Fundamentals of Vision Lighting

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ADVANCED ILLUMINATION

Objectives of Vision Lighting

- Proper lighting environment?
- Consistent lighting environment?
- Light show display to impress your supervisor?
- What do we mean by "proper" anyway?
- What we really require is control of the lighting environment for producing:

  - Sample inspection & system appropriate lighting
  - To the extent possible, standardization of components, techniques, implementation and operation
  - Reproducibility of inspection results
  - Robustness to handle variations of "all sorts"

Topics

- Review of Light for Vision Illumination
- Vision Lighting Sources
- Review of Illumination and Techniques
- Sample Applications Examples
- Using Near IR and Near UV Light
- Filters are Useful, Too!
- Standard Lighting Method

Standard Lighting Method

1) Knowledge of:
   - Lighting types and application advantages & disadvantages
   - Vision camera sensor quantum efficiency & spectral range
   - Illumination Techniques and their application fields relative to surface flatness & surface reflectivity
   - Illumination Technique Requirements & Limitations

2) Familiarity with the 4 Cornerstones of Vision Illumination:
   - Geometry
   - Structure (Pattern)
   - Wavelength (Color)
   - Filtering

3) Detailed Analysis of:
   - Immediate Inspection Environment – Physical constraints and requirements
   - Sample – Light Interactions w/ respect to your Unique Sample

Vision Lighting Development

Science?

Art?

Or *both*?

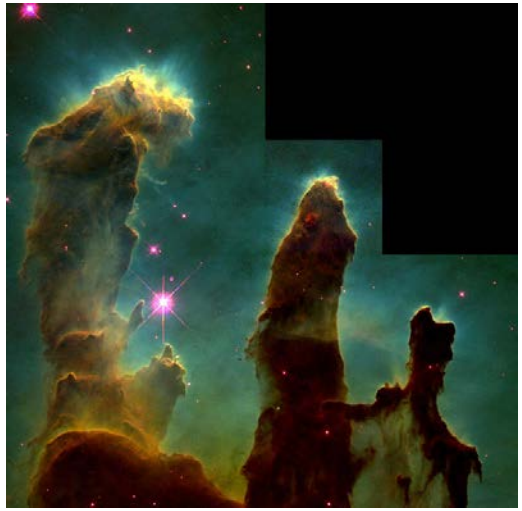


Image Courtesy NASA - HST

Images Courtesy Wikimedia Commons Public Domain

Vision Lighting Development

- Wave and Look (most common)
  - Image the part while trying different sources at different positions
- Scientific Analysis (most effective)
  - Analyze the imaging environment and short-list the best solution possibilities
- Test Lights! (saves time)
  - Test on the bench then the floor to verify your analysis

Review of Light for Vision Illumination

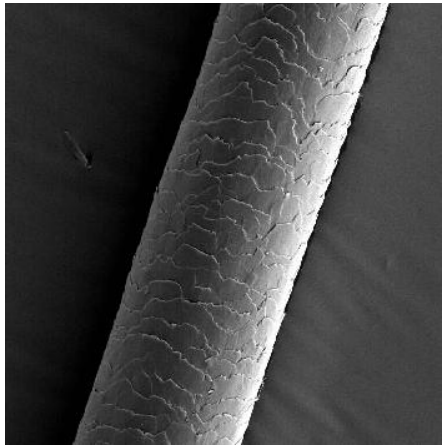
Characterizing Light for Vision

Light: Photons propagating as a transverse electromagnetic energy wave and characterized by:

- Frequency: Varies inversely with wavelength (Hz – waves/sec)

- Measured Photon Intensity: Radiometric and Photometric (more later)

- Wavelength (Most common for Machine Vision)



- expressed in nanometers (nm) or microns (um)
- 100 nm = 0.1 um = 1/10,000,000th of a meter!
- a human hair is ~ 100 um (100,000 nm) wide

Photons:

Energy packets exhibiting properties of waves and particles.

Characterizing Light for Vision

Light diffracts (bends) around edges – implications for back lighting.

It moves more slowly, thus refracts (disperses) through media of different densities.

The amount of refraction is directly proportional to its frequency, and thus inversely proportional to its wavelength.

Example - violet light has a higher frequency, thus it is refracted more than red through a given medium.

The amount of refraction also is directly proportional to the ratio of media densities and inversely proportional to the angle of incidence.

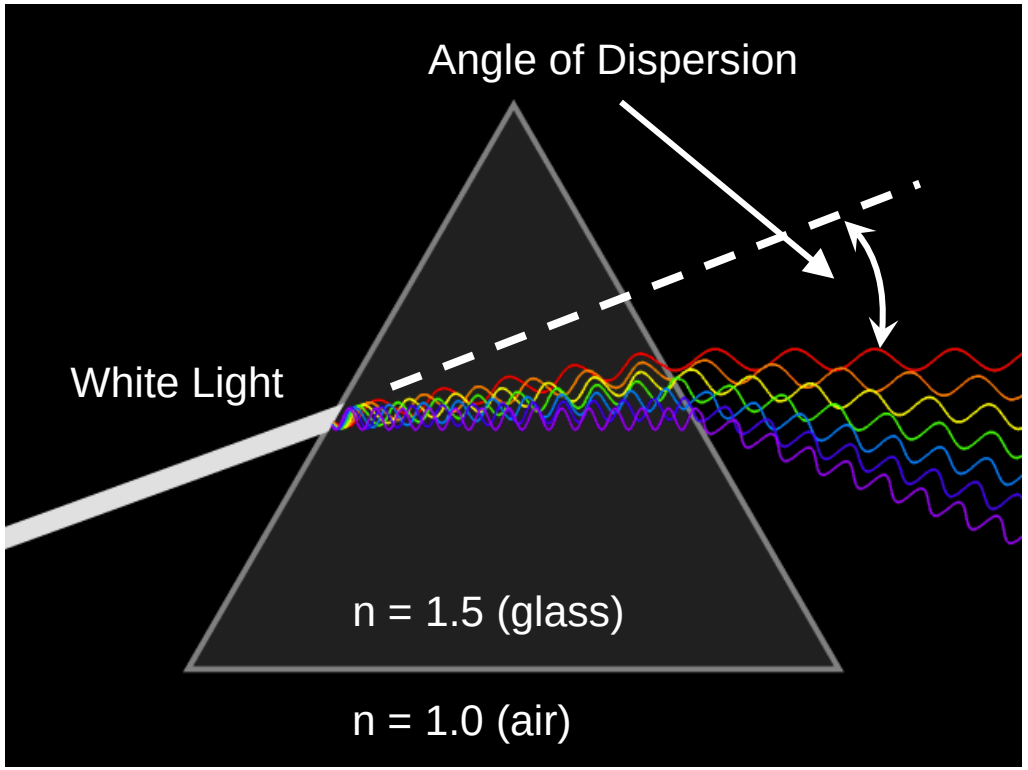
Light Refraction

Example

Light is refracted as:

n (glass) / n (air)
1.5 / 1.0 = 1.5

n = Index of Refraction



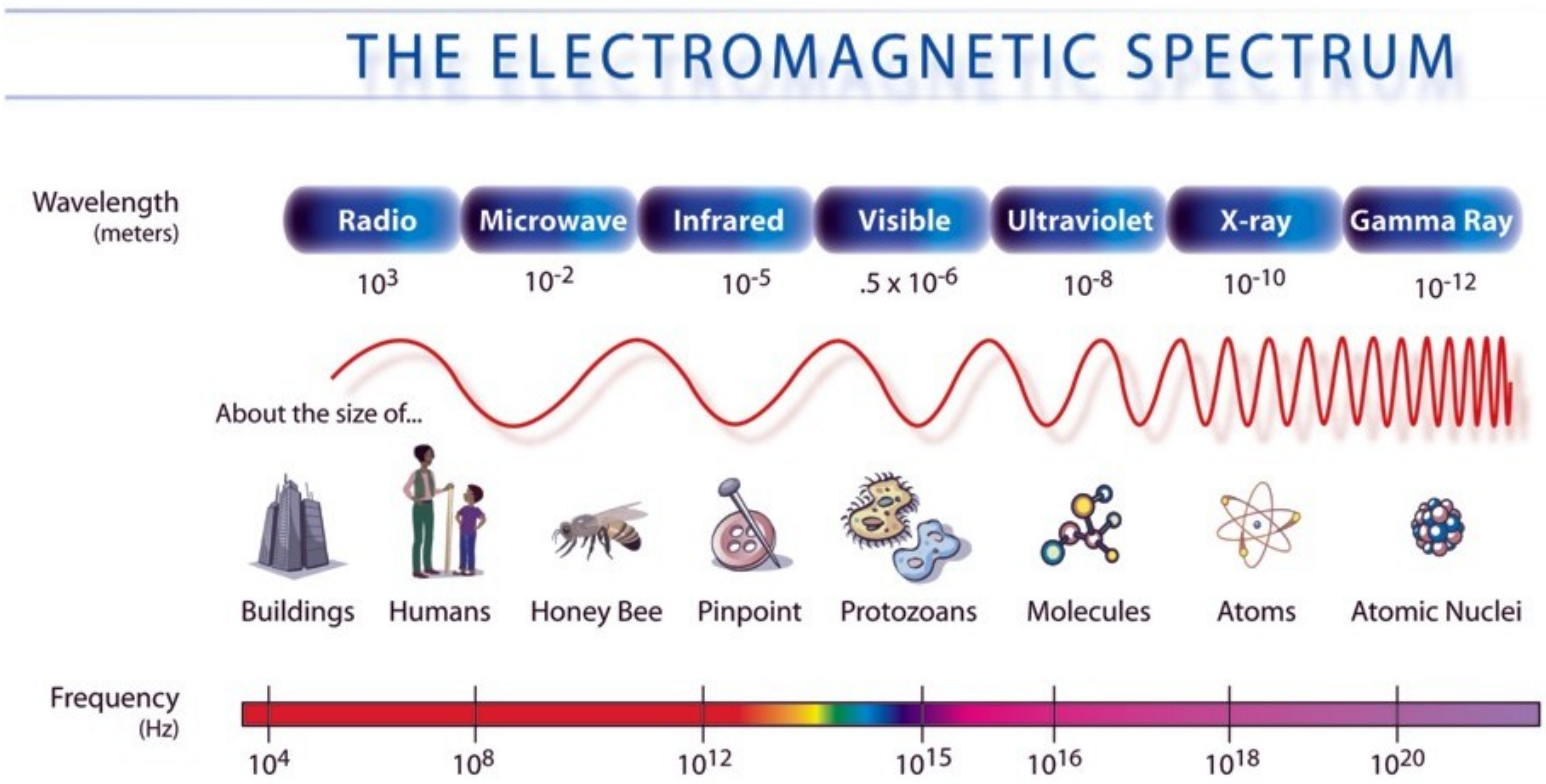
Courtesy Wikimedia Commons

Visible light is a very small portion of the “electromagnetic spectrum”

How small?

~ 1 / 1000th of 1%!

Characterizing Light



Long Wavelength

Larger # Photons, but Lower Energy ea

Low Frequency

Short Wavelength

Smaller # Photons, but High Energy ea

High Frequency

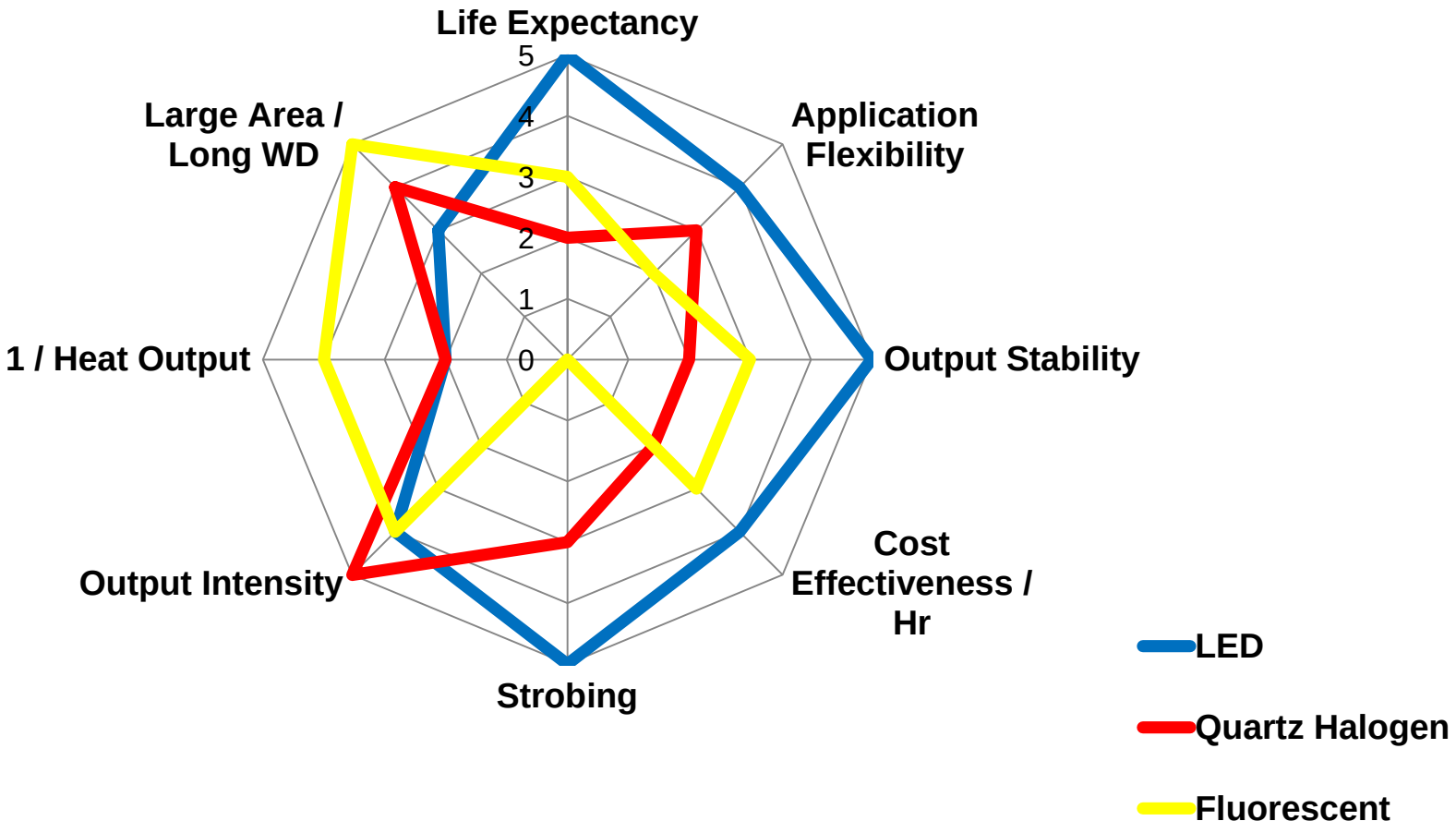
Courtesy of NASA Public Domain

Sources

- LED - Light Emitting Diode
- Quartz Halogen – W/ Fiber Optics
- Fluorescent
- Xenon (High-Performance Strobing)

