Solar Spectral Optical Properties of Pigments, or…

How to Design a Cool Nonwhite Coating

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Cool Roofing...Cutting Through the Glare
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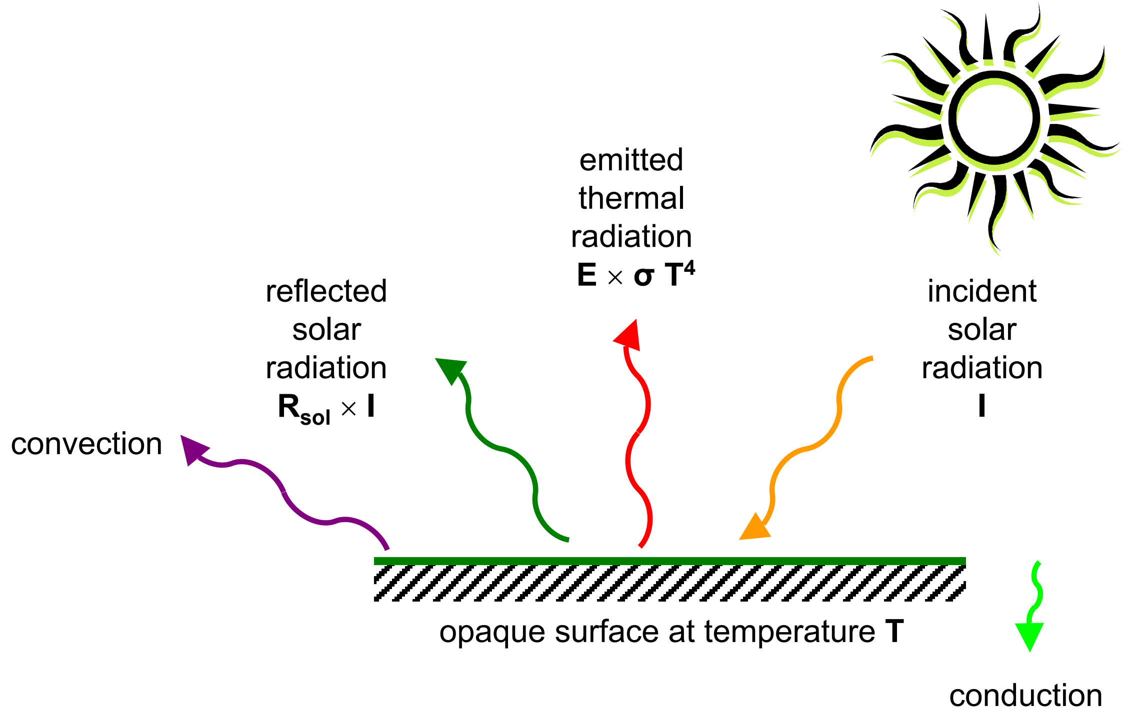
What makes a surface cool?



- **High solar reflectance** (R_{sol}) lowers solar heat gain (0.3 - 2.5 μm)
- **High thermal emittance** (E) enhances thermal radiative cooling (4 - 40 μm)

high solar reflectance + high thermal emittance = **low surface temperature**

Thermal emittance

Nonmetallic surfaces, including most polymer-coated metals, have high thermal emittance because they strongly absorb and thus strongly emit thermal radiation (Kirchoff's law).

Only metallic surfaces (e.g., exposed aluminum flakes) have low thermal emittance.

