal collectors.[1,3]

Consequently, any privacy screen material will inherently have angle-dependent transmission and reflection spectra in the visible region of the electromagnetic spectrum. For quality purposes, it will be important to ensure that the screen blocks the full spectrum of visible light at a given angle with respect to normal incidence while allowing light to transmit when viewed directly. As light can either be transmitted, reflected or absorbed by a material, and given the privacy device is acting as a micro-louvre, behavior should be observed wherein more light is transmitted at smaller angles of incidence while less light is reflected at these angles. Therefore, it is important to measure the full transmittance and reflectance spectra as a function of the angle of incidence to ensure the film is behaving as expected.

Herein, the reflectance and transmittance spectra of a commercially available privacy screen were collected using the Thermo Scientific™ Evolution™ UV-Visible spectrophotometer. Reflection spectra were collected using multiple angles of incidence through the use of the Evolution Pro spectrophotometer equipped with the Thermo Scientific™ VeeMAX™ Variable Angle Specular Reflectance Accessory (SRA) and a fixed-angle 8° SRA. The Evolution One Plus instrument equipped with a Harrick Scientific Variable Angle Transmission holder was also used to collect the transmission spectra at varying angles of incidence.

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Experimental

A commercially available privacy screen compatible with smart phones was purchased and measured as received. For specular reflectance measurements, the Evolution Pro instrument was equipped with the appropriate SRAs. The percent reflectance (%R) spectrum was collected using 8°, 30°, 60°, 70°, and 80° angles of incidence. The data collected at an 8° angle of incidence was measured using the 8° SRA while the remaining measurements were collected using the VeeMAX Variable Angle SRA. Spectra were measured between 300 nm and 800 nm using a 1.0 nm step size, 1.0 nm bandwidth, and 0.1 s integration time. A reference mirror was used to establish the background.

Angle-dependent percent transmission (%T) measurements of the privacy screen were acquired using the Evolution One Plus. The Variable Angle Transmission holder was used to hold the screen at varying angles of incidence. For the data included herein the 0°, 8°, 30°, 60°, 70° and 80° angles of incidence were used. For transmission measurements, samples were measured twice with two different orientations: vertical and horizontal. The horizontal orientation, as its name implies, was achieved by rotating the sample 90° with respect to the vertical orientation. Similar to the reflectance data collected for this sample, spectra were measured between 300 nm and 800 nm using a 1.0 nm step size, 1.0 nm bandwidth, and 0.1 s integration time. The background was collected against air by using an empty holder.

Results/Discussion

As shown in Figure 2, the entirety of the specular reflectance spectrum for the privacy screen (Figure 2a) increases with rising angle of incidence while the opposite behavior is observed in the transmission spectrum (Figure 2b). Additionally, while the %R spectrum is almost flat across the entire measured range, the %T spectrum includes a feature with an onset at ~420 nm. This feature is likely due to some absorptive material within the film. The observations made imply, as expected, that when viewed directly (normal or smaller angles of incidence) the privacy screen has greater light transmission and less reflections than if viewed at larger angles of incidence.

It should be noted that both %R and %T spectra collected for the sample held at an 8° angle of incidence (and 0° for the transmission measurements) include an interference pattern (Figure 2). Interference patterns look like oscillations across the UV-Visible spectrum and are observed when the thickness of the film is on the order of the wavelength of light used in the measurement.[4] Under these conditions, the light which reflects off the air/film interface and the film/substrate interface constructively and destructively interfere with one another, leading to the observed interference pattern. This phenomenon occurs when the various interfaces are uniform or have minimal roughness[5] and has been reported previously for a variety of thin film samples.[4-7] In terms of the privacy screen, the observed interference pattern implies the sample contains a film deposited on the substrate which is hundreds of nm thick. Furthermore, this pattern also implies the film is relatively uniform.

