Lighting Techniques for Machine Vision

October, 2022

ADVANCED ILLUMINATION

「 Lighting is our passion
Flexibility is our model 」

ADVANCED ILLUMINATION

Who is Advanced illumination?

- Ai is a full-line lighting solutions company, primarily serving the Machine Vision Industry.

Some of our firsts:

- Leading Edge Lighting Technologies
  - Collimated LED lights
  - Evenlite ® aiming Technology
  - Controllable, multi-channel and RGB LED lighting
  - Strobe overdrive LEDs
  - SignaTech ® for optimizing power safely
  - 1,000,000 BTO Products in 1-3 weeks ARO
- Complete In-house Custom Design & Prototyping
- Long-time Vision Partner to OEMs & Mfrs.

Topics

- Vision Lighting Design Method
- 9 Guidelines for Applying MV Lighting

Otherwise known as:

Vision Lighting "Best Practices"

Primary Objective of Vision Lighting

What we really require is control of the lighting environment!

Why?

- Create Feature-appropriate lighting on the Part of Interest
- Standardize components, techniques, deployment & operation
- Generate Reproducible inspection results
- Demonstrate Robustness for part variations of "all types"

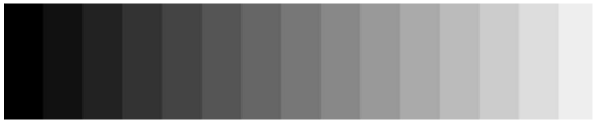
Vision Lighting Development

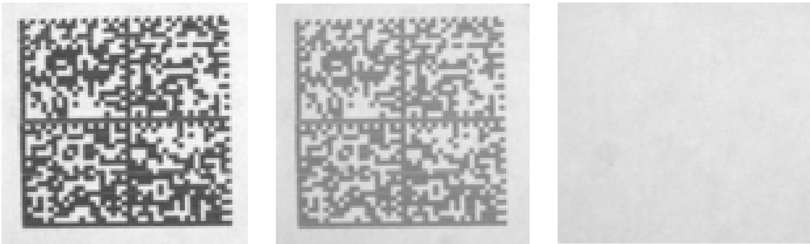
- Wave and Look (most common)
  - Image the part while trying different sources at different positions
- Scientific Analysis (most effective)
  - Analyze the imaging environment and short-list the best solution possibilities

Contrast:

(Image) Contrast: A difference in image grayscale that distinguishes an object or feature from its background.
Multiple formulas to formally quantitate "image contrast" – largely image content dependent

Grayscale: Characterizes only the amount of light (intensity information), typically calibrated from "0" (black) to "255" (white) – for an 8-bit (2^8 values) camera image.





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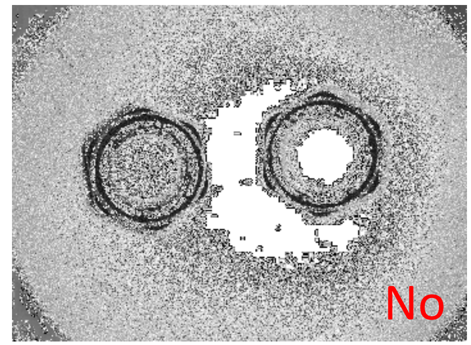
Lighting Image Contrast

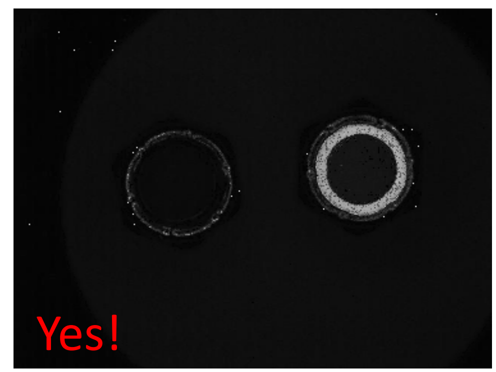
It's All About (creating) Contrast

Contrast!!

Have we? →



1) Maximize image contrast
   - Part / features of interest vs. background



2) Minimize sensitivity to normal variations affecting image contrast
   - minor part differences
   - presence of, or change in ambient lighting
   - object handling / presentation differences

Point 1 might solve some apps; # 2 can be critical!

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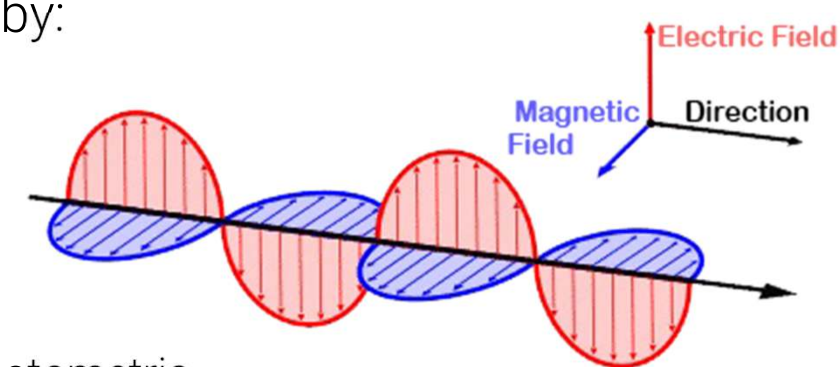
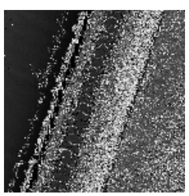
Review of Light for Vision Illumination

Characterizing Light for Vision

Light: Photons propagating as an oscillating transverse electromagnetic energy wave - characterized by:



- Measured "Intensity" (Power): Radiometric and Photometric
- Frequency: Varies inversely with wavelength (Hz – waves/sec)
- Wavelength: Expressed in nanometers (nm) or microns (um)



100,000 nm

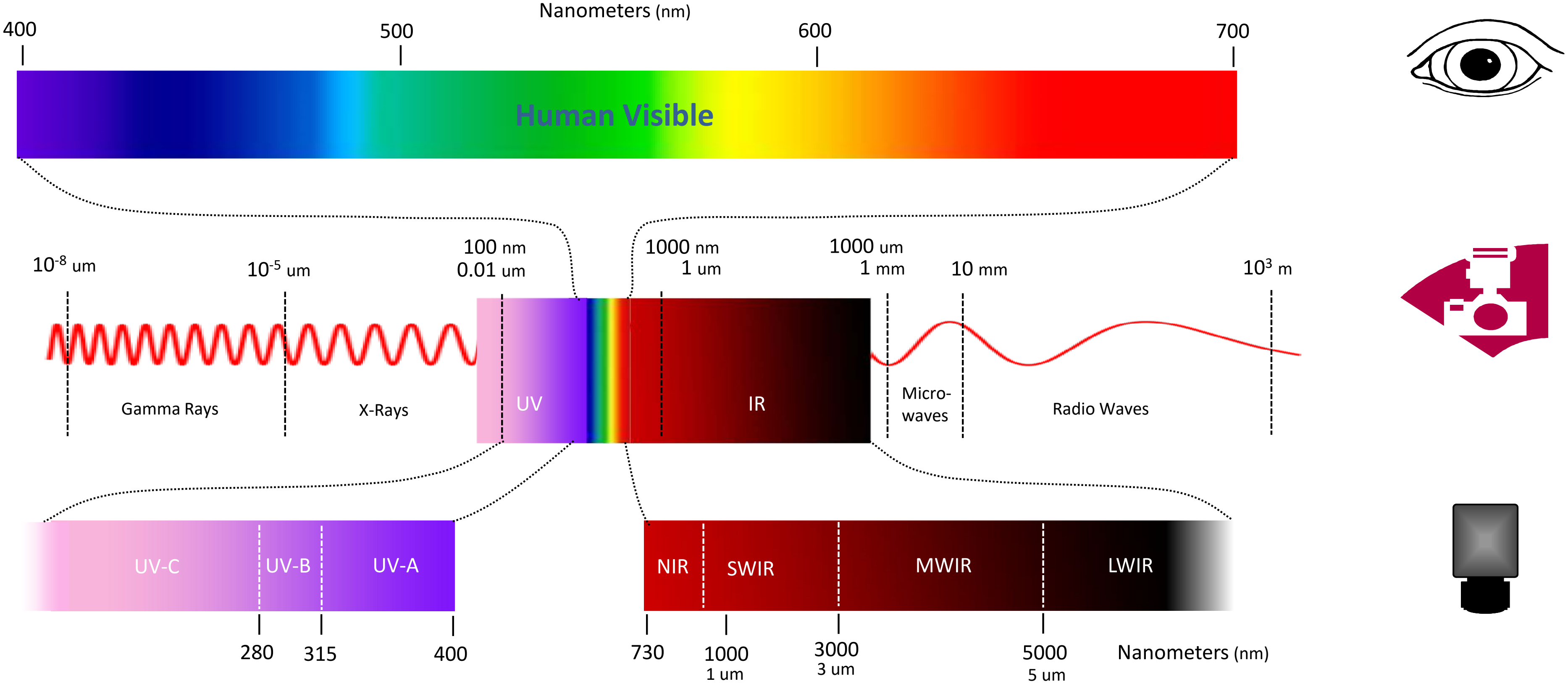
Images Courtesy Wikimedia Commons Public Domain

Photons:

Energy packets exhibiting properties of waves and particles.

MV Electromagnetic Spectrum

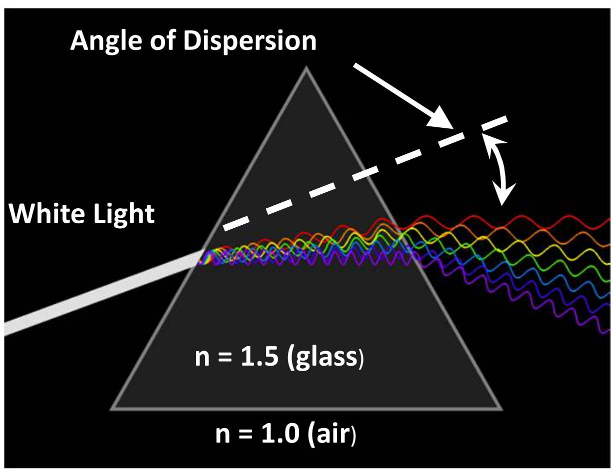
Eyes and cameras "see" differently



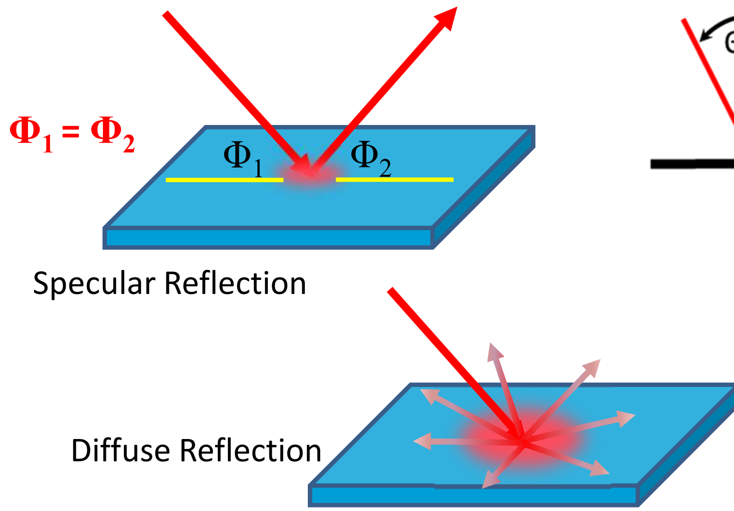
Light / Object Interaction

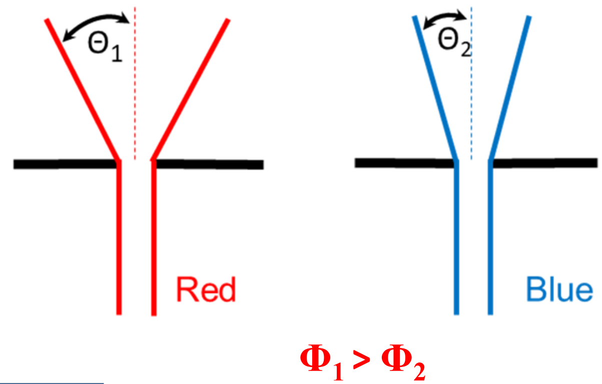
Properties when interacting with media (objects):

- Diffusion: Spreading, or dispersal of light into the object - may be wavelength specific
- Reflection: If not viewing a source directly, light must interact (mostly reflect) with objects for us to see it!
- Refraction: Wave front direction change upon entering media of a different index of refraction (violet > red)
- Diffraction: Bending around edges – Not a major factor in machine vision lighting (red > violet)



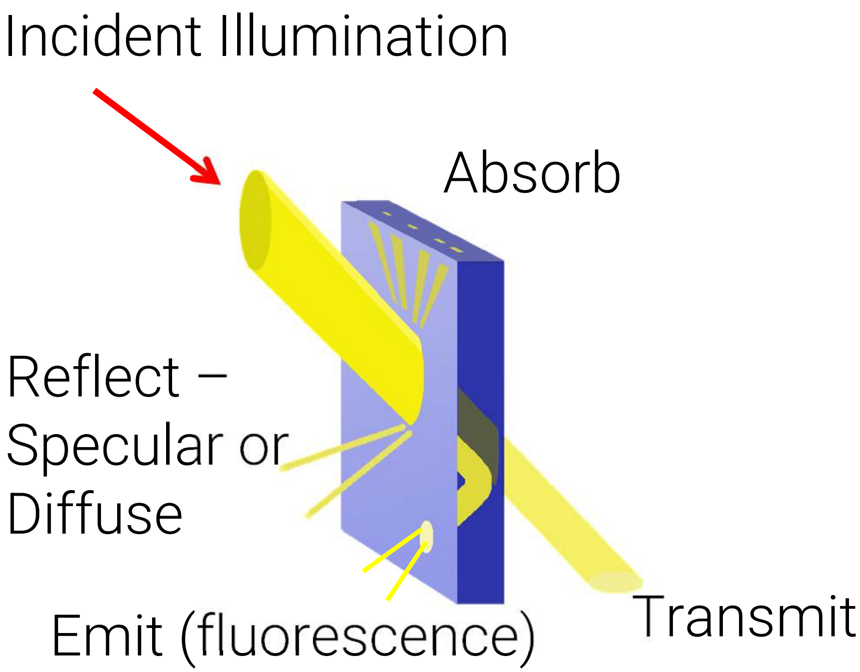
Courtesy Wikimedia Commons





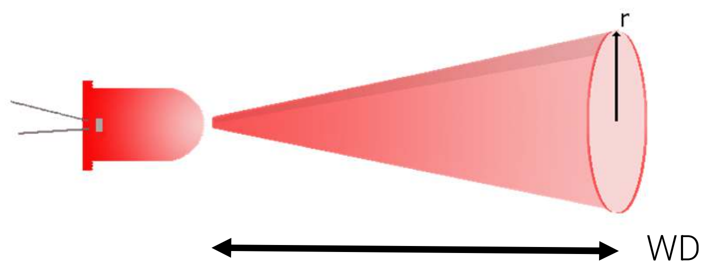
Light / Object Interaction

Total Light In = Reflected + Absorbed + Transmitted + Emitted (fluorescence) Light



