

Anti-Reflective and Anti-Glare Technologies for Display Applications



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SID MidWest Chapter Meeting
August 26, 2015

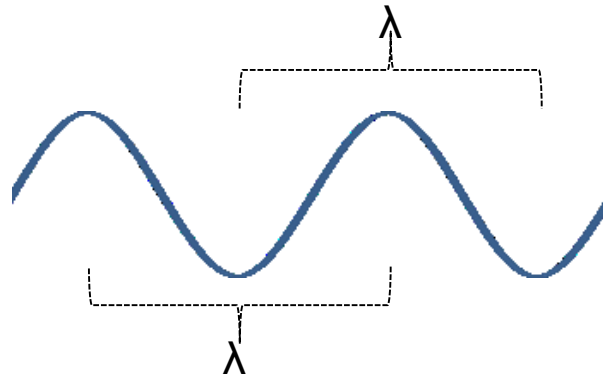
Outline

- Optics basics:
 - Why does reflection occur?
 - Color perception and measurement
- Strategies for photonic control
- Anti-glare surface modification
- Optical thin film/anti-reflective coatings
- Incorporating Tru Vue technologies into display products
- New products and developments

Why does reflection occur?

- First we might ask ourselves, what is light?

Light behaves as a wave



One Wavelength (λ) = Peak to Peak
(or trough to trough)

Light is composed of particles called photons, but these particles exhibit wave-like behavior.

Why does reflection occur?

- Light changes speed depending on the medium it travels through.
- This change of speed defines the index of refraction for that material.

$$n = \frac{c}{v}$$

c is the speed of light in a vacuum
 v is the speed of light in the medium

Why does reflection occur?

- The reflection from an interface is given by the Fresnel Equations (which account for the two possible polarizations of light):

$$R_s = \left| \frac{n_1 \cos \theta_i - n_2 \cos \theta_t}{n_1 \cos \theta_i + n_2 \cos \theta_t} \right|^2 = \left| \frac{n_1 \cos \theta_i - n_2 \sqrt{1 - \left(\frac{n_1}{n_2} \sin \theta_i\right)^2}}{n_1 \cos \theta_i + n_2 \sqrt{1 - \left(\frac{n_1}{n_2} \sin \theta_i\right)^2}} \right|^2$$

$$R_p = \left| \frac{n_1 \cos \theta_t - n_2 \cos \theta_i}{n_1 \cos \theta_t + n_2 \cos \theta_i} \right|^2 = \left| \frac{n_1 \sqrt{1 - \left(\frac{n_1}{n_2} \sin \theta_i\right)^2} - n_2 \cos \theta_i}{n_1 \sqrt{1 - \left(\frac{n_1}{n_2} \sin \theta_i\right)^2} + n_2 \cos \theta_i} \right|^2$$

Why does reflection occur?

- The magnitude of reflection can be calculated by the Fresnel Equations:

$$R_s = \left| \frac{n_1 \cos \theta_i - n_2 \cos \theta_t}{n_1 \cos \theta_i + n_2 \cos \theta_t} \right|^2 = \left| \frac{n_1 \cos \theta_i - n_2 \sqrt{1 - \left(\frac{n_1}{n_2} \sin \theta_i\right)^2}}{n_1 \cos \theta_i + n_2 \sqrt{1 - \left(\frac{n_1}{n_2} \sin \theta_i\right)^2}} \right|^2$$

$$R_p = \left| \frac{n_1 \cos \theta_t - n_2 \cos \theta_i}{n_1 \cos \theta_t + n_2 \cos \theta_i} \right|^2 = \left| \frac{n_1 \sqrt{1 - \left(\frac{n_1}{n_2} \sin \theta_i\right)^2} - n_2 \cos \theta_i}{n_1 \sqrt{1 - \left(\frac{n_1}{n_2} \sin \theta_i\right)^2} + n_2 \cos \theta_i} \right|^2$$

- Which for unpolarized near-normal light yields:

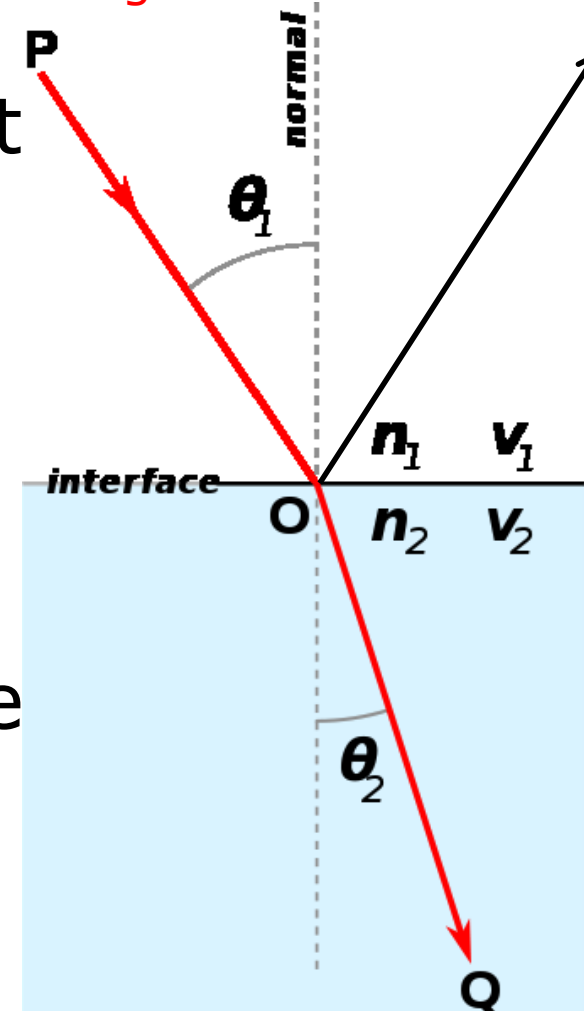
$$R = \frac{R_s + R_p}{2}$$

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2$$

Why does reflection occur?

- Reflection is the light returning from the interface with an intensity defined by the Fresnel Equations.
- Reflection magnitude is a function of the difference in indices of refraction.

Incident light Reflected Light



Transmitted light

Why does reflection occur?

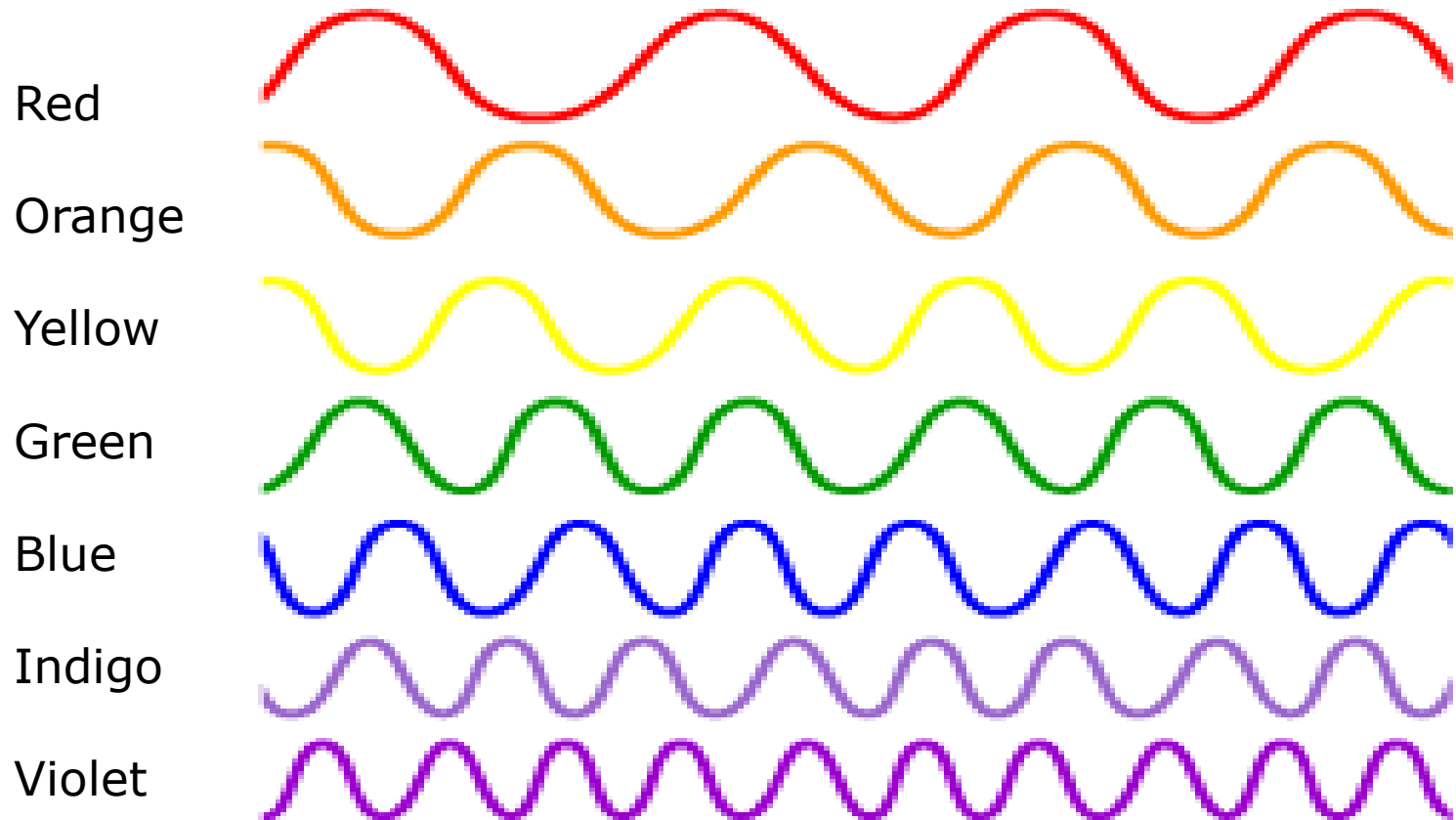
- For glass, this reflection intensity is about 4% per interface at normal incidence.
- Since light travels into the glass and out of the glass, there are two interfaces, for a total of 8% reflection.