Roofing with high thermal emittance

asphalt shingle

single-ply membrane

clay tile

polymer-coated metal

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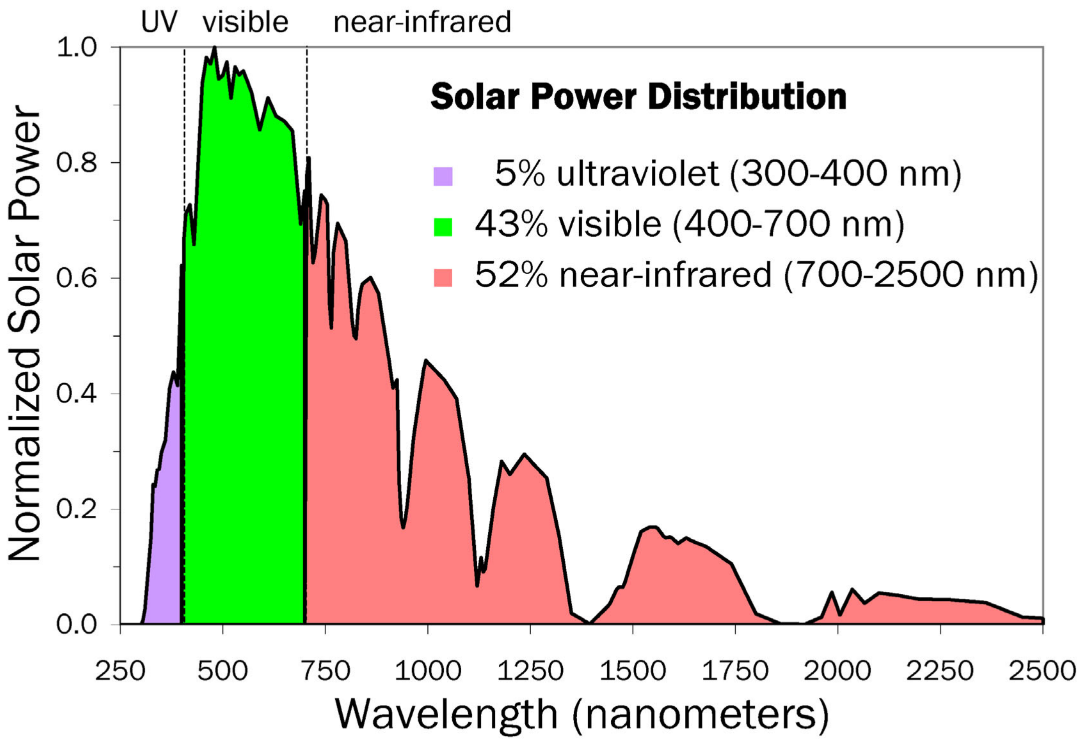
Solar reflectance



95% of sunlight arrives as visible or near-infrared (NIR) radiation.

Solar reflectance $\mathbf{R_{sol}}$ = 5% × ultraviolet reflectance $\mathbf{R_{uv}}$ +
43% × visible reflectance $\mathbf{R_{vis}}$ +
52% × near-infrared reflectance $\mathbf{R_{nir}}$

Types of hot and cool surfaces

increasing visible reflectance

- Hot, light-colored surface
  - not normally encountered

- Cool, light-colored surface
  - **high** visible reflectance
  - **high** near-infrared reflectance
  - **high** solar reflectance
  - **coolest** type of surface

- Hot, dark-colored surface
  - **low** visible reflectance
  - **low** near-infrared reflectance
  - **low** solar reflectance
  - **warmest** type of surface

- Cool, dark-colored surface
  - **low** visible reflectance
  - **high** NIR reflectance
  - **medium** solar reflectance
  - **cooler** than hot & dark, **warmer** than cool & light

increasing near-infrared reflectance

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Examples of hot and cool surfaces

increasing solar reflectance (high / medium / low)

Cool **light-** colored surfaces

titanium dioxide white (opaque)

uv=0.13
vis=0.94
nir=0.88
sol=0.87

chrome yellow over opaque white

uv=0.05
vis=0.64
nir=0.87
sol=0.73

Cool **dark-** colored surfaces

perylene black over opaque white

uv=0.05
vis=0.06
nir=0.85
sol=0.47

iron oxide red over opaque white

uv=0.05
vis=0.17
nir=0.67
sol=0.43

Hot **dark-** colored surfaces

iron oxide black over opaque white

uv=0.04
vis=0.04
nir=0.04
sol=0.04

iron blue over opaque white

uv=0.06
vis=0.10
nir=0.25
sol=0.17

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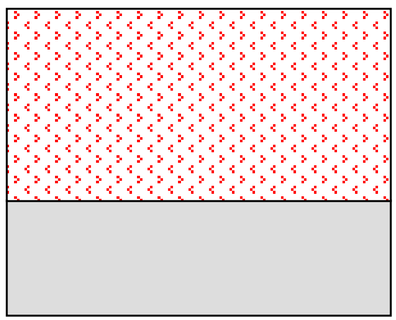
Components of a cool-coated system