- Metal Halide (Microscopy)
- High Pressure Sodium

Primary Light Sources

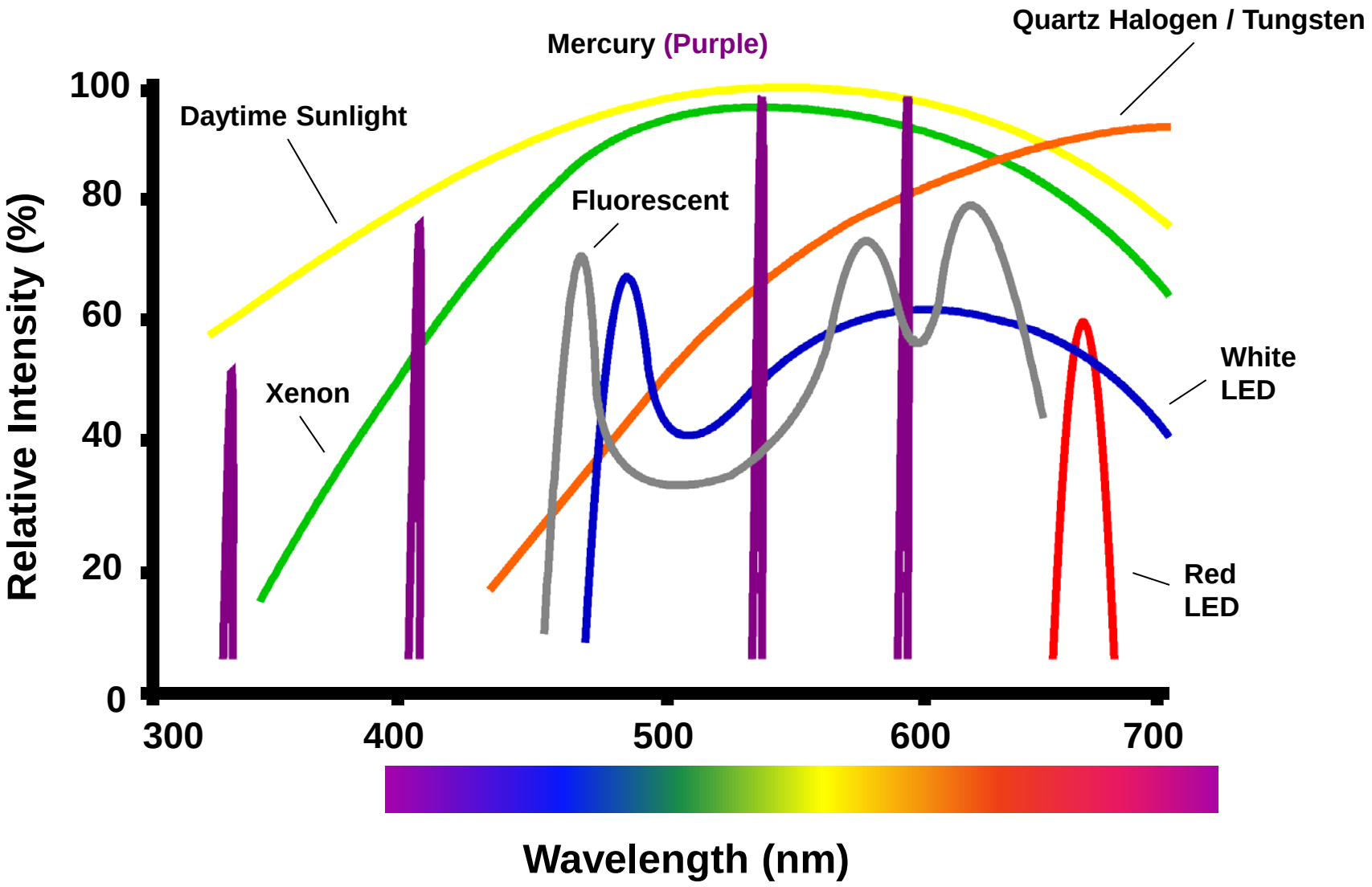


Source Comparisons

Type	Spectrum	Intensity	Life (hrs)	Comments
LED	Various	Bright to Very Bright	Up to 100,000	Long life Stable Output Small Area **
Fluorescent	White w/blue-green, yellow	Bright	5000 to 7000	Inexpensive Need High Freq Low Heat
Halogen	White w/yellow	Very Bright	200 to 3000	Inexpensive High Heat
Xenon	White w/blue	Very Bright	3000 to 7000	Expensive Stable
Electro-Luminescent	Green	Dim	2000 to 5000	Very Thin Low Heat

** Until Recently

Lighting – Intensity vs. Spectrum



Brief Review of Light and Optics for Vision Illumination

Sample-Appropriate Lighting

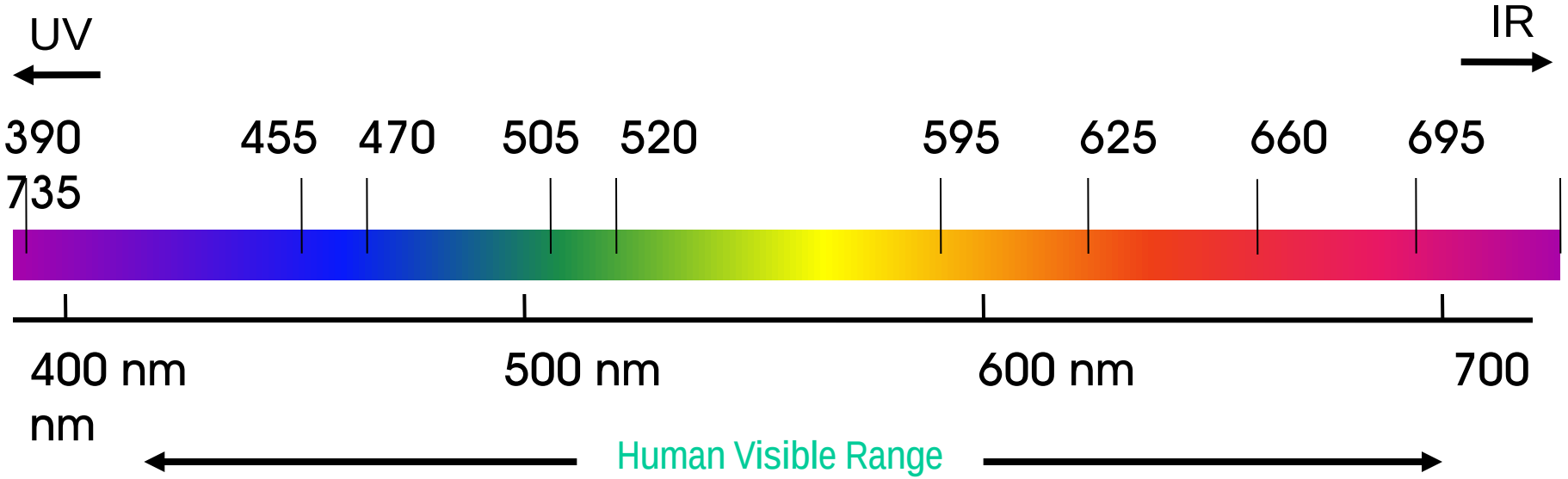
The lighting type and technique, tailored for the specific application, that allows the vision system do its job accurately and reproducibly.

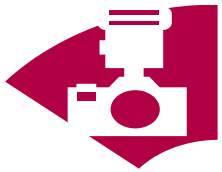
It's All About (creating) Contrast!

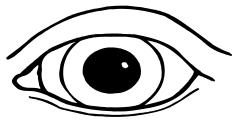
1) Maximum contrast
   - features of interest
2) Minimum contrast
   - features of no interest (noise)
3) Minimum sensitivity to normal variations
   - minor part differences
   - presence of, or change in ambient lighting
   - sample handling / presentation differences

The Visible Light Spectrum

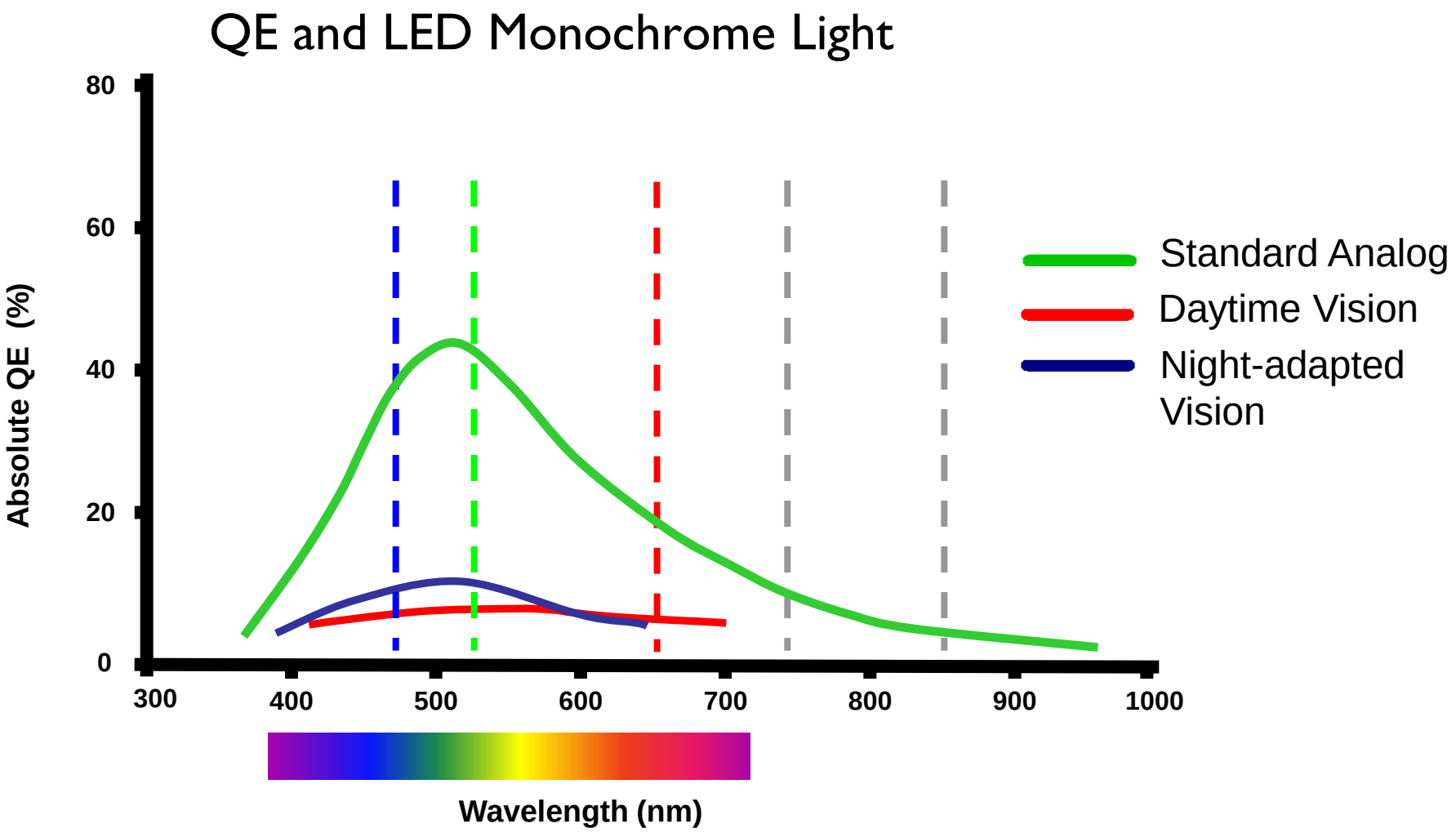
- Light is Seen Differently by film, humans and CCDs





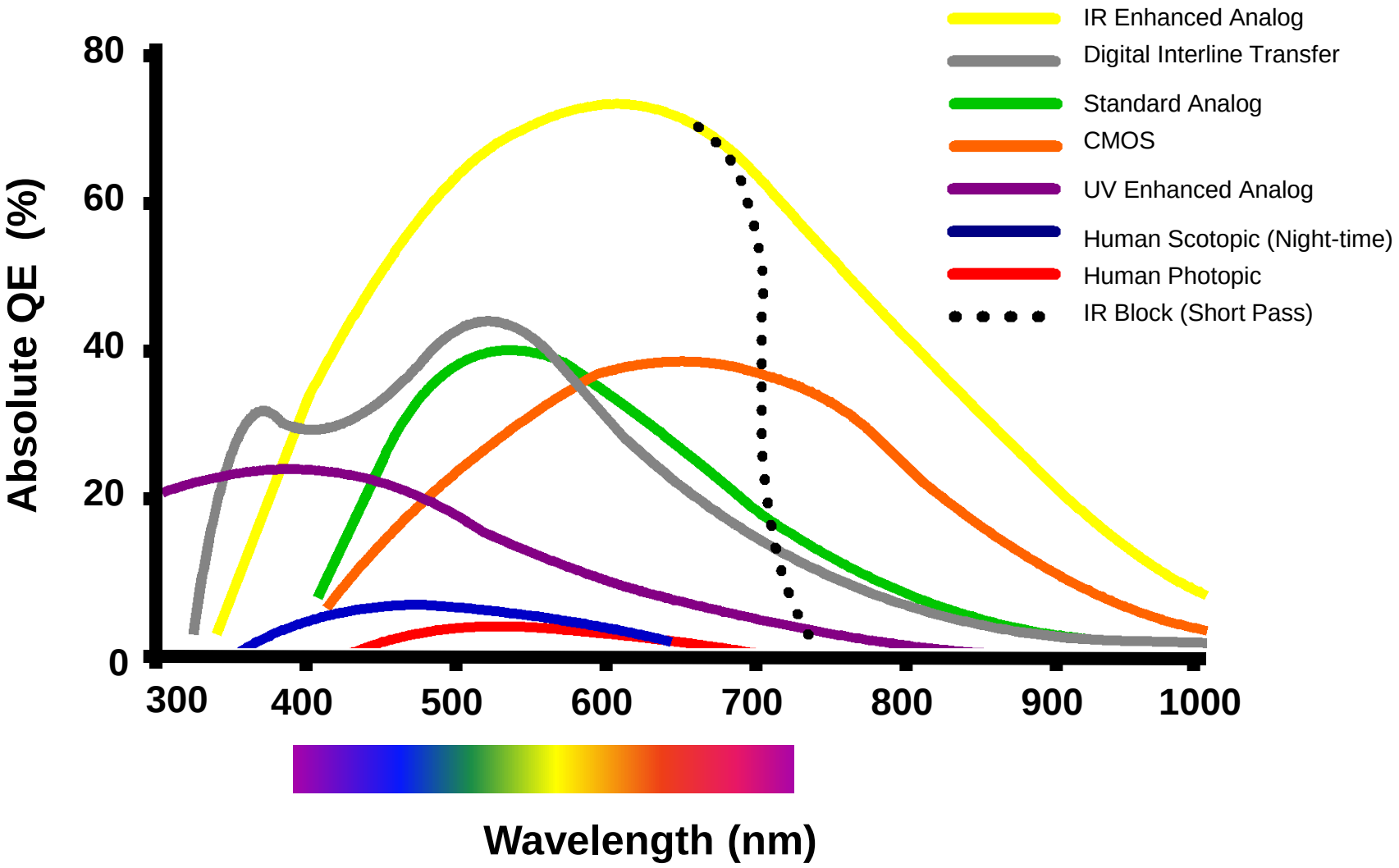


Camera vs. Eye Response



Let your vision system determine sensitivity and wavelength!