$$R = \left(\frac{n_{air} - n_{glass}}{n_{air} + n_{glass}} \right)^2$$

$n_{air} = 1.00$
 $n_{glass} = 1.52$

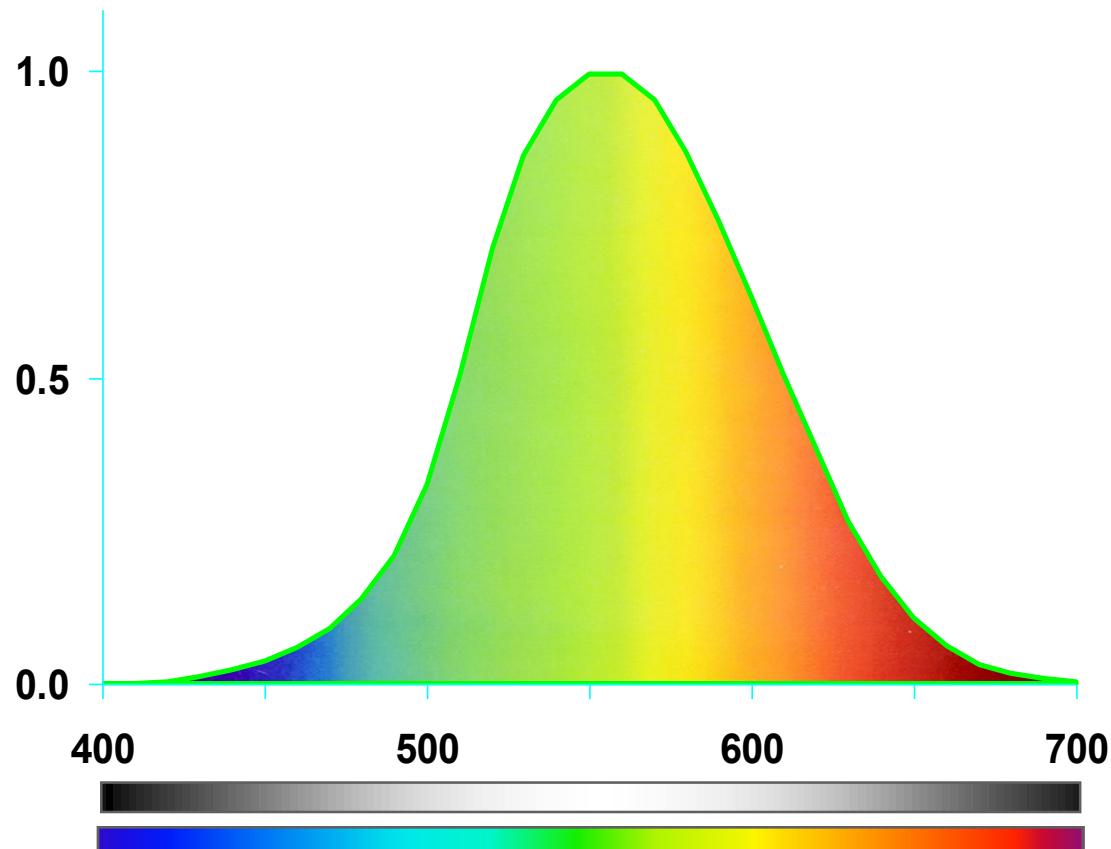
What is color?

- The wavelength of monochromatic light determines the color we see.



Human Eye Sensitivity to Light

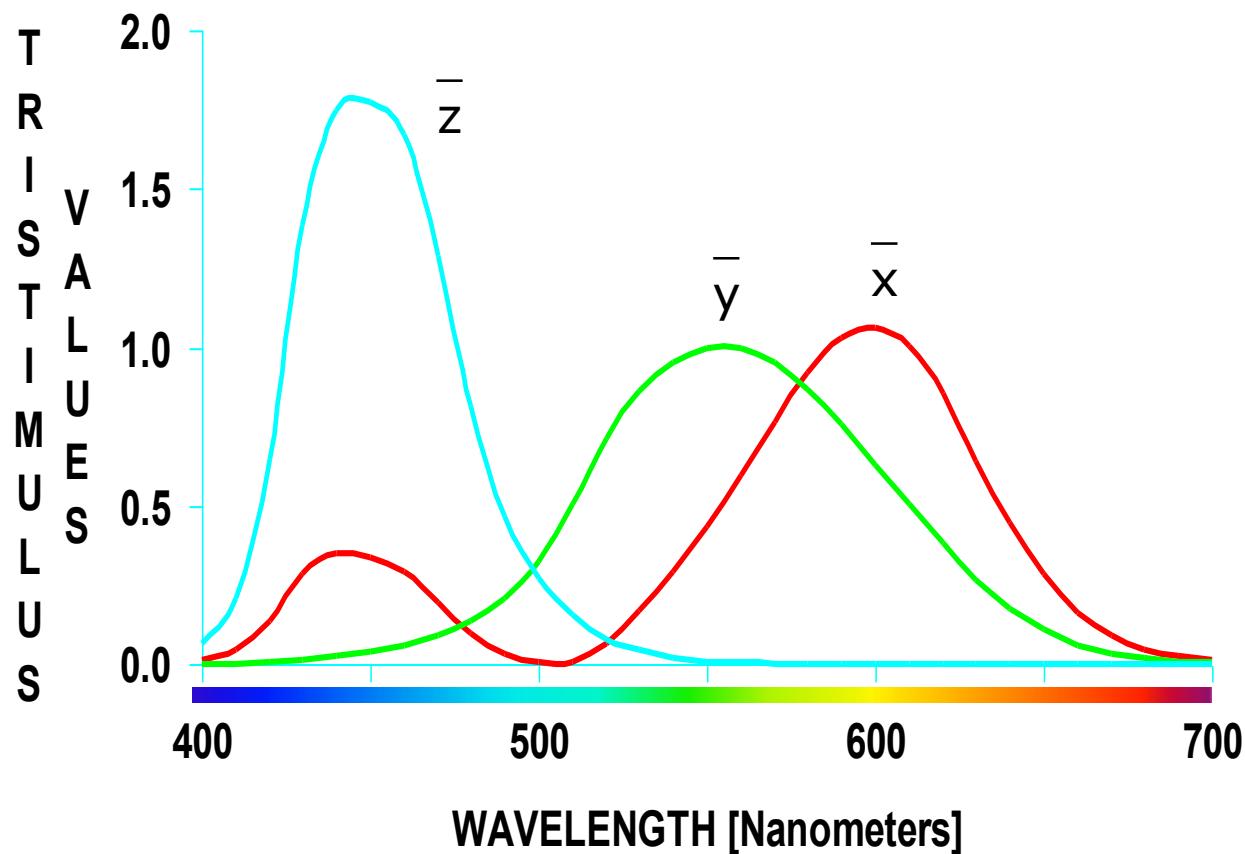
- We are not equally sensitive to all wavelengths.



Observer

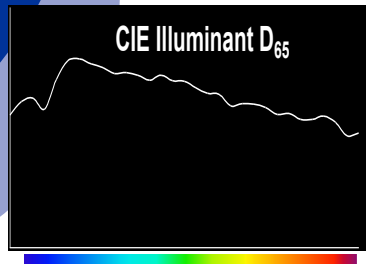
- There are three things required to perceive color: an illumination source, an object and an observer; however, our color perception is influenced by our eye's biology.
- We have **rod** (black and white) and **cone** (color) shaped light receptors.
 - There are three types of cone shaped receptors sensitive to **red**, **green** and **blue** wavelengths.
- It is necessary to quantify the eye's response to color stimulus.

CIE 2° Std Colorimetric Observer

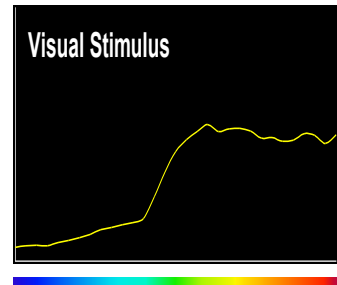


The experimentally derived \bar{x} , \bar{y} , and \bar{z} functions became the CIE 1931 2° Standard Observer. These functions quantify the red, green and blue cone sensitivity of the average human observer through comparative experimentation.

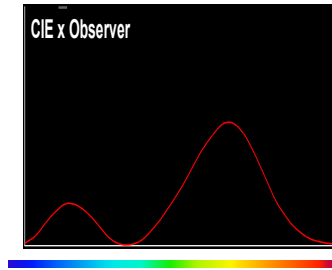
Measurement of Color



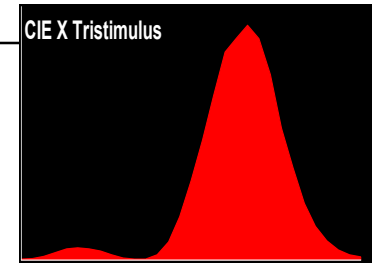
X =



X

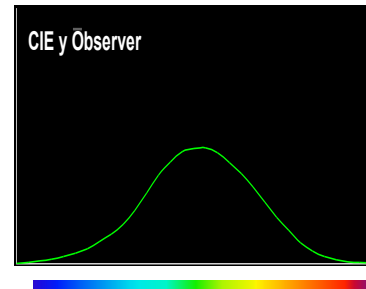


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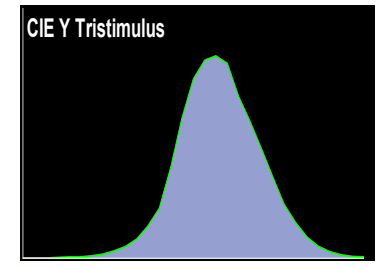


X = 41.9

X

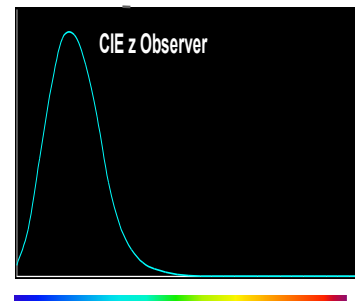


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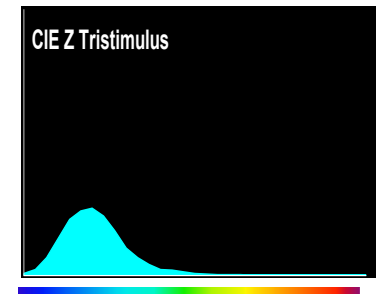