- Measured Irradiance/Illuminance falls off as the inv. sq. of the distance ($I = 1 / r^2$)

- 2X (WD) = ¼ the "intensity"



Vision Lighting Sources

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Primary Vision Light Sources

Click dark image to start video

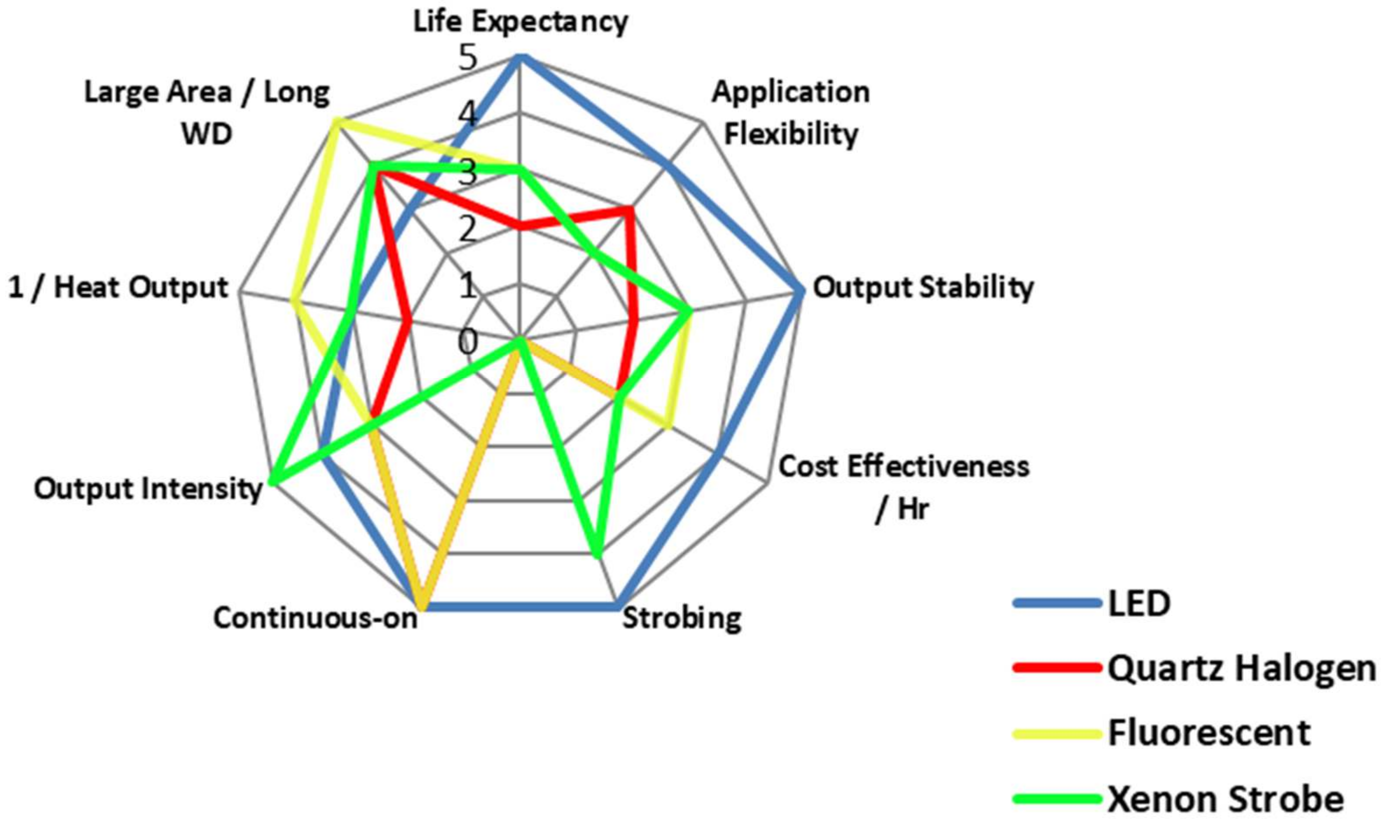
LED - Light Emitting Diode

Quartz Halogen – W/ Fiber Optics

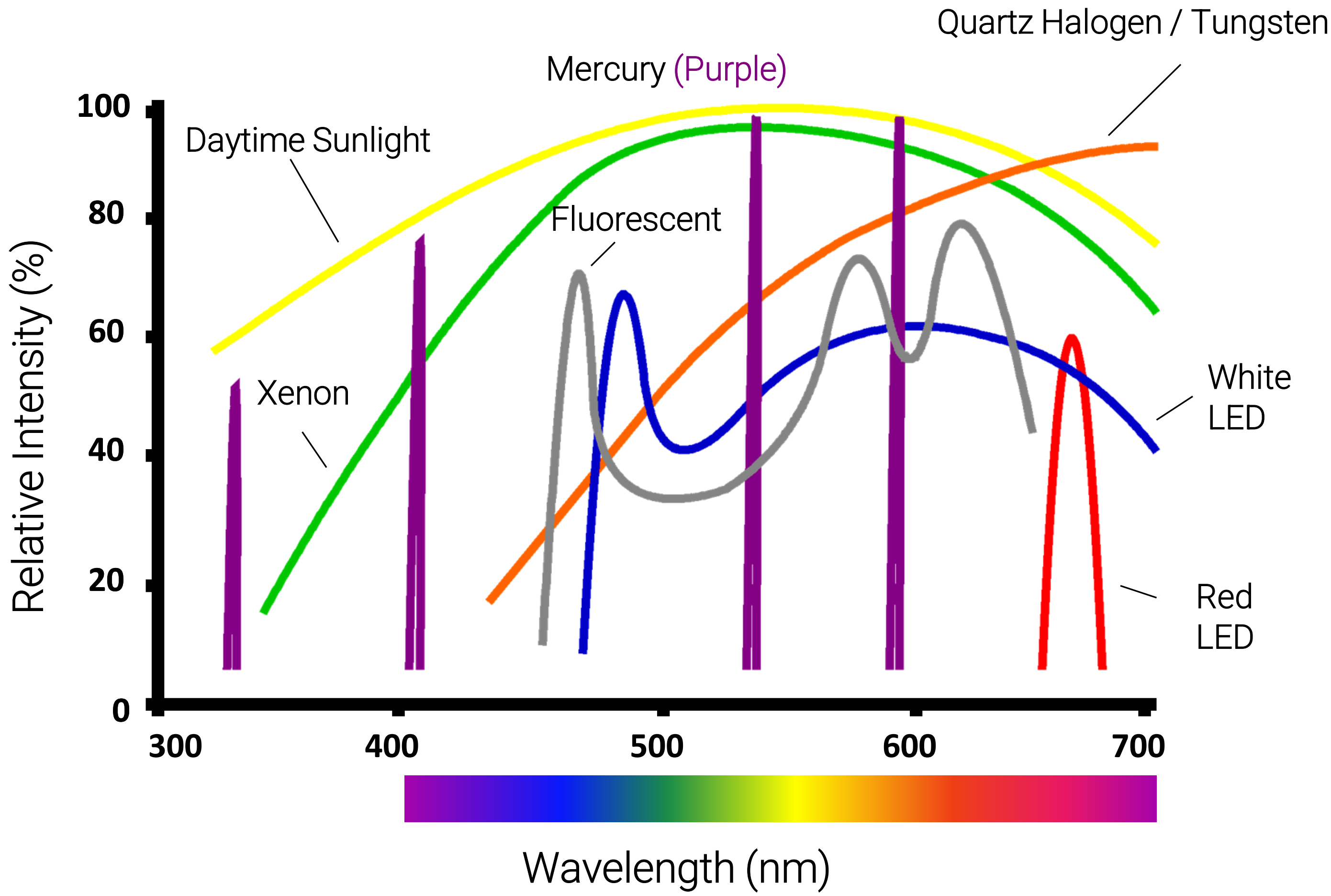
Fluorescent

Xenon Strobe

Primary Vision Light Sources



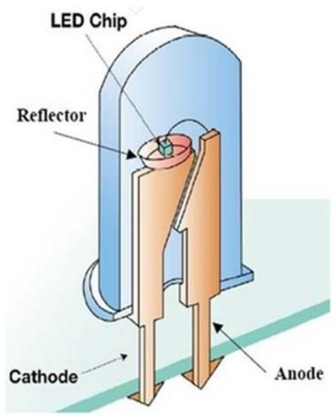
Intensity vs. Wavelength



LED Types

T1 ¾, The Standard

Courtesy Sun LED

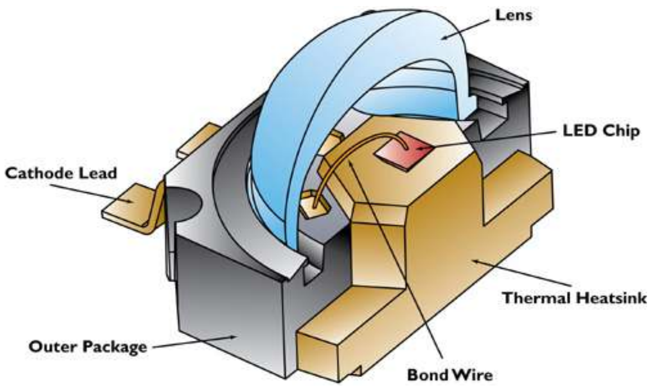


Surface Mount LEDs

Courtesy Sun LED

High Current LEDs

Courtesy Cree and Philips



HB Images Courtesy Cree and Philips

LED Lifetime

LED lifetime Specification

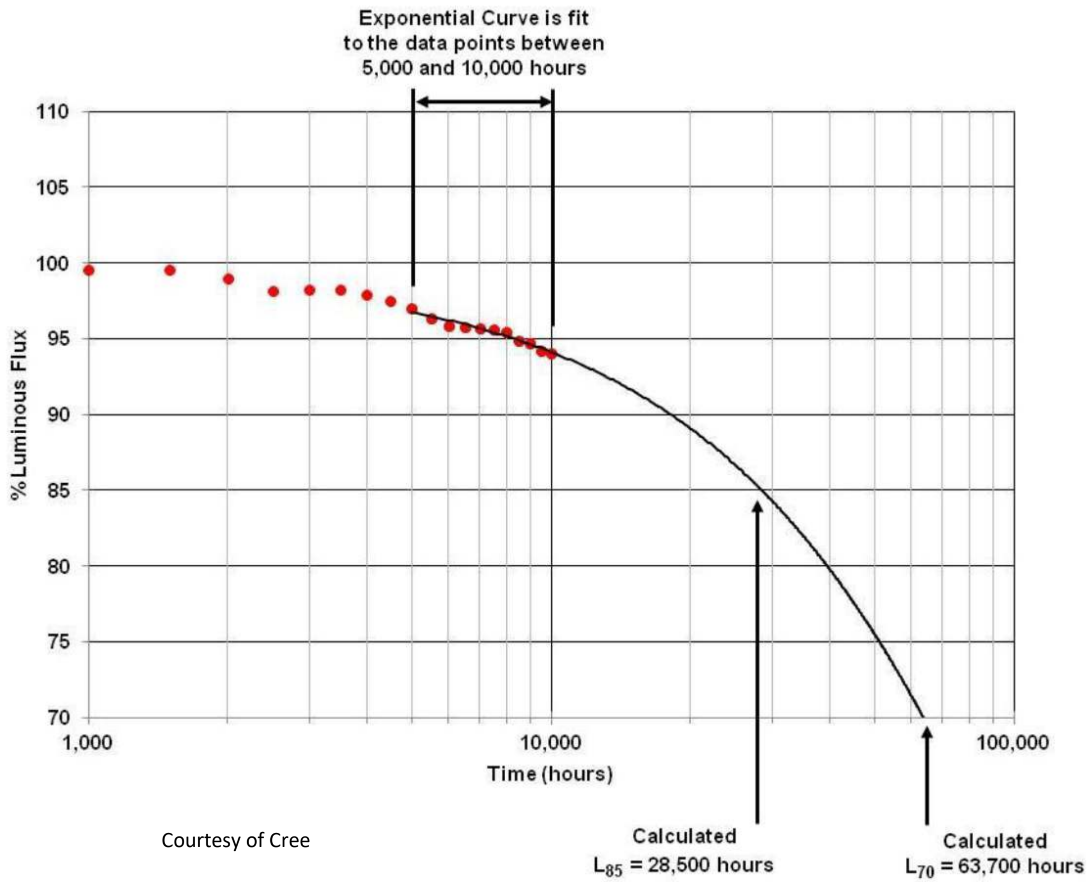
1) LED Half-life $t_{1/2}$ of 50k hr:
   - After 50k hr half of the power remains
   - After successive 50k hr half of the previous power remains

      (disfavored now)

2) Lumen Maintenance Life:

   L70 = 64,000 hr means after 64k hr,
   70% of the light power remains

      (more practical)



Courtesy of Cree

White Light Color Temperature

White LED Color Temperature:

