Advanced window coatings for drone and ground based applications

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ABSTRACT

Advanced window coatings being developed for drone applications need to be multi-functional. A typical window design includes a hydrophobic outer coating, a solar filter rejecting unwanted spectrum, an EMI layer and/or heater to prevent icing and anti-reflection films. Hydrophobic and hydrophilic thin film materials are available from various vendors. We present our experience in using these materials and their comparative performance with respect to film adhesion and durability. The window can be a common aperture for several different sensors. Adding an EMI shield using a transmitting conducting oxide (TCO) is challenged when visible and NIR transmission is needed. The trade-off between required conductivity and NIR transmission is presented.

Keywords: Interference coatings, Optical windows, Drones

1. INTRODUCTION

Higher optical performance at reduced cost, weight and size are drivers for incorporating higher capability into fewer system components. The coating design for sensor windows is not limited to a simple anti-reflection coating, but can add solar blocking, stray light rejection, surface de-icing and protection from electromagnetic interference. Hydrophobic, hydrophilic and oleophobic surface coatings and treatments can be added to enhance performance in harsh environments. The overall coating design is developed to accommodate each of the films used to meet a particular performance criterion and maximize in-band transmission and off-band rejection of stray light and heat.

A sensor system may use a common aperture for multiple spectral bands and the widow design needs to be optimized for each band with minimal compromise to the other sensor bands. Each coating requirement is developed as separate film structures and deposited with matching layers to produce an optimized solution. Consideration of potential weaknesses in coating materials is taken into consideration with the final optimized design. An example of such a consideration is when considering the use of a hydrophobic or hydrophilic surface treatment. The underlying coating is designed to function well with or without the treatment. This allows continued operational use of the window even in the event the relatively soft hydrophobic surface treatment fails with time.

A window coating is custom designed to the specific requirements of the sensor. Figure 1 presents a schematic of an example coating structure for a window offering several of these thin film characteristics. The substrate is fused silica and is initially coated with a hard oxide multilayer coating. In this example the coating passes the visible band and a laser communications band at 1550 nm while blocking the near infrared. The coating is designed for maximum transmission in the two pass bands with and without the addition of a hydrophobic outer coating.

The second surface of the window is coated with a thin layer of indium tin oxide (ITO), a set of electrodes and a final protective layer and anti-reflection film. The ITO layer is designed for a resistivity of 300 ohms and acts as a heater to maintain the temperature of the window approximately 20^{o} C above ambient to prevent icing and condensation.

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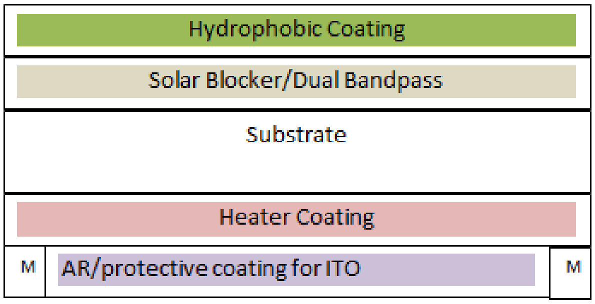

Figure 1: An example schematic of a multi-function window design is presented. Function is provided by individual film stacks optimized for final filter performance.

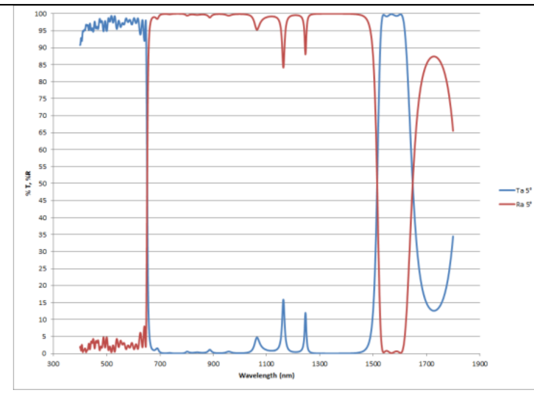

Figure 2: Spectral reflection and transmission for the window configuration shown in figure 1 is presented here. The window passes the visible and 1550nm range and rejects the NIR out to 1800nm.

2. DESIGN OF THE OUTER SURFACE COATINGS

The challenge of the outer surface coating is that it must maintain required performance despite exposure to weather. While the relative air speed of rain and dust is low to moderate for drone and ground based sensors, film hardness is nevertheless an important consideration. The outer coating is designed as a broad bandpass for the sensor. Rejecting the bulk of unwanted light at the outer surface of the window significantly reduces the potential for scattered light and ghost images within the sensor. Narrow bandpass filters within the sensor and behind the window can precisely define the passband without having to reject the full off-band spectral range.