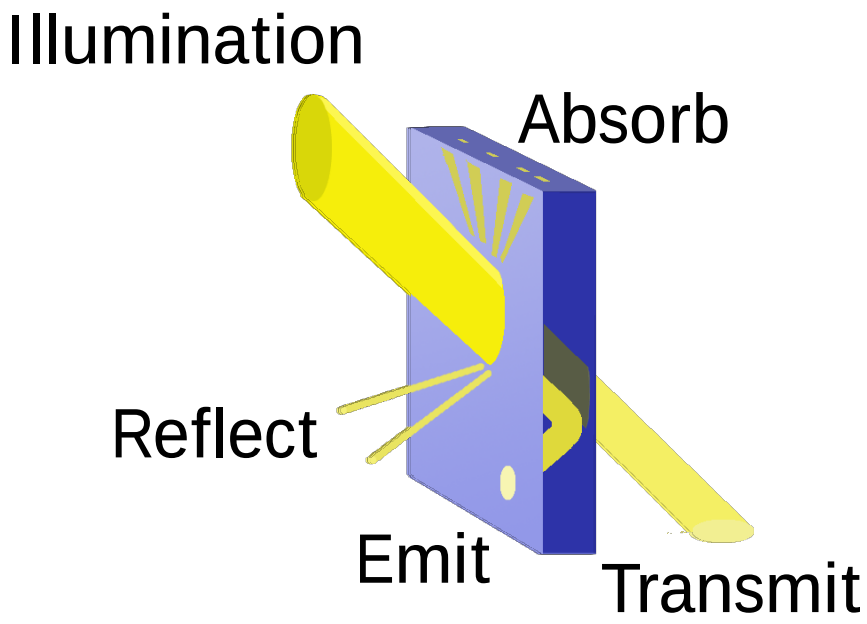
Sensors and Wavelength

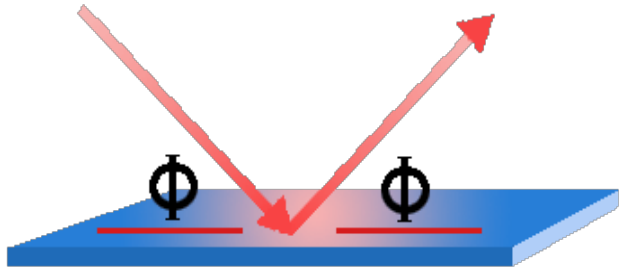


Sample / Light Interaction

Total Light In =

Reflected + Absorbed + Transmitted + Emitted Light





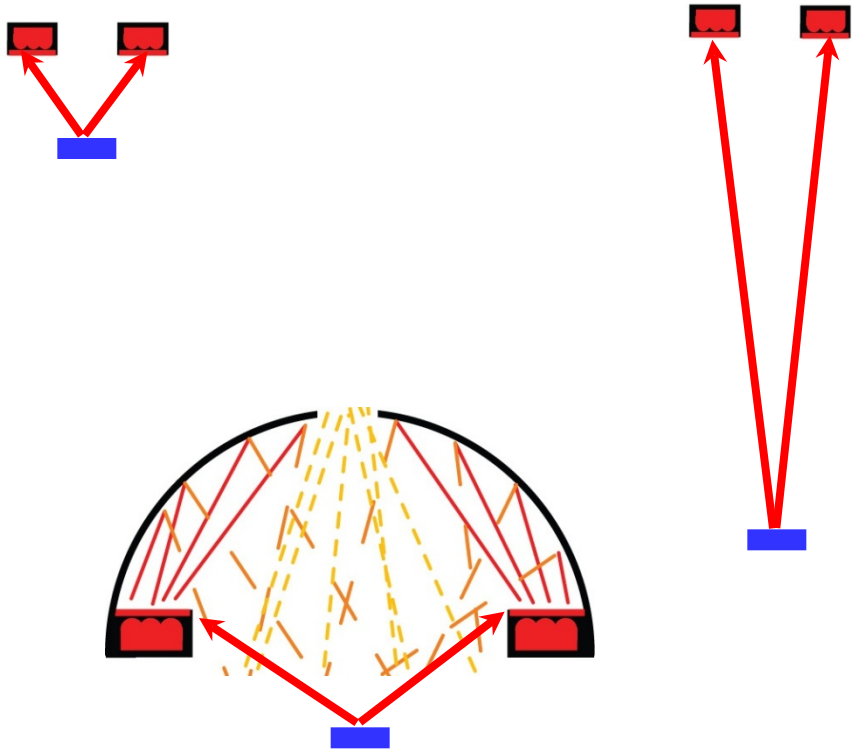
Light reflects at the angle of incidence

$$\Phi 1 = \Phi 2$$

Solid Angle and Geometry

Solid angle: Effective surface area of a light / radius^2 of the cone.

- Ring Light or Spot Light
  - Small Solid Angle
- Ring Light or Spot Light at greater WD
  - Smaller Solid Angle
- Dome, Axial Diffuse or Flat Diffuse
  - Large Solid Angle



Note: Shorter WD and larger light increase the effective solid angle.

Light Interaction

Convergence of Concepts

(Sample – Light – Lens**)

Contrast

Resolution

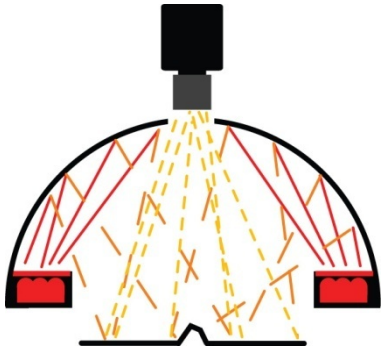
- Spatial
- Spectral

Focal Length / Field of View

Focus

Working Distance / Stand-off

Sensitivity



**3-D Working Volume: Strong inter-relationship

You cannot solve vision problems working in a vacuum!

Review of Lighting Techniques

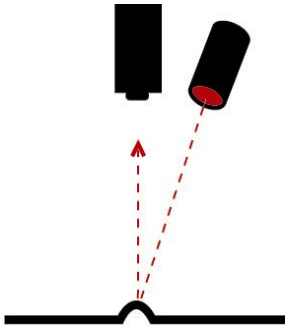
4 Lighting Cornerstones

How do we change contrast?

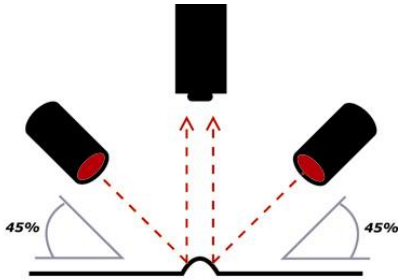
- Change Light / Sample / Camera Geometry
  - 3-D spatial relationship
- Change Light Pattern (Structure)
  - Light Head Type: Spot, Line, Dome, Array
  - Illumination Type: B.F. – D.F. – Diffuse – B.L.
- Change Spectrum (Color / Wavelength)
  - Monochrome / White vs. Sample and Camera Response
  - Warm vs. Cool color families – Object vs. Background
- Change Light Character (Filtering)
  - Affecting the wavelength / direction of light to the camera

Need to understand the impact of incident light on both the part of interest and its immediate background!

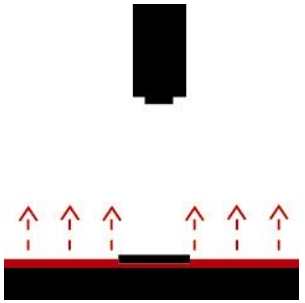
Common Lighting Techniques



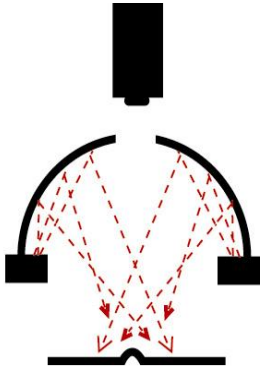
Partial Bright Field



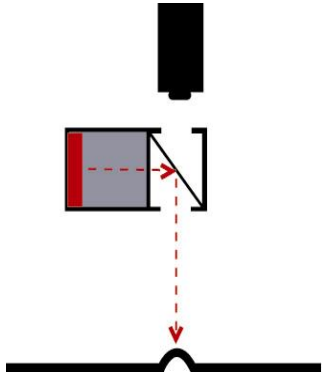
Dark Field



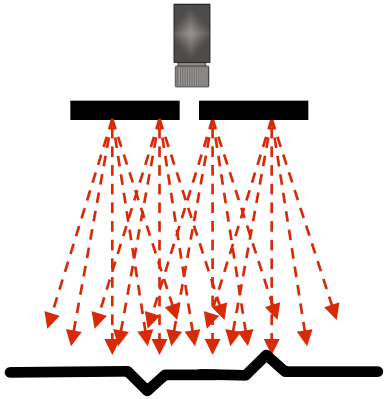
Back Lighting



Diffuse Dome



Axial Diffuse



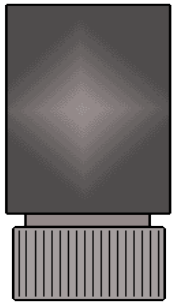
Flat Diffuse

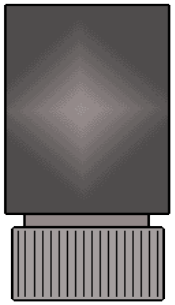
Full Bright Field

Bright Field vs. Dark Field

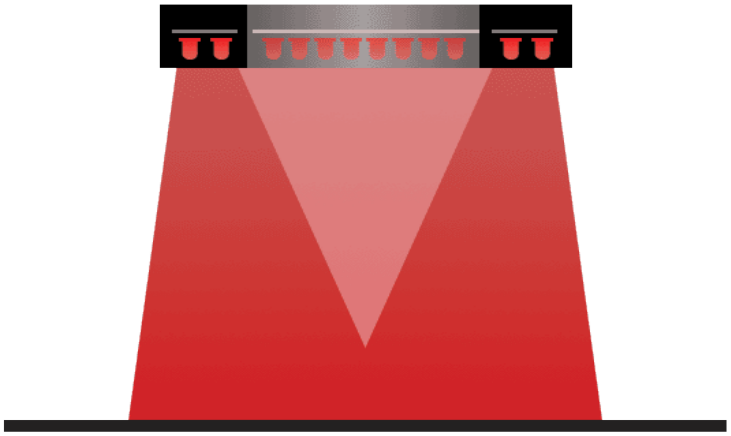
Typical Co-axial Ring Light – Sample Geometry