Y = 37.7

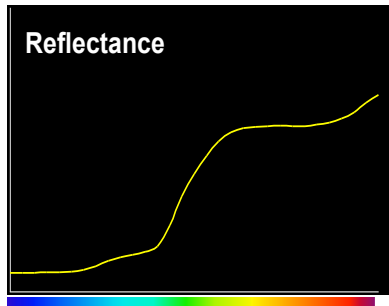
X



=



Z = 8.6

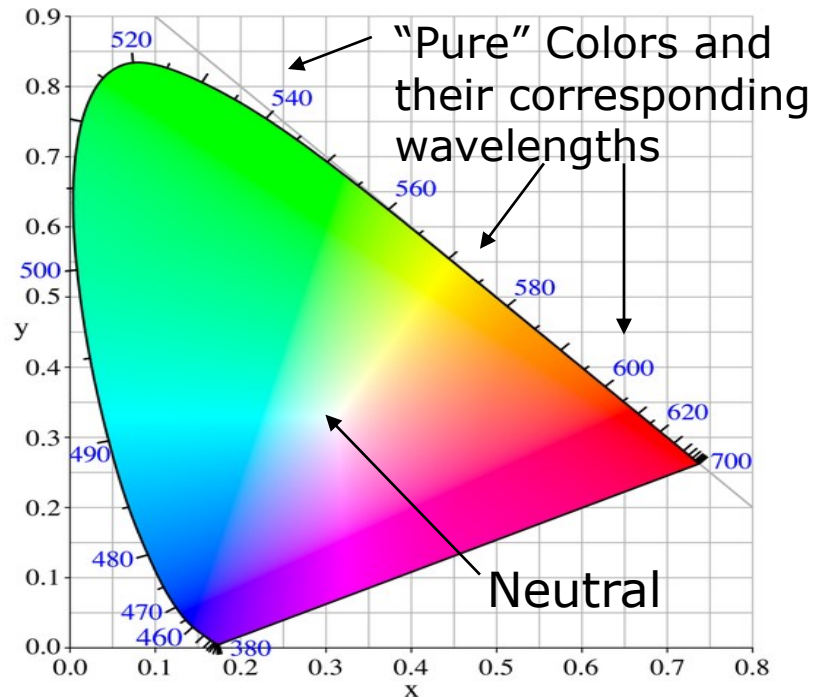


HunterLAB

So what is color?

- Color is ultimately a perception, but we can quantify the color we will perceive from a given spectral measurement allowing the development of a "color space" for color evaluation.

CIE Chromaticity Diagram



* Y, x, y is just one of several color spaces which have been developed

Why do reflection and color matter?

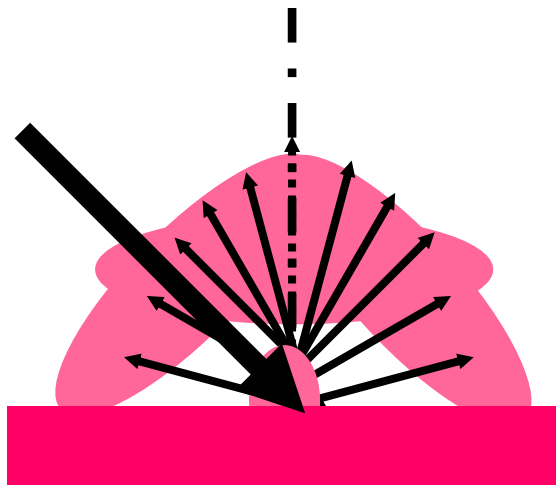
- Reflections generate competing visual stimulus making it harder to perceive images and information through transparent substrates.
- Attempts to control reflection may alter the color of the transmitted and reflected light introducing desirable or undesirable effects.

Strategies for Photonic Control

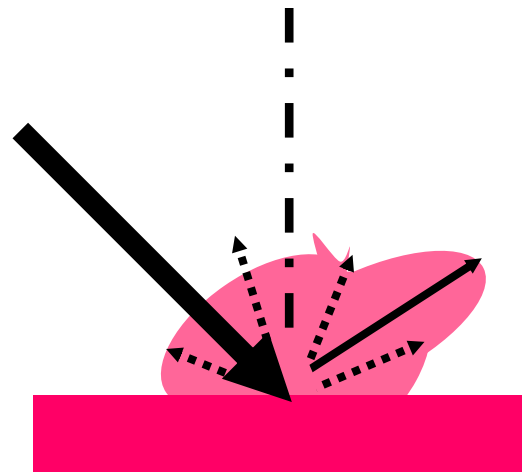
- Reflection and transmission of light can be altered through the strategic use of surface modifications.
- Options for photonic control include:
 - Scattering by surface roughness
 - Thin film optical coatings
 - Absorptive films (not discussed today)

Scattering from Surface Roughness

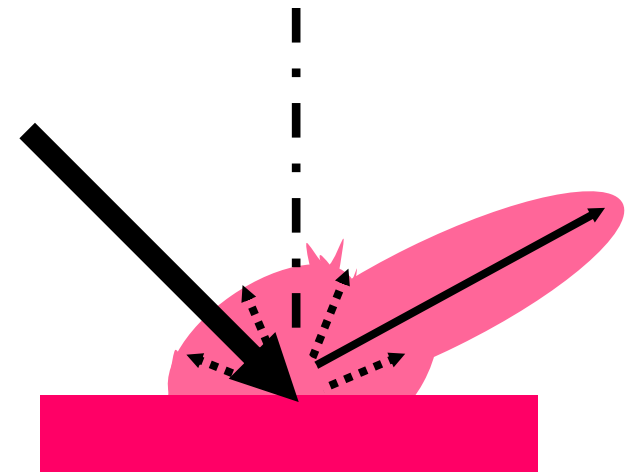
- Surface roughness can affect the distribution profile of the reflected light.



Matte



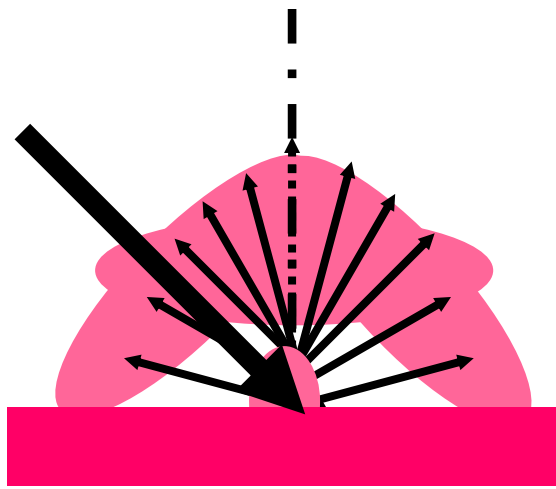
Semi-Gloss



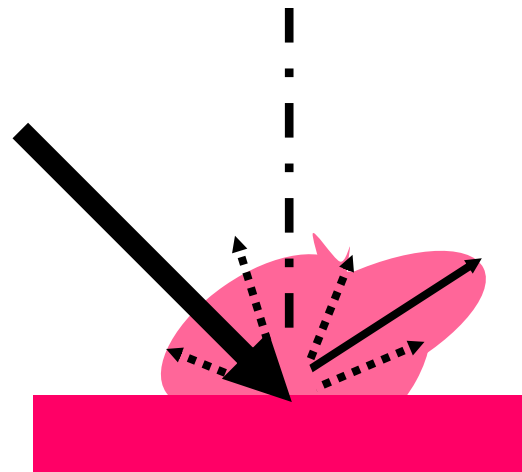
High Gloss

Scattering from Surface Roughness

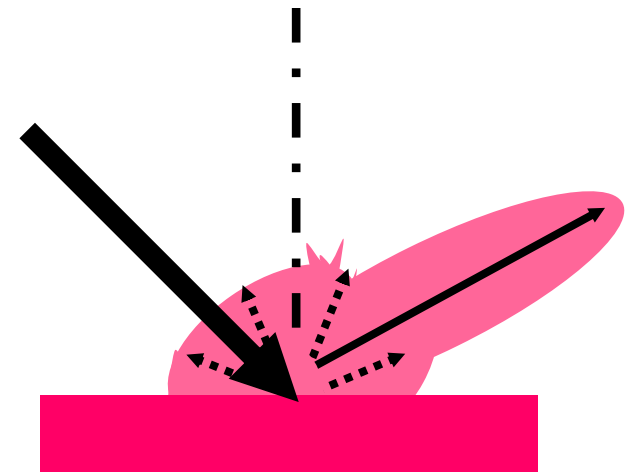
- Increasing surface roughness does not decrease overall reflection, but it does reduce the perceived intensity of reflection.



Matte



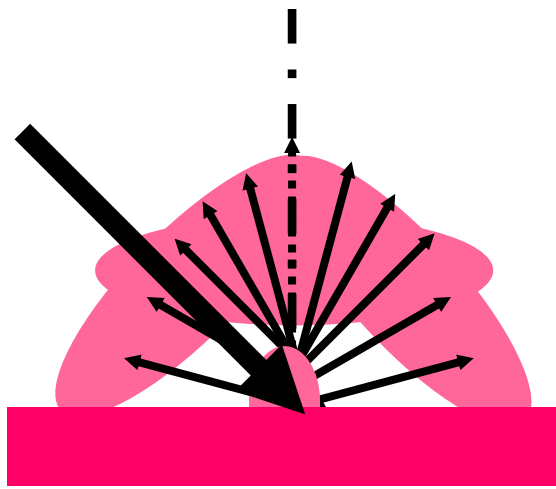
Semi-Gloss



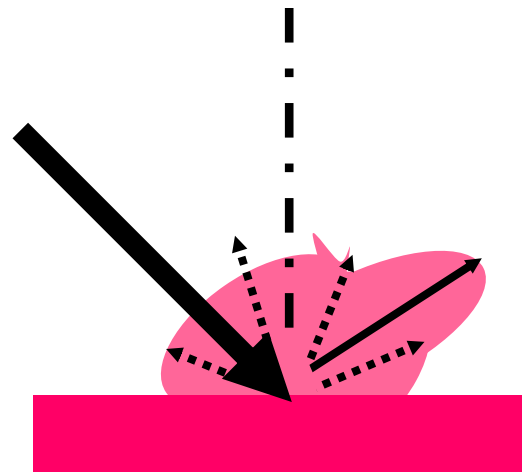
High Gloss

Scattering from Surface Roughness

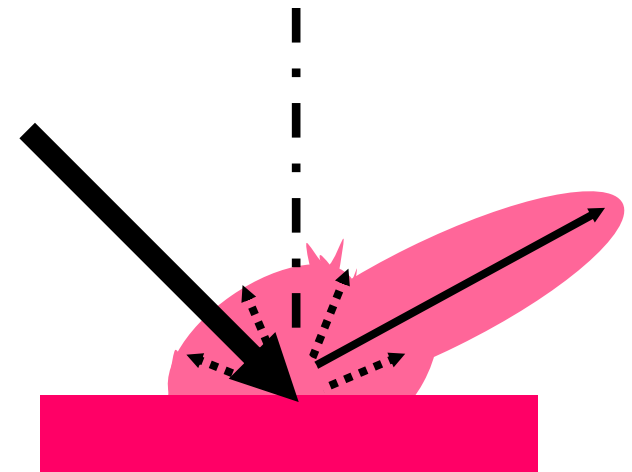
- Tru Vue, Inc. utilizes acid etched substrates with controlled surface roughness to break up the specular reflection of images and light.



