SCIENCE AND TECHNOLOGY IN KP PIGMENTS' PEARLESCENT AND COLORSHIFTING PIGMENTS

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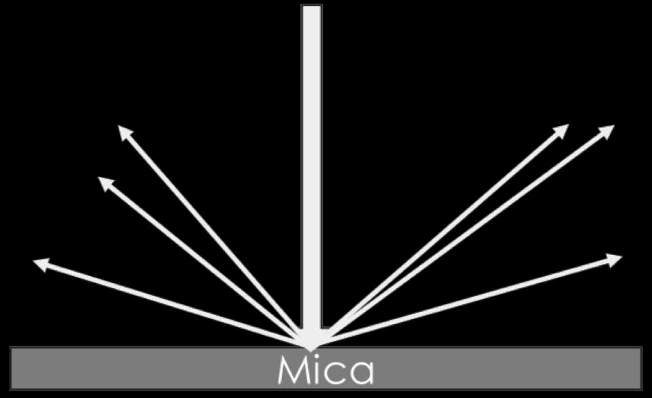
INTRODUCTION TO "PEARL PIGMENTS"

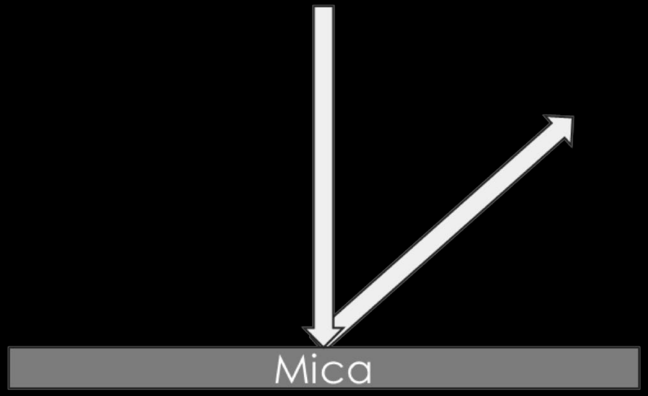
- We currently offer over 200 different pearlescent and metallic pigments
  - Solid/Metallic Pearls
    - Mica-based pigments
    - Metallic effects that range from a smooth satin to an almost glitter like sparkle.
  - Interference Pearls
    - White powder mica with highly transparent platelets
    - Faint flop over lighter or clear bases
    - Strong color over darker bases (absorbs transmitted color and scattered light)
  - Effect/ColorShift Pigments (Optically Variable Pigments)
    - Appear to change color either subtly or drastically based on viewing angle or illumination angle.
    - ColorShift pigments divide incoming light instead of absorbing it.

DIFFERENCES BETWEEN PIGMENTS



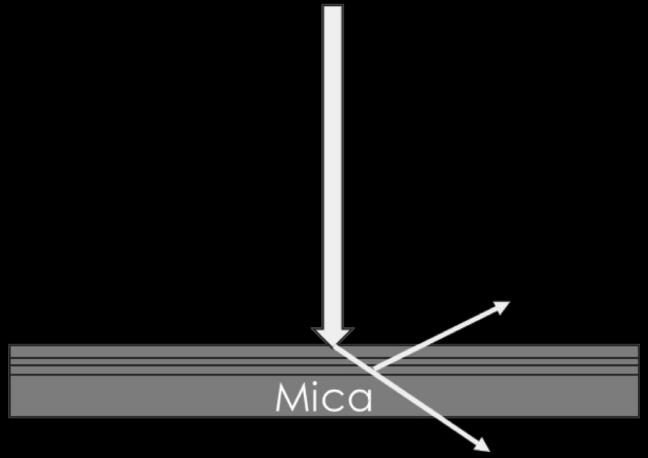
Absorption Pigments

1-Dimensional
Irregular absorption
No luster
Flat



Metallic Pigments

2-Dimensional
Lustrous
Highly reflective



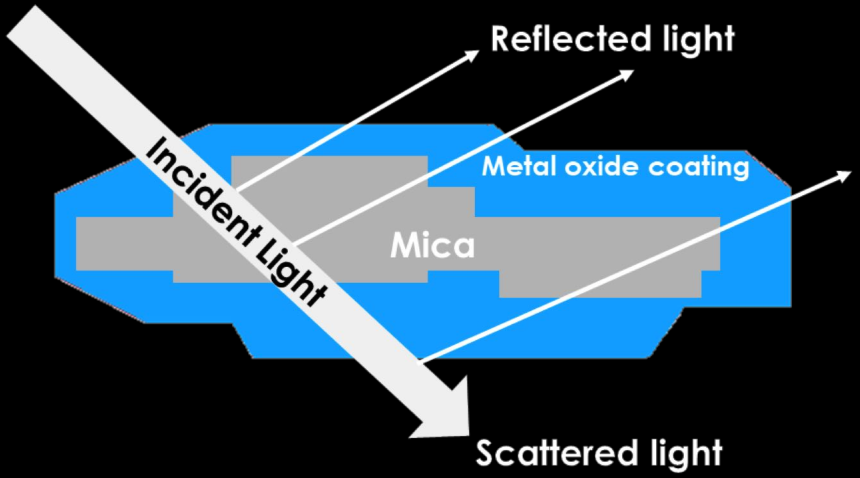
ColorShift (Pearl) Pigments

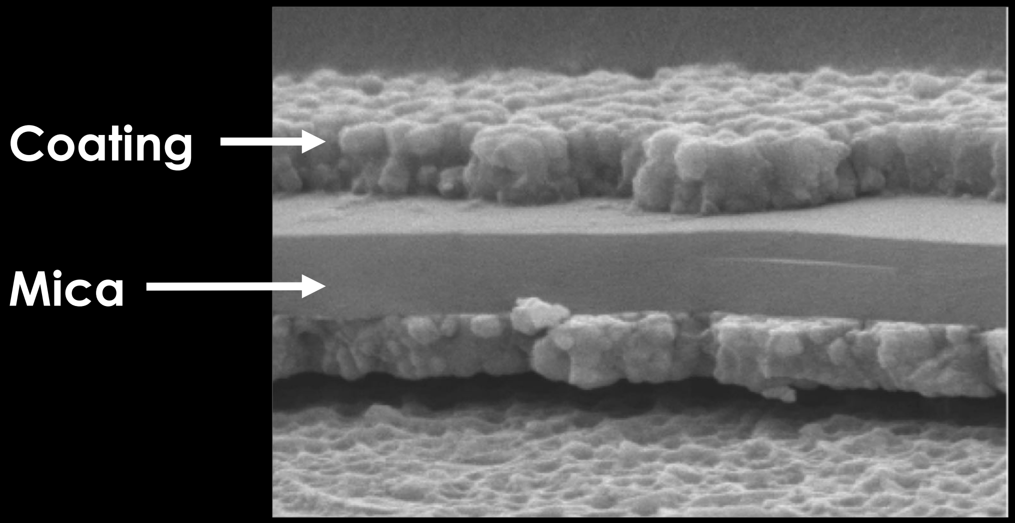
3-Dimensional
Variety of colors

- ColorShift pigments are comprised of different layers, which affects the color.
- The colors produced by ColorShift pigments depend on the viewing angle.
- As the viewer changes position, the observed color will also change.