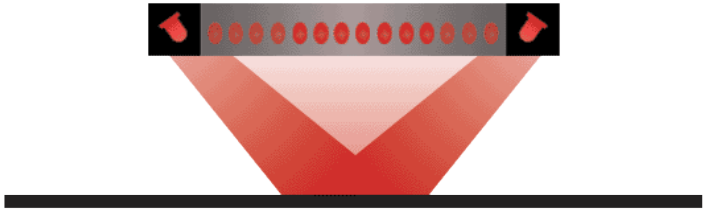
Bright Field



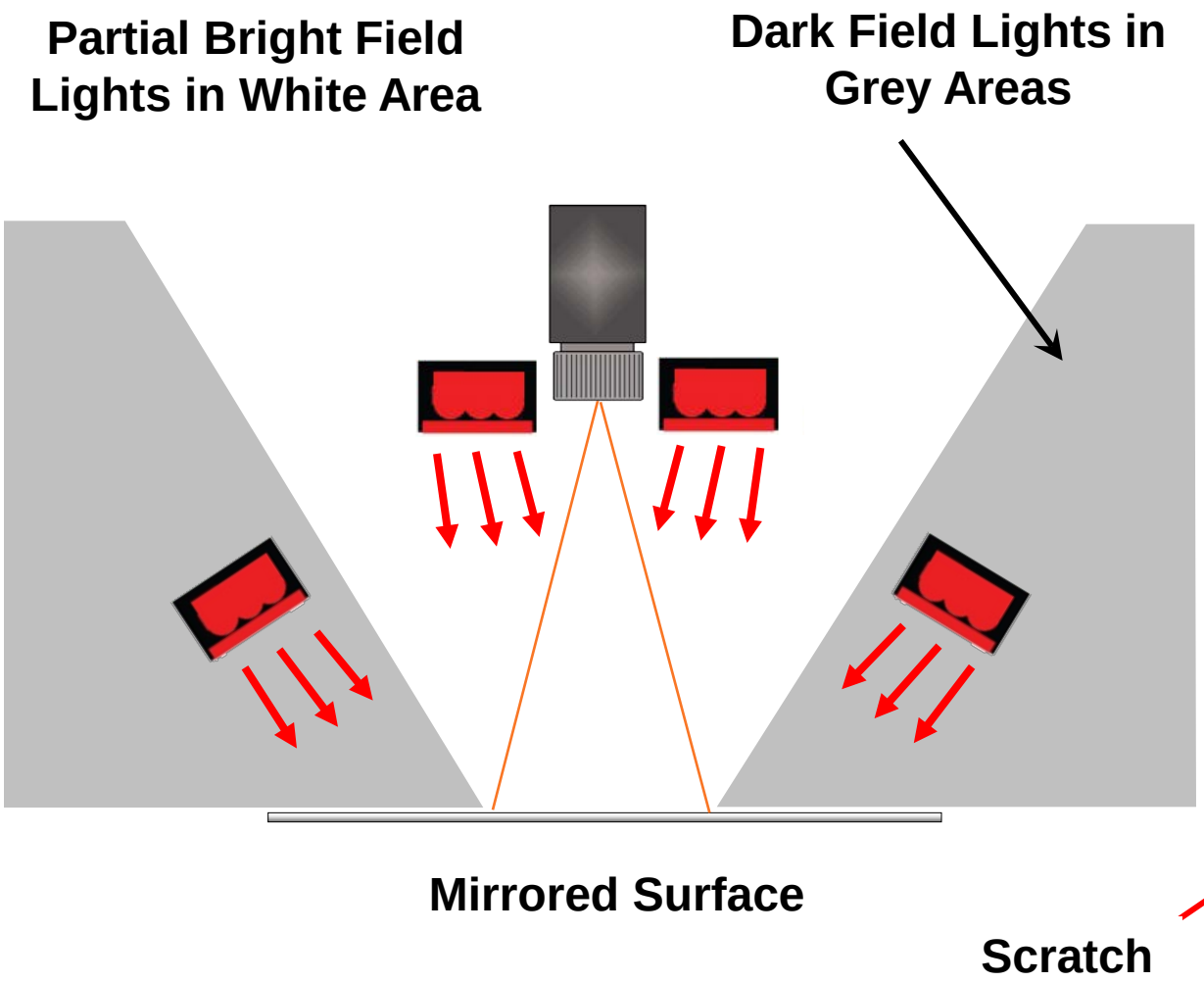


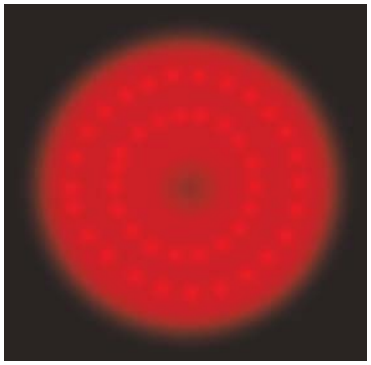
Dark Field

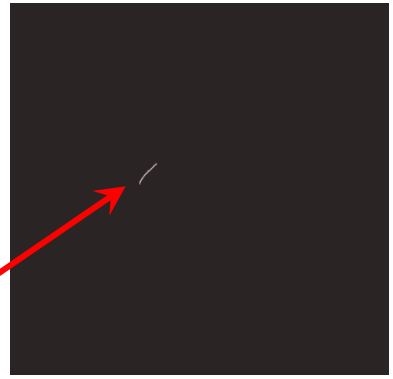




Dark Field vs. Bright Field

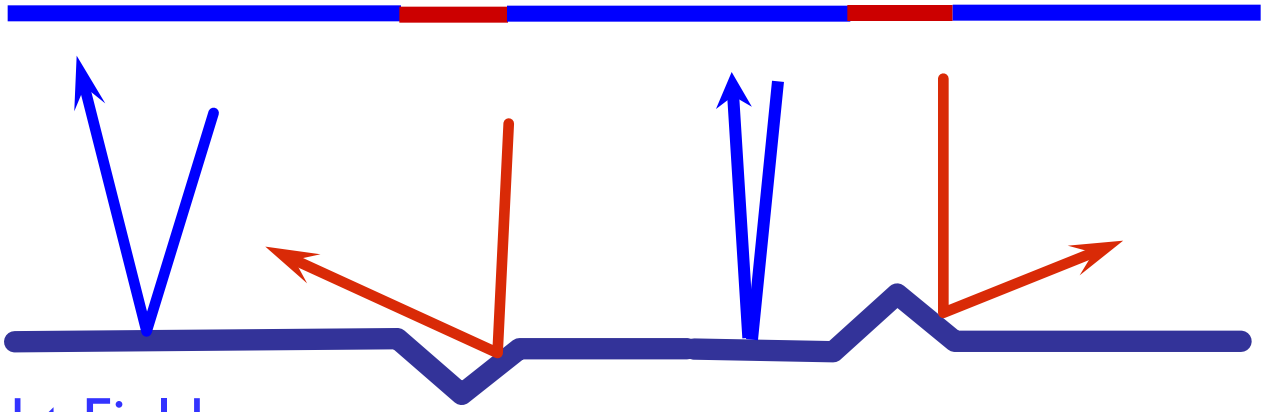




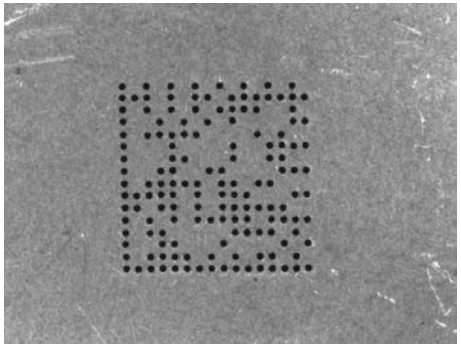


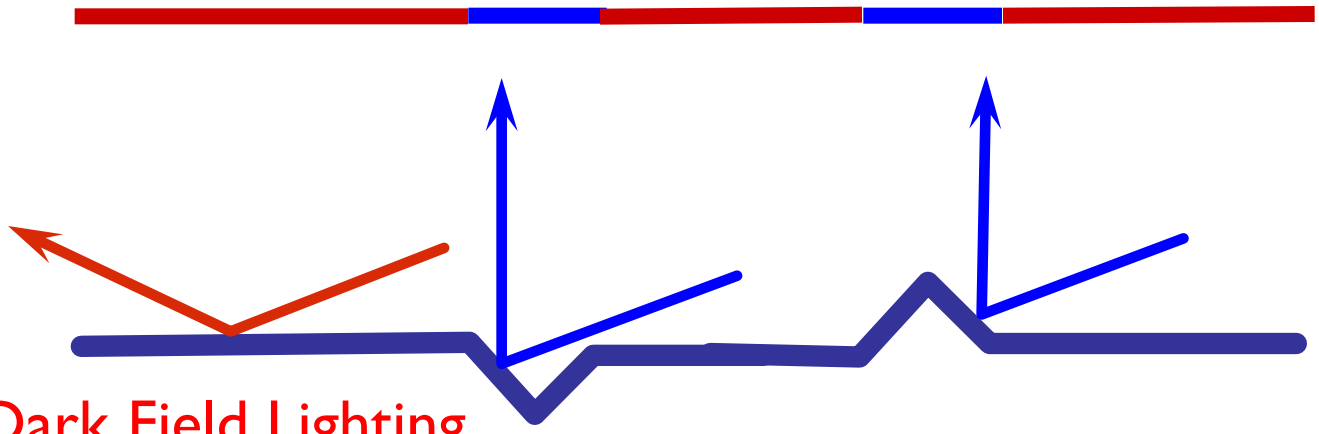
Scratch

Bright Field vs. Dark Field

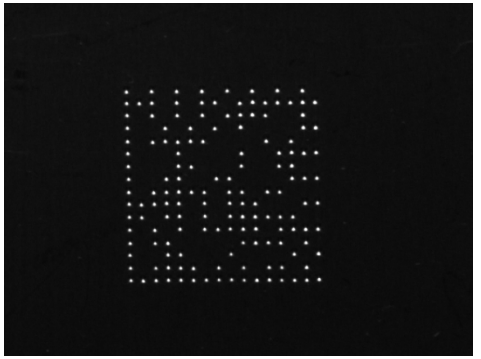


Bright Field Lighting

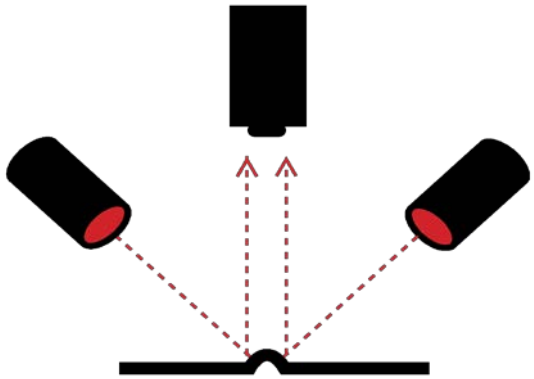




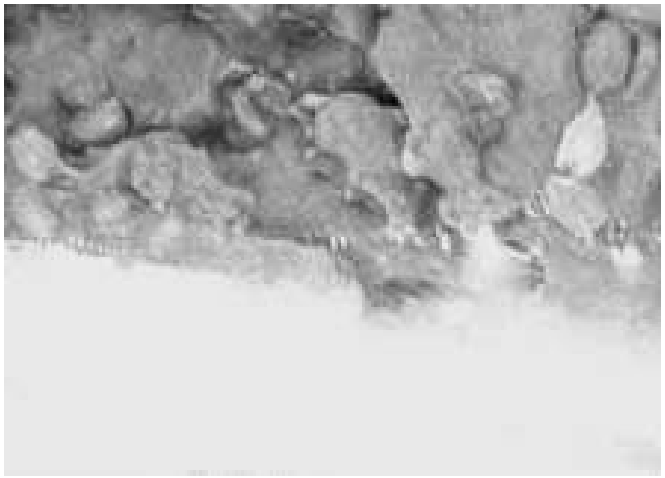
Dark Field Lighting

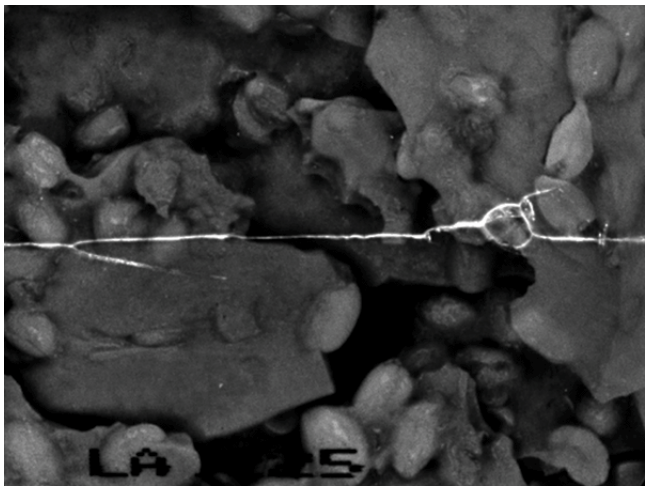


Dark Field Example



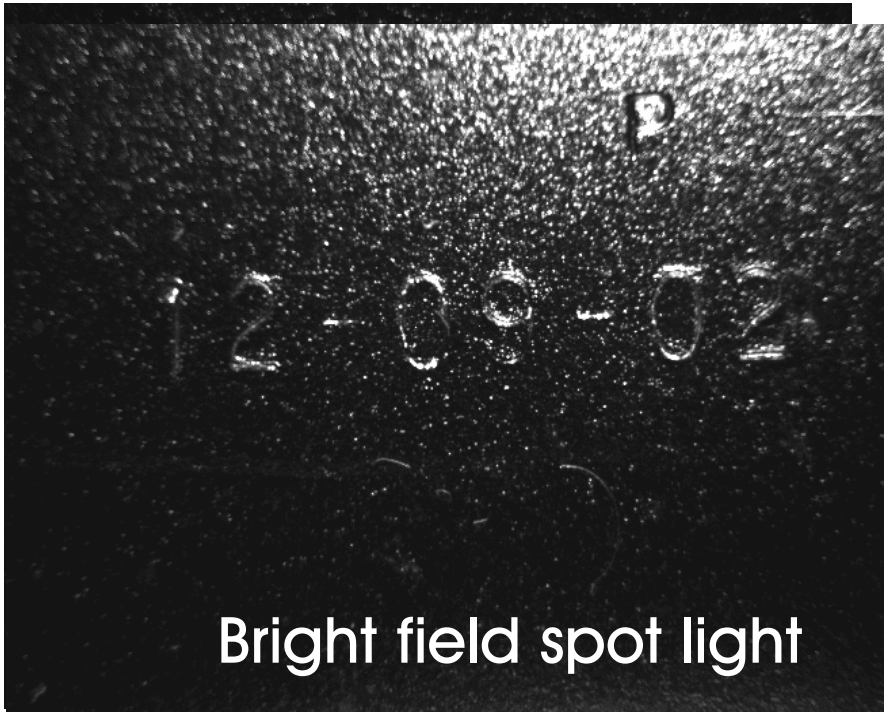
- Angled light – 45 degrees or less
- Used on highly reflective surfaces
- OCR or surface defect applications





Stamped Date Code

- Recessed metal part
- Reflective, textured, flat or curved surface

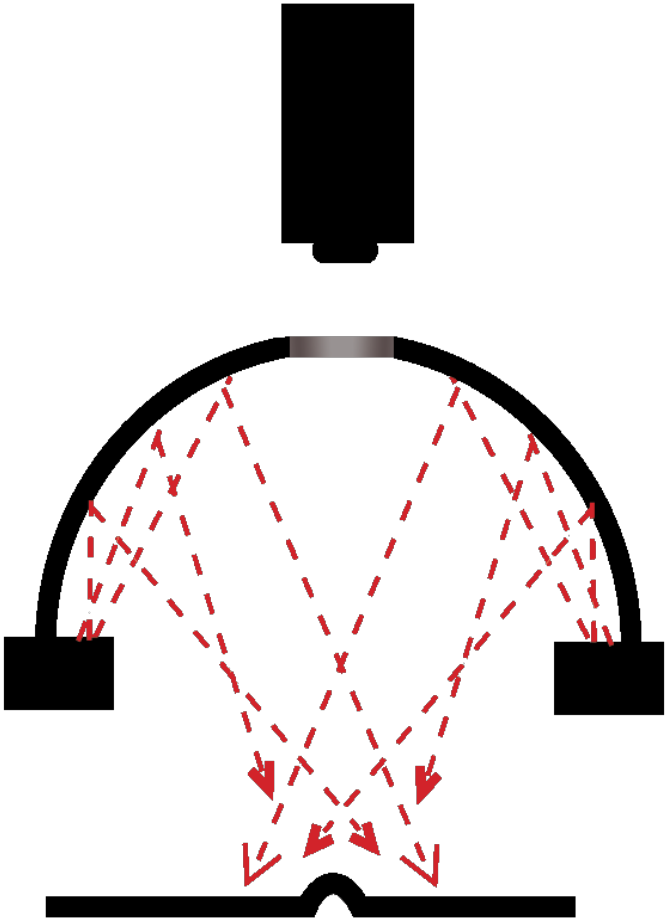


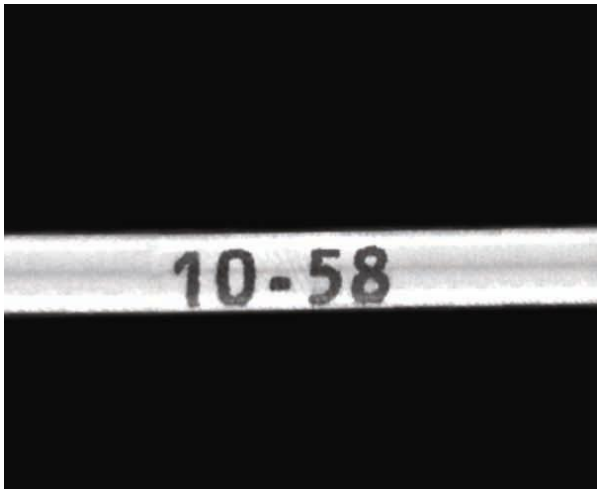
UPC Bar Code

Reading under
Cellophane

Diffuse Dome

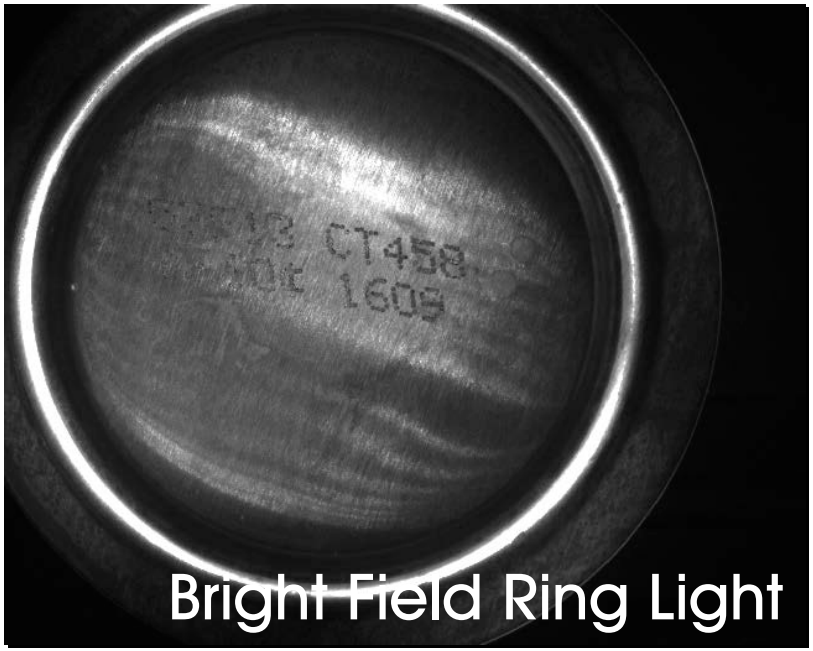
- Similar to the light on an overcast day.
- Creates minimal glare.