- Select various color temp bins
- LED die chemistry and mostly phosphor mix

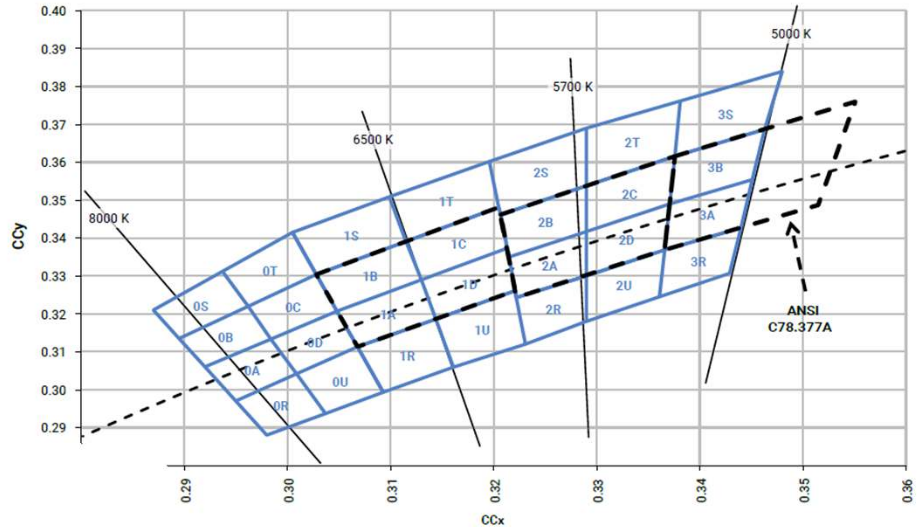


Image Courtesy of Cree

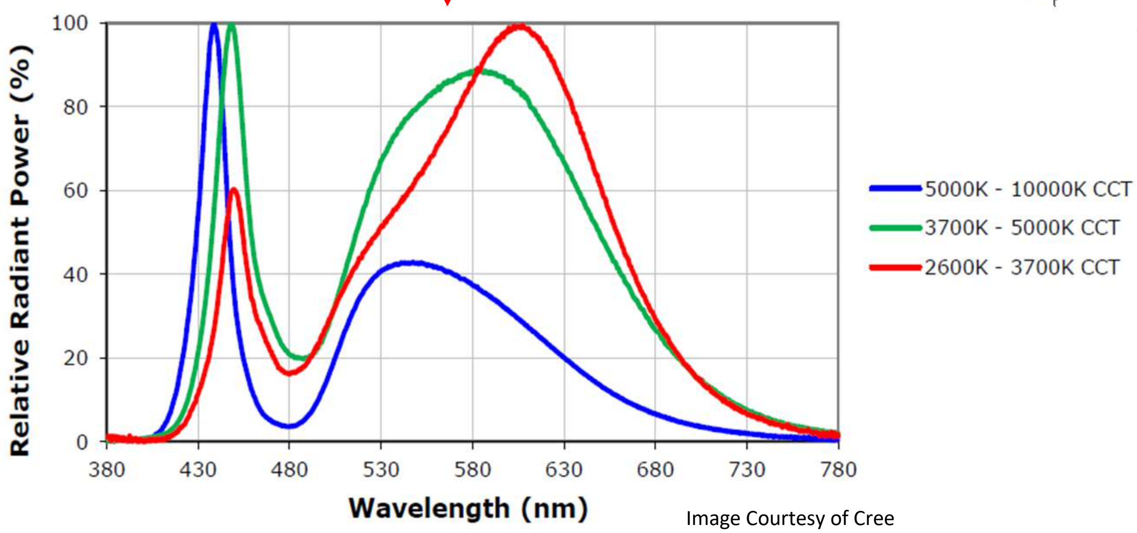


Image Courtesy of Cree

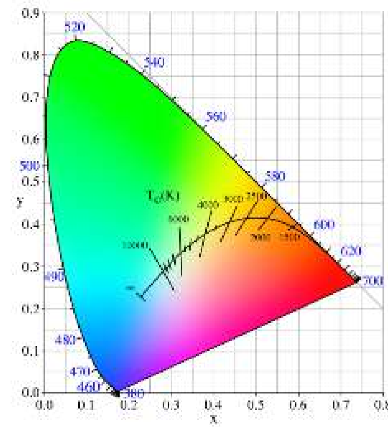


Image Courtesy Wikimedia Commons Public Domain

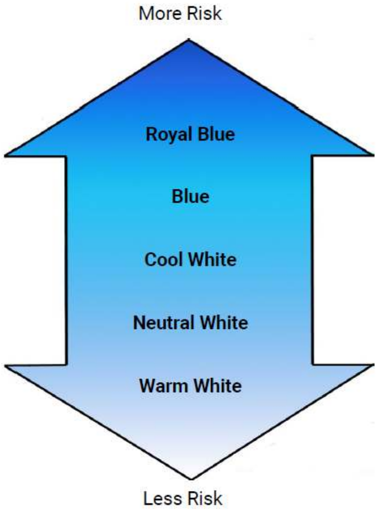
LED Safety

IEC 62471 Photobiological Safety

- Identify light hazards specific to UV/blue, blue, visible and Thermal/IR Wavelength range categories
- Assign a "Risk Group" classification and Mitigation/Guidance Measures as follows:

Guidance Control Measures

	Exempt Risk Group (None)	Risk Group 1 (Low Risk)	Risk Group 2 (Moderate Risk)	Risk Group 3 (High Risk)
Definition / Hazard	No Photobiological Hazard	No Photobiological Hazard under Normal Behavior	No Hazard due to Aversion Response to Bright Light or Thermal Discomfort	Hazardous even for Momentary Exposure
Ultraviolet hazard 200 nm to 400 nm	Not required	Minimize exposure to eyes or skin. Use appropriate shielding.	Eye or skin irritation may result from exposure. Use appropriate shielding.	Avoid eye and skin exposure to unshielded product.
Retinal blue light hazard 300 nm to 400 nm	Not required	Not required	Do not stare at operating lamp. May be harmful to the eyes.	Do not look at operating lamp. Eye injury may result.
Retinal blue light or thermal hazard 400 nm to 780 nm	Not required	Not required	Do not stare at operating lamp. May be harmful to the eyes.	Do not look at operating lamp. Eye injury may result.
Cornea/lens infrared hazard 780 nm to 3000 nm	Not required	Use appropriate shielding or eye protection.	Avoid eye exposure. Use appropriate shielding or eye protection.	Avoid eye exposure. Use appropriate shielding or eye protection.
Retinal thermal hazard, weak visual stimulus 780 nm to 1400 nm	Not required	Do not stare at operating lamp.	Do not stare at operating lamp.	Do not look at operating lamp.



Images Courtesy of Cree

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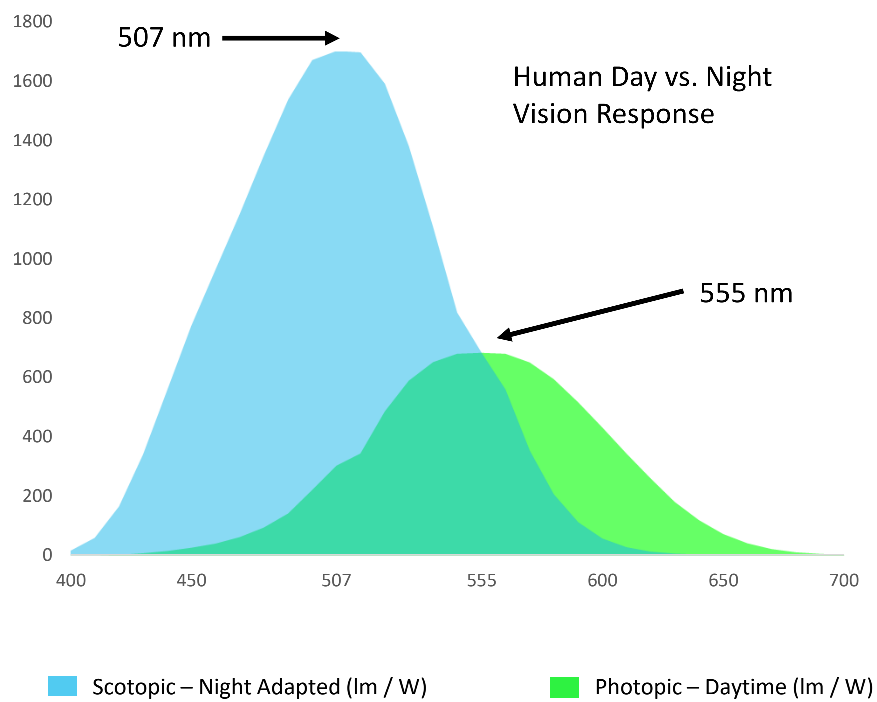
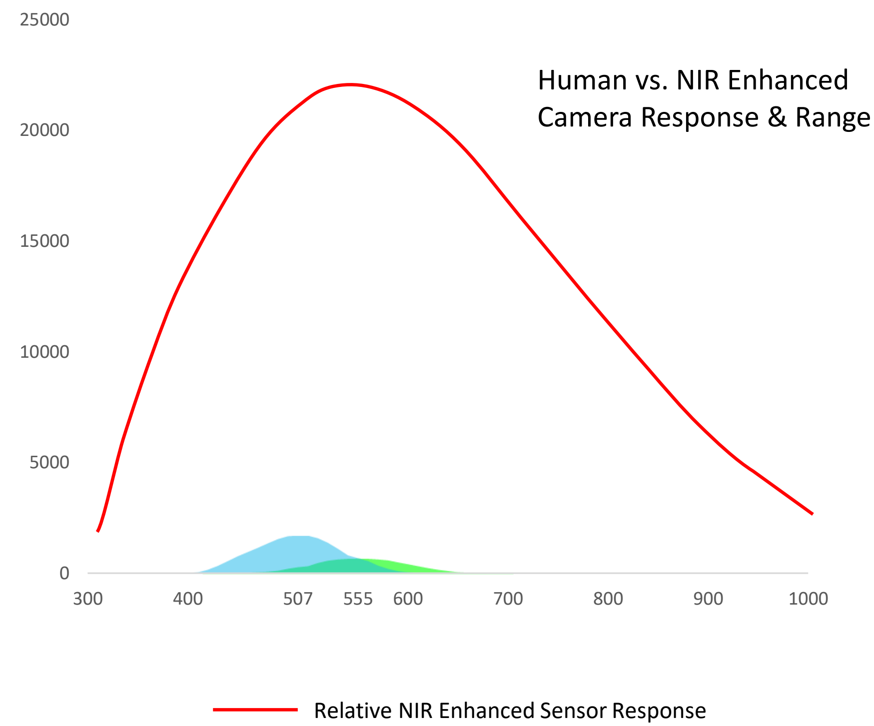
Human Eye vs. Camera

Radiometric: Measured radiant power considering the entire electromagnetic spectrum

Photometric: Radiometric measures scaled to the human eye response (visible spectrum only)





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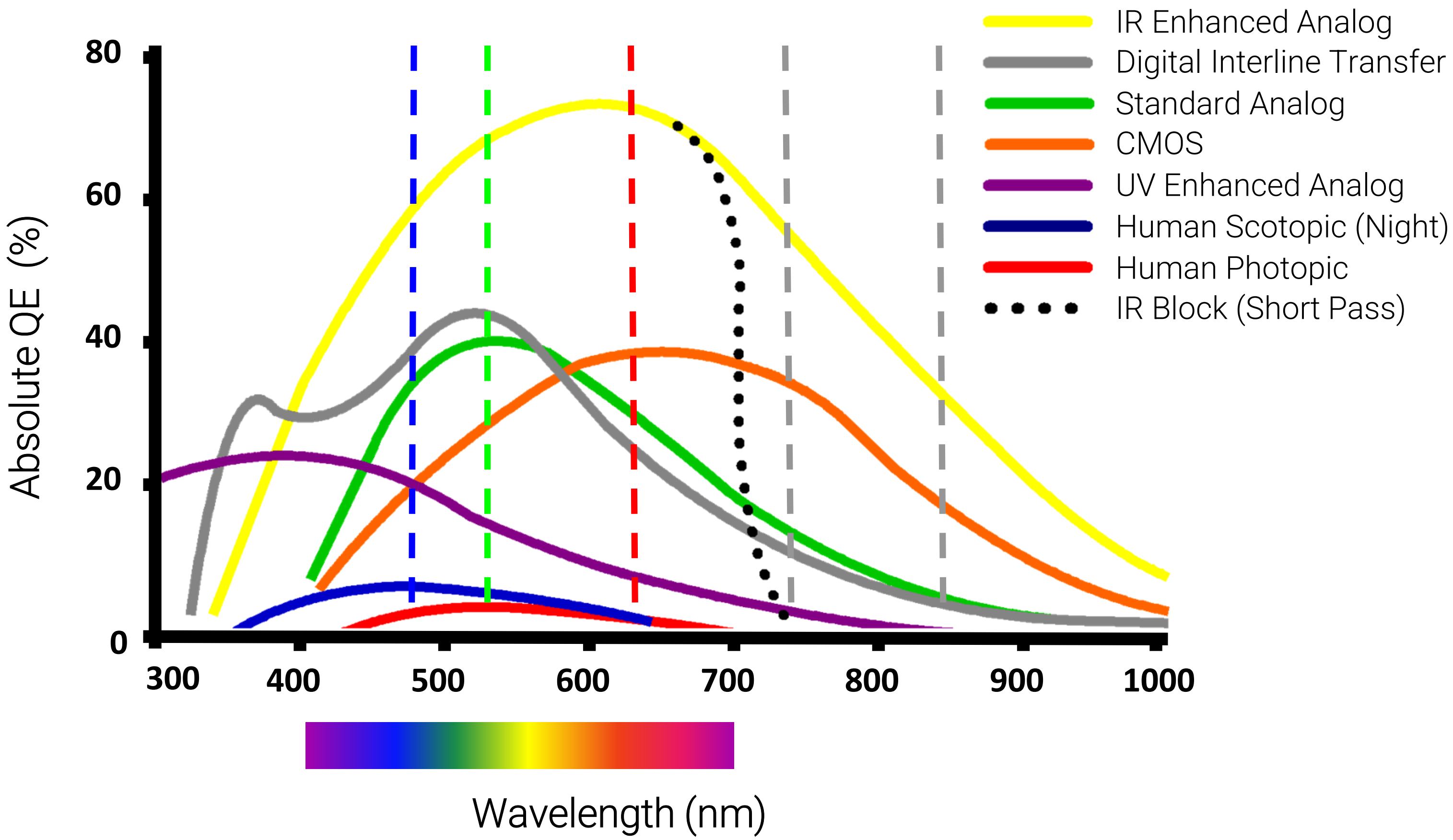
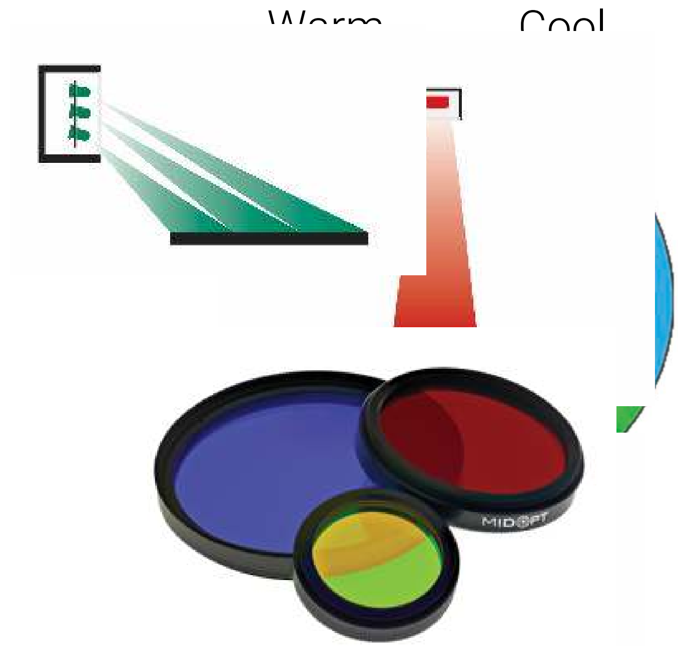
Sensors and Wavelength



4 Contrast Enhancement Concepts

How do we change (create) contrast?

- Change Light / Object / 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. Object and Camera Response
  - Warm vs. Cool color families – Object vs. Background
- Change Light Character (Filtering)
  - Affecting the wavelength / direction of light to the camera



Filter Image Courtesy Midwest Optical Systems
Palatine, IL

Important: impact of incident light on the part and its immediate background!