HOW ARE THE COLORS PRODUCED?

- When an incident ray of light interacts with the coated particles, some of the light is scattered (transmitted through the particle) and some is reflected.
- Interference pigments "split" light into two complementary colors.
- Since the particle is non-uniform, the light will be reflected at different angles depending on the incident surface.





FACTORS AFFECTING PERFORMANCE

- Several factors affect the colors observed in these pigments:
  - Film thickness
    - Determines base color
  - Viewing/illumination angle
    - Changes the observed color
  - Pigment composition
    - Substrate identity
    - Coating composition
  - Transparency/opacity
  - Particle size

- Of these factors, film thickness, pigment composition, transparency/opacity, and particle size can be controlled experimentally.

SUBSTRATES

- Mica
  - Tiny, thin transparent flake.
  - Inexpensive and abundant in nature
  - Mica flakes are usually 5-200 μm in diameter
  - Mica is both transparent and reflective
    - Some light is reflected while some continues to travel farther, allowing it to be reflected by other layers
- Silica
  - Also abundant in nature
  - Formed from a web-coating process
  - 300-400 nm in size
  - A more uniform and controllable thickness than mica
  - Smoother surface
- The substrate is coated with a metal oxide to a certain thickness.

PRODUCTION OF PIGMENTS

- The production method of substrates depends on the material used.
- Mica
  - Typically produced by the deposition of metal oxides in an aqueous suspension
  - The coated substrate is then subjected to calcination (heating to high temps.)
  - 200-500 nm flake size
- Silica
  - Produced by a web-coating technique using silicon precursor compounds (e.g. sodium silicate)
  - The film on the web is dried to form a solid coat which is then removed and processed further to create silica flakes
  - Typically 300-400 nm in size
- Once the substrates are formed, they are then coated with metal oxide layers.

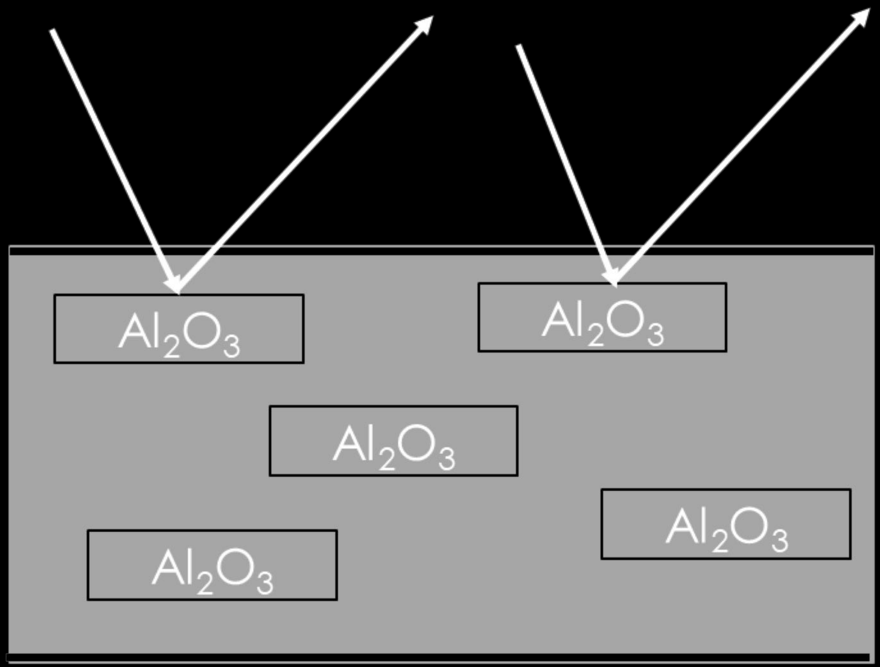
SUBSTRATE TRANSPARENCY/OPACITY

- Opacity
  - All of the light is reflected at the first layer, like a mirror.
  - This means that the platelets act like a reflecting mirror, causing all the light to be reflect and none of it to be refracted.
  - The resulting effect is color with strong hiding abilities and that show a strong change in intensity and chroma depending on viewing angle.

- Transparency
  - Light is reflected and refracted from multiple layers of the pigment. Light passes through the coated platelets (since they're transparent) and bounces and defuses both further down to other platelets and up.
  - This creates the depth effect that is often referenced when mentioned pearlescent pigments.

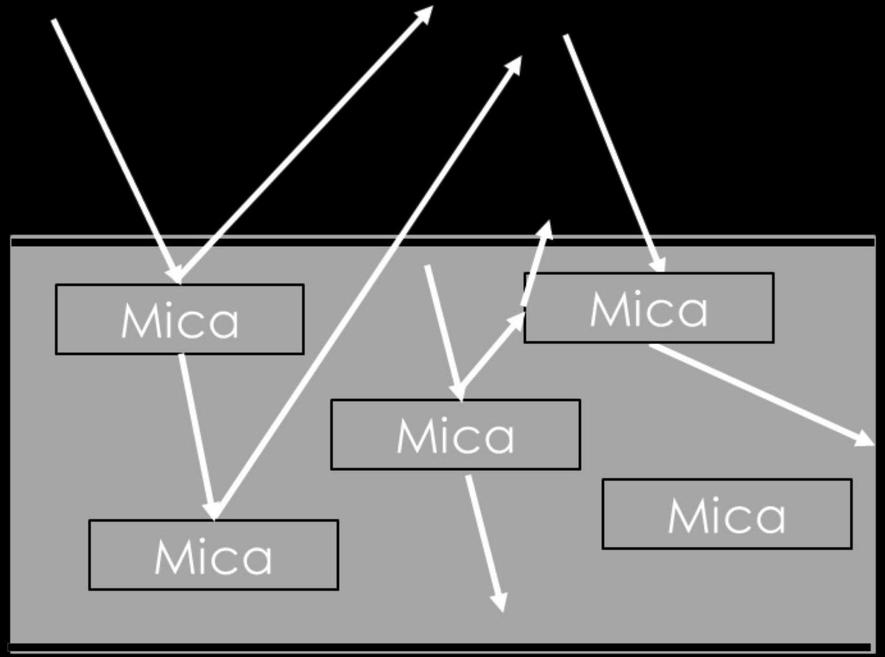
- This difference is illustrated in the diagram on the next slide.