Matte



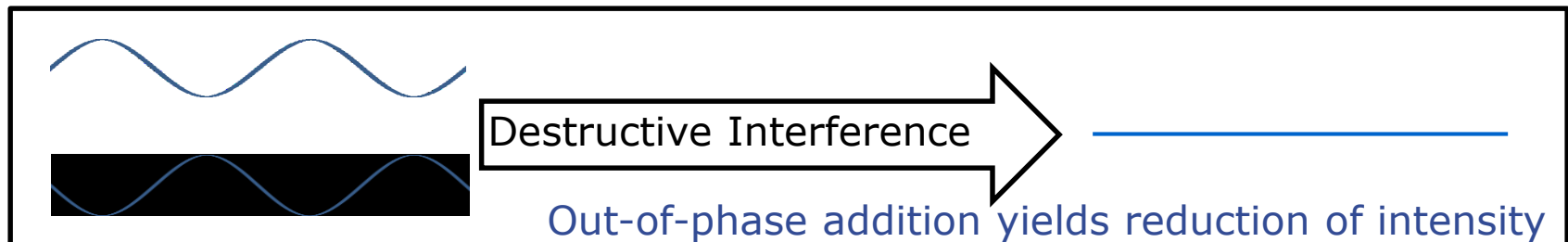
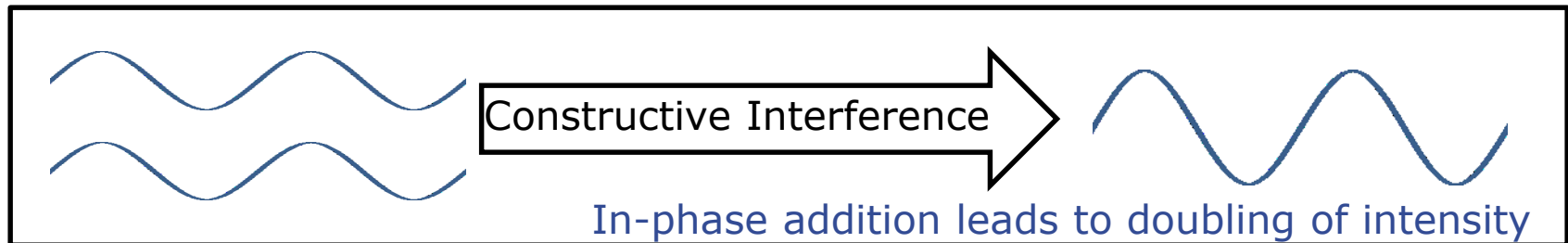
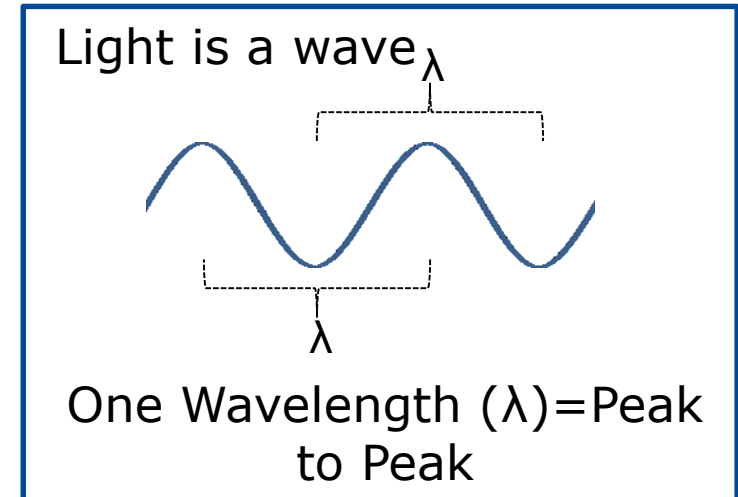
Semi-Gloss



