Reflection Properties of AR Coated Flat and AG Glass Surfaces

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Information displays are common in modern vehicles and their use, size and form factors continue to increase. Display visibility in sunlight remains an issue even with the use of anti-glare glass, which breaks up the specular reflection, but does not reduce the overall intensity of reflected light. Aircraft cockpit displays require both anti-reflection (AR) and anti-glare (AG) functionality to provide optimum viewability. The same design considerations apply to the automotive use case. The use of touchscreen panels requires an effective oleophobic (anti-fingerprint) treatment to maintain appearance and for ease of cleaning.

The CIE 1976 L*a*b* color space is commonly used to numerically describe color. Color is expressed as three numerical values, L* for the lightness and a* and b* for the green–red and blue–yellow color components.

The difference between two colors is useful for the purposes of evaluating color match or perceived differences in color. This can be expressed mathematically as ΔC (or ΔE if lightness is included). It is generally accepted that the threshold for a noticeable color change is about deltaC ~ 2.2.

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

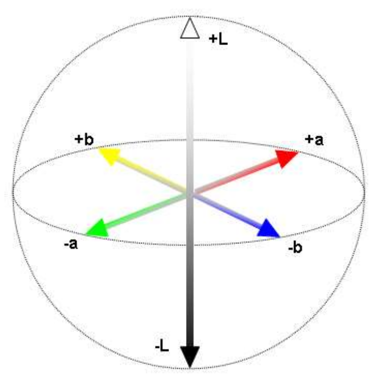

Figure 1: Graphical Representation of CIE 1976 L*a*b* color in 3-dimensional space

The reflected color and color shift when changing viewing angle are critical considerations when designing a thin film anti-reflection coating for avionic or automotive displays. This reflected color is most noticeable most when the display is off. The position of the sun with respect to the observer and associated viewing angle changes with vehicle position and the time of day, among other factors. It is critical to maintain a consistent reflected color over a wide range of angles to ensure pleasing display aesthetics and meet the demands of interior designers.

An optimized AR coating with integrated oleophobic (anti-fingerprint) properties coated onto AG glass surfaces provides the optimal solution for reducing glare from touch panel displays. The design approach is to create a broadband visible anti-reflection (AR) coating with a nominal blue-green reflected color which maintains low color saturation across a wide range of incident angles. The theoretical reflected color for this coating design is shown in Table 1. ΔC is kept below 2.2 between the most extreme viewing angles.

Table 1: Nominal Coating Design Color Values

Incident Angle	Y	a*	b*	ΔC
10	0.21	-0.85	-2.89	ref
20	0.20	-0.75	-1.83	1.06
30	0.26	-0.91	-0.17	1.67
40	0.54	-1.45	1.54	1.79
50	1.38	-1.36	1.64	0.13
60	3.84	-0.25	0.19	1.83

The coating design proposed in Table 1 was produced by MAC Thin Films, Inc. The measured properties were found to be in good agreement with theory as shown in Table 2.

Table 2: Actual Measured Values

Incident Angle	Y	a*	b*	ΔC
10 deg	0.23	-1.70	-3.84	ref
20 deg	0.17	-0.79	-2.99	1.25
30 deg	0.16	-0.05	-1.53	1.64
40 deg	0.30	-0.23	0.27	1.81
50 deg	0.86	-0.83	0.50	0.64
60 deg	2.87	-0.12	0.08	0.82

Thin film AR coatings are comprised of multiple layers of high and low refractive index materials with each individual layer typically < 150 nm. Critical control of the thickness of each layer is required to achieve the designed visual functionality. Fingerprints on the coating can change the AR behavior. A successful design approach requires an anti-fingerprint treatment to reduce the transfer of skin oils to the display and allow for them to be easily cleaned from the surface.

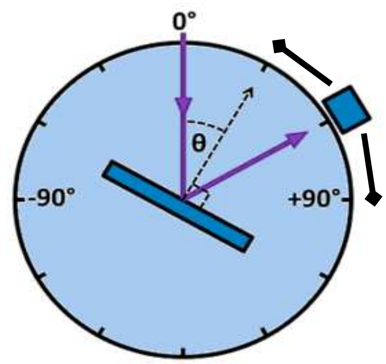

Figure 2: Measurement configuration

The measurements of the reflected light scattered from the AR coating on AG glass were made according to the setup shown in Figure 2. The nominal angle of incidence is represented by theta (θ). The collection aperture is moved at "+" and "-" angles from primary incident angle to collect the scattered light. A glass wedge and n=1.52 matching oil were used to eliminate the second surface reflection and simulates the case of an optically bonded display.