Image Contrast Enhancement Concepts 1&2: Lighting Geometry/Structure Techniques

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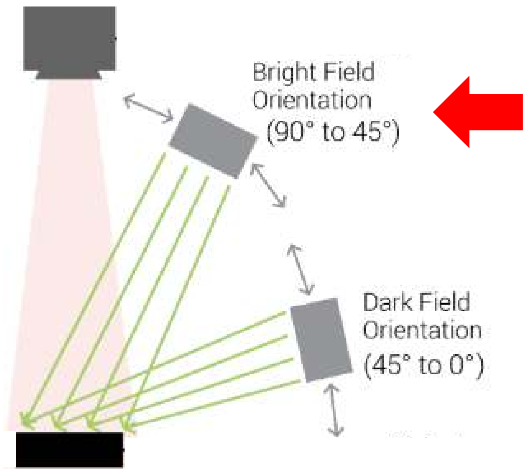
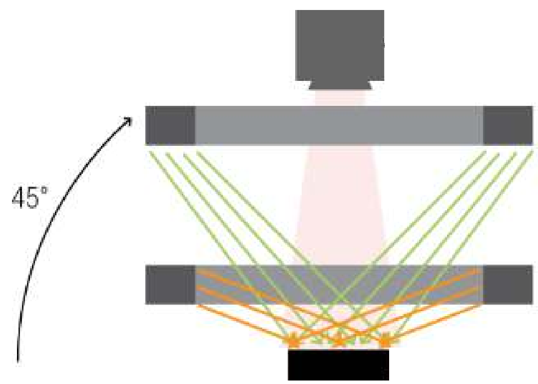
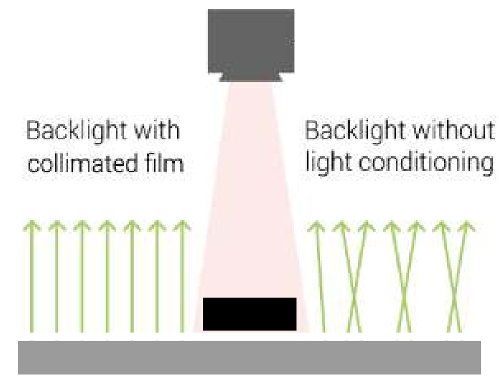
Basic Lighting Techniques



1 – Partial (Directional) Bright Field

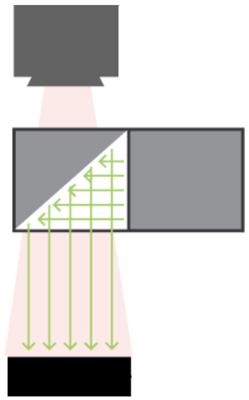


2 - Dark Field

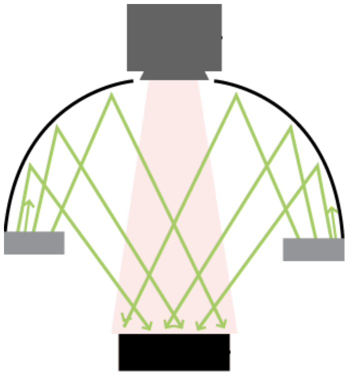


3 - Back Lighting

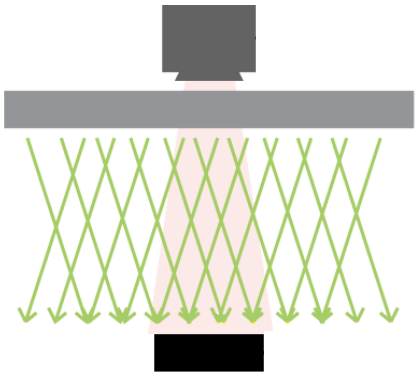
Advanced Lighting Techniques



4- Coaxial Diffuse (DOAL)*



5 - Diffuse Dome



6 - Flat Diffuse

Full Bright Field

Collimated

Coaxial Diffuse
Back Lighting

Multi-Axis / Combo

Dome + Dark Field
Bright and Dark Field
Addressable Rows

Structured

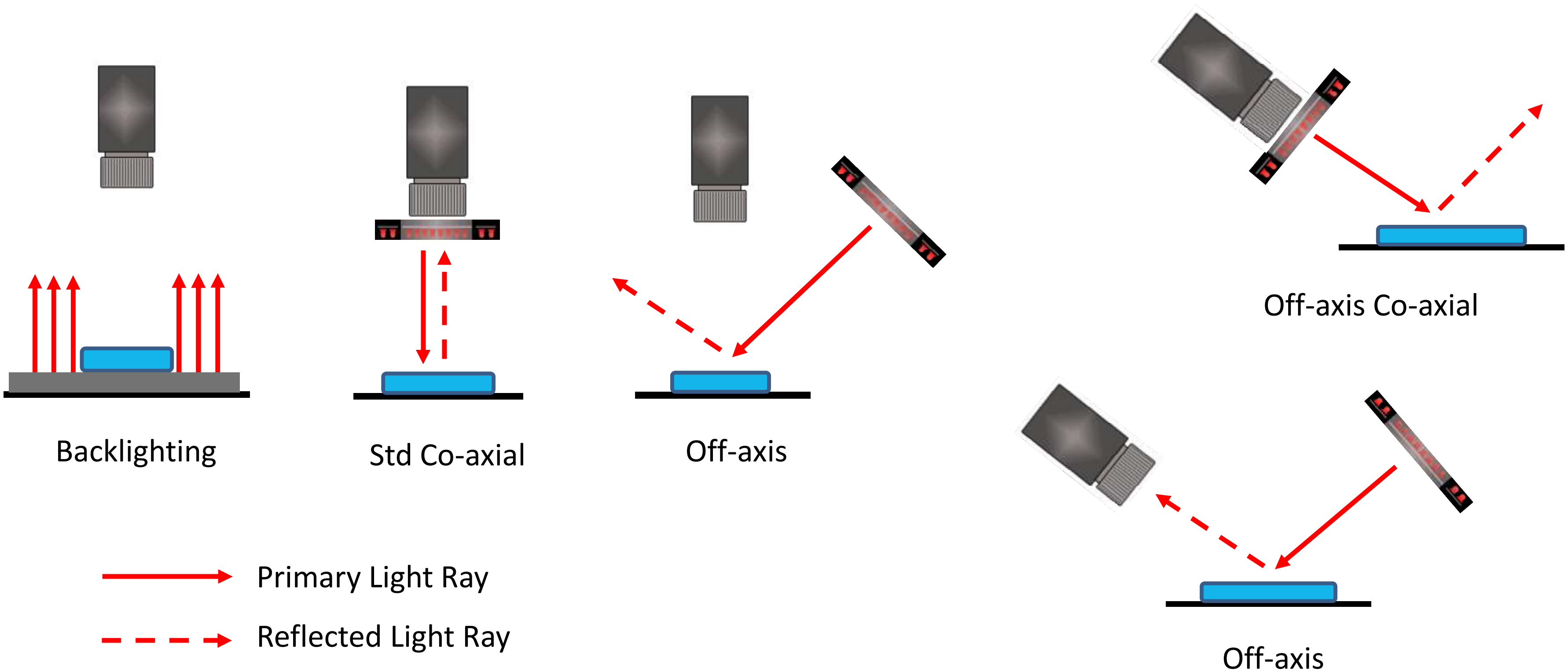
Laser/LED grids, lines
Focused Linears

* It should be noted that strictly defined, Co-axial Diffuse lighting is a partial bright field Technique.

System vs. Light Ray Geometry

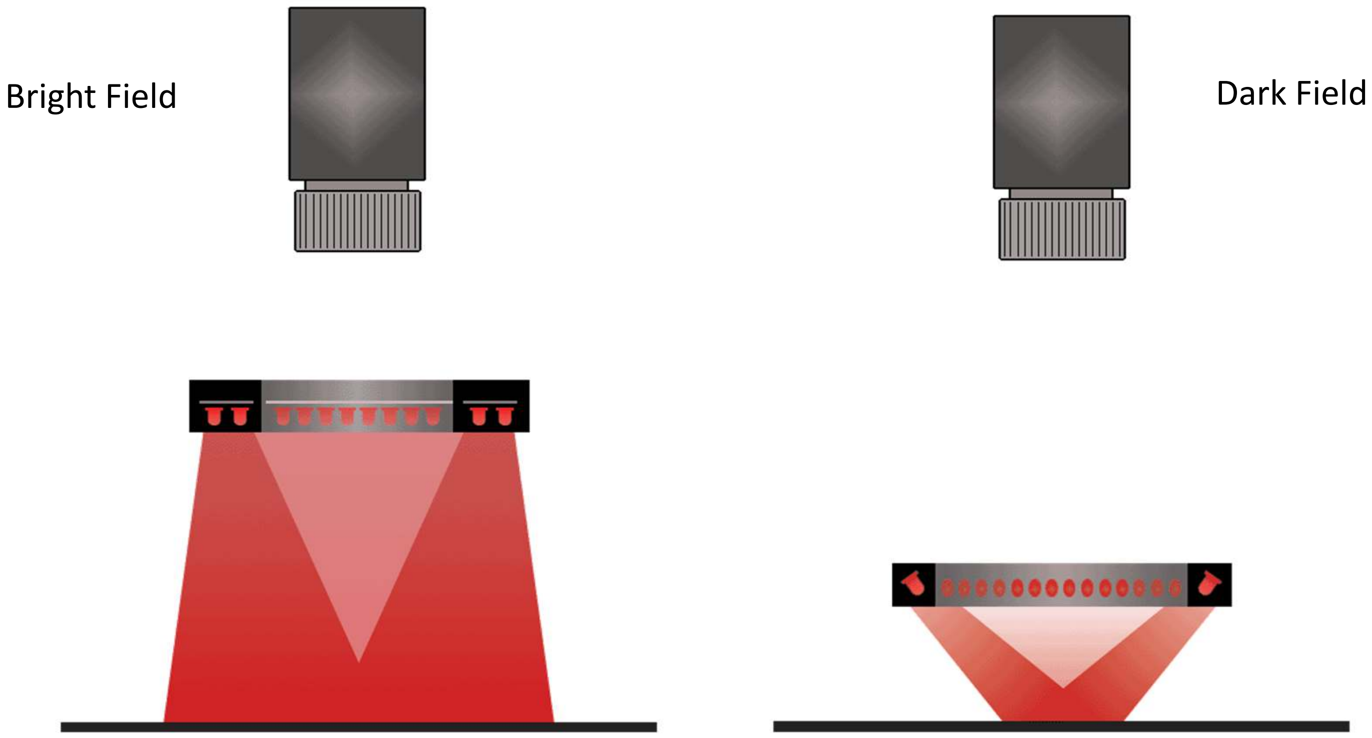
System Geometry: Relative position in 3-D space of light, camera/lens & part

Light Ray Geometry: Direction & angles-of-incidence of light rays w/r to the part

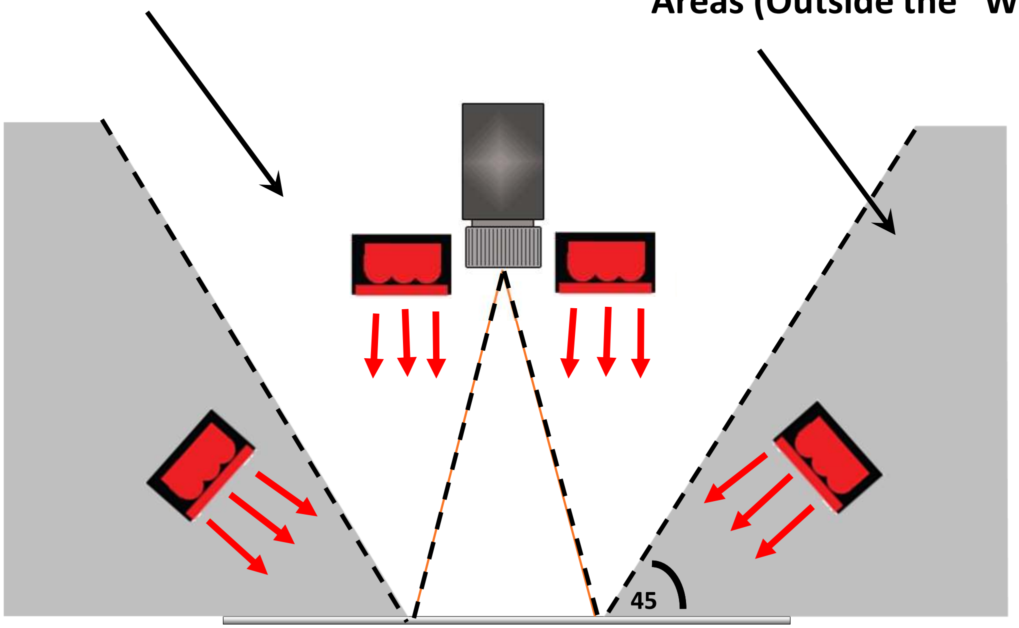


Bright Field vs. Dark Field

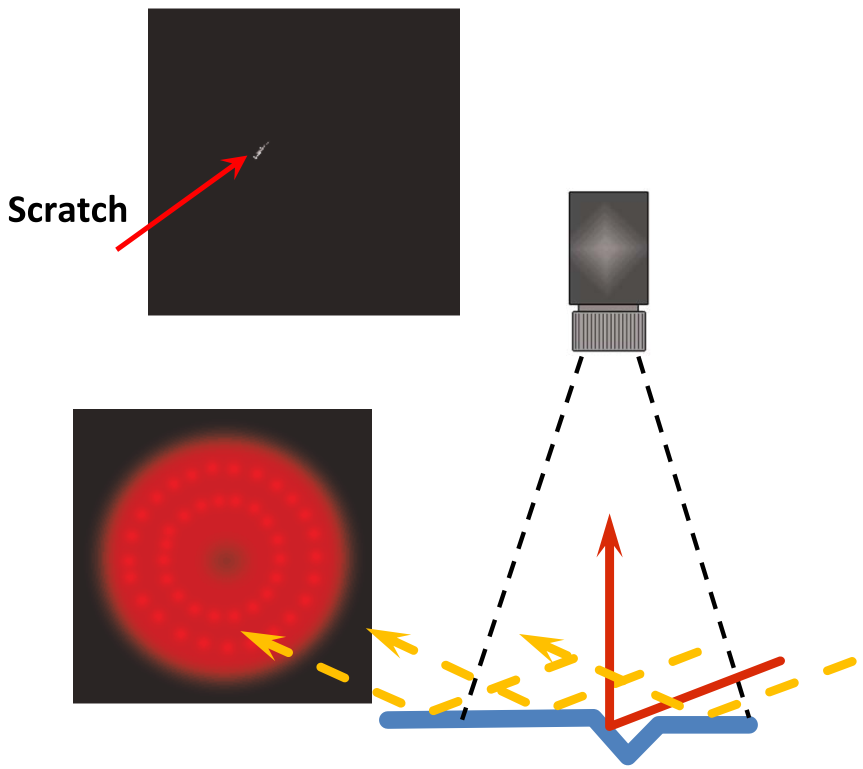
Typical On-Axis Ring Light – Sample Geometry