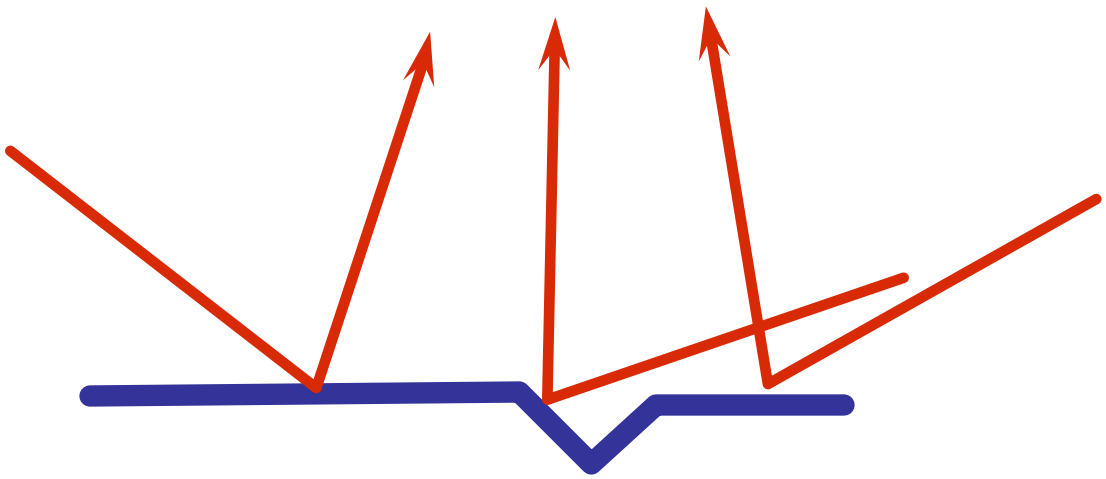
Ink Jet OCR

- Purple Ink
- Concave, reflective surface

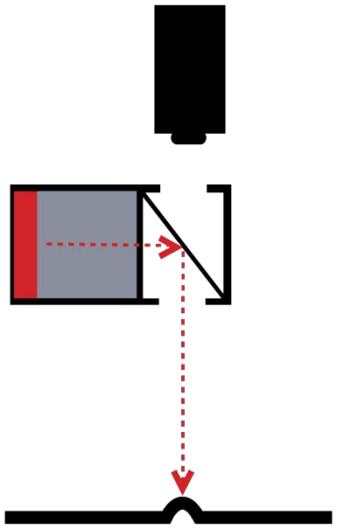


Diffuse Dome Illumination

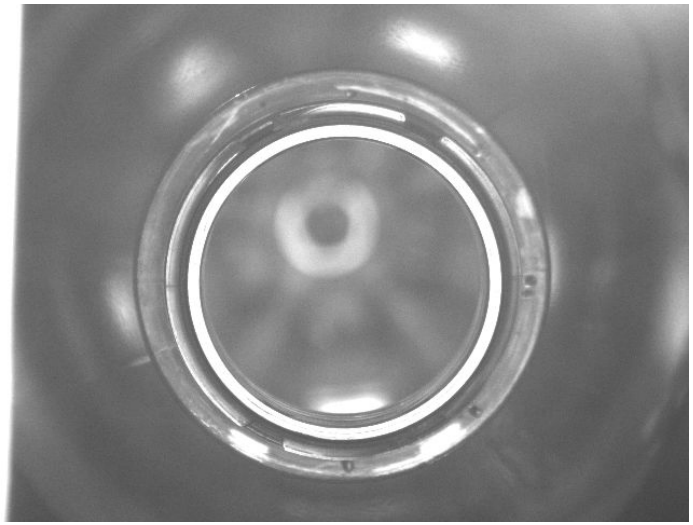
- Surface Texture Is Deemphasized
- Best Choice for Curved Shiny Parts

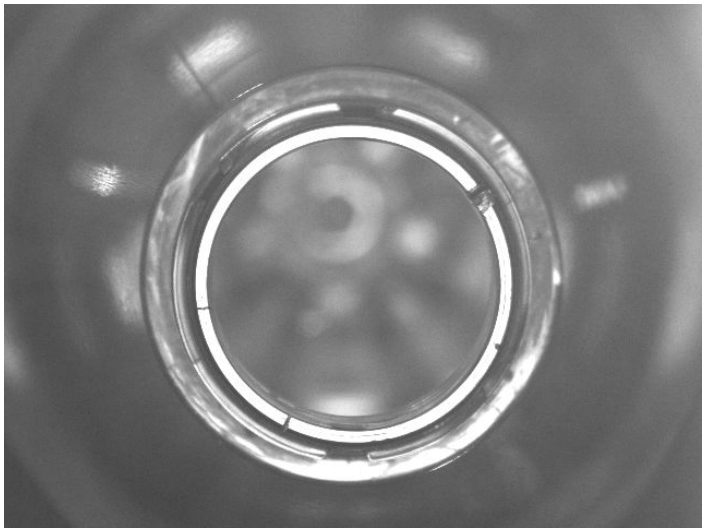


Axial Diffuse



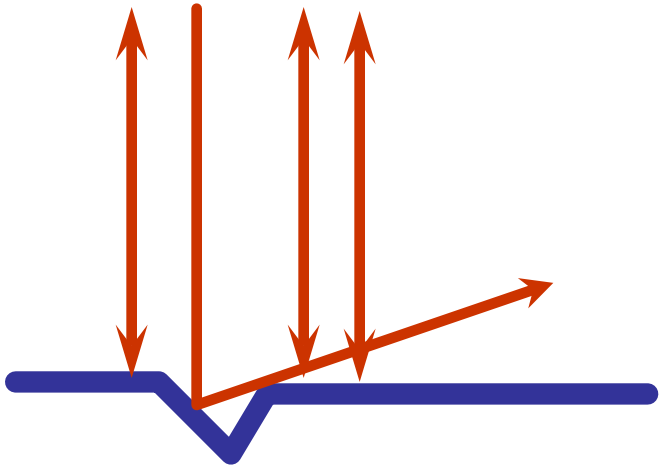
- Light directed at beam splitter
- Used on reflective objects



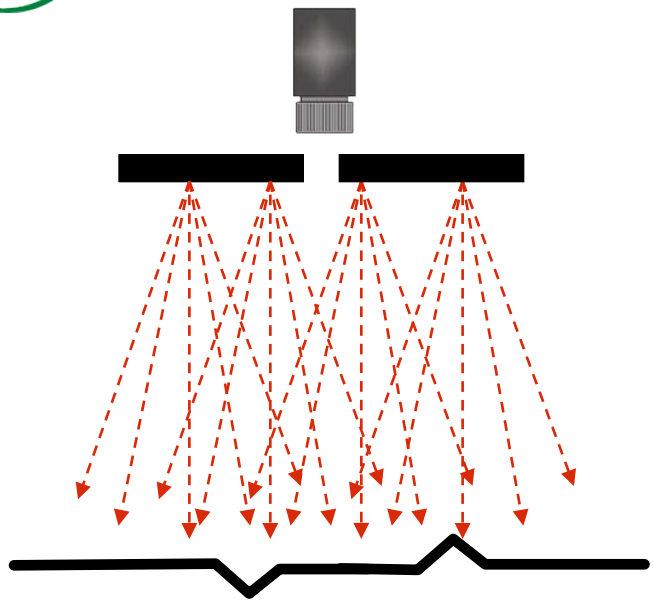


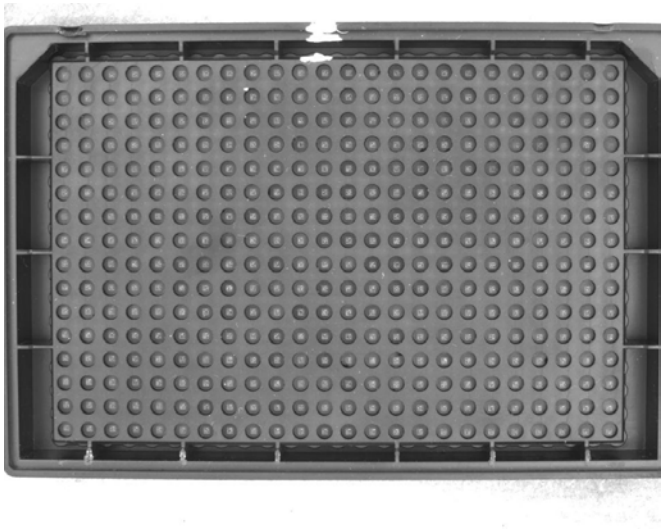
Axial Diffuse Illumination

- Surface Texture Is Emphasized
- Angled Elevation Changes Are Darkened

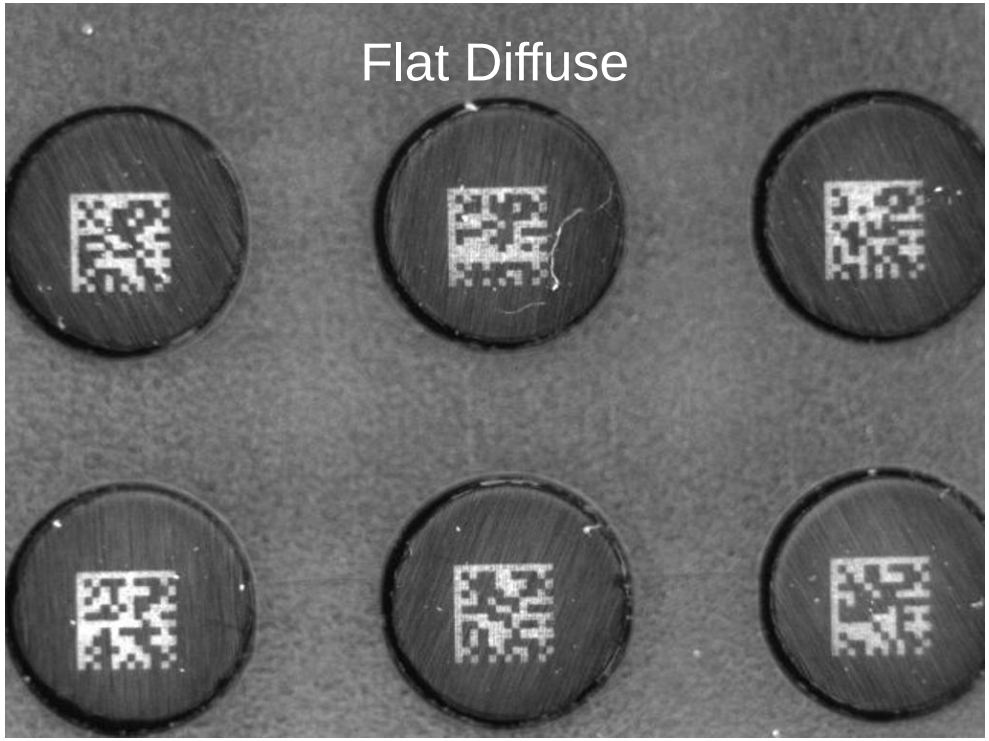


Flat Diffuse

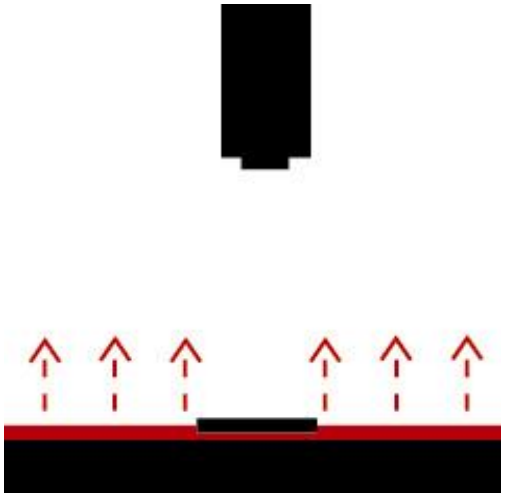




- Diffuse sheet directed downward
- Long WD and larger FOV
- Hybrid diffuse (dome and coaxial)

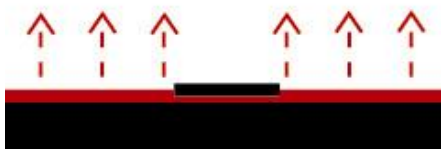


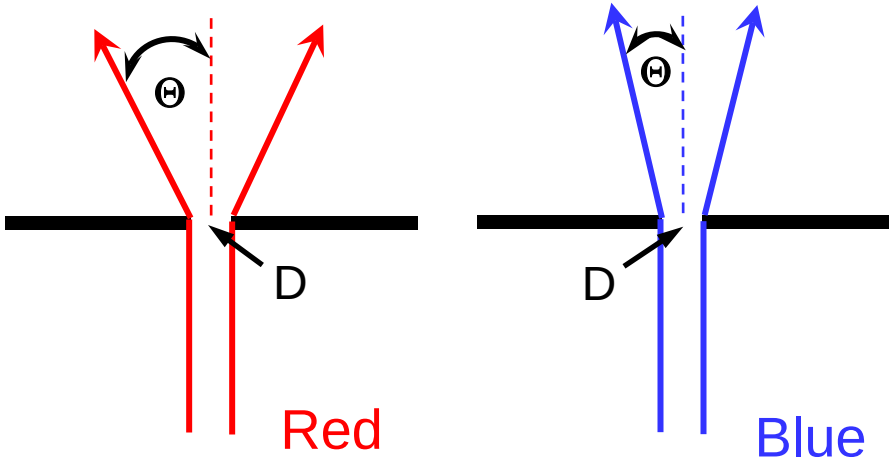
Backlight Illumination



- Locates edges – Gauging
- Internal defects in translucent parts
- Hole-finding
- Presence / Absence
- Vision-Guided Robotics: Incl. Pick & Place
- Useful for translucent materials

Backlight Illumination





Light Diffraction:

Bending around obstacles

$\Theta = \lambda / D$, where Θ is the diffraction angle and D is opening width

High-accuracy gauging:

Use monochrome light

Shorter wavelengths best

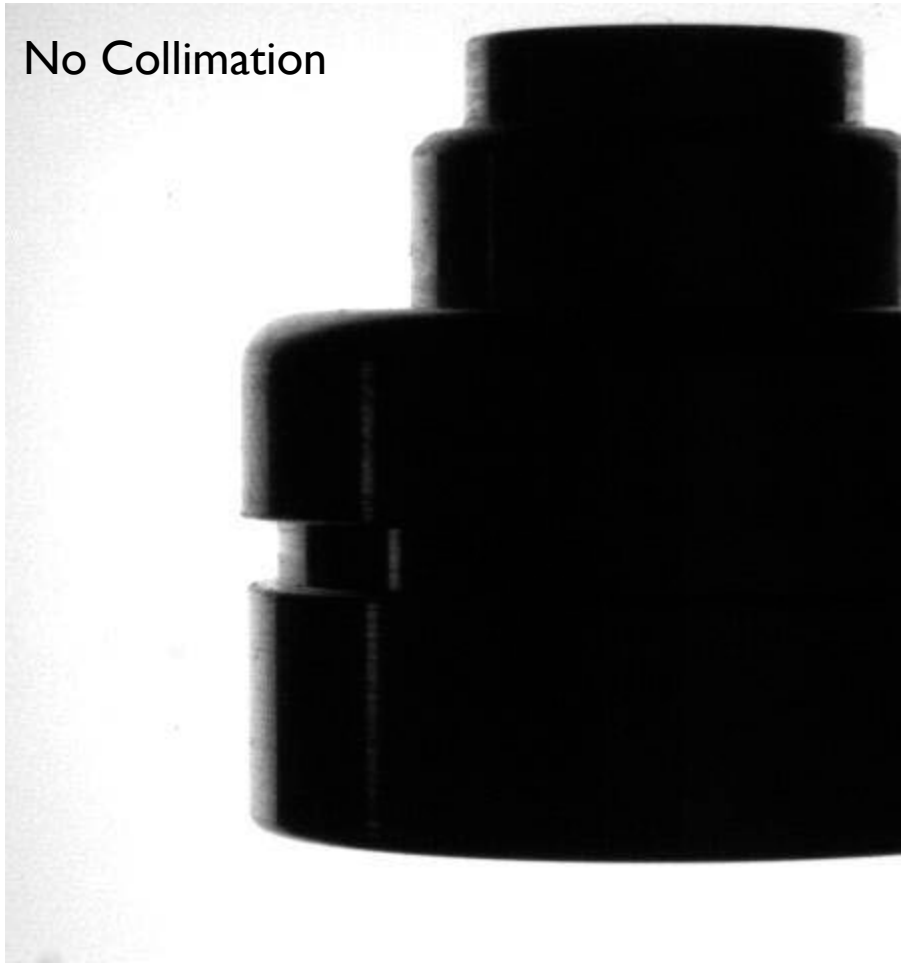
Use collimation – parallel rays

Longer λ light penetrates samples better

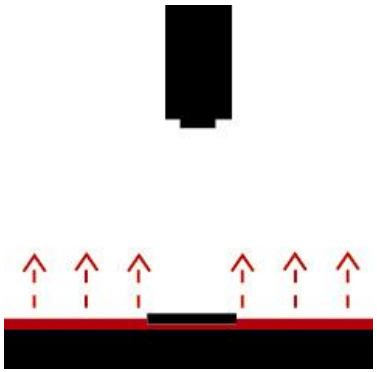
Simple Back Lighting Example

- Small Bottle – blue-green
- Consider colors and materials properties also.
- Longer wavelength isn't always best for penetration!