SUBSTRATE EFFECT ON OPACITY AND TRANSPARENCY



Opaque (Aluminum Oxide)

Light is reflected *only* at the top layer.



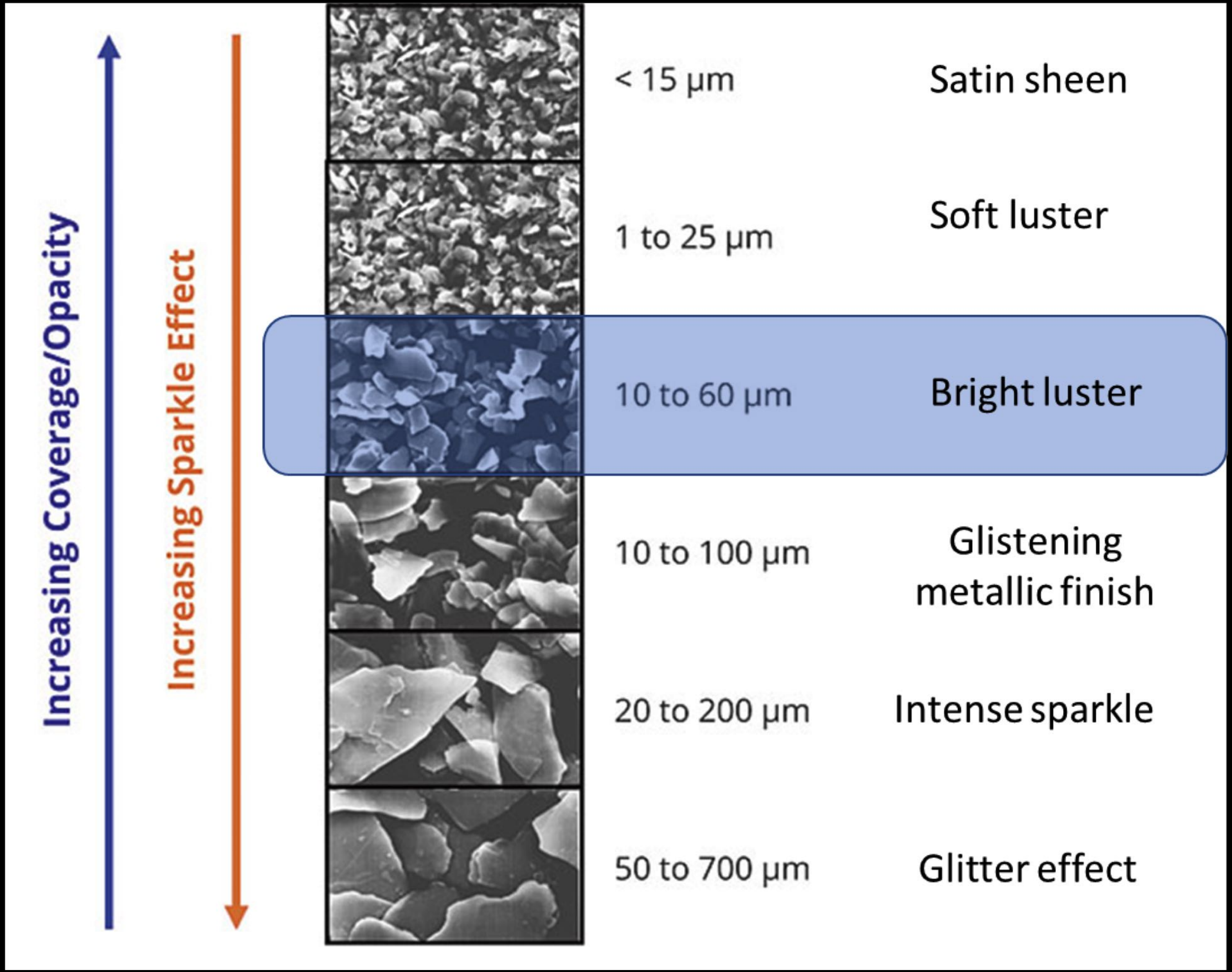
Transparent (Mica)

Light is reflected and refracted from multiple layers.

Multiple reflections cause interference, giving the coating a pearlescent effect.

PARTICLE SIZE

- The overall size of the pigments will affect several properties
  - Luster
    - Increases with increasing particle size
  - Coverage
    - Favors smaller sizes
  - Appearance
- Larger pigments are used at lower loadings
  - Gives sparkle effect
- Optimal distribution: 10-60 μm
  - Most of our colors fall in this range