Bright Field vs. Dark Field



Classic "W" Pattern



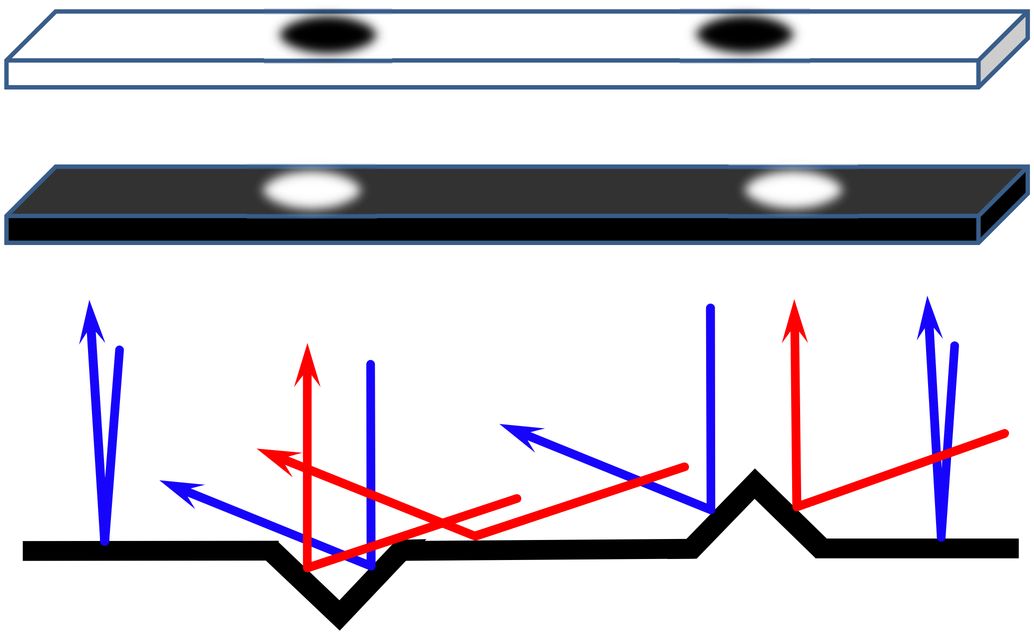
Bright Field vs. Dark Field Light

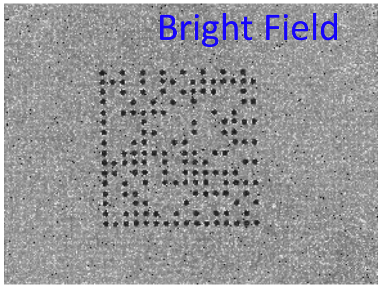
Bright Field

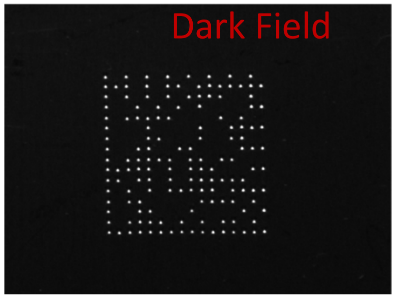
- Specular surfaces reflect glare if light is high-angle
- Diffuse, flat and smooth surfaces reflect evenly

Dark Field

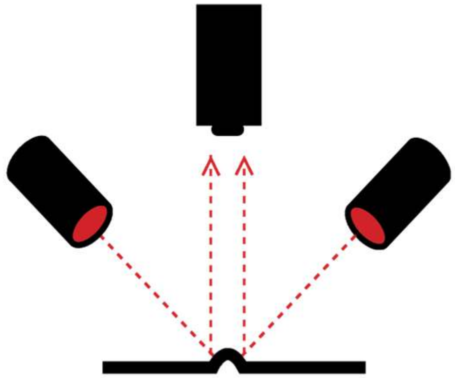
- Emphasizes Height, Edges, Shape, Contours
- Diffuse Surfaces Bright
- Flat Polished Surfaces Dark



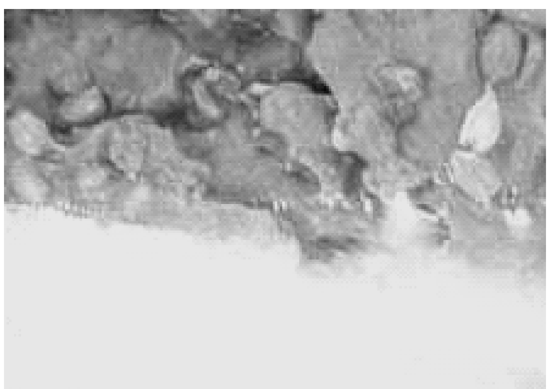


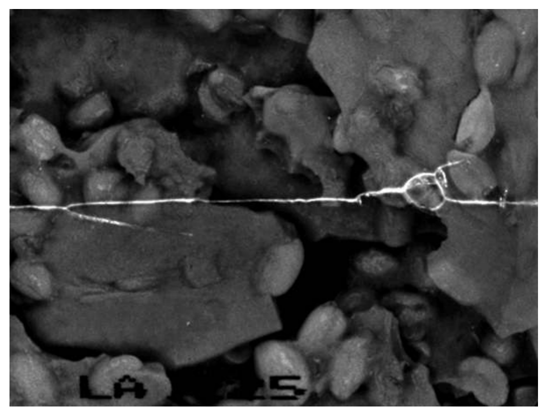


Dark Field Example

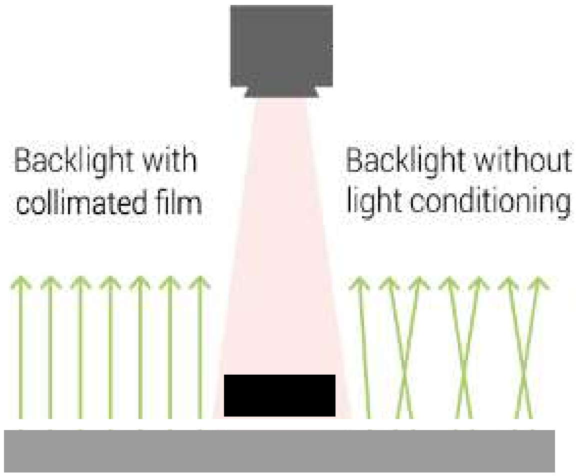


- Angled light – 45 degrees or less
- Used on highly reflective surfaces
- OCR or surface defect applications





Back Lighting



- Edge or hole detection
- Useful on translucent materials

  Liquid fill levels

  Glass/plastic defects

  Longer λ light may penetrate some objects better
- Part P/A, location and/or orientation
- Vision-Guided Robotics: Pick & Place
- Gauging

High-accuracy gauging:

- Use monochromatic light
- Shorter wavelengths best
- Use collimation – parallel rays

Limiting factor is lens optics and/or camera sensor resolution, not the light wavelength

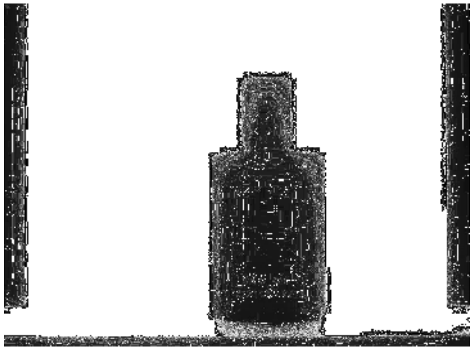
Back Lighting Example

Small Bottle – Determine Fill Level

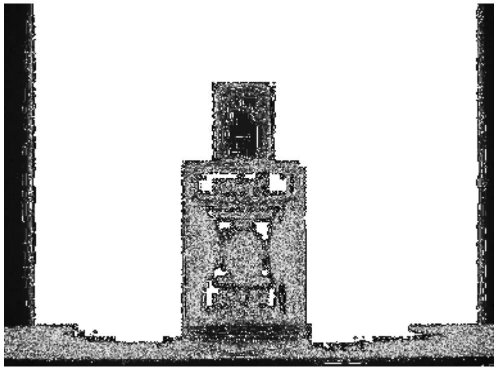
Consider colors and materials properties also.

Longer wavelength isn't always best for penetration!

660 nm Red Backlight



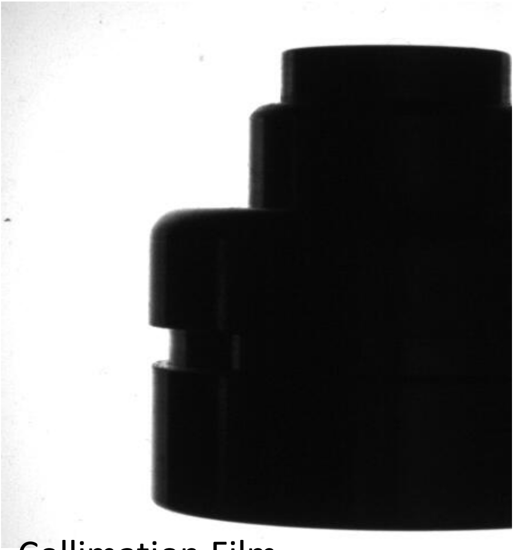
880 nm IR Backlight



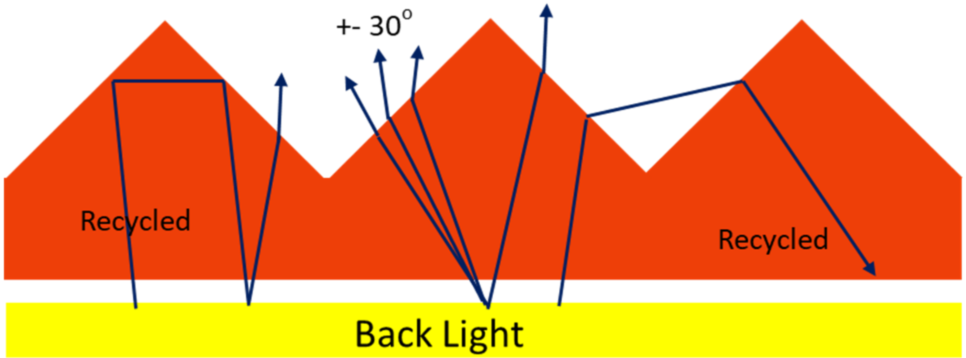
470 nm Blue Backlight

Collimated Backlight Illumination

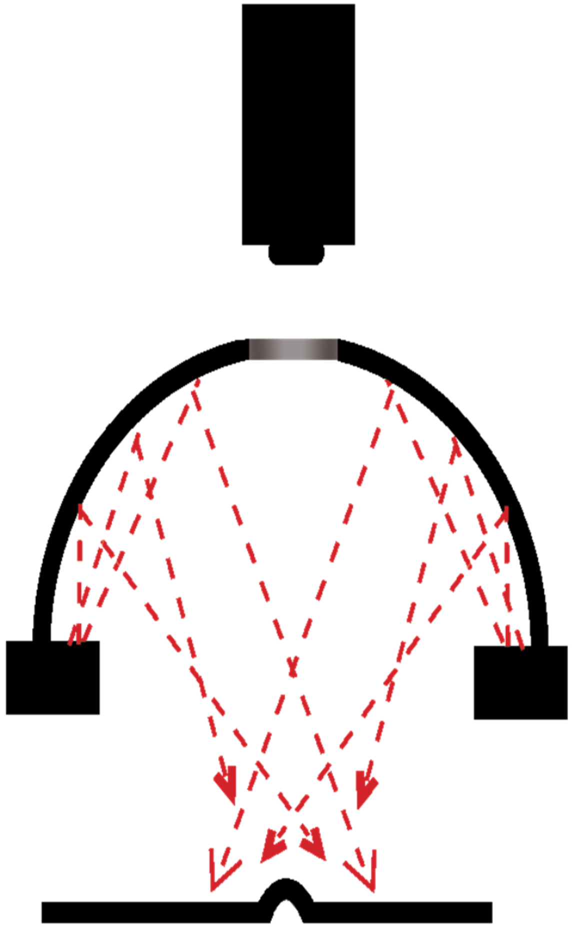
No Collimation



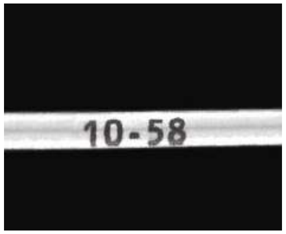
Collimation Film



Diffuse Dome

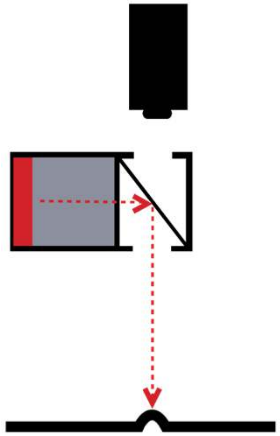


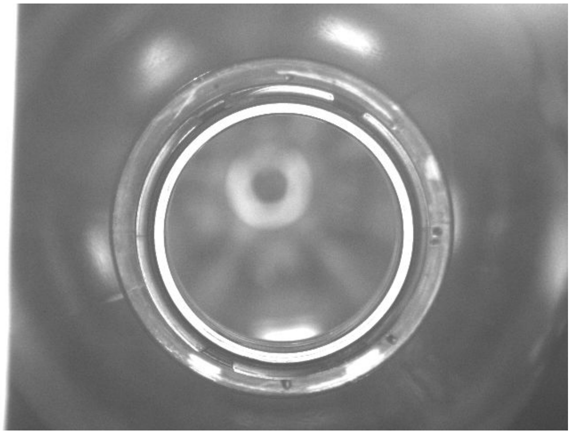
- Similar to the light on an overcast day.
- Creates minimal glare.

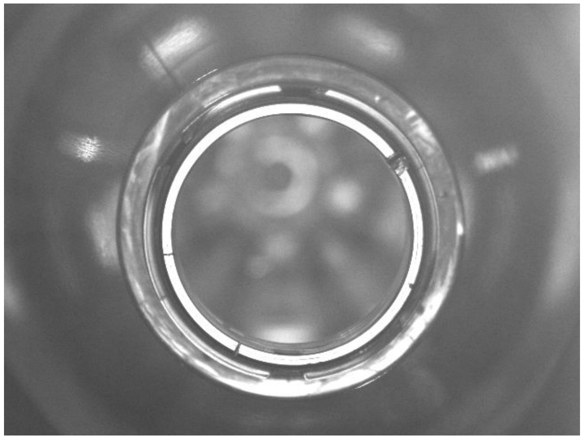


Co-Axial Diffuse Illumination

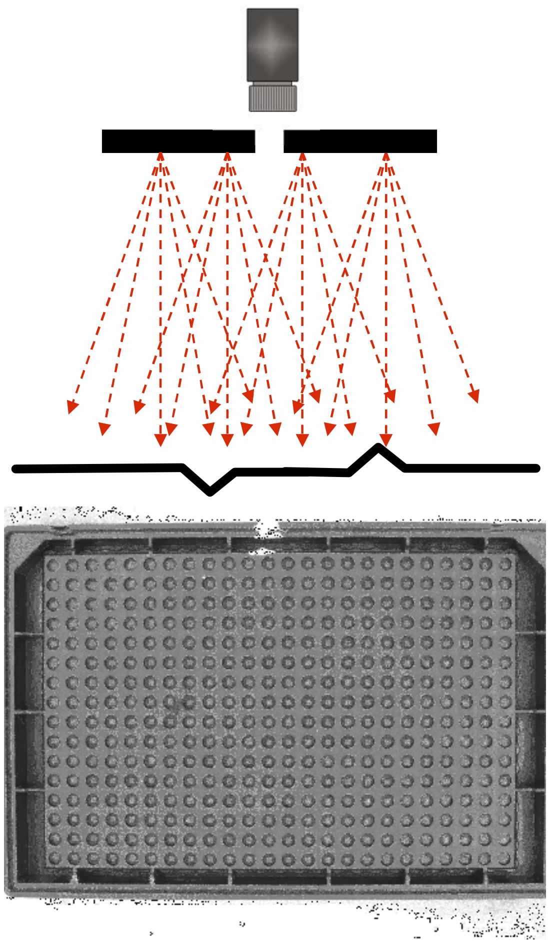
- Light directed at beam splitter
- Used on non-curved, reflective objects