Collimated Backlight Illumination



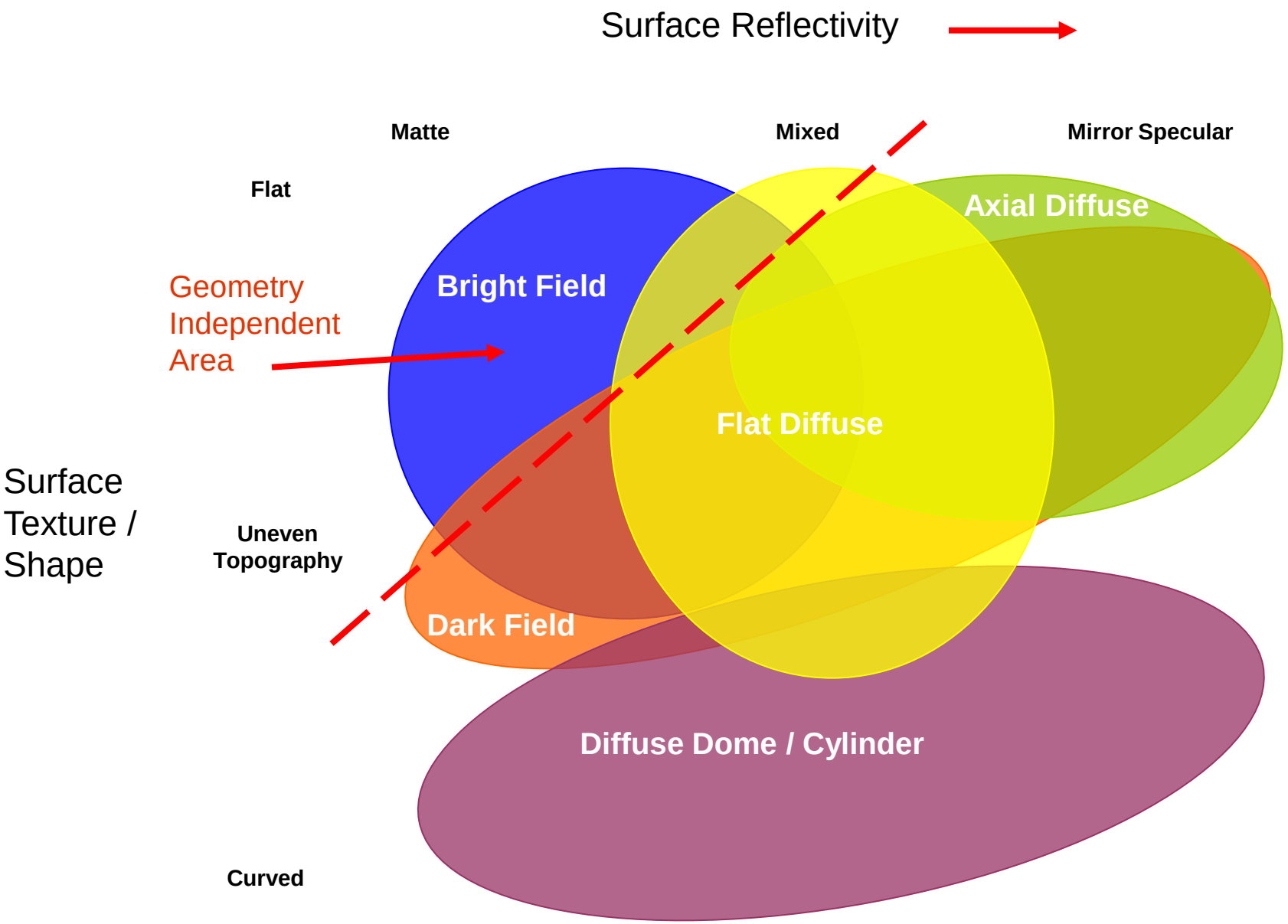
High- Accuracy Gauging



- Back lighting
- Monochrome light better
  - Shorter wavelength a little better
- Collimation even better
  - Optical collimation better than film
- Minimal distortion lens
  - Telecentric lens best
- Measurement calibration – CRITICAL*
- Focus - CRITICAL*

* Less critical if using a telecentric lens

Technique vs. Sample Surface



Inspection Environment

Physical Constraints

- Access for camera, lens & lighting in 3-D (working volume)
- The size and shape of the working volume
- Min and max camera, lighting working distance and FOV

Part Characteristics

- Sample stationary, moving, or indexed?
- If moving or indexed, speeds, feeds & expected cycle time?
- Strobing? Expected pulse rate, on-time & duty cycle?
- Is the part presented consistently in orientation & position?
- Any potential for ambient light contamination?

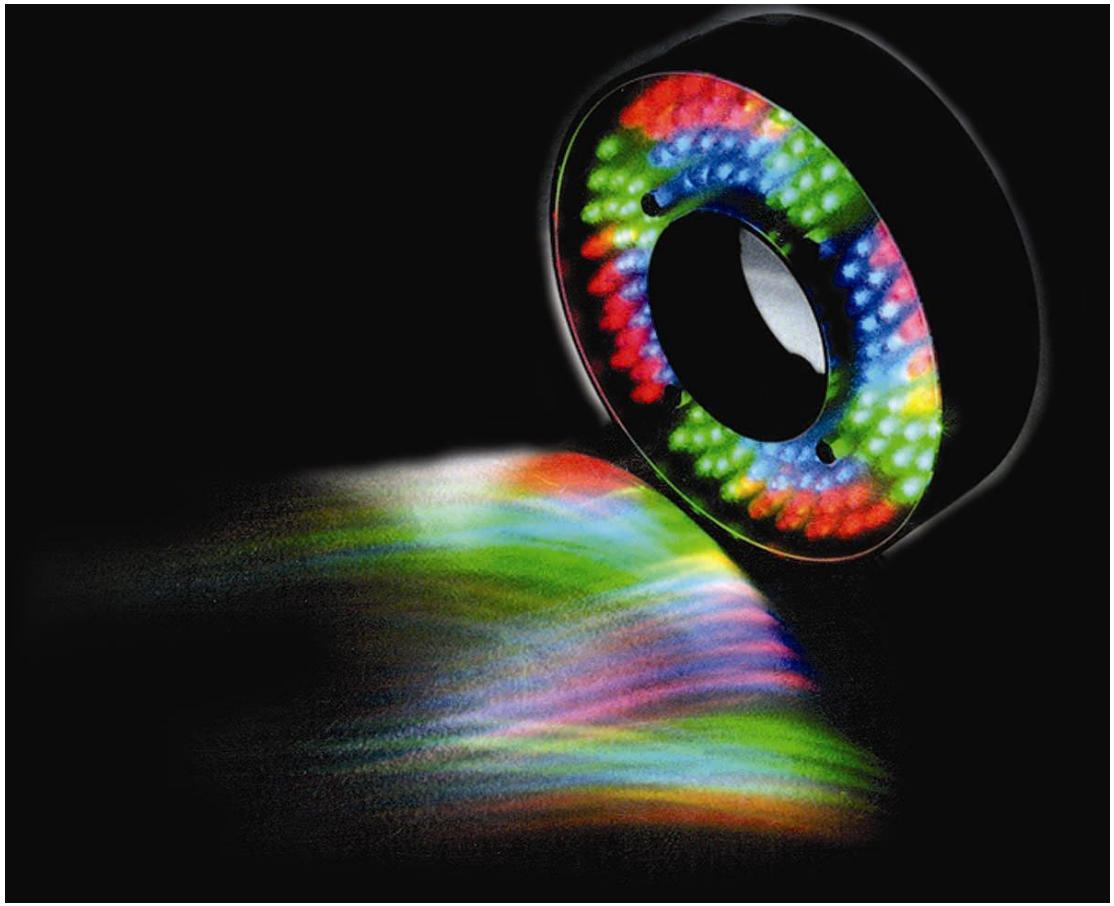
Ergonomics and Safety

- Man-in-the-loop for operator interaction?
- Safety related to strobing or intense lighting applications?

Lighting Technique Requirements

	Partial Bright Field	Dark Field	Diffuse Axial Full Bright Field	Diffuse Dome Full Bright Field
Lighting Type	Ring, Spot	Angled Ring, Bar	Diffuse Box	Dome
	No Specular	Negate Specular	Use Specular	Use Specular
When To Use	-Non specular -Area lighting -May be used as a dark field light	-Specular / Non -Surface / Topo -Edges -Look thru trans-parent parts	-Specular / Non -Flat / Textured -Angled surfaces	-Specular / Non -Curved surfaces -If ambient light issues
Require ments	-No WD limit (limited only to intensity need on part)	-Light must be very close to part -Large footprint -Limited spot size -Ambient light may interfere	-Light close to part -Large footprint -Ambient light minor -Beam splitter lowers light to camera	-Light close to part -Large footprint -Camera close to light -Spot size is ½ light inner diameter

Using Color Lighting to our Advantage

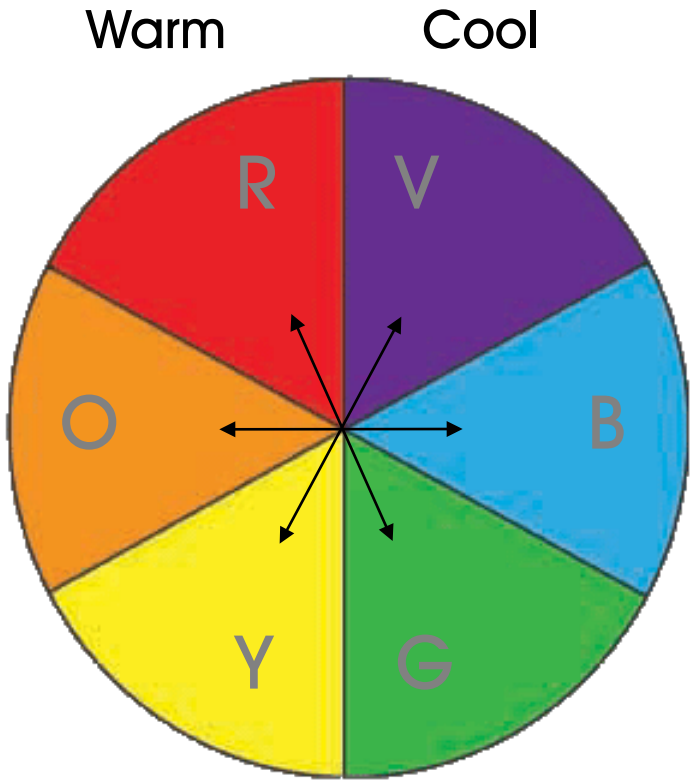


Using Color

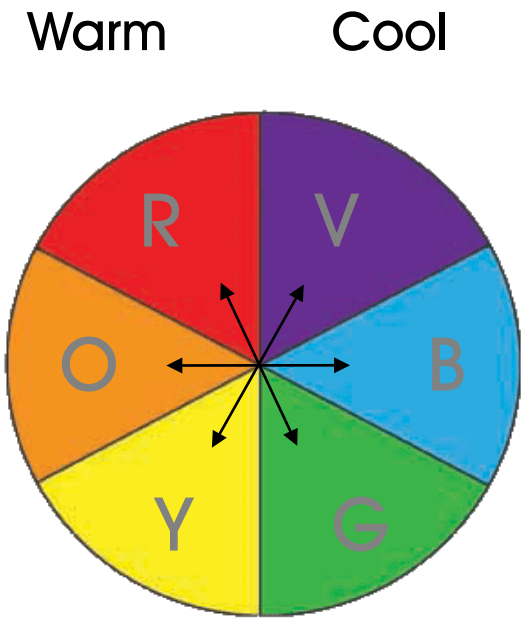
Use Colored Light to Create Contrast

- Use Like Colors or Families to Lighten (green light makes green features brighter)

- Use Opposite Colors or Families to Darken (red light makes green features darker)



Increasing Contrast with Color



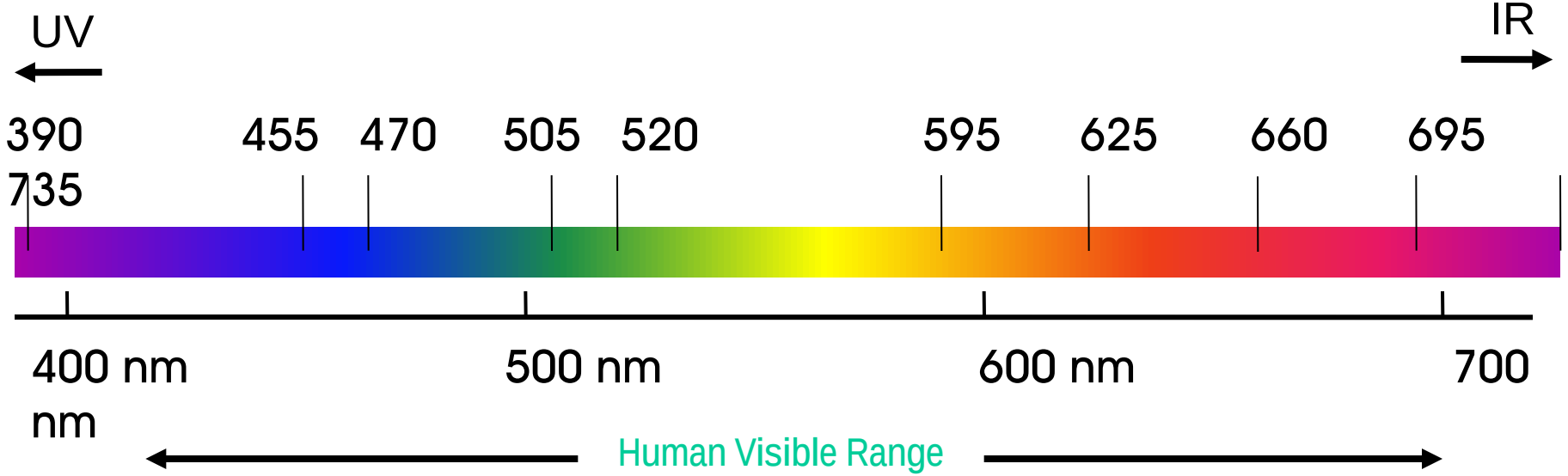
Consider how color affects both your object and its background!

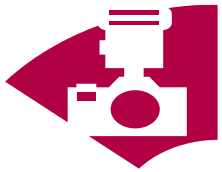
White light will contrast all colors, but may be a contrast compromise.

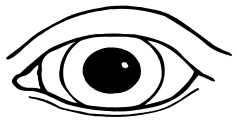
Using Near IR and Near UV Light

The Visible Light Spectrum

- **All** Light is seen differently by film, humans and CCDs



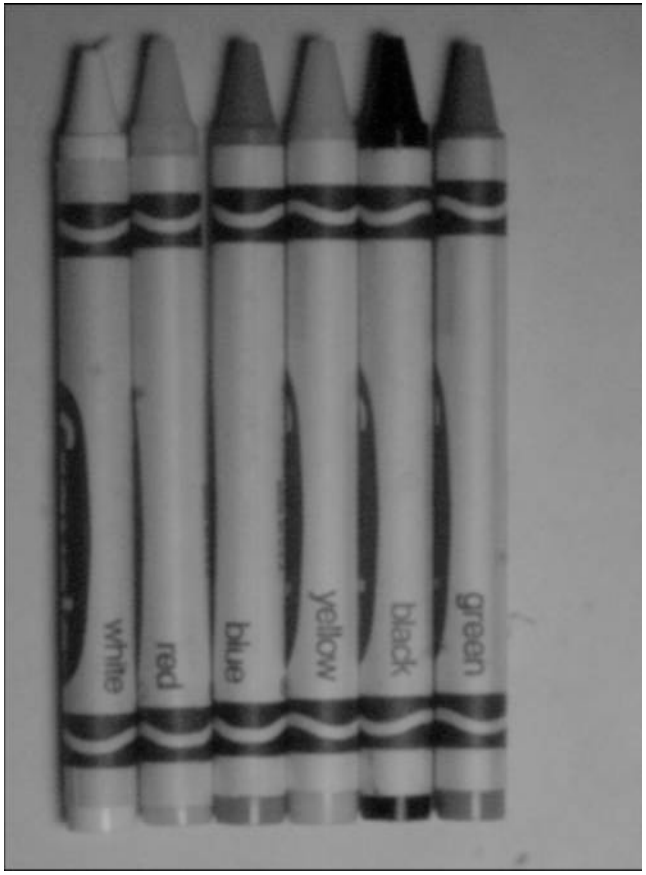




Imaging Beyond "Visible" – Near IR

- Infra-red (IR) light interacts with sample material properties, often negating color differences.