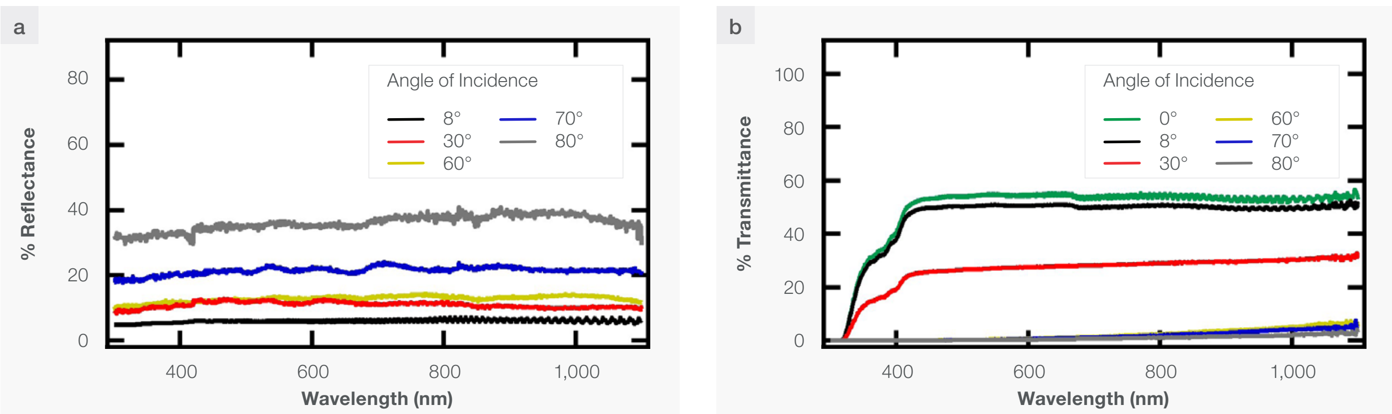

Figure 2. (a) Specular Reflectance and (b) transmittance spectra of a privacy screen collected at different angles of incidence.

Figures 3a and 3b include %T spectra collected using 0˚ and 80˚ angles of incidence, respectively. %T measurements of the privacy screen were also collected at two different orientations: vertical (Figure 3c) and horizontal (Figure 3d). As is shown, the sample held at a vertical orientation transmits less light, regardless of the angle of incidence, than if the sample were positioned horizontally. Given this screen is made for a smart phone, where the device is commonly held vertically, this behavior meets expectation that less light is transmitted when viewed under this orientation, especially at wide angles.