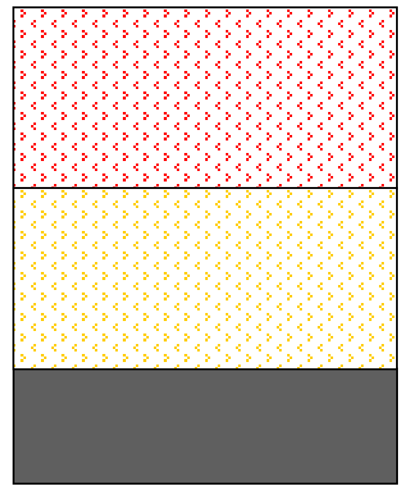
one-coat system (for NIR-reflective substrate)



cool topcoat
(e.g., iron oxide red in acrylic)

opaque substrate
(e.g., aluminum)

two-coat system (for NIR-absorbing substrate)



cool topcoat
(e.g., iron oxide red in acrylic)

NIR-reflective basecoat
(e.g., titanium dioxide white in acrylic)

opaque substrate
(e.g., gray granule)

- A substrate with high NIR reflectance requires only a topcoat
- A substrate with low NIR reflectance requires a topcoat and a basecoat

Basecoat and topcoat design

NIR-reflecting basecoat

- Use pigment(s) with
  - **weak NIR absorption**
  - **strong NIR backscattering**
- Good pigments include
  - **titanium dioxide (rutile) white**
  - nickel titanate yellow
  - chrome titanate yellow
  - aluminum or coated mica flakes
- Thick and/or densely pigmented
  - 100s of microns (100 μm ~ 4 mil)
  - NIR reflectance produced by backscattering (inefficient)