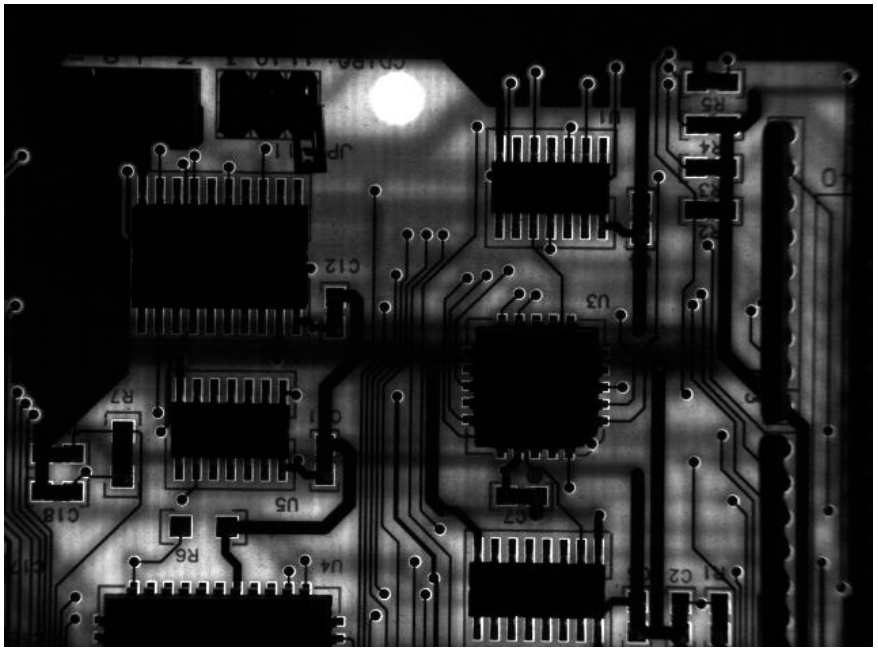
White light – B&W Camera



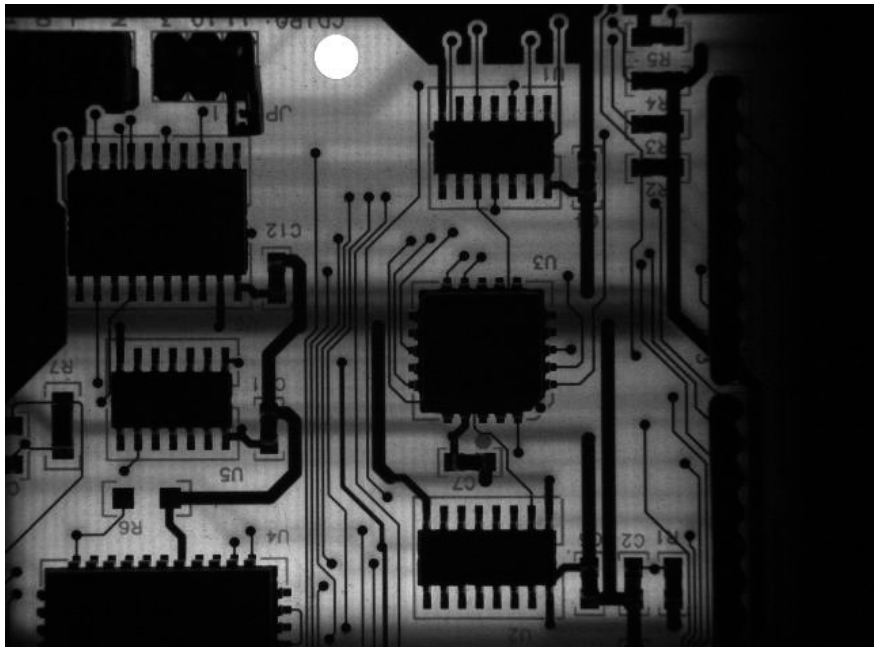
IR light – B&W Camera

Imaging Beyond "Visible" – Near IR

- Near IR light can penetrate materials more easily because of the longer wavelength.



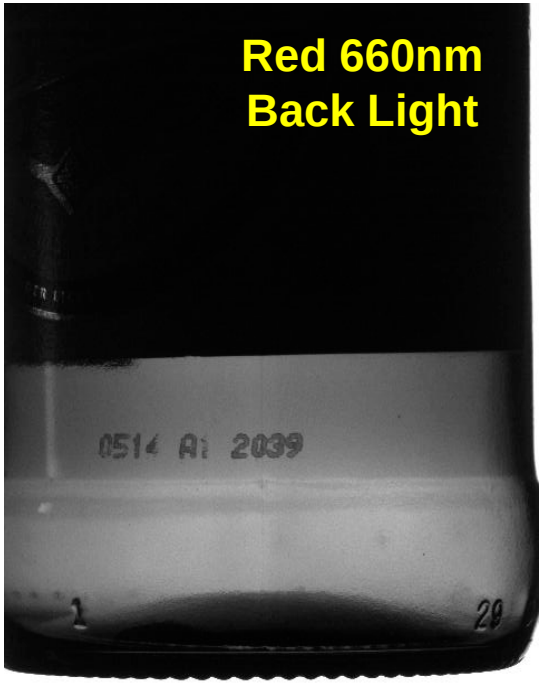
Red 660 nm Back Light



IR 880 nm Back Light

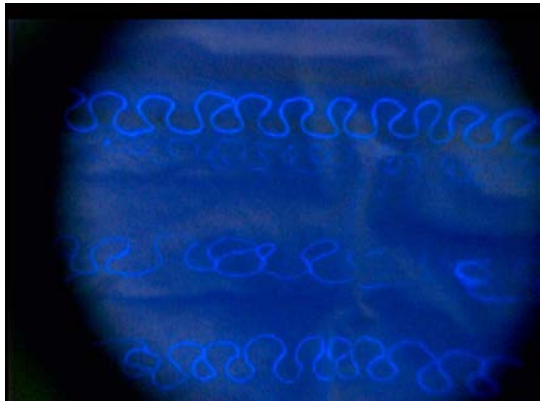
Imaging Beyond "Visible" – Near IR

- Red 660 nm light reveals the blue dot matrix printed bottle date & lot codes.

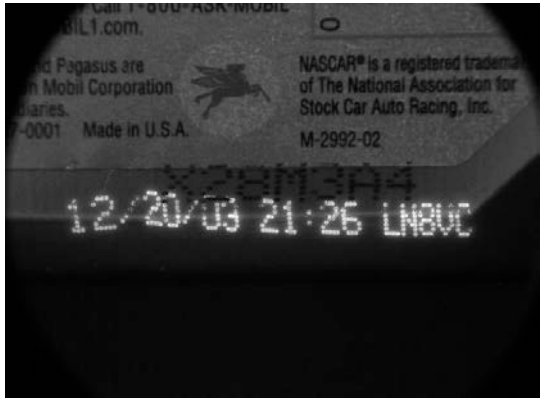


Imaging Beyond "Visible" – Near UV

- Near UV light when used w/ a matched UV excitation dye, illuminates codes and structural fibers.



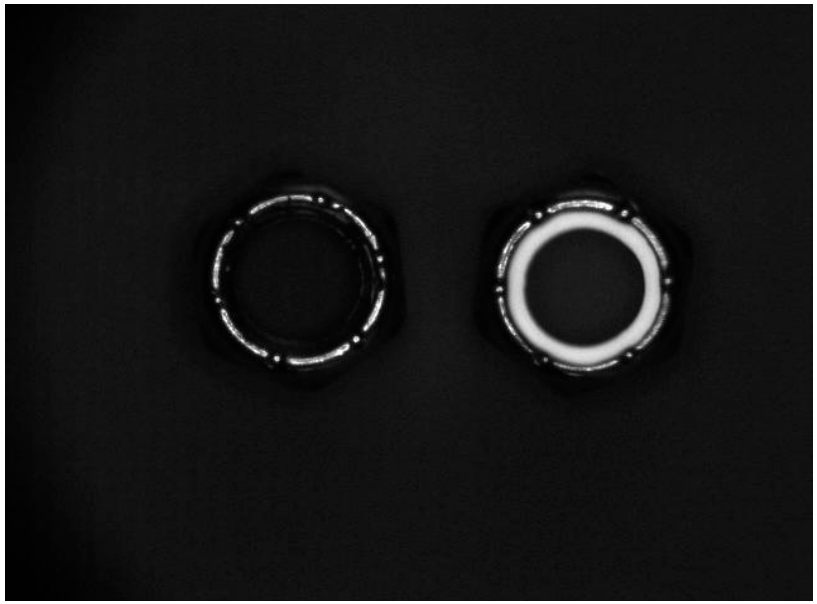
- Top Image Set: Diaper



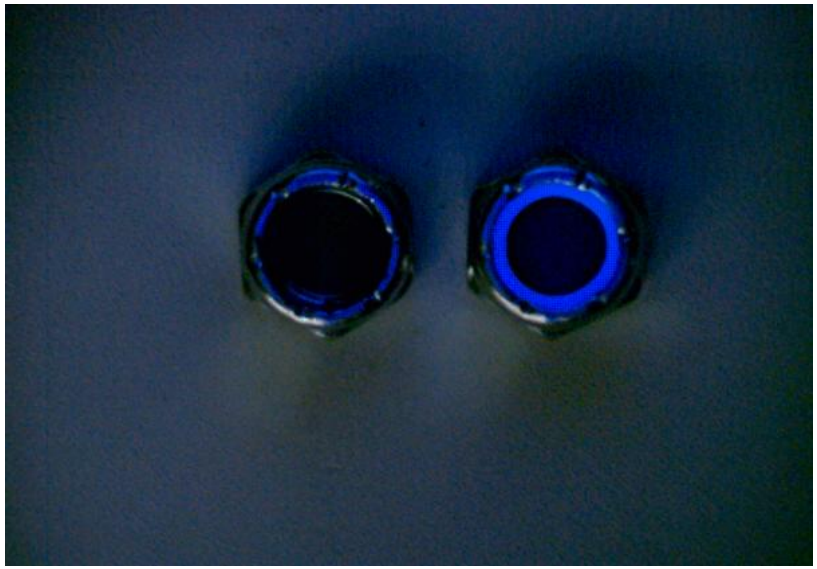
- Lower Image Set: Motor Oil Bottle

Imaging Beyond "Visible" – Near UV

- Near UV light fluoresces many polymers, including nylon.



- Top Image: UV Light, B&W CCD
- Lower Image: UV Light, Color CCD



Filters are useful too!

Blocking Ambient Light – Band Pass
Blocking Glare – Polarization
Avoiding Surface Glare w/o Polarization

Ambient Light

Ambient Light: Any light, other than the vision-specific lighting that the camera collects.

- Overhead plant lighting

  Mercury, HP Sodium, Fluorescent Tubes

- Other nearby task lighting

  Incandescent, Fluorescent Tubes

- Indicator status lights
- Temporary lighting – construction, emergency
- Sunlight – Weather and time-dependent
- Interference from other nearby vision-specific lighting!

Ambient Light

Controlling and Negating Ambient Light

Turn off the ambient contribution
- Most effective . . . Least Likely!

Overwhelm the ambient contribution w/ strobing
- Effective, but requires more cost and complexity

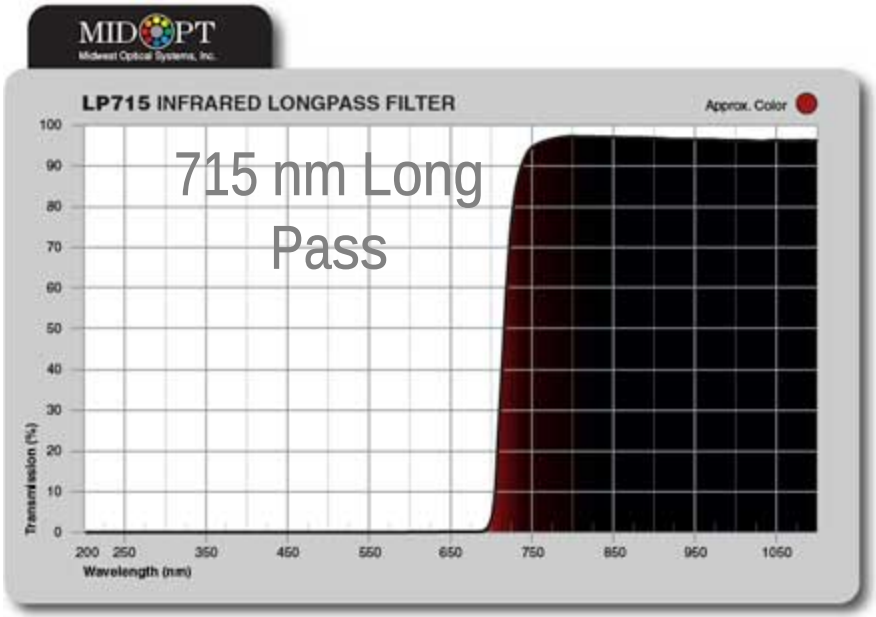
Build a shroud
- Very effective, but time-consuming, bulky and expensive

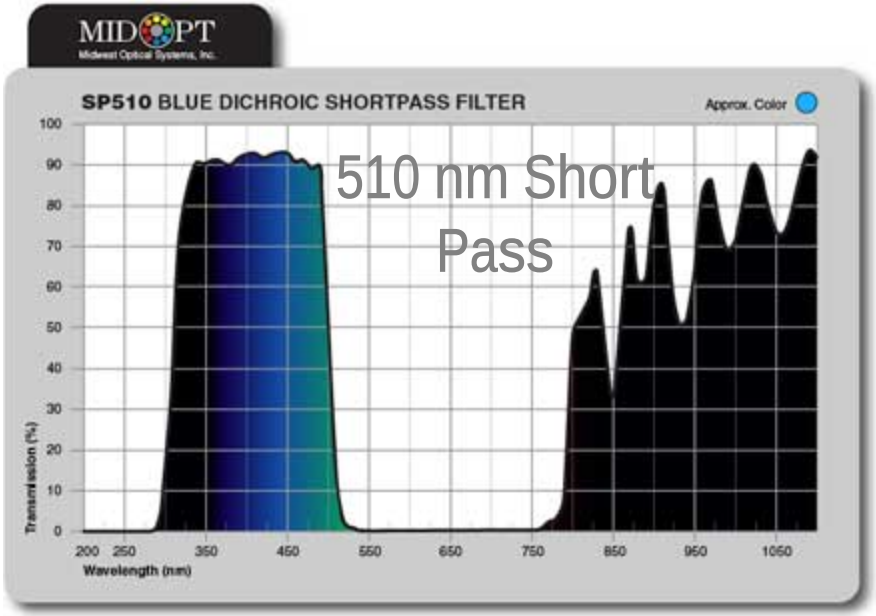
Control it with pass filters
- Very effective, but requires a narrow-band source light