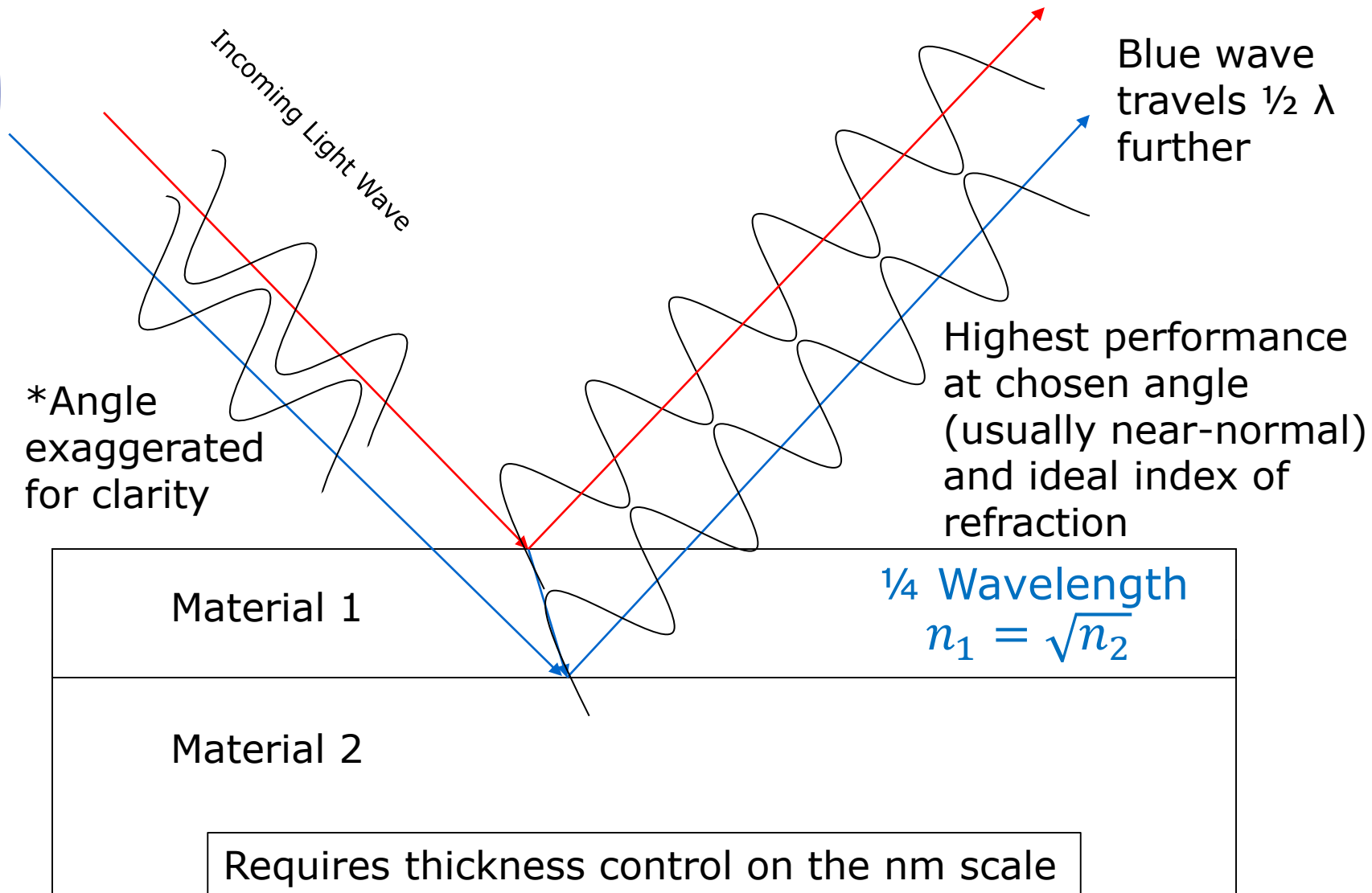
High Gloss

Optical Thin Films

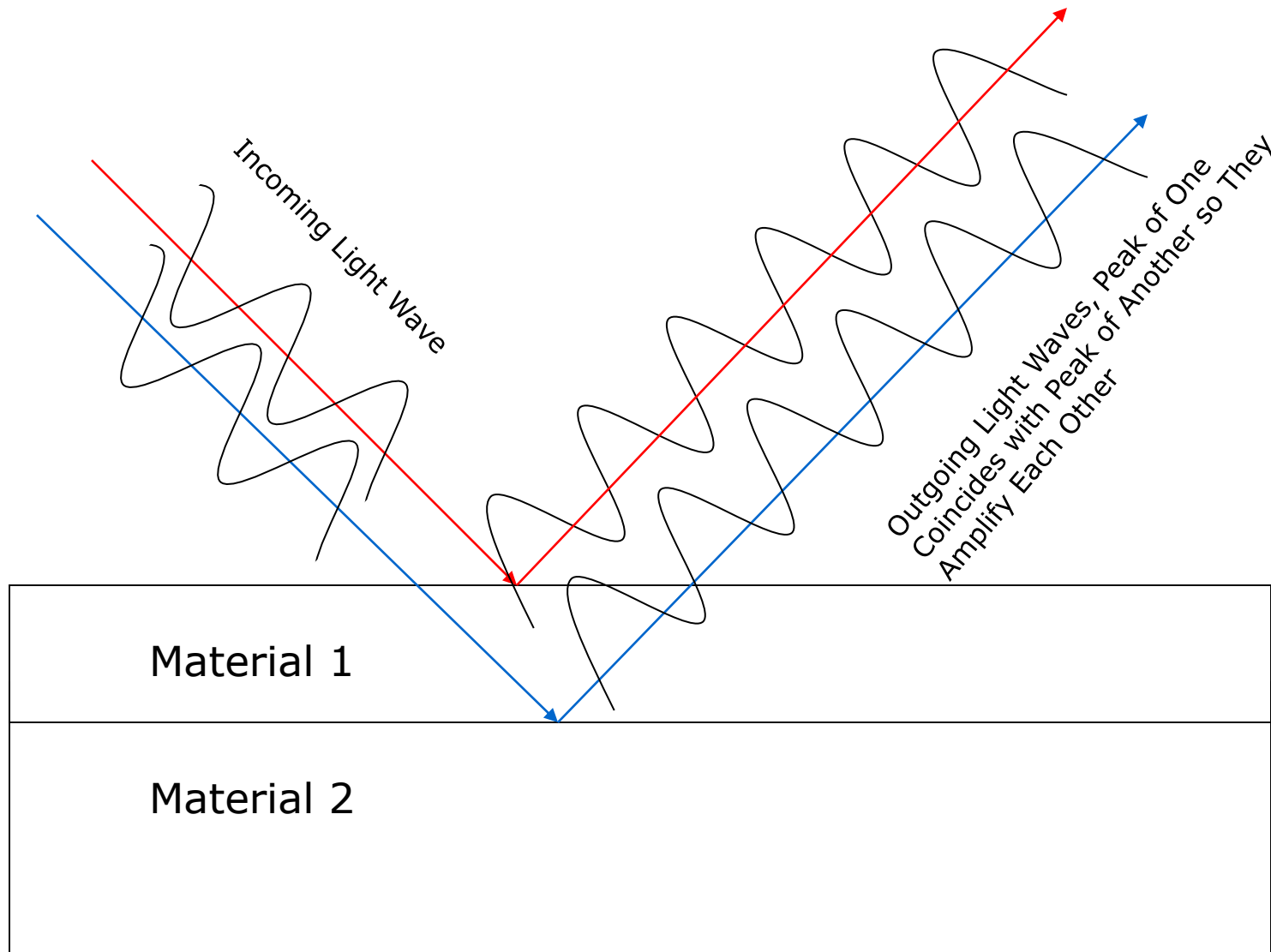
- Anti-reflective coatings are based on optical interference of light waves.
- Wave Arithmetic:



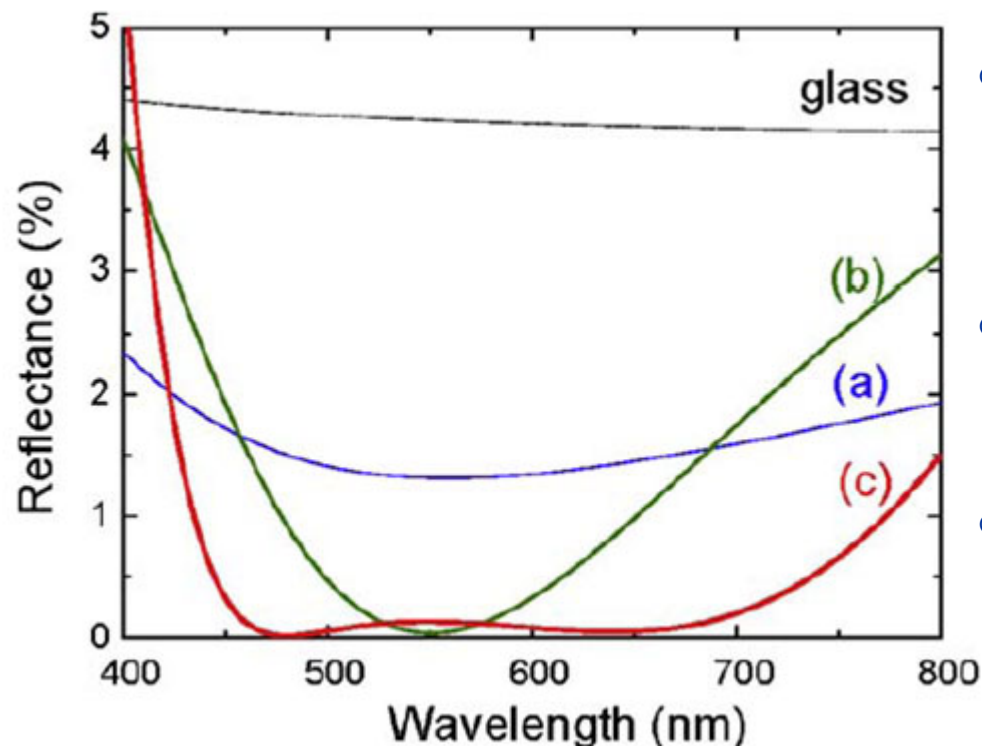
Destructive Interference – AR Coating



Constructive Interference – Mirror Coating



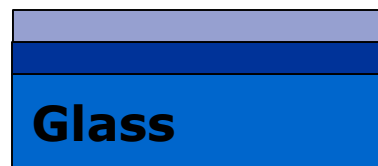
Multi-layer AR Coating Design



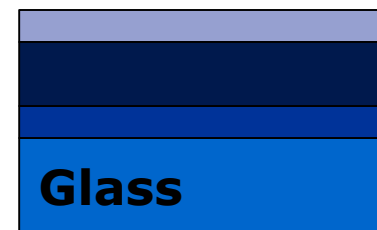
- (a) single-layer AR coating: Air ($n_0 = 1.0$) / $0.25t$ -MgF₂ ($n = 1.38$) / Glass ($n_s = 1.52$)
- (b) two-layer AR coating: Air / $0.25t$ -MgF₂ / $0.25t$ -Al₂O₃ ($n_1 = 1.69$) / Glass
- (c) three layer AR coating: Air / $0.25t$ -MgF₂ / $0.5t$ -ZrO₂ ($n_m = 2.05$) / $0.25t$ -CeF₃ ($n_1 = 1.64$) / Glass.



(a)



(b)



(c)

Large-scale optics by sputtering

- Tru Vue uses large-scale sputter coaters to deposit precision optical coatings with nanometer control.
- Similar coatings to prescription lenses, but on a larger scale.
- High durability compared with other AR deposition techniques.
- Deposit on a variety of glass and plastic substrates.

Large-scale optics by sputtering

- Sputtering utilizes magnetic fields to accelerate charged ions (often Ar^+) from a plasma into a target surface ejecting material by ballistic collisions.
- Plasma is lit and maintained by a suitably designed power supply
 - AC or DC mode
- Magnetic field forms a racetrack on the target surface

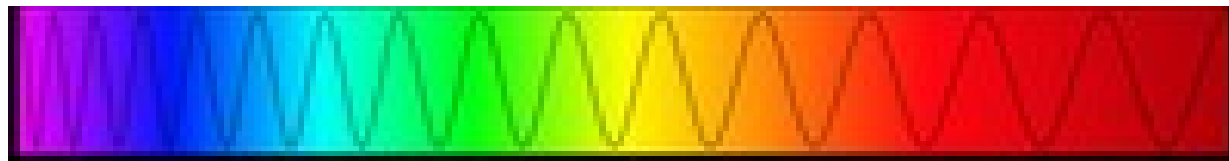
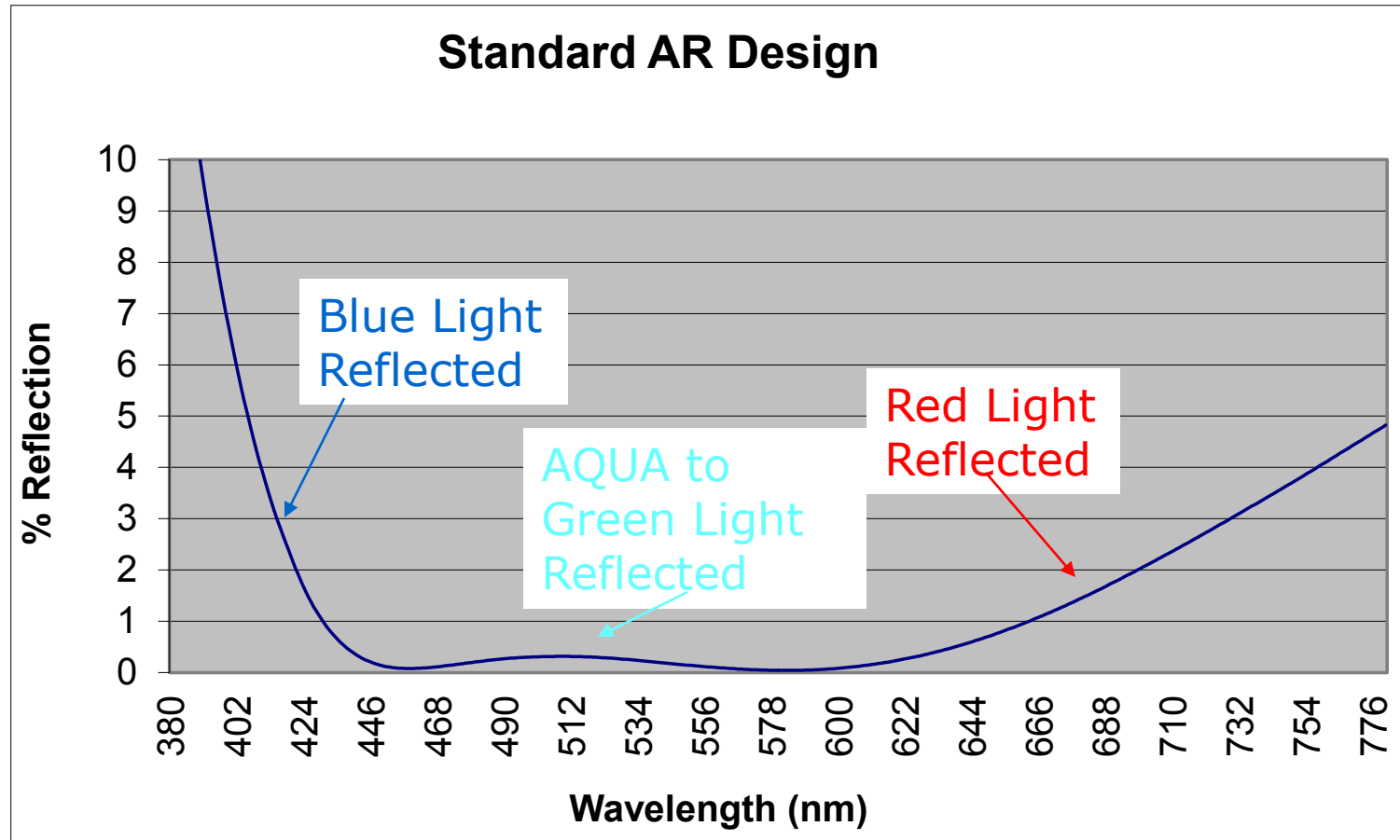
Large-scale optics by sputtering