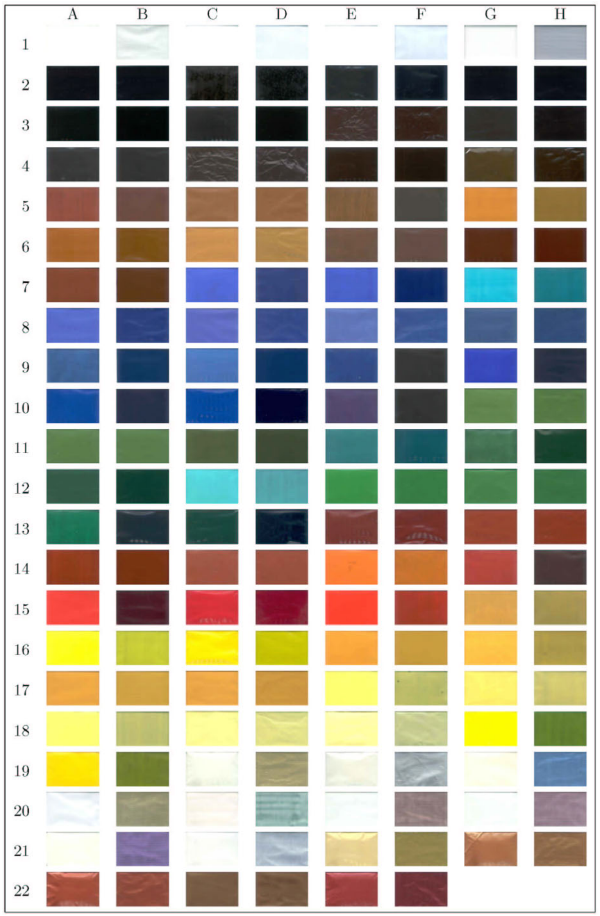
Cool topcoat

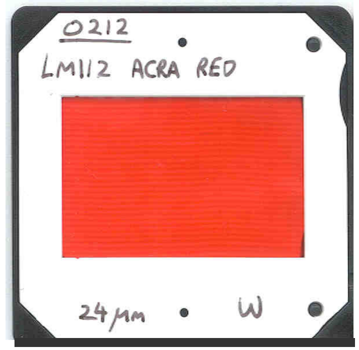
- Use pigment(s) with
  - **weak NIR absorption**
  - strong NIR backscattering (optional)
  - strong visible absorption and/or backscattering (for color)
- May be thin
  - 10s of microns
  - color produced primarily by absorption (efficient)

Absorption
converts light to heat
Backscattering
reverses direction of light

Survey of architectural, artist pigments

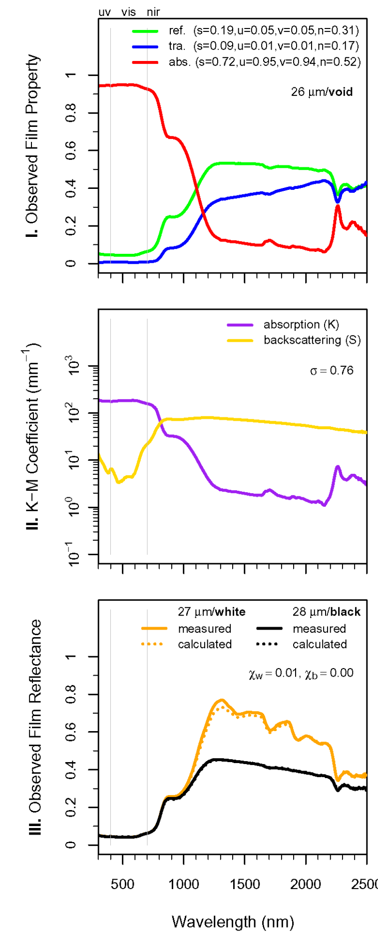
Prepared 87 pigments





…in polymer films over white, black backgrounds

…to characterize their solar spectral optical properties



Some cool pigments (use in cool coatings)

…with strong NIR scattering

- white, yellow titanates
  - titanium dioxide white
  - nickel titanate yellow
  - chrome titanate yellow
  - cobalt titanate green
- titanium dioxide on mica flakes
  - various interference colors

…with moderate NIR scattering

- green, brown titanates
  - cobalt titanate green
  - iron titanium brown spinel
- red, brown iron oxides
- cadmium orange, yellow
- green, black mixed-metal oxides
  - modified chromium oxide green
  - chromium iron oxide black

… with weak NIR scattering

- cobalt blue, green
  - cobalt aluminate blue
  - cobalt chromite blue
  - cobalt chromite green
- ultramarine blue
- *many* organics, including
  - perylene black
  - phthalocyanine blue, green
  - quinacridone red
  - dioxazine purple

Some hot pigments (avoid in cool coatings)

exclude these strong NIR absorbers
from topcoat, basecoat

- carbon black
- bone black (carbon black + calcium phosphate)
- copper chromite black
- iron oxide black (magnetite)
- iron blue $[KFe_2(CN)_6 \cdot H_20]$

Summary of cool coating design

The principles

- High solar reflectance + high thermal emittance = low surface temperature
- Light-colored surfaces with high NIR reflectance are coolest
- Dark-colored surfaces with low NIR reflectance are hottest
- Dark-colored surfaces with high NIR reflectance lie in-between

The engineering

- Nonmetallic surfaces have high thermal emittance
- Use substrate or basecoat with high NIR reflectance
- Use pigments with low NIR absorption, and preferably high NIR backscattering
- **Avoid pigments with strong NIR absorption**

For more information

Visit the website of the

Cool Colored Roofing Materials Project

http://CoolColors.LBL.gov

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