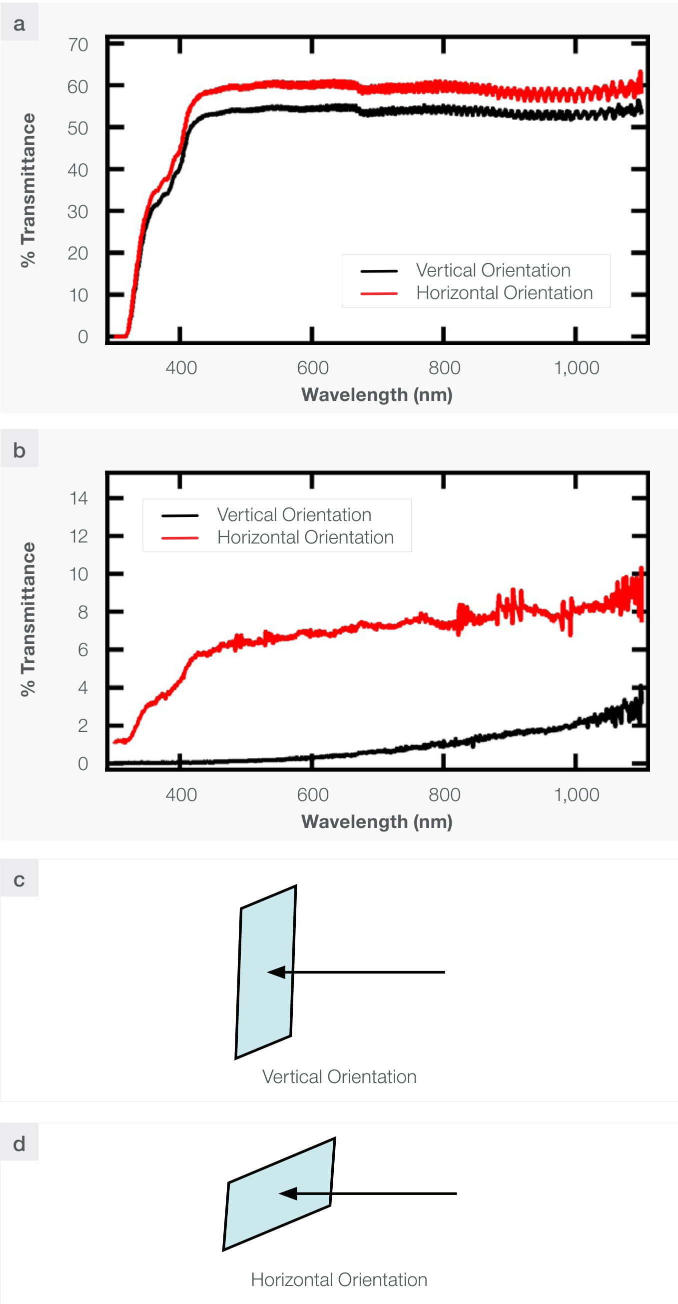

Figure 3. Orientation dependence of the transmission spectrum of a privacy screen oriented vertically (black) or horizontally (red). The sample was measured using a (a) 0˚/normal and (b) 80˚ angle of incidence. Diagrams depicting the difference between vertical (c) and horizontal (d) orientation. For both diagrams, the arrow indications the direction of the incident beam.

The orientation dependence of the privacy film sample is similar to the behavior a polarizer exhibits. A polarizer is an optical component often used in spectroscopic measurements. Polarizers allow light of a given polarization to pass through while rejecting light of different polarizations. These materials are highly orientation dependent, such that rotating the polarizer changes the allowed transmittable polarization (Figure 4).

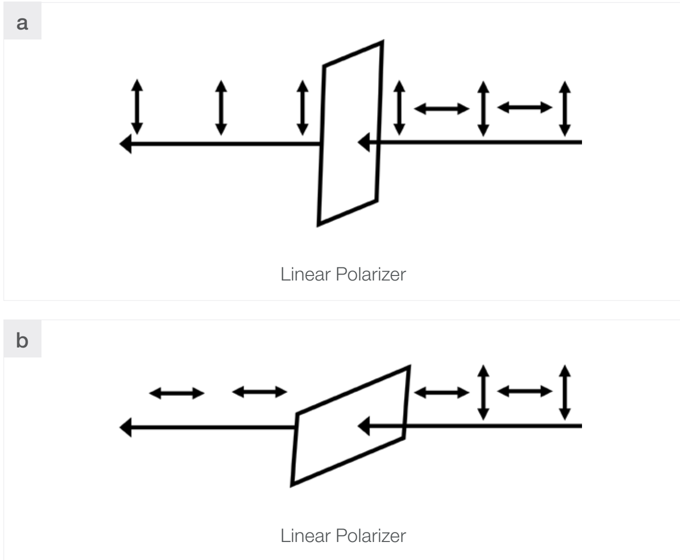

Figure 4. Depiction of how a polarizer only allows light of a specific polarization to transmit. As is shown, the orientation of the polarizer affects what polarization is allowed to pass.

In the context of samples, polarization can also have an impact on the measured absorption spectrum. For both solution- and solid-phase samples, molecules can absorb light of varying polarizations differently. Often, this behavior is dependent on the molecule's orientation.[8] The ability for molecules to "tumble" in solution effectively allows for the sample to remain isotropic. This behavior prevents orientation effects from influencing the overall measured spectrum. However, polarization dependence can be present in a variety of solid-state samples where the compounds cannot freely rotate like they would in solution. Because this degree of freedom is lost for solids, the orientation of the compounds within the matrix can affect the measured spectrum; rotating the sample can change the observed spectrum. As a result, it is generally helpful when analyzing solid-state samples to collect data at more than one sample orientation as a check to determine if perceived differences in spectra are a product of polarization-dependence.

Conclusions

Herein, the ability to measure %R and %T spectra of film samples at varying angles of incidence was demonstrated using the Evolution instruments with appropriate accessories. By increasing the angle of incidence, the %R spectrum was found to increase while the %T spectrum was found to increase, meeting the expected results for the privacy screen. Furthermore, the orientation dependence observed highlights the need to ensure solid-state samples are reproducibly placed when measured.

References

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