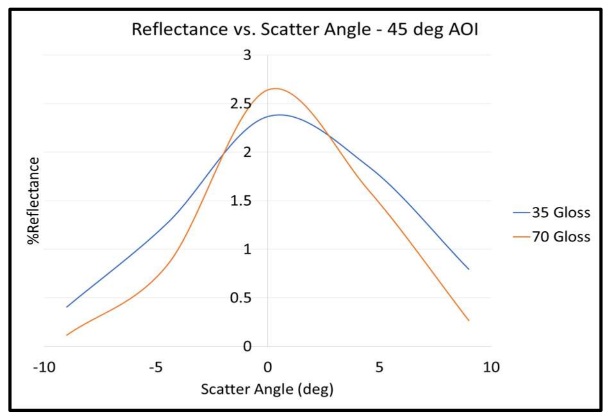

Figure 3: Scatter behavior by gloss value

The degree of scattered light increases as the gloss value of the AG glass decreases. This is indicated by a reduced peak at 0 deg scatter angle, which represents the specular component of the reflected light, as shown in Figure 3. A corresponding increase in the proportion of the reflected light at larger scatter angles was observed.

The ratio of diffuse (Rde) to total (Rdi = specular + diffuse) reflectance is a convenient way to describe the degree of light scattering of an optical surface. Figure 4 summarizes the behavior of various uncoated AG glasses as well the color neutral AR coating on 70 gloss AG glass. For uncoated AG glass, the proportion of scattered light increases with increasing incident angle in a linear manner. The addition of the AR coating significantly reduces the specular component, thereby increasing the ratio of scattered to total reflected light. The visual effect is a significant reduction and glare and an improvement in sunlight readability.

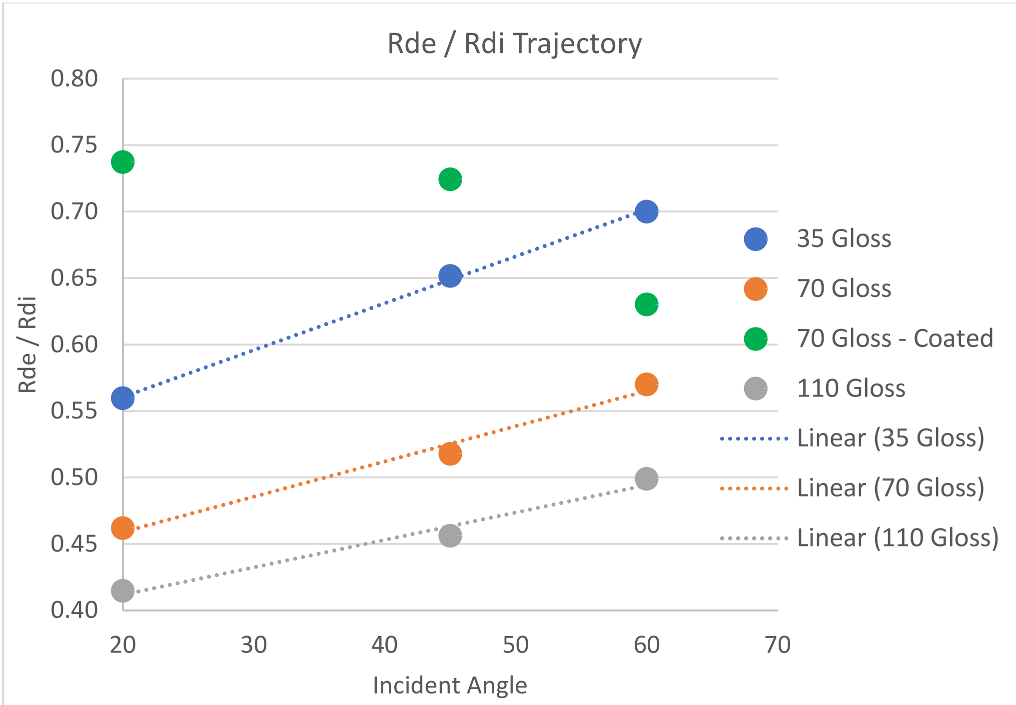

Figure 4: Scatter characteristics of AG glasses by incident angle

The measured reflected color values for the AR coated samples produced for this study are shown in Figure 5 below. The results obtained are in good agreement with the design target. The use of AG glass reduces the visible color change by scattering light at larger and smaller angles to the primary incident angle, which has the effect of blending the reflected color.