https://www.pcimag.com/articles/105225-pearlescent-pigments-in-coatings-a-primer

COATINGS

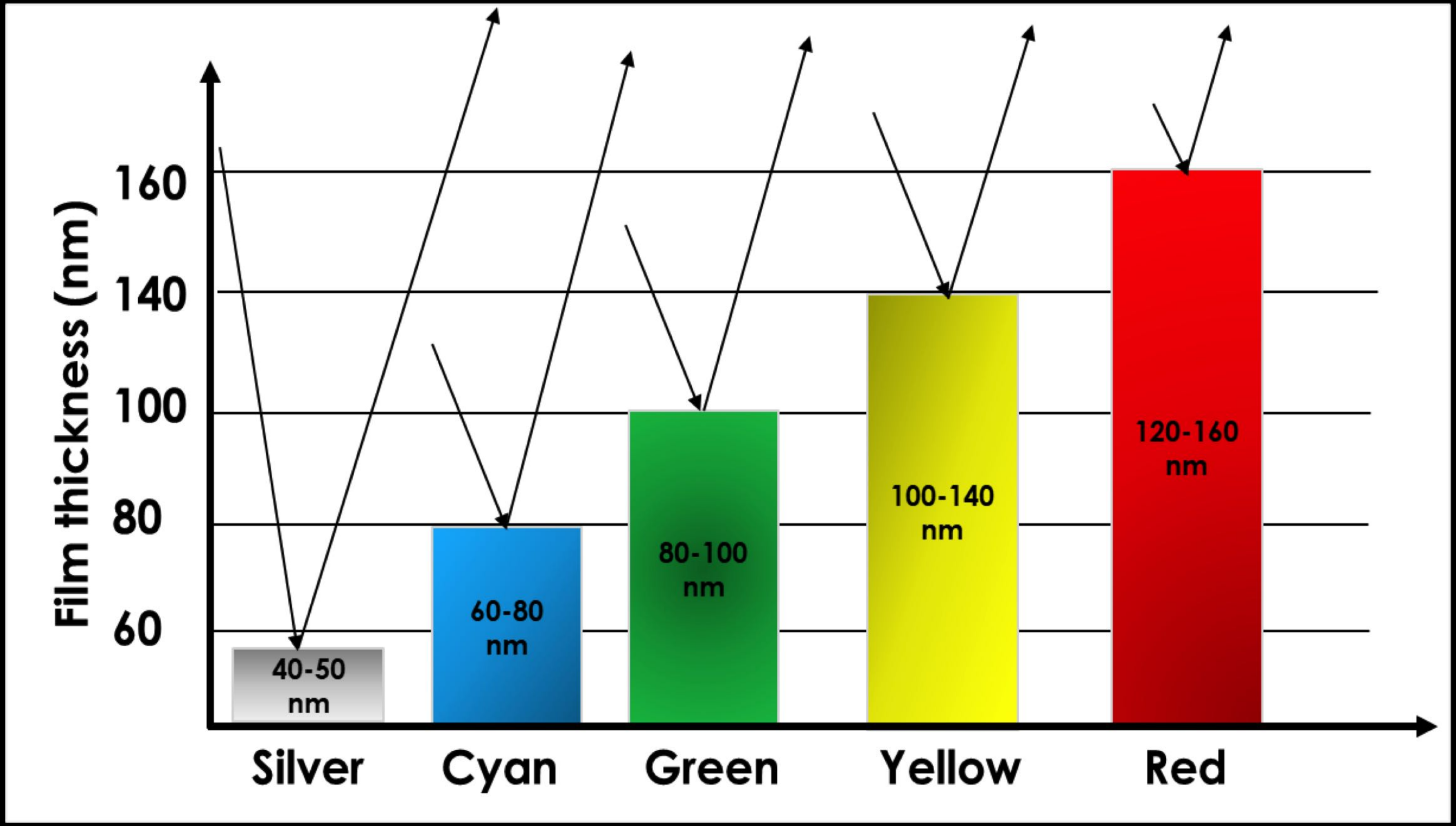
- The coatings should have highly refractive and reflective properties, meaning they can bend and bounce back light.
- Two popular coatings are titanium oxide (TiO_2) and iron oxide (Fe_2O_3), which are applied using the chemical reactions outlined below.
- Both iron oxide and titanium oxide have similar refraction indexes and interference properties.
- The main difference again is in reference to color. Since iron oxide has it's own inherent reddish hue, this causes changes in the pearl color due to the absorption properties of the iron oxide.

Titanium oxide on silica: $TiOCl_2 + 2\ NaOH + SiO_2$ flakes $\rightarrow TiO_2/SiO_2$ flakes $+ 2\ NaCl + H_2O$

Iron oxide on silica: **Step 1:** $FeCl_3 + 3\ NaOH + SiO_2$ flakes $FeOOH/SiO_2$ flakes $+ 3\ NaCl + H_2O$
Step 2: $FeOOH/SiO_2$ flakes Fe_2O_3/SiO_2 flakes $+ H_2O$