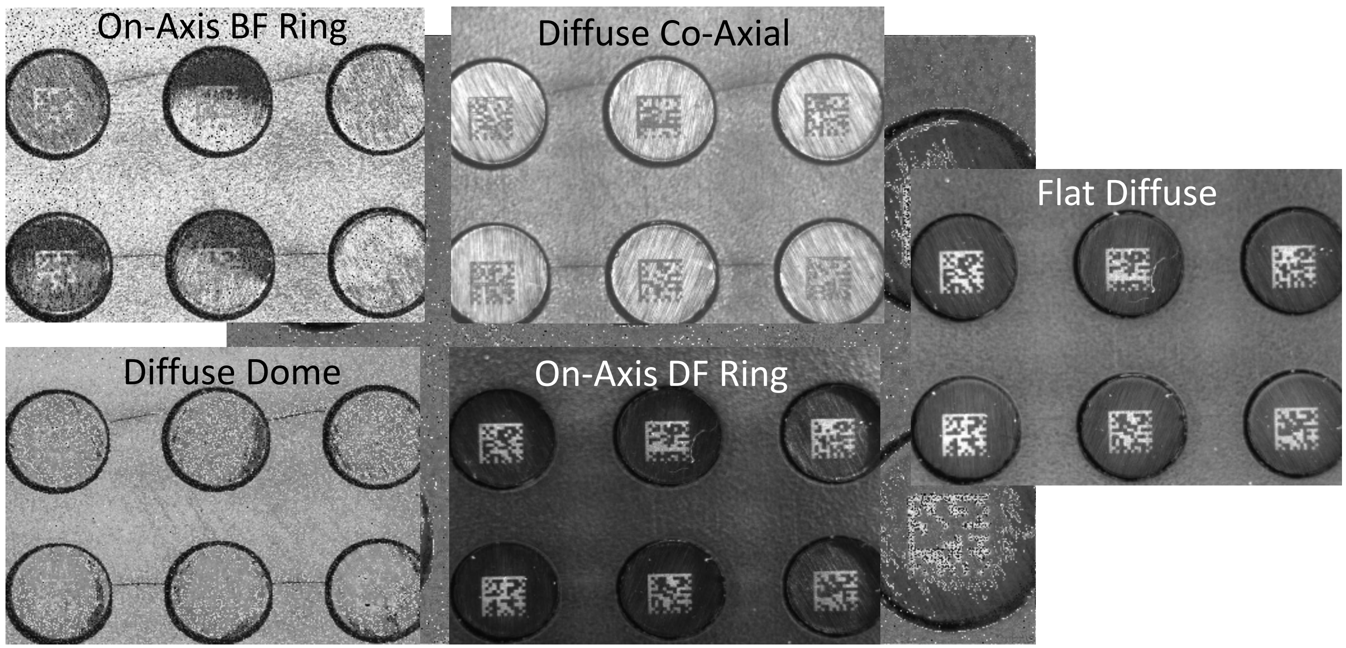




Flat Diffuse



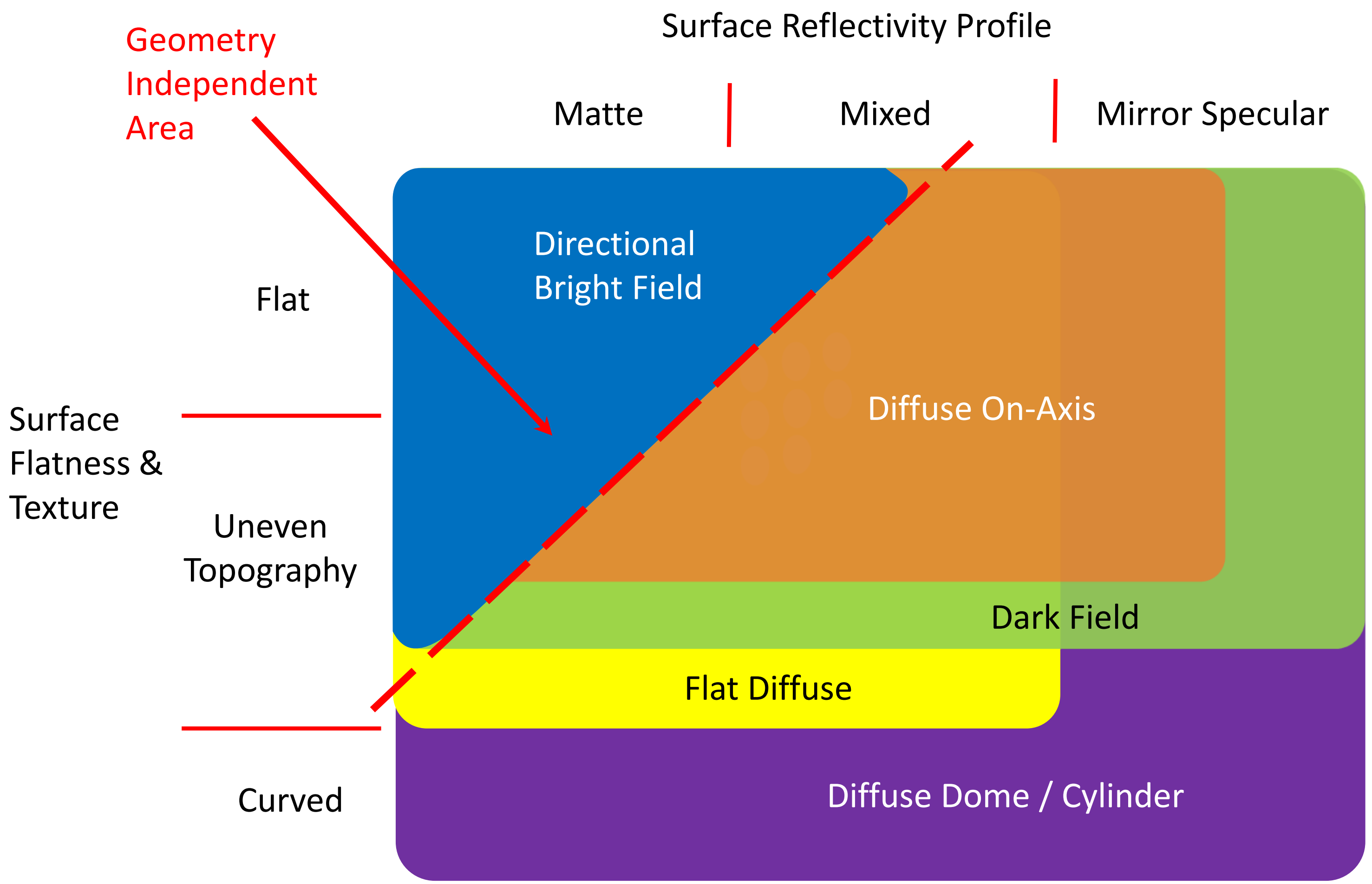
- Diffuse sheet directed downward
- Long WD and larger FOV
- Hybrid diffuse (dome and Co-Axial)



Advantages - Disadvantages

	Partial Bright Field	Dark Field	Diffuse Axial Full Bright Field	Diffuse Dome Full Bright Field
Lighting Type	Ring, Spot, Bar	Angled Ring, Bar	Diffuse Box	Dome Flat Diffuse
When To Use	-Non specular -Area lighting -May be used as a dark field light	-Non Specular -Surface / Topo -Edges -Look thru trans-parent parts	-Non Specular -Flat / Textured -Angled surfaces	-Non Specular -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

Technique vs. Object Surface



Inspection Environment

Physical Constraints

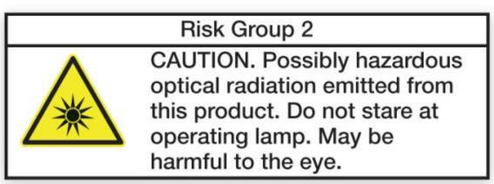
- Access for camera, lens & lighting in 3-D (working volume)
- The size and shape of the working volume
- Min and max camera, lighting working distance and FOV

Part Characteristics

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

Ergonomics and Safety

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



Contrast Enhancement Concept 3: Using Color and Wavelength

Create Contrast with Color

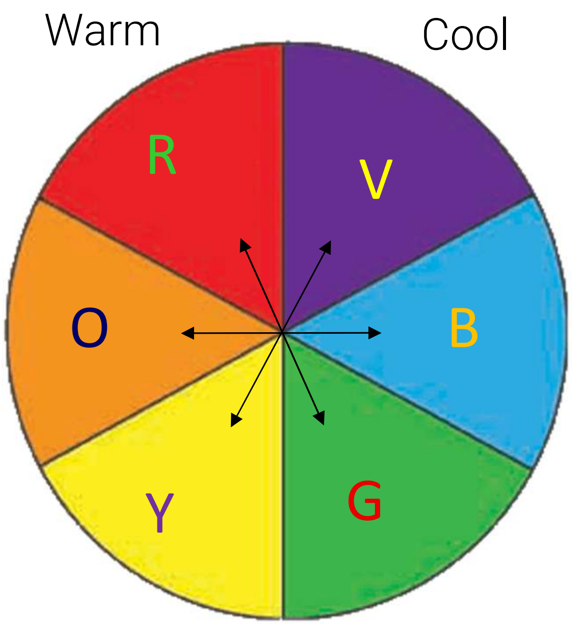
Use Monochrome Light to Create Contrast

1 - Use Like Colors or Families to Lighten:

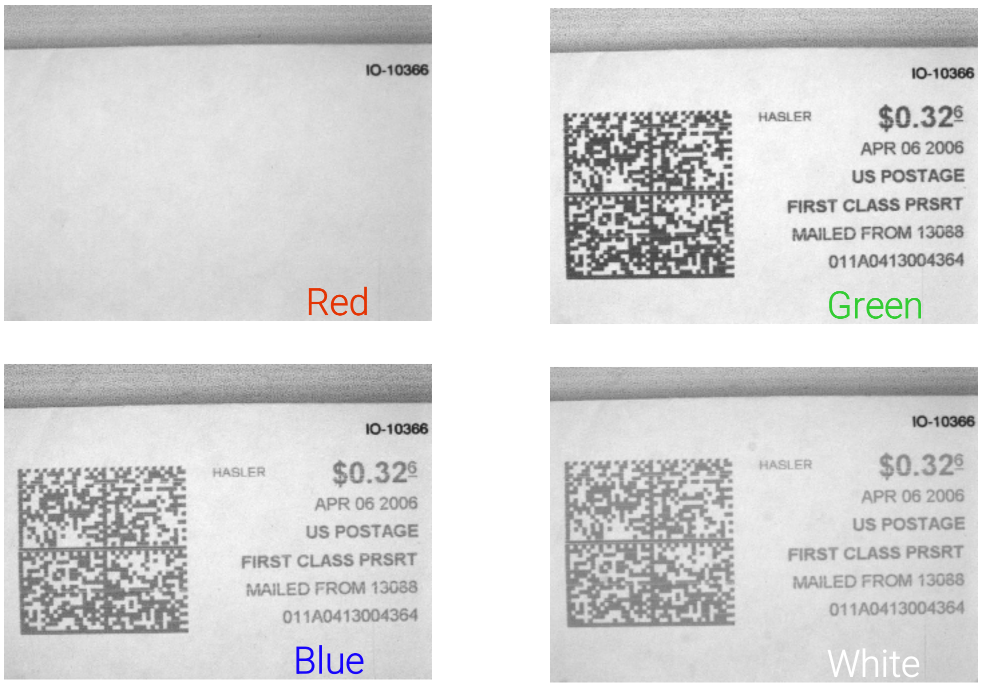
(red light makes red features brighter)

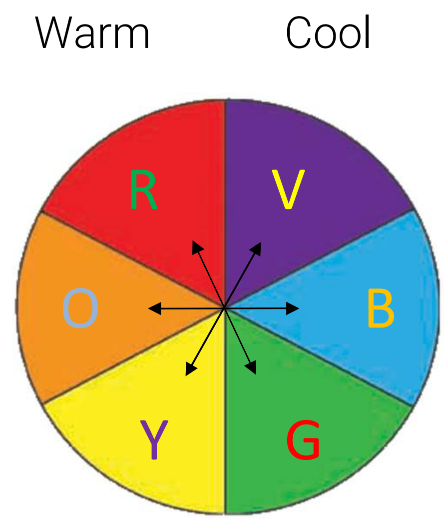
2 - Use Opposite Colors or Families to Darken:

(red light makes green features darker)



Create Contrast with Color





White light will contrast all colors; may be a compromise.

1 - red light makes red features brighter

2 - red light makes green features darker

3 - Color affects both the object and its background!

4 - Hint: You are creating more contrast in this case…

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Wavelength vs. Composition

	Monochrome						
	UV	B	G	R	IR	RGB	WHI
Doped w/ UV Fluorescing Agent	X						
Dark Rubber		X					X
Dark Plastics					X		X
Transparent Plastics / Glass				X	X		
Semi-metallic				X	X		X
Metallic		X	X	X	X		X
Mixed Color Parts						X	X
General Purpose				X			X
Ambient Light Problems		X	X	X	X		
Strobe / Ergonomic Issues					X		

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Contrast Enhancement Concept 4: Using Pass and Polarizing Filters

Ambient Light

Any light other than the vision-specific lighting that the camera collects.

Controlling and Negating Ambient Light

Turn off the ambient contribution

Most effective . . . Least Likely!