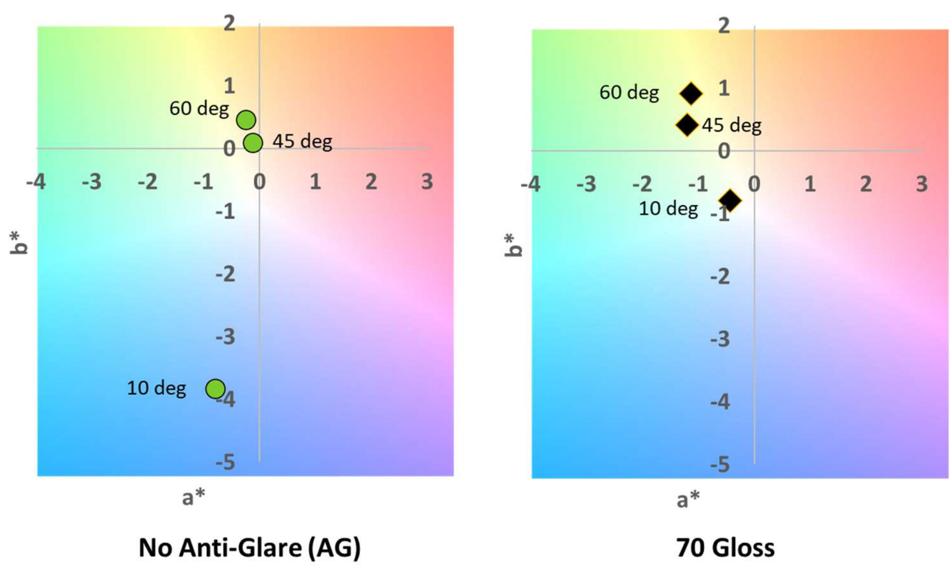

Figure 5: Reflected Color Measurements of Coated Samples

Photographic samples of the reflected color were made for the purpose of making a visual comparison and are shown in Figure 6. The uncoated glass has a neutral color but a strong reflection with Y = 4.2% and L* = 24.4. This can make the display hard to read in sunlight. A "Standard AR" coating greatly reduces the magnitude of the reflected light with Y < 0.3% and L* < 2.7, an order of magnitude reduction in apparent intensity, as indicated by a comparison of L* values. However, this coating demonstrates a noticeable red-shift in the reflected color when the viewing angle changes from 10 degrees to 45 degrees. This color shift is typical of common AR coatings in use today.

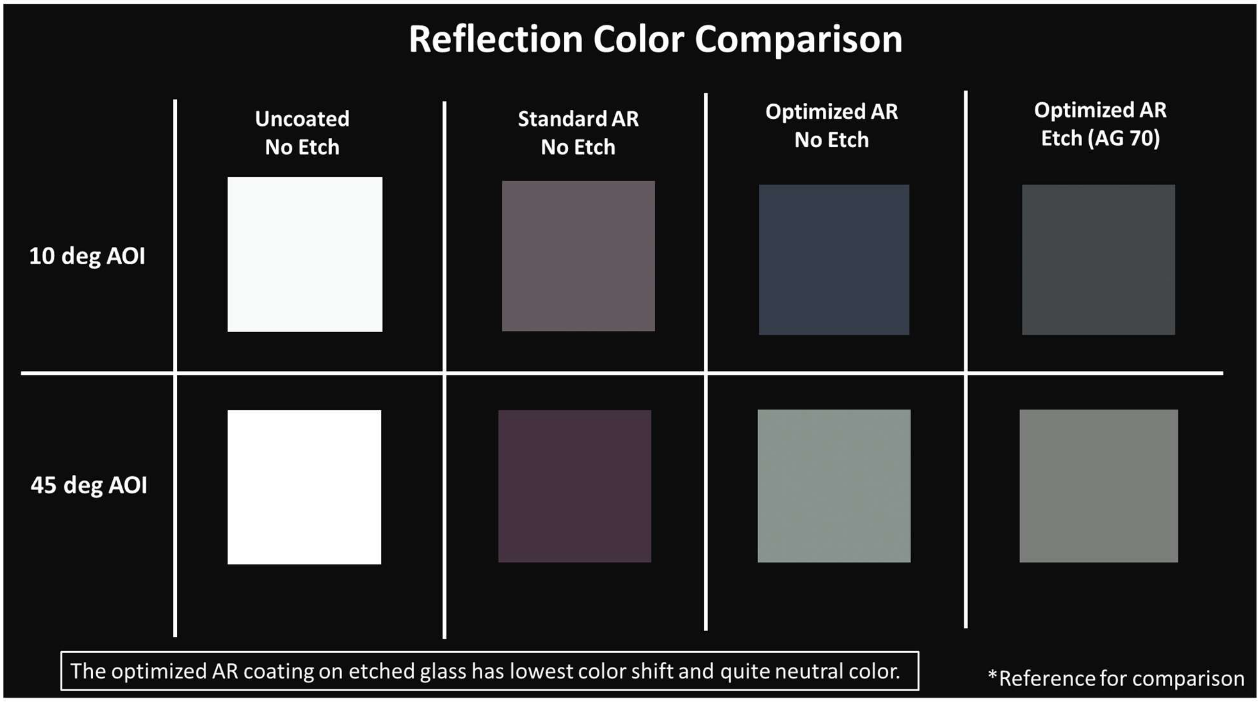

Figure 6: Reflected Color Measurements of Coated Samples

The optimized AR coating on standard flat glass maintains a blue-green reflected color over the range of viewing angles while still providing a drastic reduction in the magnitude of the reflected light. Combining this coating with an AG glass reduces the color saturation at all viewing angles.

A comprehensive AR coating design, including an oleophobic optical layer, has been developed and manufactured. This coating provides minimal color saturation and consistent color over a wide range of viewing angles. The addition of this AR coating to AG glass significantly reduces reflectance and increases the ratio of diffuse to total reflected light. Consequently, it drastically reduces glare from the sun. Like in avionic displays, automotive display viewability is optimized by the addition of an AR coated AG cover glass with effective anti-fingerprint treatment.