- Reactive sputtering is the process of sputtering a metal in a reactive gaseous environment.
 - Sputtering dielectrics such as SiO_2 can be challenging, so reactive sputtering is used.
 - Also can produce nitride, fluorides and other materials not suitable for direct sputtering.
- Greatly aided by cylindrical rotating magnetrons

Coating Reflection

- The sputter process deposits target materials at (nearly) atomically controlled thicknesses to create a coating stack
- Stack design allows us to create a particular reflection spectra.
- What we refer to as the “design” is a curve or plot of the percentage of light reflected across all the wavelengths of the visible spectrum

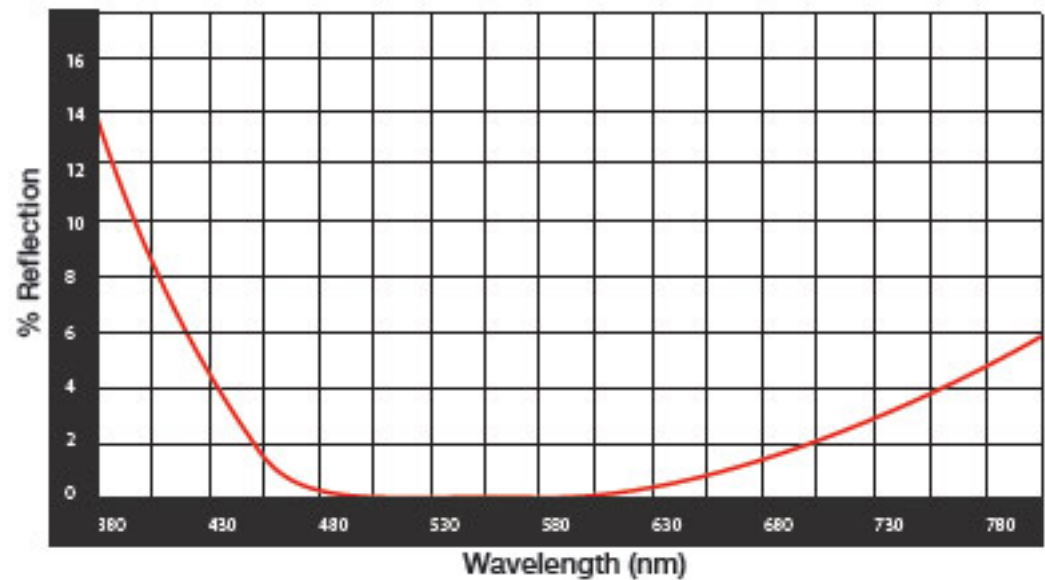
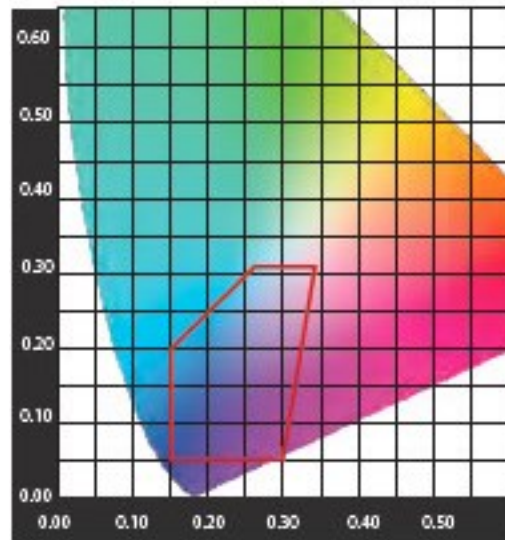
Standard Design



Low-Reflection Design

Reflectance Curve for Glass Substrates

Maximum allowable reflectance of the coated surface: $\leq 0.30\%$



The total reflectance and transmittance of a filter depends on the type of glass used, the rear surface coating, and the combination of coatings involved: The thickness of the substrate does impact reflection.

Display Enhancement Quick Guide

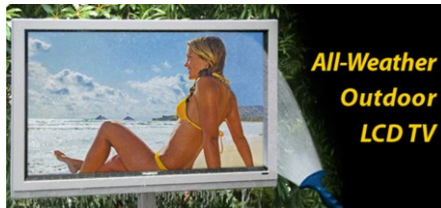
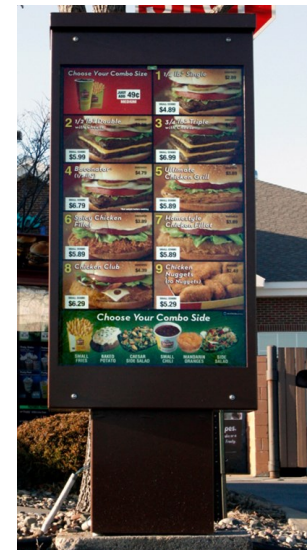




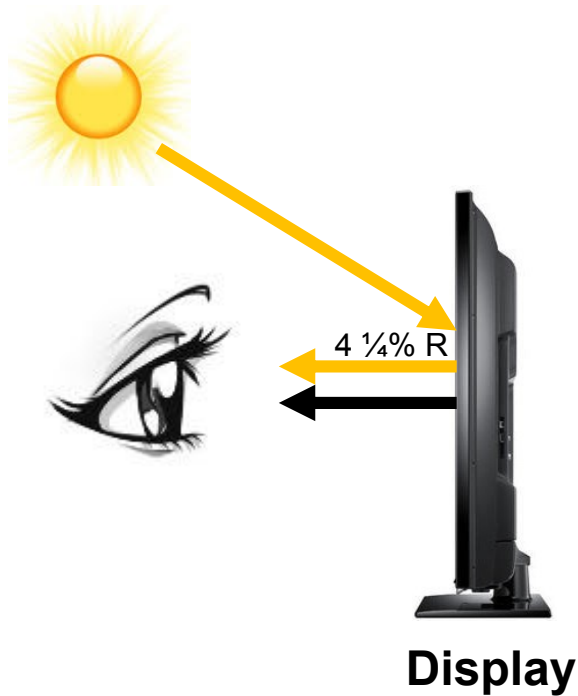
Vista AR™ Glass/Acrylic Anti-Reflective Coating

Outdoor or Indoor Applications Things to consider:

- High Brightness Environment
- Heat Load
- Vandal Resistance
- Large Format
- Durability
- Touch Technology
- Haptics for Touch Screens



Display Basics



Enhancement Options:

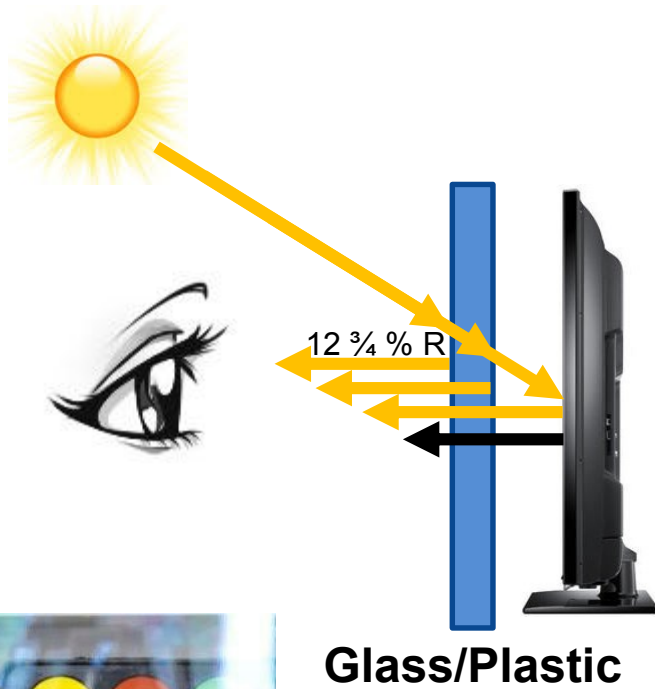
- Air Gapped Glass or Plastic Front Cover Plate
- Bonded Glass or Plastic Front Cover Plate

Glass or Plastic Options:

- No Surface Treatment
- Anti-glare (AG) on one or both sides
- Anti-Reflection (AR) on one or both sides
- AR combined with AG
- Tempered
- Chemically Strengthened
- Laminated Safety Glass

Air Gapped Enhancement

(No Surface Treatment)



Air Gapped Solution

- May be required for the necessary air cooling of the display
- Desirable for ease of LCD repair/replacement
- May be required for ruggedization

No Surface Treatment

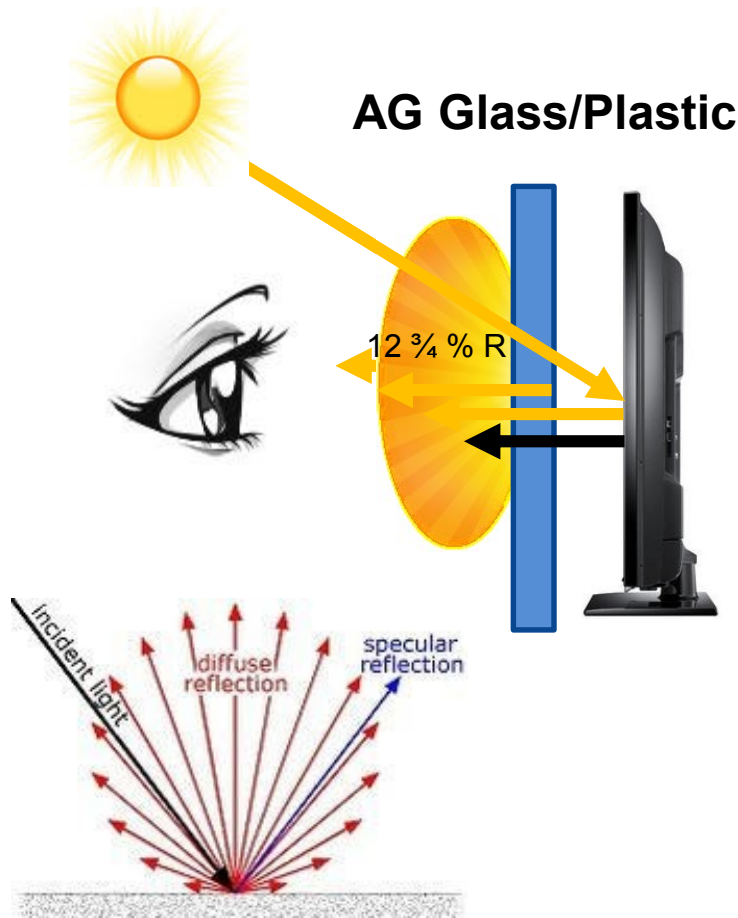
- Each surface of the untreated plate contributes $\sim 4 \frac{1}{4}\%R$, therefore, this approach has $\sim 12 \frac{3}{4}\%R$ reflection
- In a bright environment this approach would have terrible visibility.
- Untreated surfaces will have poor haptics for touch screen applications