Build a shroud

Very effective, but time-consuming, bulky and expensive

Overwhelm the ambient contribution w/ high-power lighting (Continuous-on or Strobe over-drive)

Effective, but requires more cost and complexity

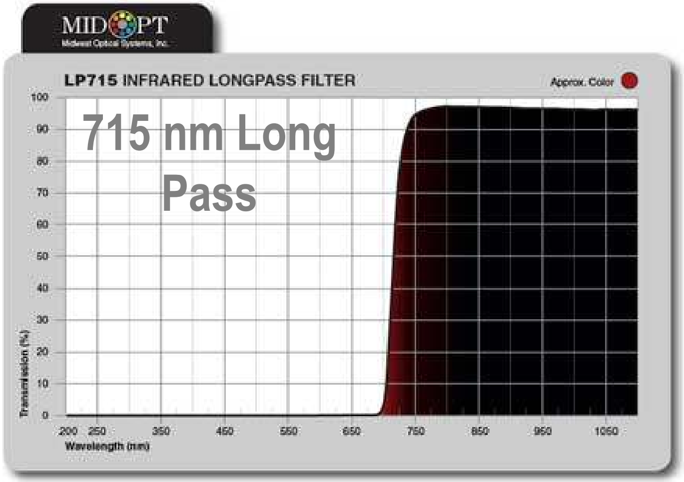
Control it with pass filters

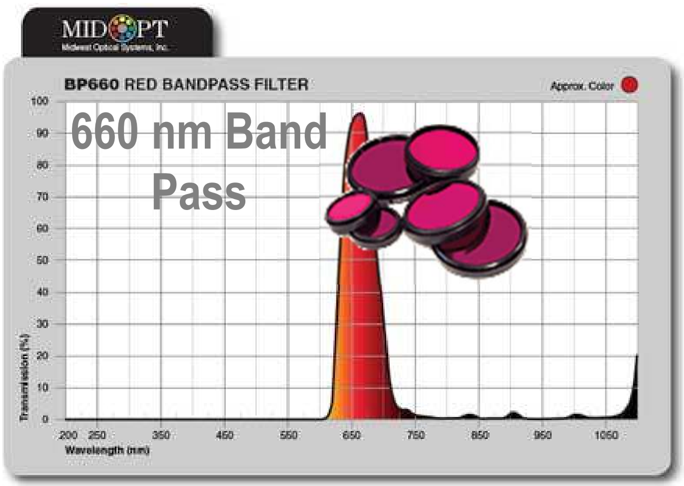
Very effective, but requires a narrow-band source light

Pass Filters in Machine Vision

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

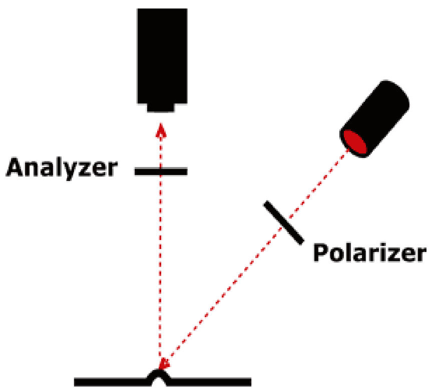
Graphics courtesy of Midwest Optical, Palatine, IL

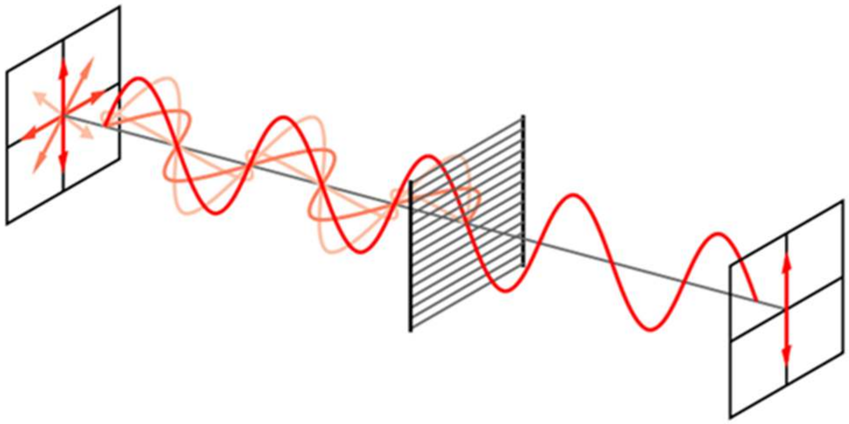




Avoiding Surface Glare

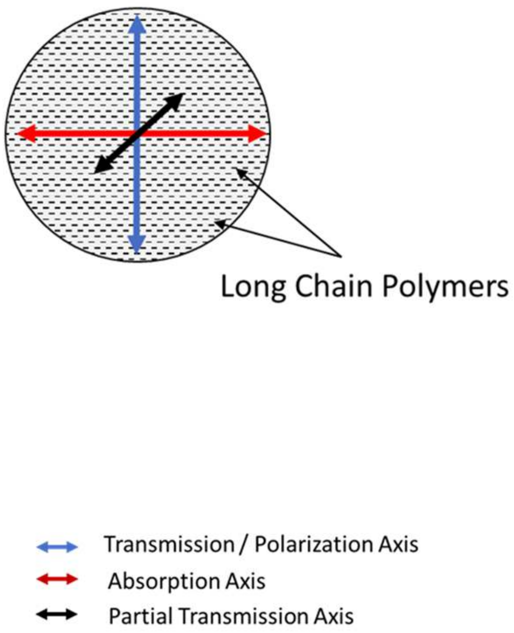
- ➢Change Geometry – 3D spatial arrangement of Light, Sample, and Camera (preferred)
- ➢Strobe to overwhelm glare from ambient sources
- ➢Use polarization filters (least preferred)

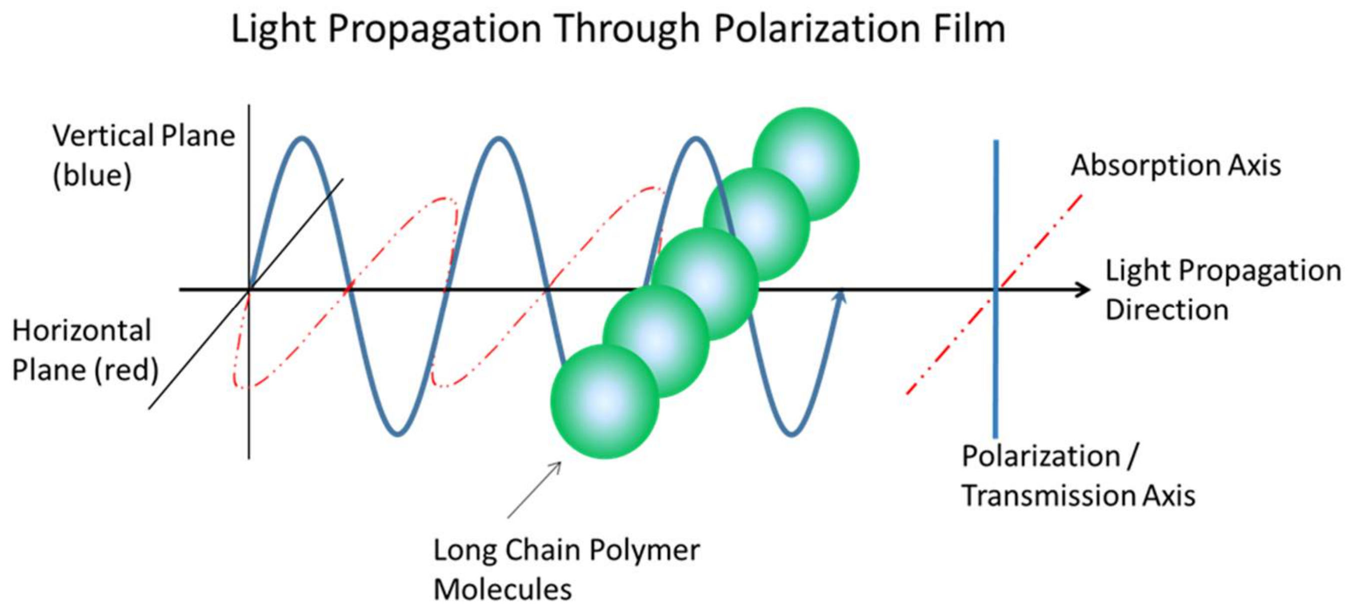




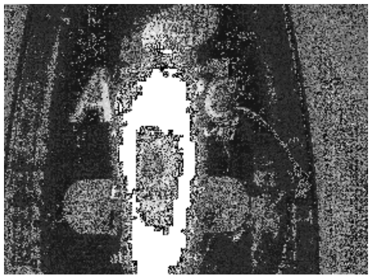
Courtesy Wikimedia Commons

Polarizing Filters in Vision

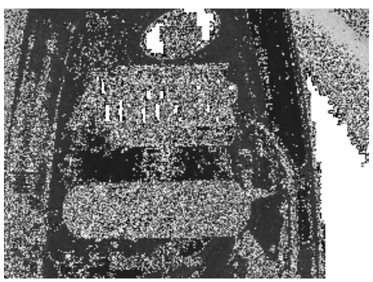




Polarizing Filters in Vision

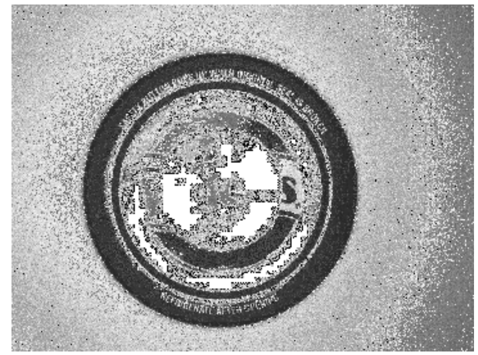


On-axis Light w/o Polarizers



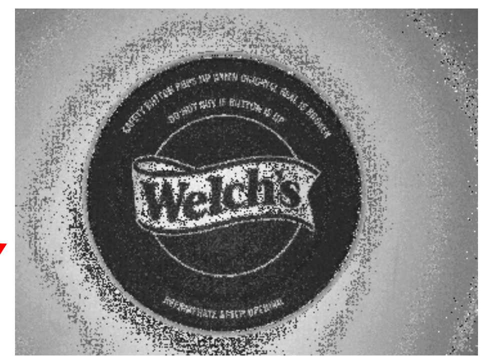
Off-axis Light w/o Polarizers

On-axis Light w/ Polarizers



w/o Polarizers

Up to 2 ½ f/stops opened!



w/ Polarizers

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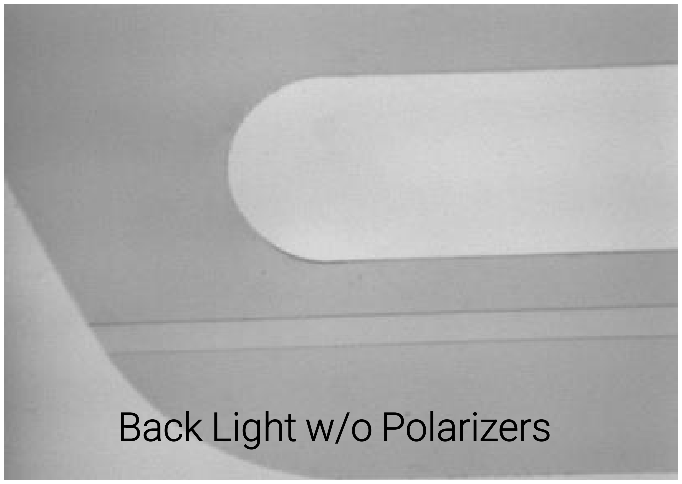
Polarizing Filters in Vision