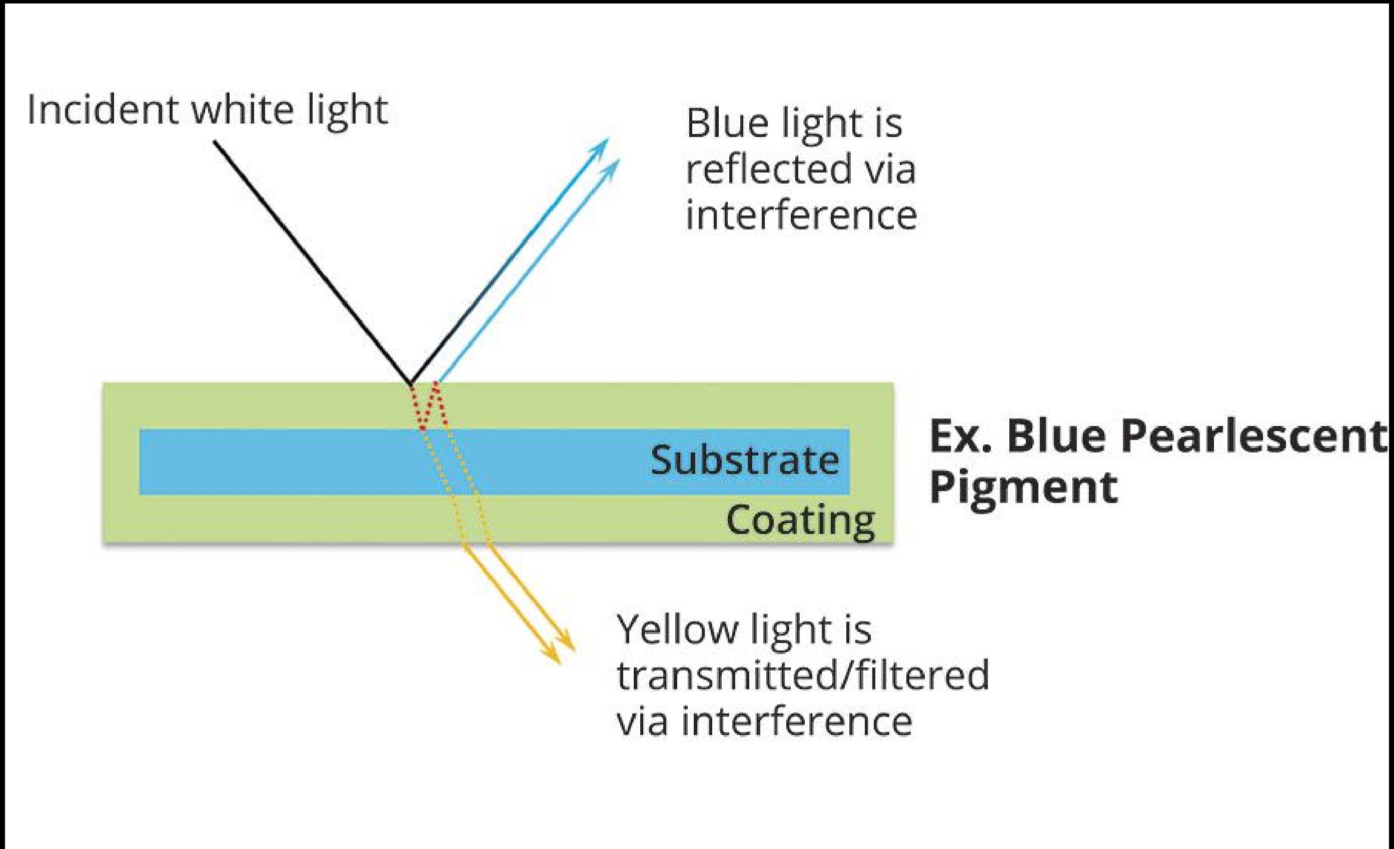
COLOR CUSTOMIZATION: FILM THICKNESS

- The base color depends on the thickness of the films used to coat the mica or silica substrates.
- Thickness determines which colors reflect (visible color).
- Thus, we can tailor the apparent color of the pigment by simply varying the thickness of the coating of the pigments.



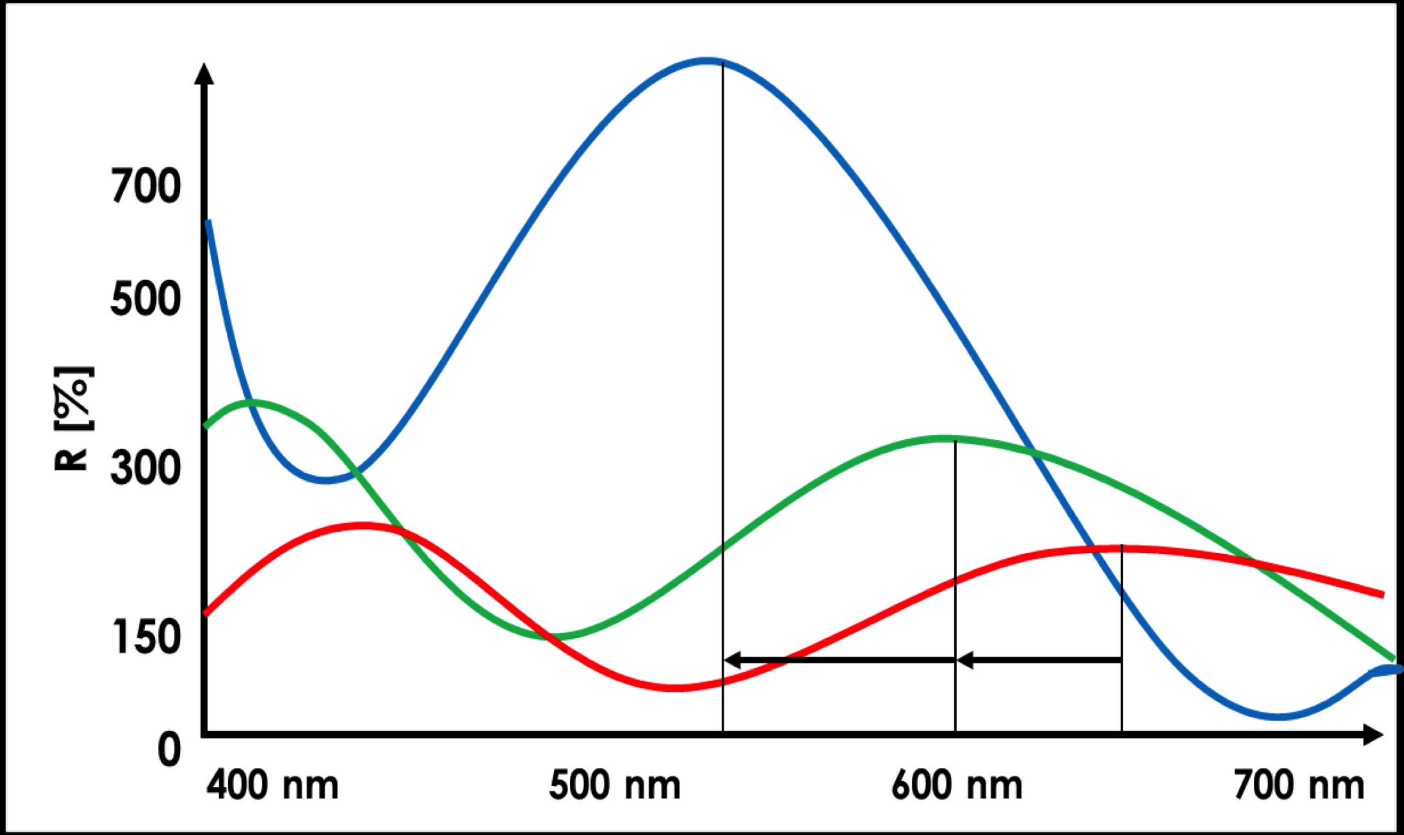
INTERFERENCE EFFECTS ON COLOR

- When one or more thin layers are placed on top of the substrate, light will be reflected via interference as shown in the diagram to the right.
- In addition, some of the light is transmitted through the pigment, which has a different wavelength (color), also because of interference.