Untreated Cover Plate

Air Gapped Solution (cont)

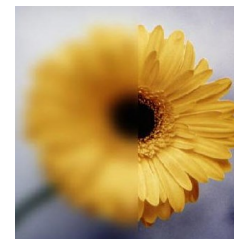
(AG Surface Treatment)



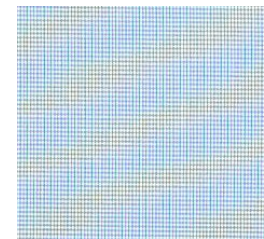
AG Reflection vs. Specular

AG Surface Treatment

- Each surface of the AG plate still contributes $\sim 4 \frac{1}{4}\%R$,
- The rough AG surface is measured in “Gloss Units” The lower the gloss number, the rougher the surface
- Lower gloss numbers can be used as the cover plate is moved closer to the image plane
- The higher the gloss number the clearer the transmitted image becomes but there will be more of a specular reflection bounced back to your eye.
- The higher the gloss level the more “sparkle” (twinkling small rainbows similar to moiré) will appear in transmission of your image.
- Each manufacturers AG material behaves significantly differently even with the same gloss
- AG surfaces will offer good haptics for touch devices
- Careful consideration and understanding of tradeoffs need to be reviewed before an AG solution can be employed



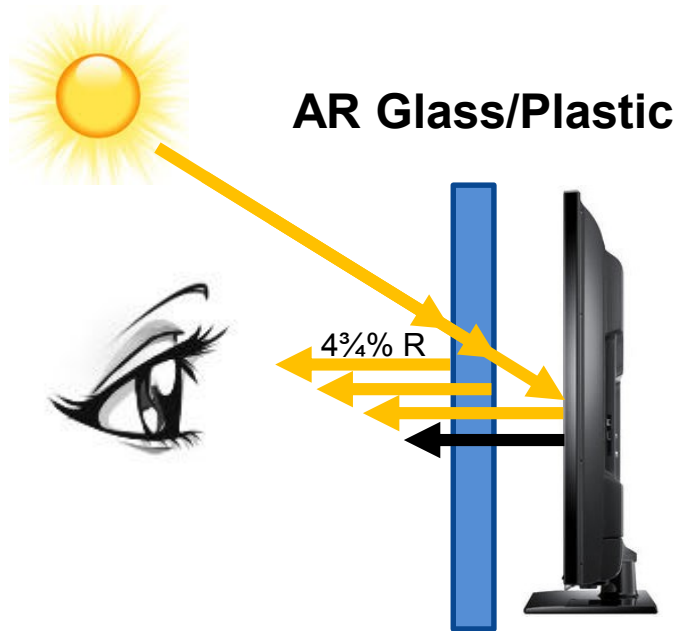
AG Resolution Loss



Sparkle Effect

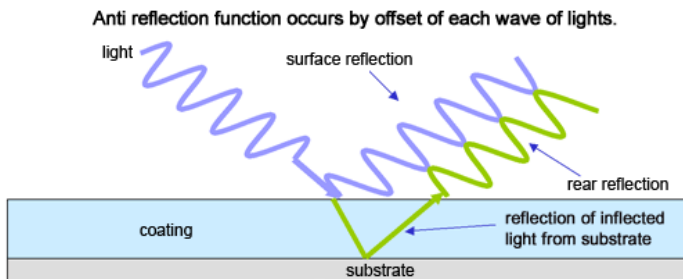
Air Gapped Solution (cont)

(AR Surface Treatment)

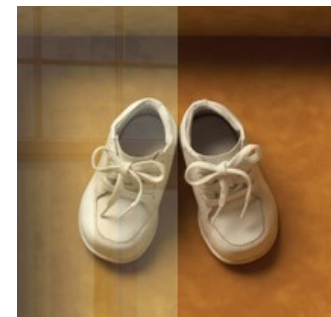


AR Surface Treatment

- Each surface of the AR plate contributes $<0.3\%R$, therefore, this approach reduces reflection to only $\sim 4\frac{3}{4}\%R$ (LCD contributes the most)
- In a bright environment this approach would have very good clarity/visibility.
- Care must be taken to select rugged AR's verses delicate AR's that would have poor environmental durability
- The small residual reflection may have a hue (color); most people prefer a soft violet/blue hue.



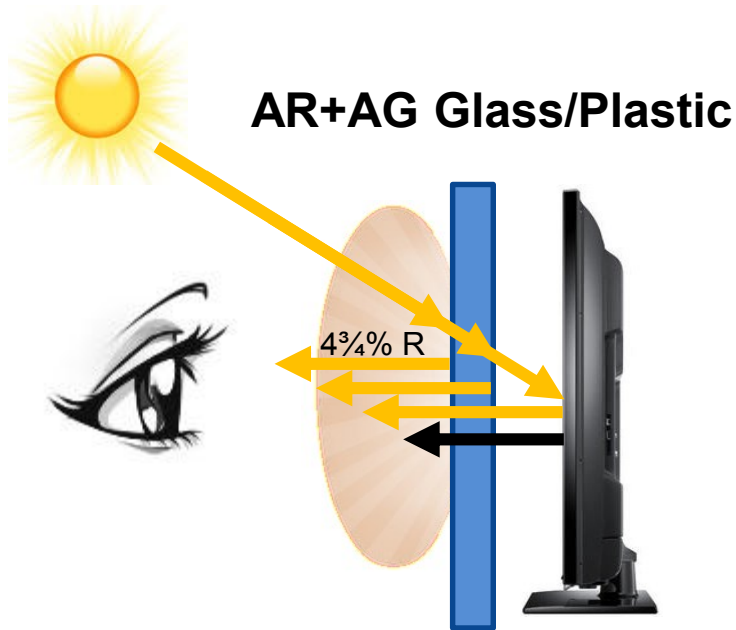
Anti-reflection Coating Principles



Uncoated Glass vs. Anti-reflection Coated Glass

Air Gapped Solution (cont)

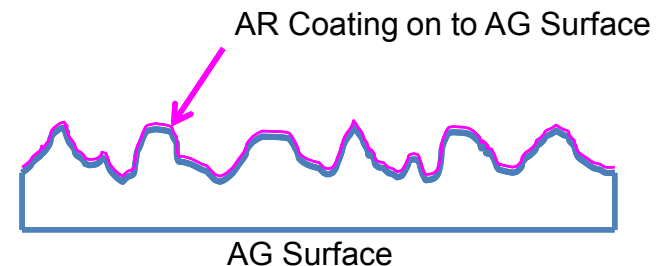
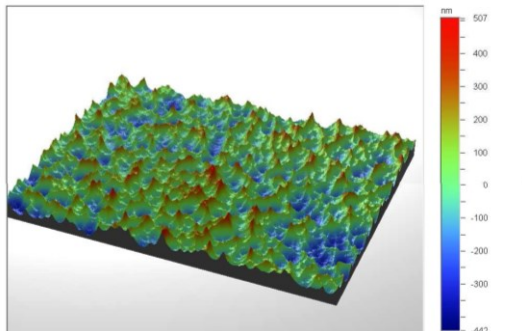
(AR+AG Surface Treatment)



AR+AG Surface Treatment

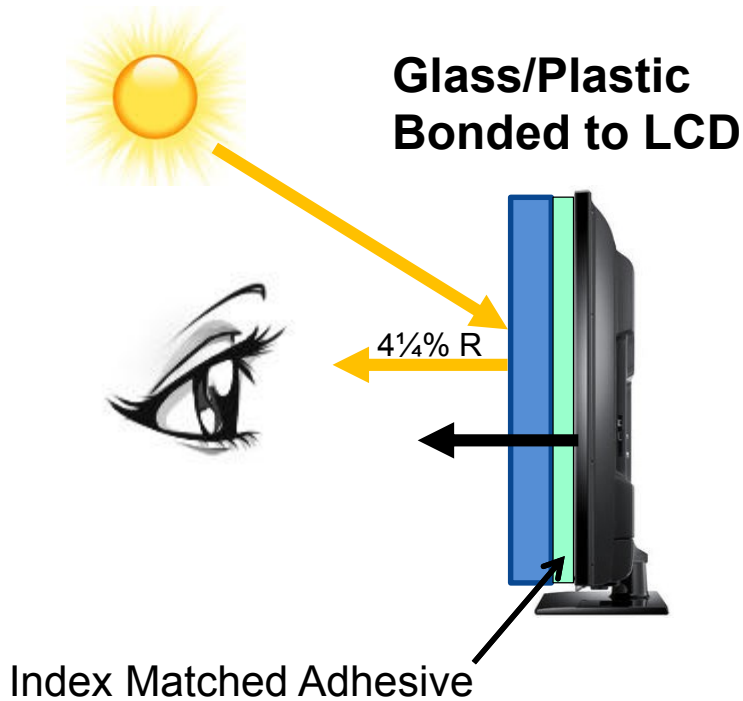
- Each surface of the AR+AG plate will only contribute <math><0.3\%R</math>,
- The AG surface roughness is measured in micrometers and the AR thickness is measured in nanometers (1000 times thinner) It will not “fill in” the AG surface
- All of the AG trade-offs are still valid even with an AR applied to the surface
- Careful consideration and understanding of tradeoffs need to be reviewed before an AR+AG solution can be employed
- If the parameters are carefully optimized this combination could offer excellent view-ability, however, it is best suited for laminated options.