Back Light w/o Polarizers

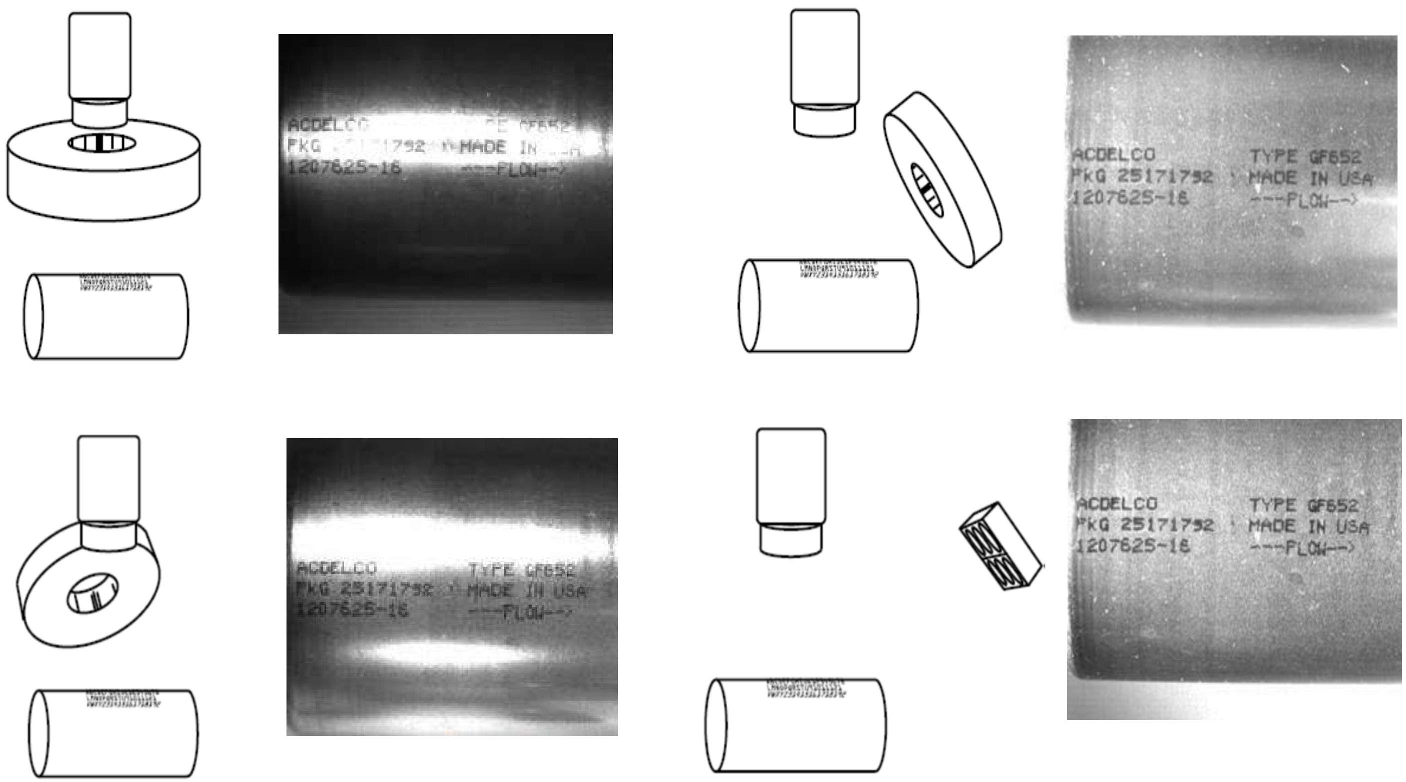
6-pack Plastic Ring Carrier

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


Back Light w/ Polarizers

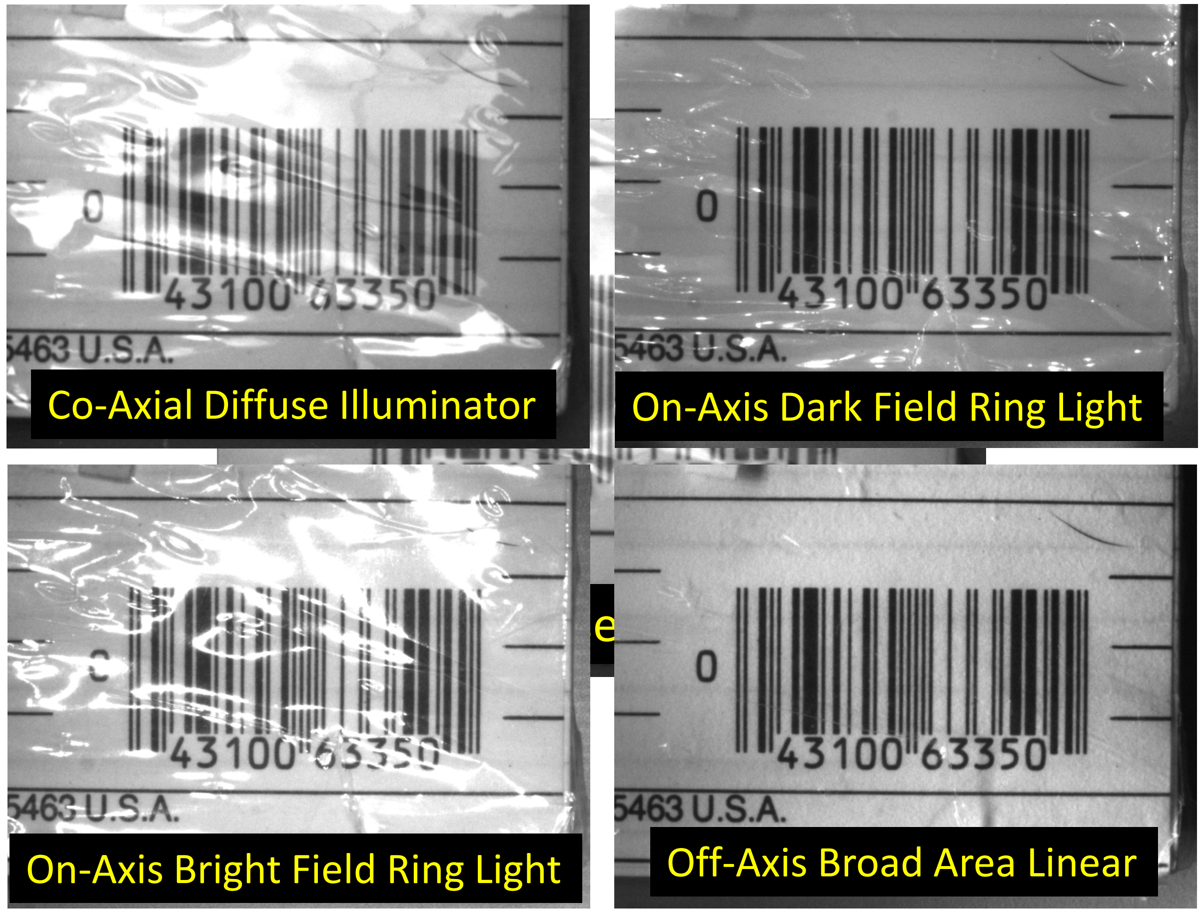
Avoiding Surface Glare

3-D Reflection Geometry: Light - Sample - Camera



Avoiding Surface Glare - Bar Code

Printing beneath cellophane wrapped package

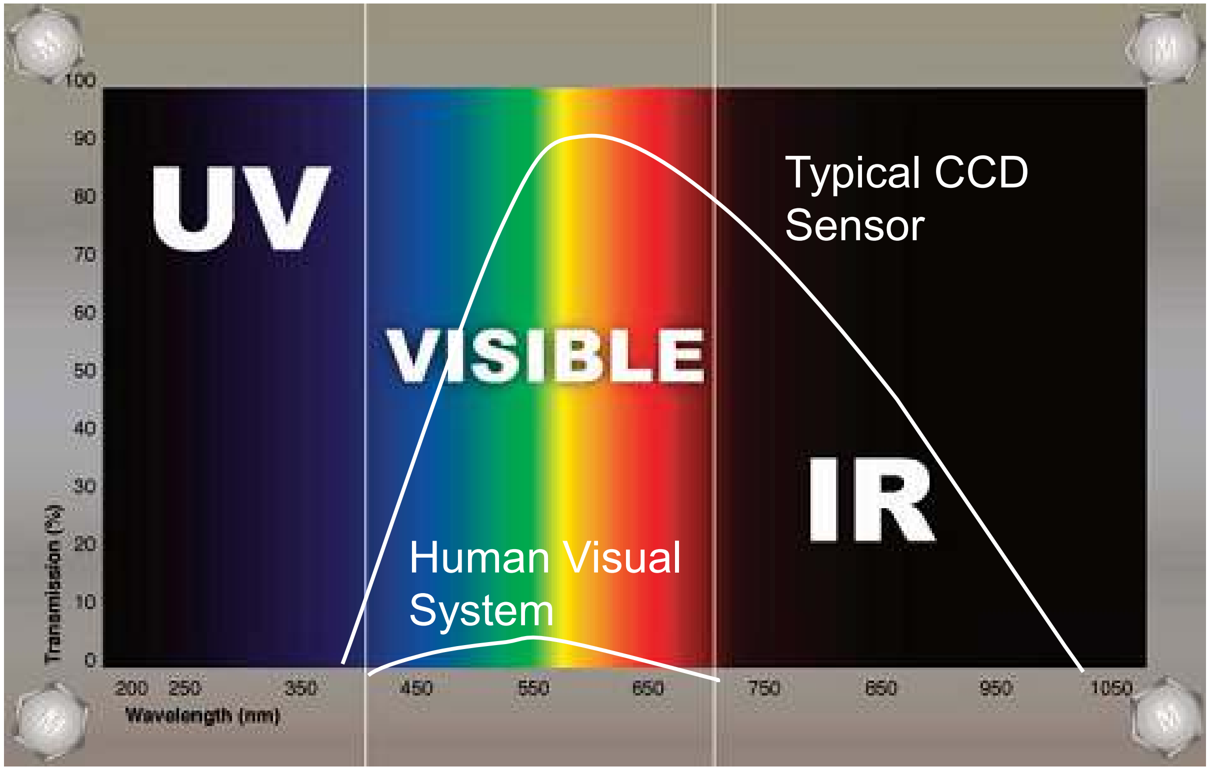


ADVANCED ILLUMINATION

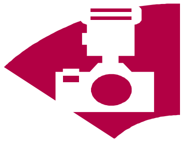
Imaging with UV & Near IR Light Contrast Enhancement Concepts 3 & 4

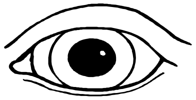
ADVANCED ILLUMINATION

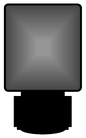
Vision Lighting Spectrum



Graphics courtesy of Midwest Optical, Palatine, IL

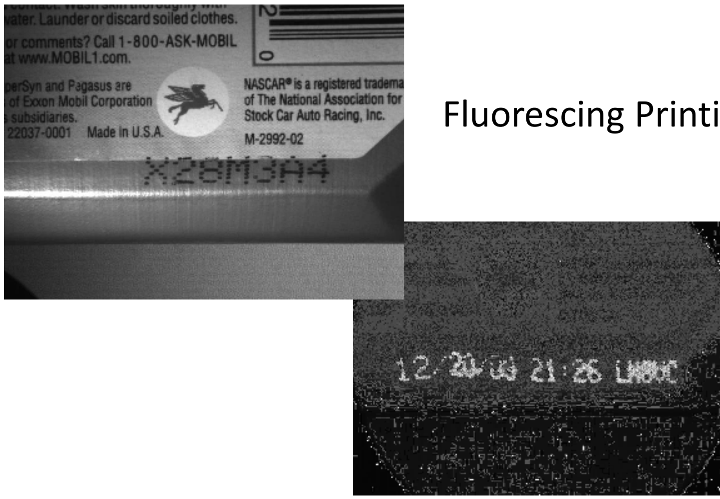




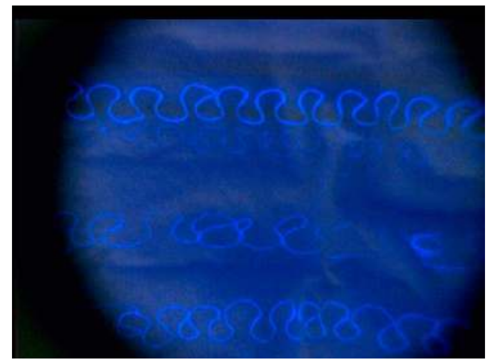


Imaging with UV Light - Fluorescence

Colors (wavelengths) and filters work together



Fluorescing Printing



Fluorescing Polymers
(nylon)

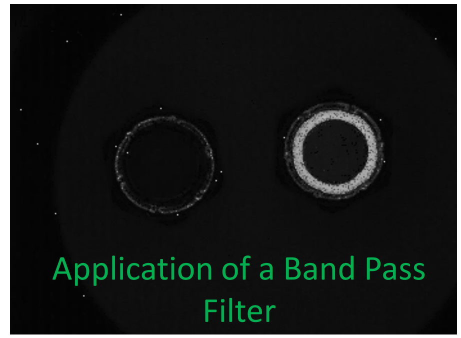
Caveats:

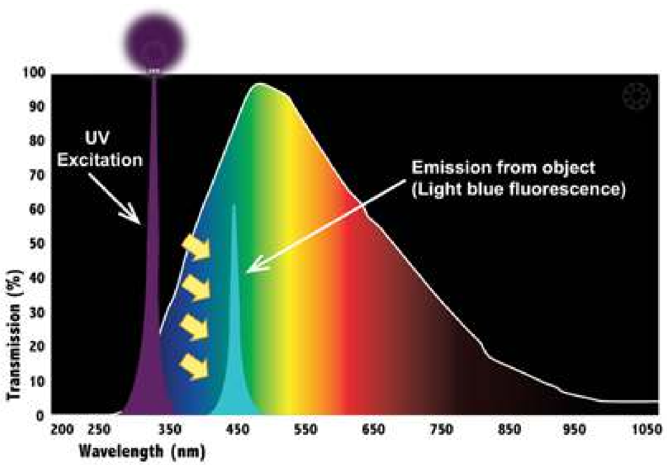
1) UV light is not always needed – part dependent
2) Use band pass filters to enhance feature contrast
3) Goal is collecting emitted light from part, NOT excitation source light (unlike visible)
4) Emitted (fluorescent yield) light from part is always:

   - longer wavelength, thus less energy and less “bright” than source

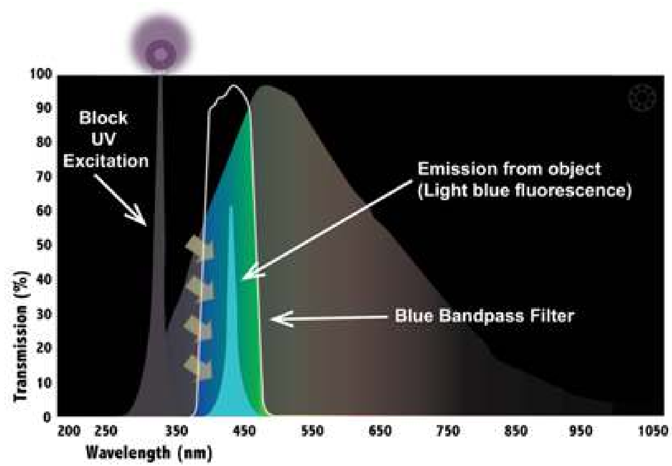
ADVANCED ILLUMINATION

Imaging with UV Light - Fluorescence





Camera detects overpowering UV excitation light source



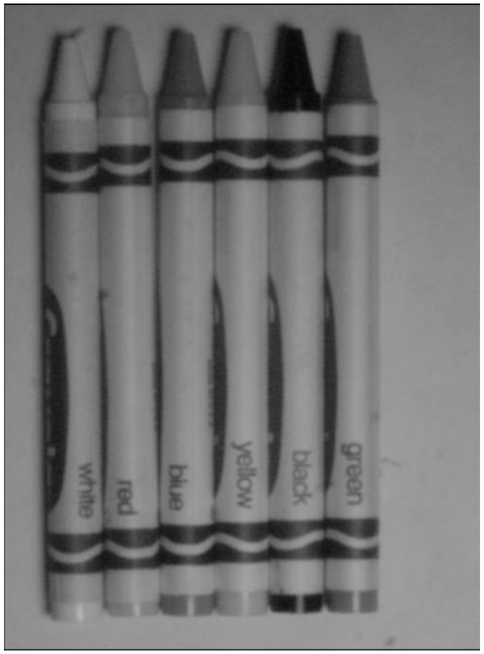
Filter blocks overpowering UV excitation light source

Graphics courtesy of Midwest Optical, Palatine, IL

Imaging with Near IR (NIR)

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

White light – B&W Camera



IR light – B&W Camera

Vision Lighting Design Method

1) Determine the Exact Features of Interest

2) Analyze Part Access / Presentation
   - Clear or obstructed, Moving / Stationary
   - Min / Max WD range, Sweet Spot FOV, etc.

3) Analyze Surface Characteristics
   - Texture
   - Reflectivity / Specularity
   - Effective Contrast – Object vs. background
   - Surface flat, curved, combination

4) Understand Light Types and Applications Techniques
   - Rings, Domes, Bars, Spots, Controllers, etc
   - Bright Field, Diffuse, Dark Field, Back Lighting

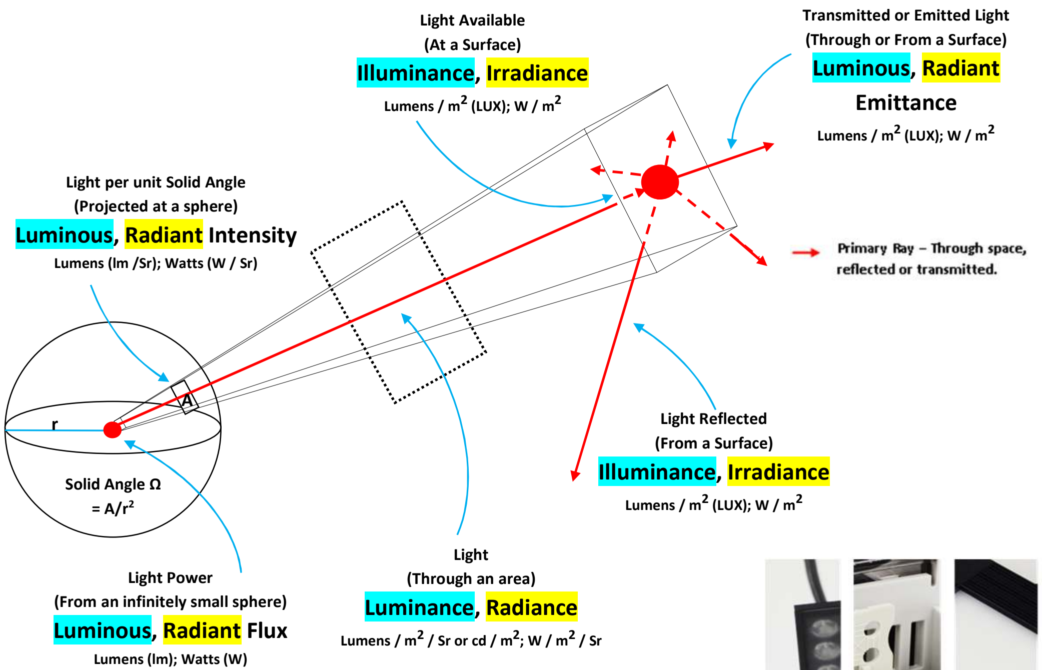
5) Determine Critical Image Contrast Enhancement Issues
   - 3-D Geometry, Structure, Color & Filters

6) Eliminate Ambient Light Effects / Environmental Issues

9 Guidelines for Applying MV Lighting

1) Coordinated Lighting & Optics are crucial – when properly selected, they provide the foundation for the MV system.
2) Develop the lighting solution early in the vision system design process – on the bench first, if necessary.
3) Dedicated Lighting = Control of the Lighting Environment.
4) A primary key for producing accurate, reproducible, robust & standardized inspection results is creating Feature-Appropriate Lighting image contrast.
5) Understand that a final lighting solution may require considerable compromise.
6) Apply the 4 image contrast enhancement concepts.
7) Consider that light MAY interact differently w/ respect to surface texture, color, composition and incident wavelength, especially UV and NIR.
8) Be aware of your camera sensor's spectral sensitivity and range, understanding that it will be considerably better in both factors compared with your eyes.
9) Understand the Inspection Environment w/ respect to Physical Constraints, Object Characteristics, Ambient Light and Ergonomic / Safety aspects.

Contact Information



Photometric Measures: Perceived light power - weighted to the eye response.

Radiometric Measures: Un-weighted optical radiation power.

Presentation courteously of Advanced Illumination

For technical support, contact 1stVision

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