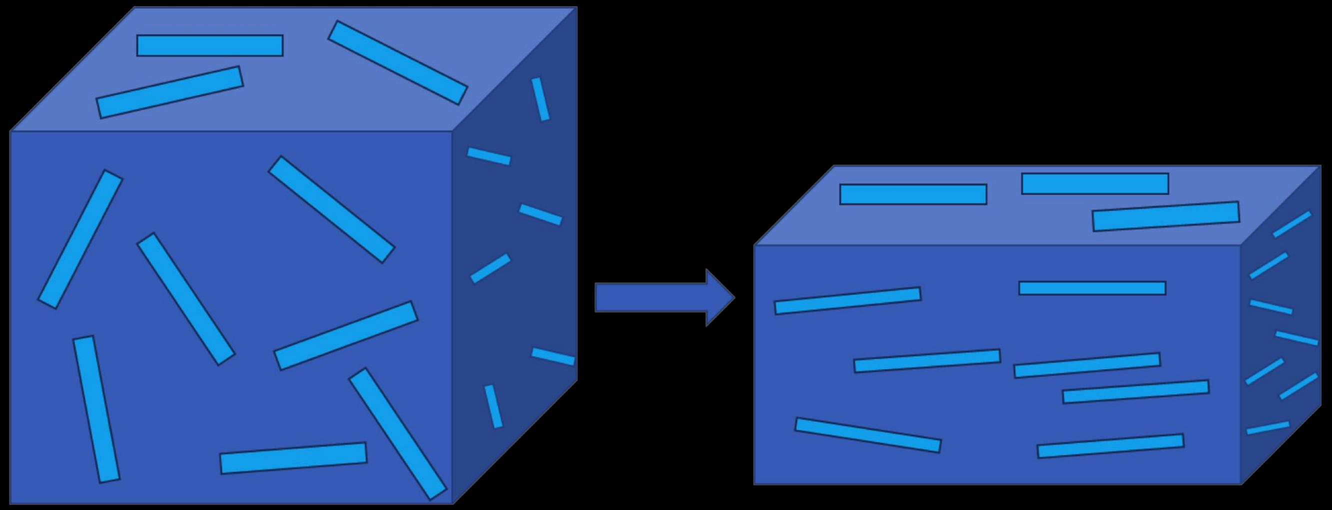
EFFECT OF VIEWING ANGLE ON COLOR

- The film thickness determines the base color of the pigment.
- The viewing angle also affects the color observed
  - Shifts to shorter wavelengths as the angle varies rom steep to flat.
- Since the light is scattered and reflected in numerous directions, a large range of colors is produced with interference pigments.



ORIENTATION OF PIGMENTS

- The pigments must be oriented parallel to the substrate.
- The orientation occurs while the film is drying.
- Films with a low content of solids will shrink less than those with a high content, so they will be more well-ordered.
- Slow-evaporation solvents or longer flashing times can also improve orientation.



Wet
Disordered

Dry
More Ordered

PIGMENT DISPERSION

- Once the pigments are formed, they need to be dispersed in a fluid medium.
    - 25-35% pigment in 65-75% fluid vehicle
    - Add the pigments in gradually
    - Once all pigments have been added, mix for an additional 15 minutes to ensure good dispersion
    - Low-shear mixing equipment is best to avoid further fragmenting the pigments or stripping the metal oxide coatings off

- Mixing ratio depend on the medium being used.
    - Please refer to the mixing chart on our website.

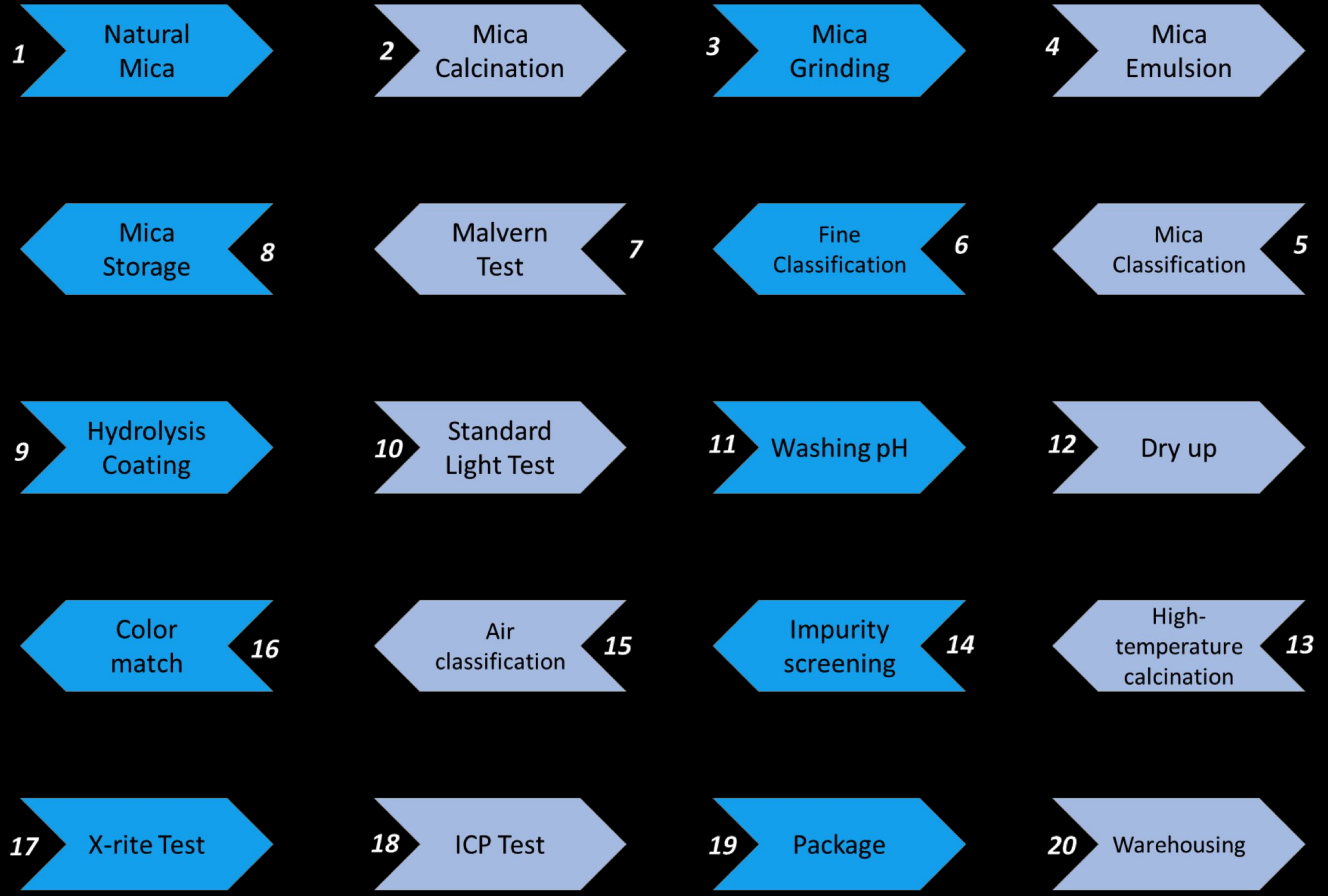
- A good dispersion is critical to obtaining desired coating properties!
    - Poor dispersion can lead to low tinting strength and poor appearance!