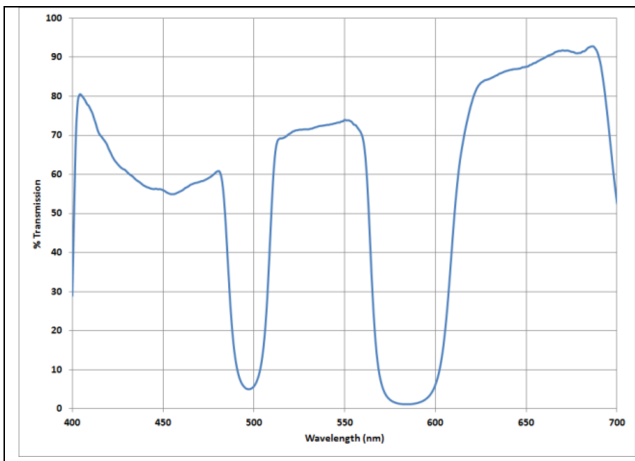

Figure 3: Spectral scan for a tri-stimulus filter used to improve color saturation of a low cost color CCD. The filter provides better RGB separation and color balance.

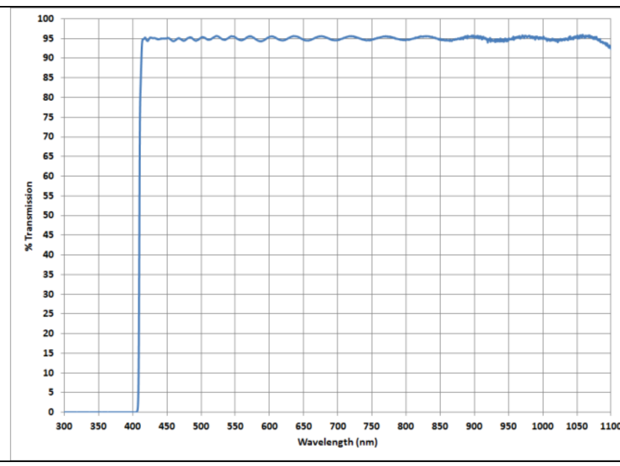

Figure 4: Long pass visible filter with strong UV rejection to improve image sharpness and extend camera life by rejection of the UV. Rejection of out of band spectrum at the window eliminates the need to handle it as stray light in the sensor.

The outer broad bandpass coating is fabricated using hard oxide layers and a plasma assist. This process densifies the films preventing water absorption and any resulting shift in performance with changes in humidity. An alternate approach to hardening the window to wind abrasion is to sandwich or laminate the bandpass filter to a sapphire outer window. In this configuration the film is designed to match the refractive index of the epoxy and reflected light passes efficiently out of the senor.

Figure 2 through 4 present examples of the outer surface coating designs. Figure 2 presents a dual bandpass coating for the visible spectrum and a 1550nm laser communications link. The coating provides high near infrared rejection greater than OD5. The laser communication channel includes a narrow bandpass filter to precisely tune the laser pass band and maximize signal to noise. Figure 3 presents a tri-stimulus filter used to enhance the Bayer filter response of a color CCD sensor and provide color balance. The filter rejects light where the Bayer filter regions cross over and the result is higher color saturation. Figure 4 presents a longpass sensor band filter with strong UV blocking to improve image contrast and focus across the visible spectrum.

3. HYDROPHOBIC AND HYDROPHILIC COATINGS

Hydrophobic coatings cause a water droplet to bead up and either roll or blow off the window. A hydrophilic coating causes the coating to wet the surface and form a relatively uniform layer across the surface. Hydrophobic coatings are preferred for drone applications where there is a wind blowing across the window. Hydrophilic coatings are preferred where the sensor is stationary such as ground terminals.

Hydrophobic coating materials fall into two categories: organic and inorganic materials. Organic materials are polymers and while they offer high contact angles, they are soft and may be prone to degradation from UV exposure. Inorganic options such as aluminum oxide are much more stable and cleanable over time, but do not offer the higher performance of the organic options.

An outer layer of aluminum oxide can be used as an intermediately performing hydrophobic [1]giving a surface angle of 67 to 70^{o}. Aluminum oxide contact angle can be modified by the deposition process. Table 1 reports our findings that the contact angle can be significantly reduced from 67^{o} to 27^{o} by post deposition plasma conditioning. Aluminum oxide nano-particles have been reported to allow for surface tuning from hydrophobic to hydrophilic[2].

The materials we have evaluated are listed in tables 1 and 2. We have generally followed deposition instructions offered by the material vendors or in literature, but emphasize that these results may be improved with further deposition process development and present only our experience with these materials. Table 1 summarizes the method we used to deposit each material. Table 2 presents results for adhesion and 24 hour humidity. Several of the hydrophobic materials passed the standard tape test by virtue the tape not sticking to the surface.