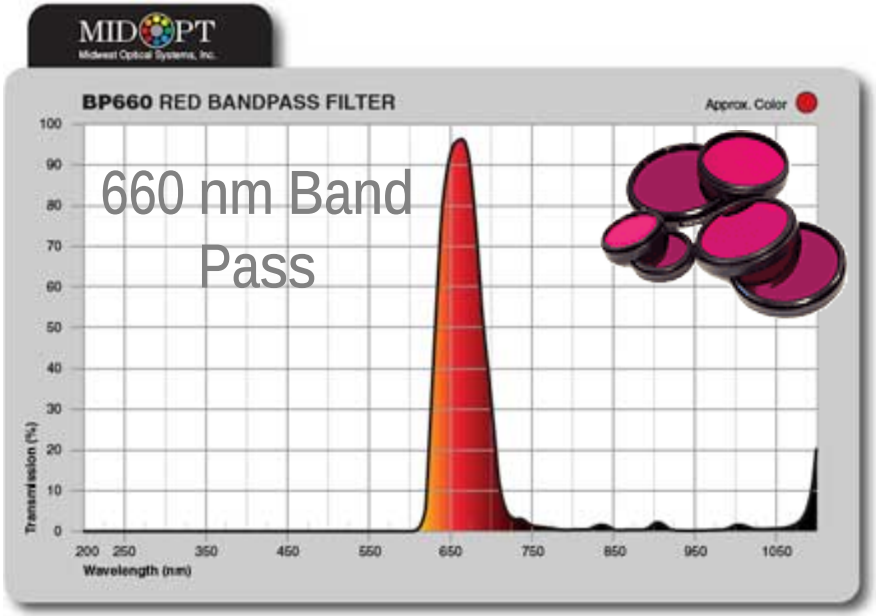
Pass Filters in Machine Vision

- Pass filters exclude light based on wavelength.
- Reduce sunlight and mercury vapor light **4X**
- Reduce fluorescent light **35X**

Graphics courtesy of Midwest Optical, Palatine, IL

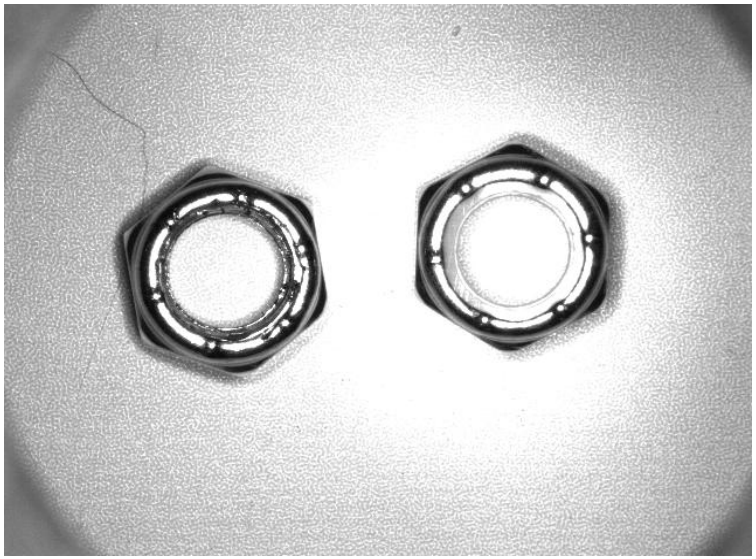




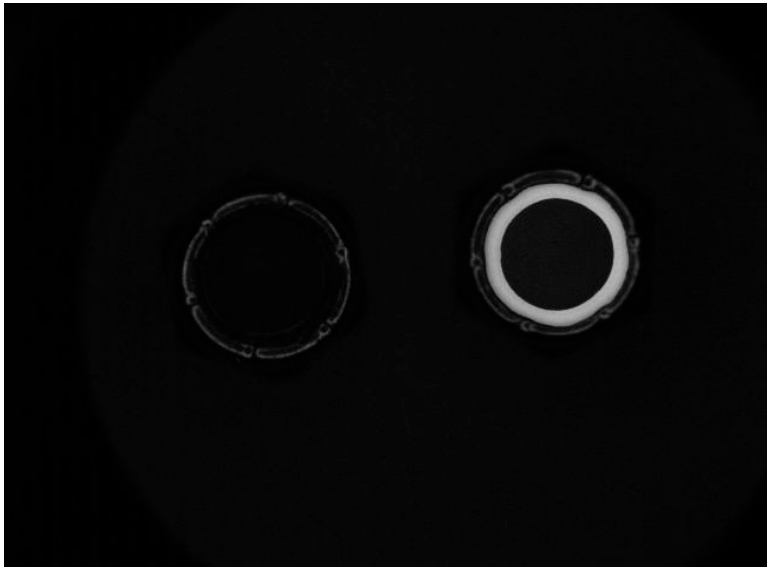


Pass Filters

- Top Image: UV light w/ strong Red 660 nm "ambient" light.

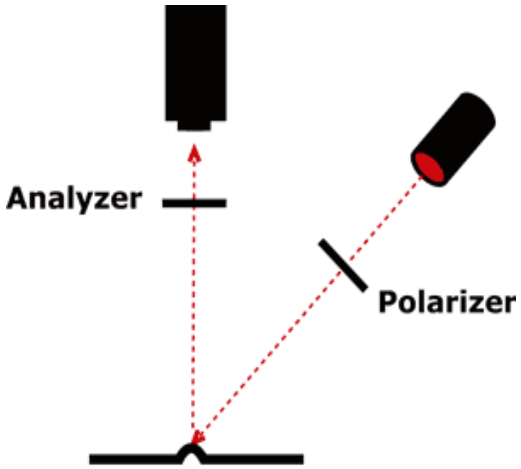


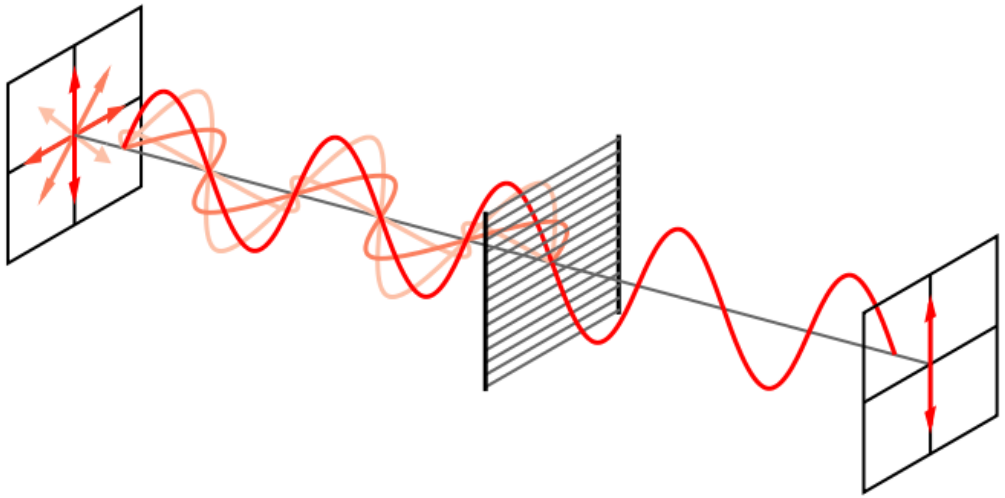
- Bottom Image: Same UV and Red 660 nm "ambient" light, with 510 nm Short Pass filter applied.



Avoiding Surface Glare

- Change Geometry – 3D spatial arrangement of Light, Sample, and Camera (preferred)
- Strobe to overwhelm glare from ambient sources
- Use polarization filters (least preferred)

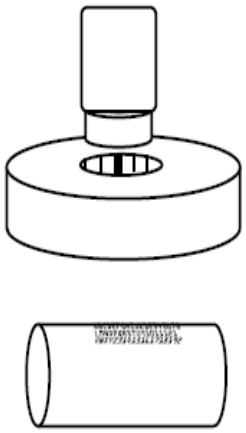


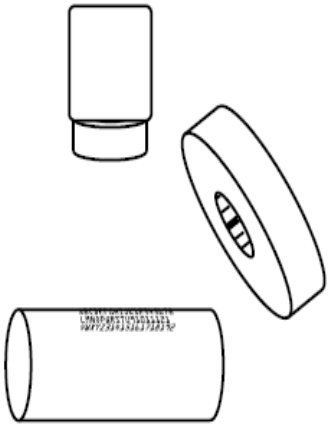


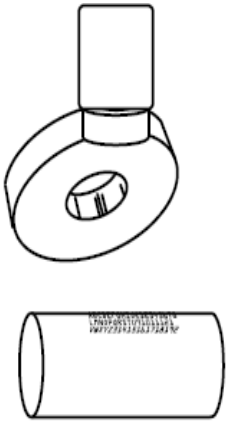
Courtesy Wikimedia Commons

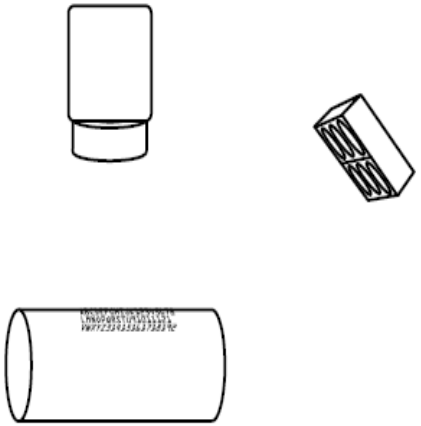
Avoiding Surface Glare

3-D Reflection Geometry: Light - Sample - Camera









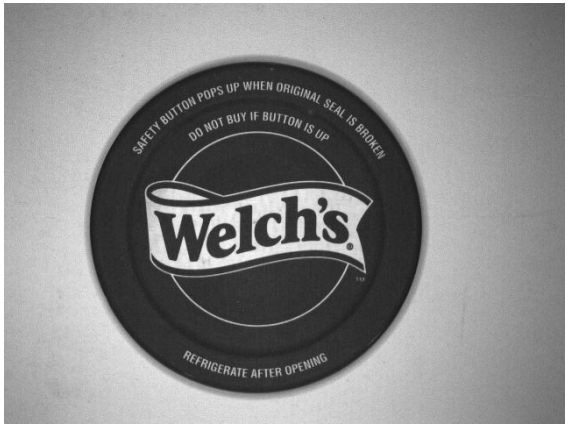
Polarizing Filters in Machine Vision

Coaxial Ring Light
w/o Polarizers

Coaxial Ring Light
w/ Polarizers

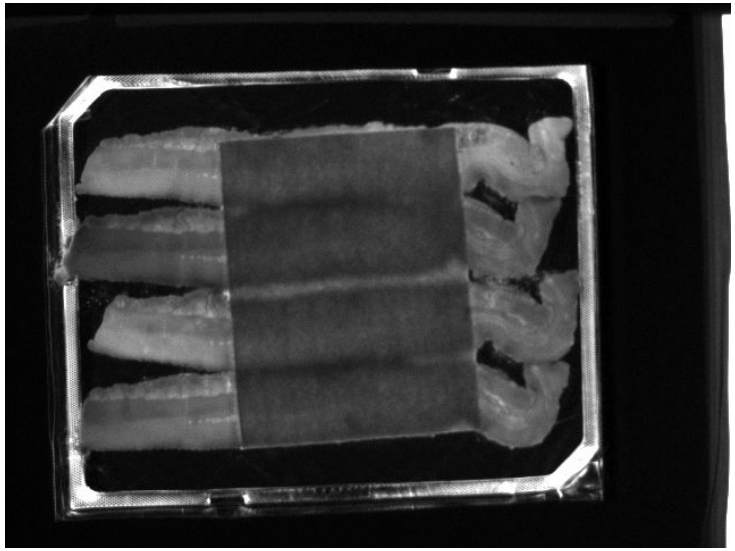
Coaxial Ring Light
w/o Polarizers

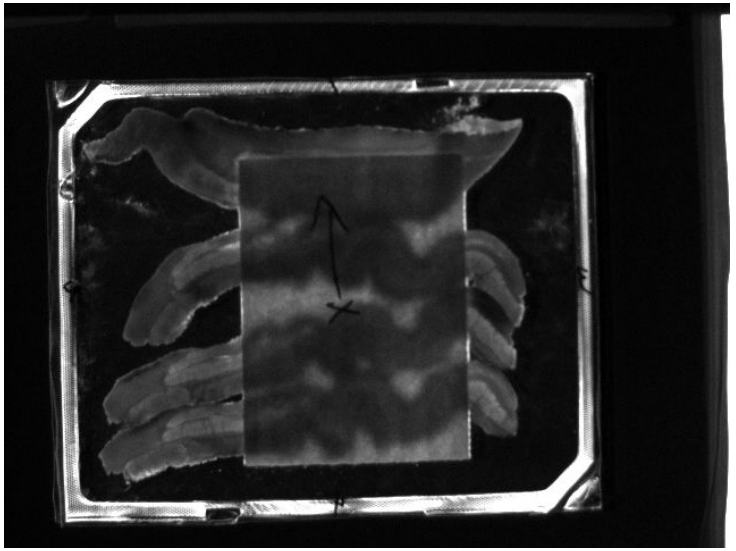
Off-Axis Ring Light
w/o Polarizers



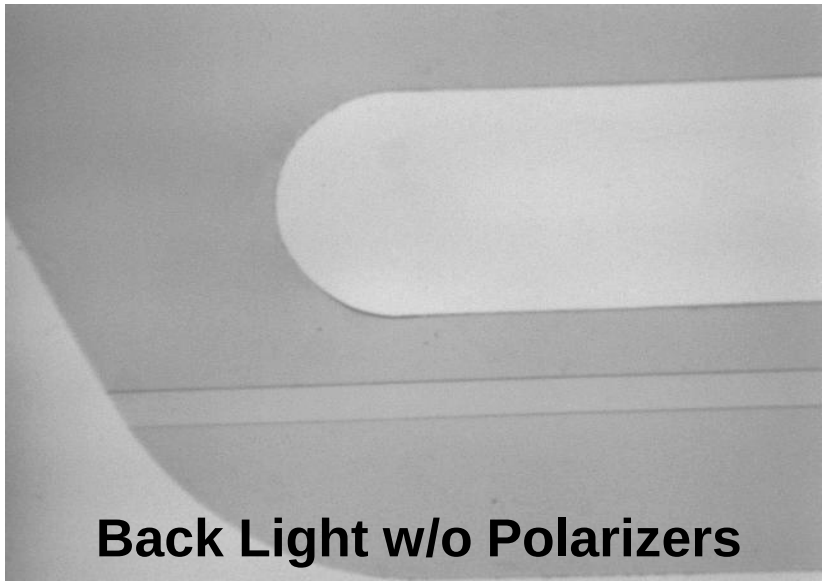
Coaxial Ring Light
w/ Polarizers

Polarizing Filters in Machine Vision





Polarizing Filters in Machine Vision



6-pack Plastic Ring Carrier

Polarized backlighting is best used to detect internal anisotropy in transparent materials.

Standard Lighting Method

- Determine the Exact Features of Interest
- Analyze Part Access / Presentation
  - Clear or obstructed, Moving / Stationary
  - Min / Max WD range, Sweet Spot FOV, etc.
- Analyze Surface Characteristics
  - Texture
  - Reflectivity / Specularity
  - Effective Contrast – Object vs. background
  - Surface flat, curved, combination
- Light Types and Applications Techniques Awareness
  - Rings, Domes, Bars, ADIs, Spots, Controllers
  - Bright Field, Diffuse, Dark Field, Back Lighting
- Determine Cornerstone Issues
  - 3-D Geometry, Structure, Color & Filters
- Ambient Light Effects / Environmental Issues

Summary and Conclusions

Develop the lighting solution early on in the vision system process

Determine appropriate light geometry techniques

Consider reflection geometry

Be aware of and block ambient light

Consider camera wavelength sensitivity

Use monochrome light for high-accuracy gauging

Remember that light MAY interact differently w/ respect to surface texture, color and composition

Make the lighting solution robust

Need more help? – Call your lighting professional!!

Ai Company Contacts

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