- Settling of pigments should be slow to occur. If/when it does occur, it is simple to re-disperse the pigments by following the outlines suggestions above!

MANUFACTURING PROCESS FLOW

- Through our extensive experience, we account for all the various factors that affect performance.

- We use this knowledge to develop pigments using the process flow shown on the right.



MIXING RATIOS

- We take the guesswork out of things by providing our clients with mixing ratios on our website. The chart below details some basic mixing ratios as a percentage based on weight.

Paint Application

Paint Type	Concentration (%)
Automobiles*	5-10
Construction Materials	5-10
Powder Coatings	2-7
Plastics	5-10
Epoxy/Resin	5-10

Printing Application

Ink Type	Concentration (%)
Screen Ink	5-20
Gravure Ink	10-20
Off-set Ink	30

- In addition to these two methods, our pigments can also be used in paper, leather (natural and synthetic), and even plastic resins!

MIXING COLORS

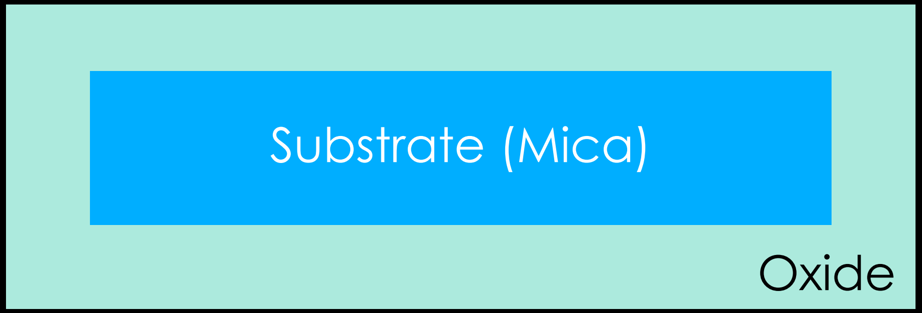
- Although KP Pigments has a wide variety of colors, there will always be the need for a custom mixed color.

- Due to the nature of pearlescent pigments, mixing is not only possible, but a very simple process that does not require use of mills or specialized machinery.

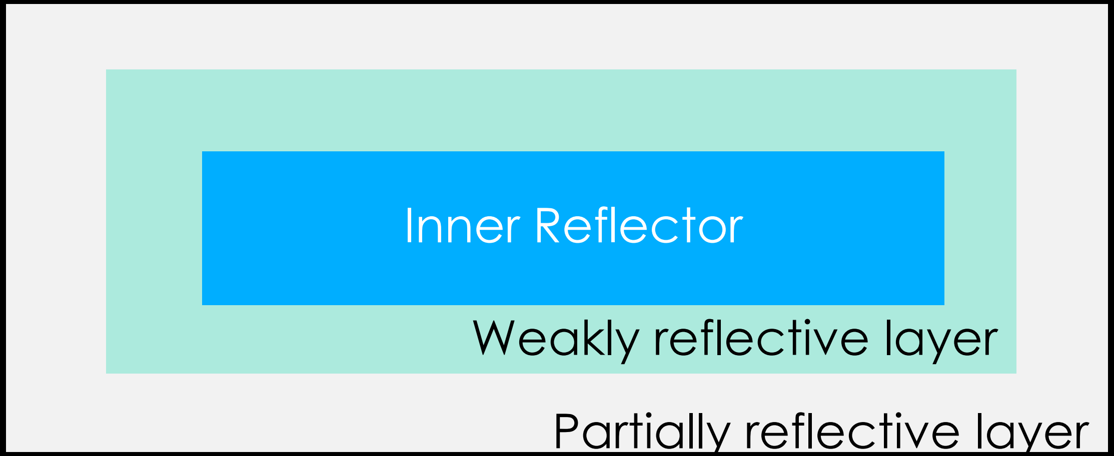
- For best results:
  - Mix two similarly-sized pigments
  - Mixing interference and colorshift pigments can cause a muting or drowning out effect as the colors cancel themselves out to eventually produce an off white / brown color.

OPTICALLY VARIABLE PIGMENTS

- In these types of pigments, no light is absorbed. Rather, the color is produced solely through interference effects as the light travels between layers of the pigment.



Pearlescent Pigments

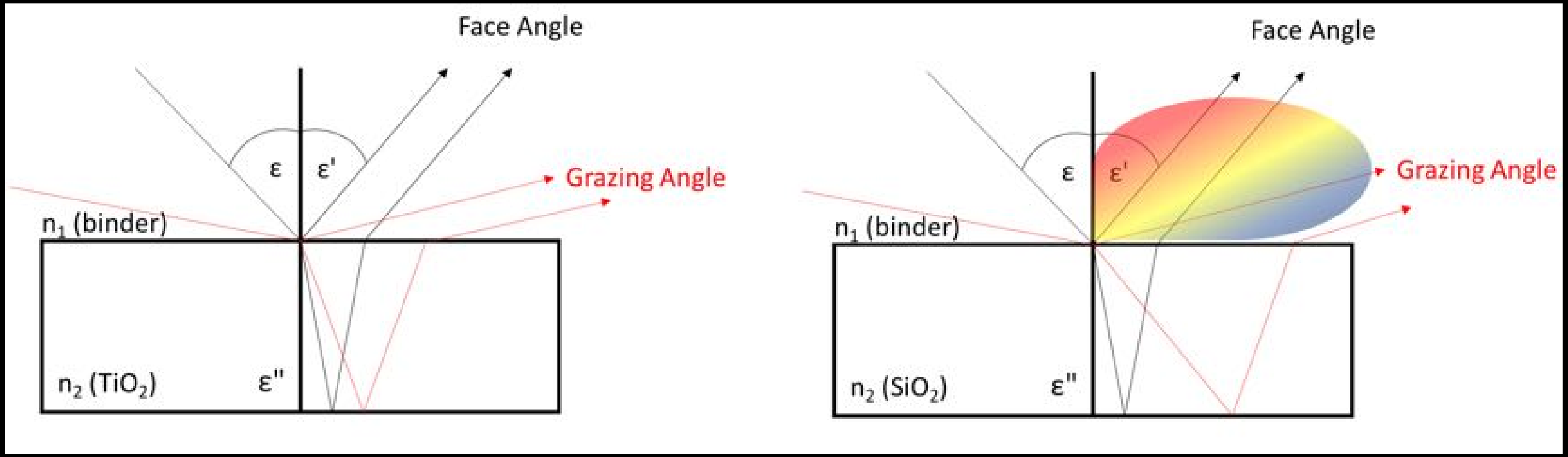


Optically-Variable Pigments
Certain colors are reflected while others are transmitted.