Figure 5 presents an overlay of measured transmission for an uncoated substrate and a substrate coated with WR4. The material's refractive index is well matched to that of glass. Figure 6 presents a photograph of water droplets on uncoated glass. Figure 7 presents a photograph of water droplets on a substrate coated with aluminum oxide and figure 8 presents water droplets on a substrate coated with WR4 and highlights the difference between inorganic options like aluminum oxide and polymer based coatings.

Table 1: Hydrophobic Coating Materials/Processes

Material	Process	Contact Angle (CA)	Comment
Al_2O_3	E-beam with IAD	67.25	Tough outer layer
Al_2O_3	MagnetronSputtered with plasma	67.4	Tough outer layer
Al_2O_3	Sputtered + 5 min post plasma	40.25	
Al_2O_3	Sputtered + 15 min post plasma	27.0	Comparable to bare glass
Umicore[3]TopCoat	Resistive boat	92	
Umicore[3] EverClean	Resistive boat	115	10 -15^{o} roll
EMD Substance WR4[4]	Resistive boat, no heating	115-117	10-15^{o} roll Exhibits oleophobic surface
Phelly H-202[5]	Resistive boat – sensitive to substrate temperature (115 C)	>125	<5^{o} roll angle

Table 2: Hydrophobic Coating Test Results

Material	Contact Angle (CA)	Tape	24hr Humidity 810E	Tape	Abrasion
Al_2O_3	67.4	Pass	Pass	Pass	Passes severe abrasion (>40 full strokes)
EMD Substance WR4	115-117	Pass (tape doesn't stick to coating)	Pass: CA remains at 115. Slide angle seems to be better	Pass, no change	Passes severe abrasion (>40 full strokes)
Umicore Everclean	>115	Pass (tape doesn't stick to coating)	Pass	Pass, no change	Passes severe abrasion (>40 full strokes)
Phelly H-202	>125	Not tested	Not tested, but eventually failed while in a humid climate.	Not tested	Not tested

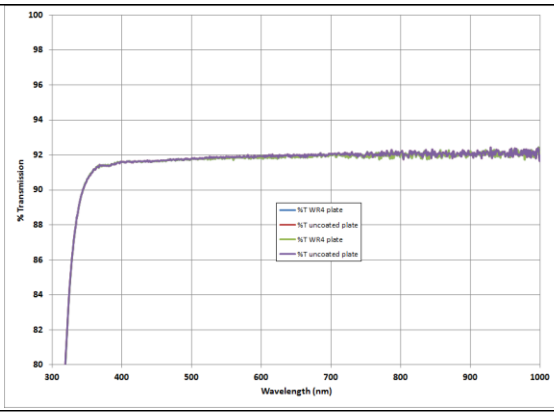

Figure 5: Transmission of an uncoated substrate and a substrate coated with substance WR4 are overlaid.

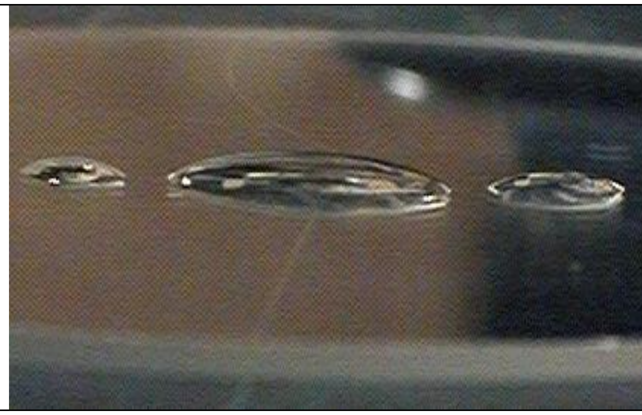

Figure 6: Water droplets on an uncoated window.

Figure 7: Water droplets on an Al_2O_3 coated window

Figure 8: Substance WR4 on a borofloat substrate

4. HEAT MIRRORS, HEATER AND EMI COATINGS

The window can also be configured with an optically transparent heater to prevent condensation and ice formation. The heater consists of a thin layer of a transparent conductive coating (TCO). Figure 9 presents a photograph of a heater designed to hold the window temperature 20° C above ambient temperature with a power dissipation of 1 watt. Figure 10 is an infrared photograph of the heater in operation demonstrating good thermal uniformity across the window surface. The heater is typically placed on the inner surface of the window and is anti-reflection coated to maximize throughput and also to protect the transparent conductive layer.

A transparent conductive layer, in this case indium tin oxide (ITO) can also be used to act as an EMI shield to isolate and prevent electromagnetic interference from passing through the window. For a heater application, the resistance is typically in the range of 150 to 350 ohms/sq. For an EMI shielding application, the resistance is typically in the range of 10 to 30 ohms/sq. Specific coating resistance can be tailored to the available power supply.