3-Dimensional Interactive Display



Laminated Solution

(No Surface Treatment)



Glass/Plastic Bonded to LCD

Bonded Solution

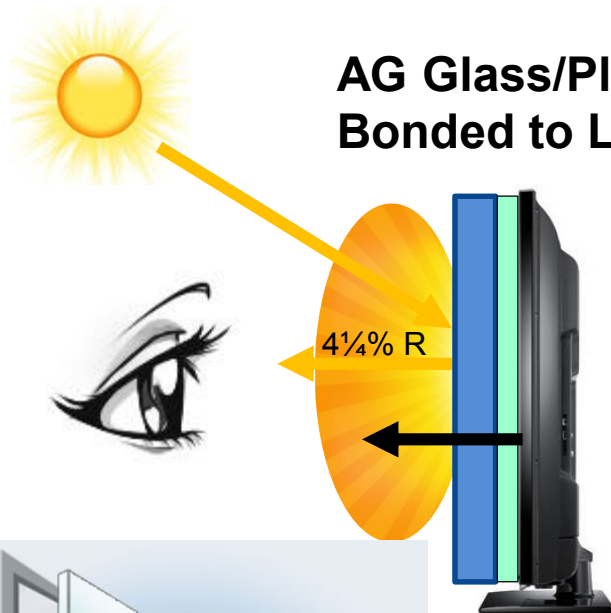
- Offers the best overall optical solution (removes two reflective surfaces)
- Replacement or repair of the LCD would be more difficult
- Very rugged front plate selection would help to ensure that the system could survive abusive environments

No Surface Treatment

- The front surface of the untreated plate still contributes $\sim 4 \frac{1}{4}\%R$,
- In a bright environment this approach would have poor visibility.

Bonded Solution (cont)

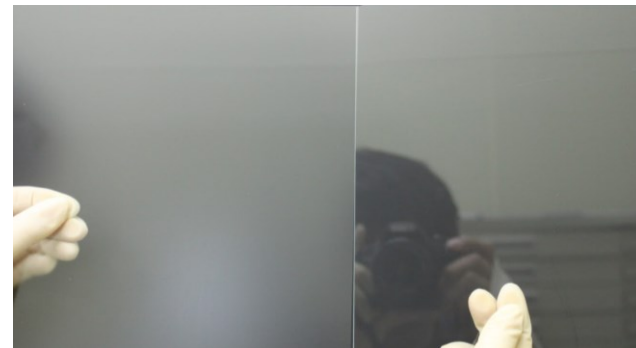
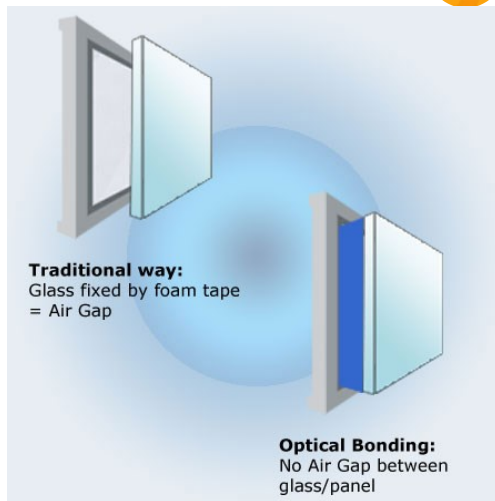
(AG Surface Treatment)



AG Glass/Plastic Bonded to LCD

AG Surface Treatment

- The front surface of the AG plate still contributes $\sim 4\frac{1}{4}\%R$
- If the plate can be made from thin material and placed close to the image plane then a low gloss number may be used. This helps remove specular reflections.
- The plate only needs to have an AG on the front surface, however, if it is necessary to use double sided AG glass then the second surface will “wet out” in the adhesive and not have any AG properties.
- Note: if a double sided AG glass is specified at a specific gloss level when it is bonded the effective gloss numbers will move higher since the rear surface no longer contributes to the lower gloss value.

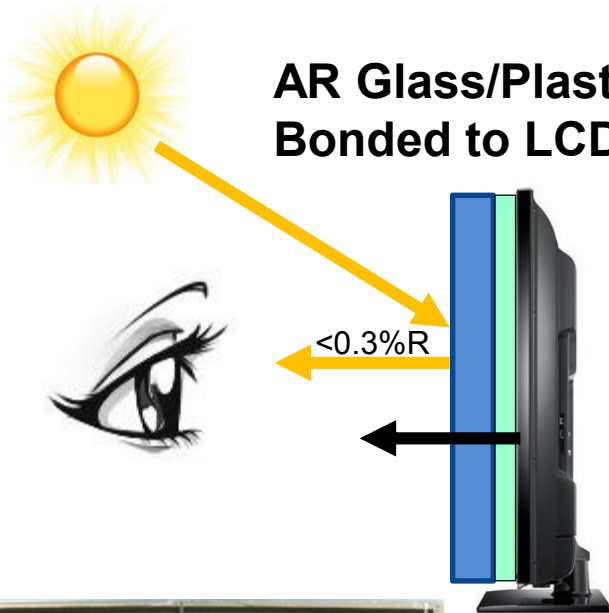


AG vs Clear Glass

Bonded Solution (cont)

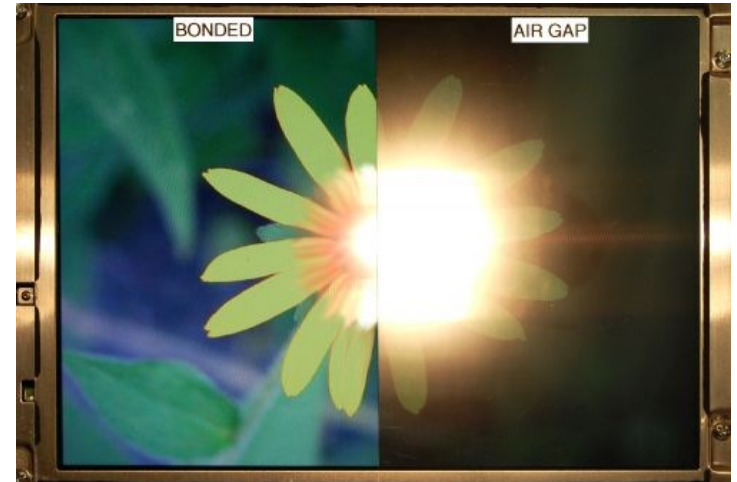
(AR Surface Treatment)

AR Glass/Plastic Bonded to LCD



AR Surface Treatment

- The surface of the AR plate contributes $<0.3\%R$; therefore, reflected energy is effectively removed.
- In a bright environment this approach would have excellent clarity/visibility.
- Rugged AR's are very beneficial for surviving the lamination process as well as enduring many years of operation in your specific environment.
- Final optimization may be required from the LCD mfg to reduce internal reflections from the LCD layers.



Bonded Solution (cont)

(AR+AG Surface Treatment)

AR+AG Glass/Plastic Bonded to LCD

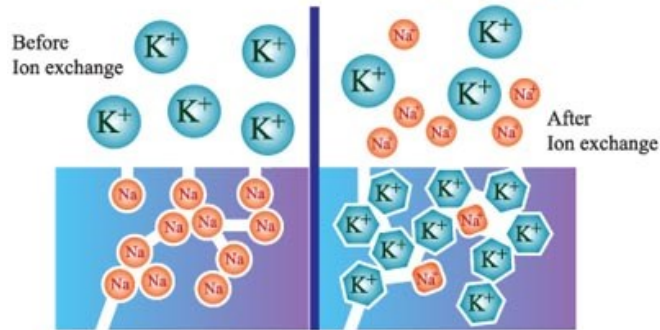
AR+AG Surface Treatment

- The surface of the AR+AG plate will only contribute $<0.3\%R$
- The small amount of reflected energy is now diffuse
- Sparkle must be minimized since the screen image will be very clear without any obscuring reflections that might have “masked” this issue
- AG surface will offer good haptics for touch applications
- Careful consideration and understanding of tradeoffs need to be understood, however, if the parameters are optimized and the physical requirements suit the AG restrictions, then this could offer the very best control of glare and reflections for your display



Glass Options

CHEMICAL STRENGTHENING (Ion exchange)

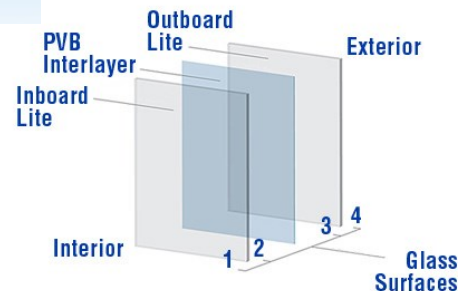
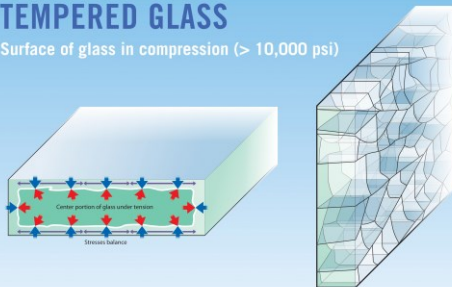


Enhancing the Glass Durability

- Chemical Strengthening
 - Soda lime glass can yield a depth of penetration (DOP) of $\sim 12\mu m$
 - Alumina Silicate (Gorilla, Dragon Trail) can yield a DOP of $\sim 50\mu m$
- Heat tempering can be achieved on glass that is thicker than 3mm
 - Care must be taken during the tempering cycle as warping, waviness, and pits can be introduced to the glass
 - Typically glass is tempered before anti-reflection coatings are applied
- Glass can also be laminated to another piece of glass to make “safety” glass
 - This approach keeps the broken shards off glass together and makes a tough vandal resistant window

TEMPERED GLASS

Surface of glass in compression ($> 10,000$ psi)



Acknowledgements

- Tru Vue, Inc.
- SID, MidWest Chapter
- James Lupino
- Tru Vue Engineered Optics Team, including Chad Carter and Dave Soberanis



Questions?

Thank you.