REFRACTION

- Snell's law describes the correlation between refraction and refractive indices.
  - In the case of a high refractive index material, rays at both face and grazing angles are refracted near the perpendicular.
  - When a lower refractive index material is used, the face angles refract close to the perpendicular, while the grazing angles refract farther away.
  - This causes there to be a drastic difference in the interference behavior between face and grazing angles
  - This is the behavior that gives rise to optically-variable pigment behavior.

$$n_1 \sin \varepsilon = n_2 \sin\varepsilon''$$

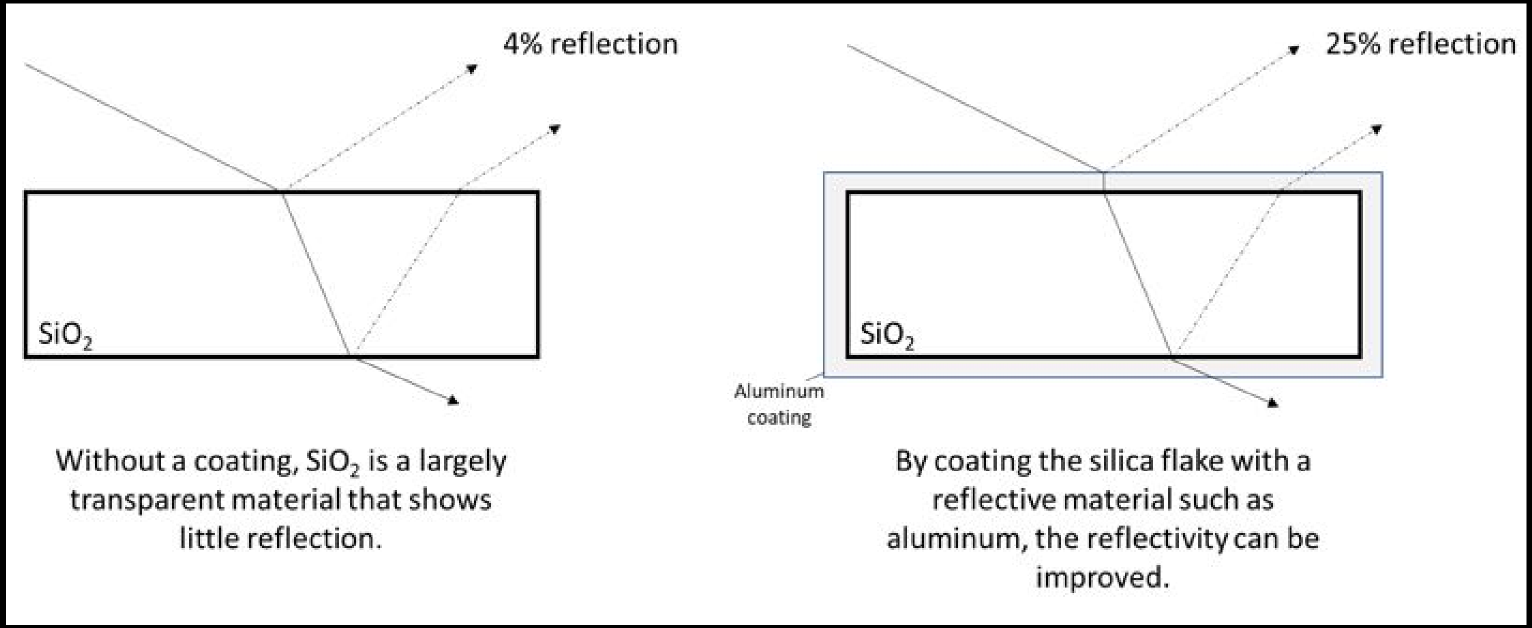


High refractive Index
TiO_2

Low refractive Index
SiO_2

REFLECTION

- Although a low refractive index material like SiO_2 gives more angle-dependent (color changing) behavior, its low reflectivity is a problem.
- This can be easily solved by coating the silica flake with a highly-reflective material (such as aluminum) at a thickness of 5-15 nm.



Low reflection **Higher reflection**

- Coating the pigments with a reflective layer increases the reflection and chroma (colorfulness) of the pigments

CHARACTERIZING THE PIGMENTS

- Once the pigments are formed, we need to gather information about them in order to classify them by their angle-dependent behavior.
- Due to the angular dependence of the pigment colors, regular spectroscopic techniques will not work. We need a technique that is also angle-dependent.
  - This requires both angle-variable illumination sources and observation points.
- A variety of tools allow us to precisely determine what colors are apparent at what angles.
- Many of the spectrometers available on the market today have a very limited set of illumination and observation angles which makes it difficult to measure the full range of colors in this type of pigments.

HYPERSHIFT™ PIGMENTS

- We can exploit the basic design principles of other pigments to design pigments that change their apparent color.
- In practice, colorshift pigments, such as our HyperShift™ pigments, produce effects like the ones shown below.
- The effect can vary from a subtle gradient, like the top example, to drastically different colors, as in the bottom example.

PRACTICAL EXAMPLES

- In practice, these pigments can be used to produce a wide variety of color changing effects on a variety of surfaces where a striking visual effect is desired.

ZTM HYPERSHIFT™

The apparent color changes depending on the viewer angle.

ZTN HYPERSHIFT™

ZTR HYPERSHIFT™

ZTX HYPERSHIFT™

CASABLANCA

JEDI COLORSHIFT

ROSE GOLD