Figure 11 presents measured reflection for an ITO coating used as a heat mirror designed for a silicon based sensor. ITO has the spectral property of high transmission in the visible and near infrared while having strong reflection through the long wave infrared. The property can be used on the sensor window as a heat mirror. The ITO layer reflects longwave heat radiation thus reducing the heat load on the sensor.

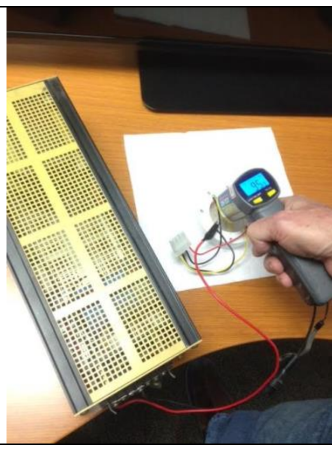

Figure 9. Photograph of the test heater window coated with transparent conductor. At 12 volts, the heater runs 20° over ambient with power consumption of 1W

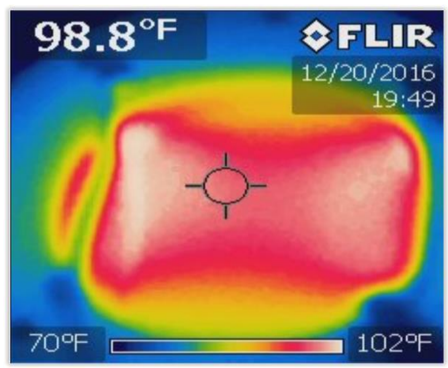

Figure 10. Infrared photograph of the heater demonstrating good thermal uniformity across the window surface.

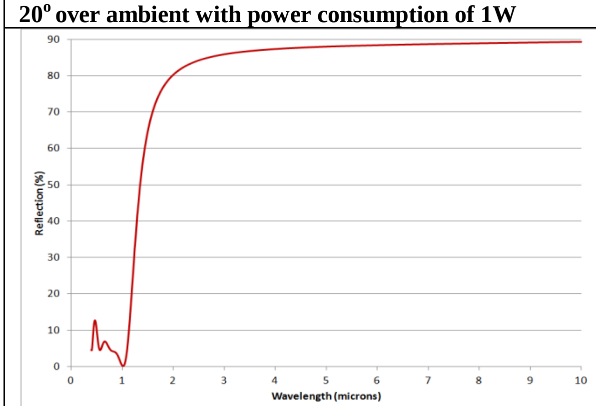

Figure 11. Spectral performance of ITO coating showing reflection of IR wavelengths for use as a heat filter. The use of an ITO heat film on the sensor window provides good longwave rejection of solar radiation for silicon based sensors.

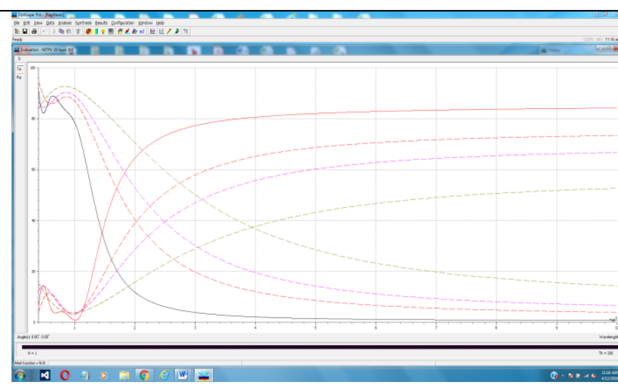

Figure 12: ITO reflection and transmission are plotted for thickness of 45, 75, 100 and 200 nm. Film thickness and composition control transition edge wavelength and resistivity allowing for optimized heater and EMI coating layers.

The electrical resistance of an ITO film and its spectral properties is controlled by the relative ratio of indium to tin oxide and the thickness of the film layer. When a particular film resistance and NIR transmission is required, the film properties must be optimized for both requirements. Figure 12 presents the design trade-off in performance when NR transmission is required and film thickness is used to control the transmission to reflection transition edge.

5. SUMMARY

Sensor performance can be significantly enhanced by incorporating multi-functional capabilities in the outer window. Placing out of band rejection coatings on the window reduces the need to handle stray light within the sensor reducing the need for stray light baffles and heat control. Hydrophobic coatings can be added with little or no impact on transmission through the visible and NIR spectral regions. The outer hard oxide coating can be designed to perform well with and without the presence of the hydroscopic coating and therefore maintain performance even if the hydroscopic coating should fail.

Condensation and surface ice can be controlled using a transparent conductive oxide layer. We have demonstrated development of an ITO heater layer that offers better that 90% transmission at 1550 nm and a 20^{o} temperature increase over ambient with a power consumption of 1 watt. ITO coatings can also be added to provide EMI shielding.

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