Laser Processing of Materials

Laser Safety

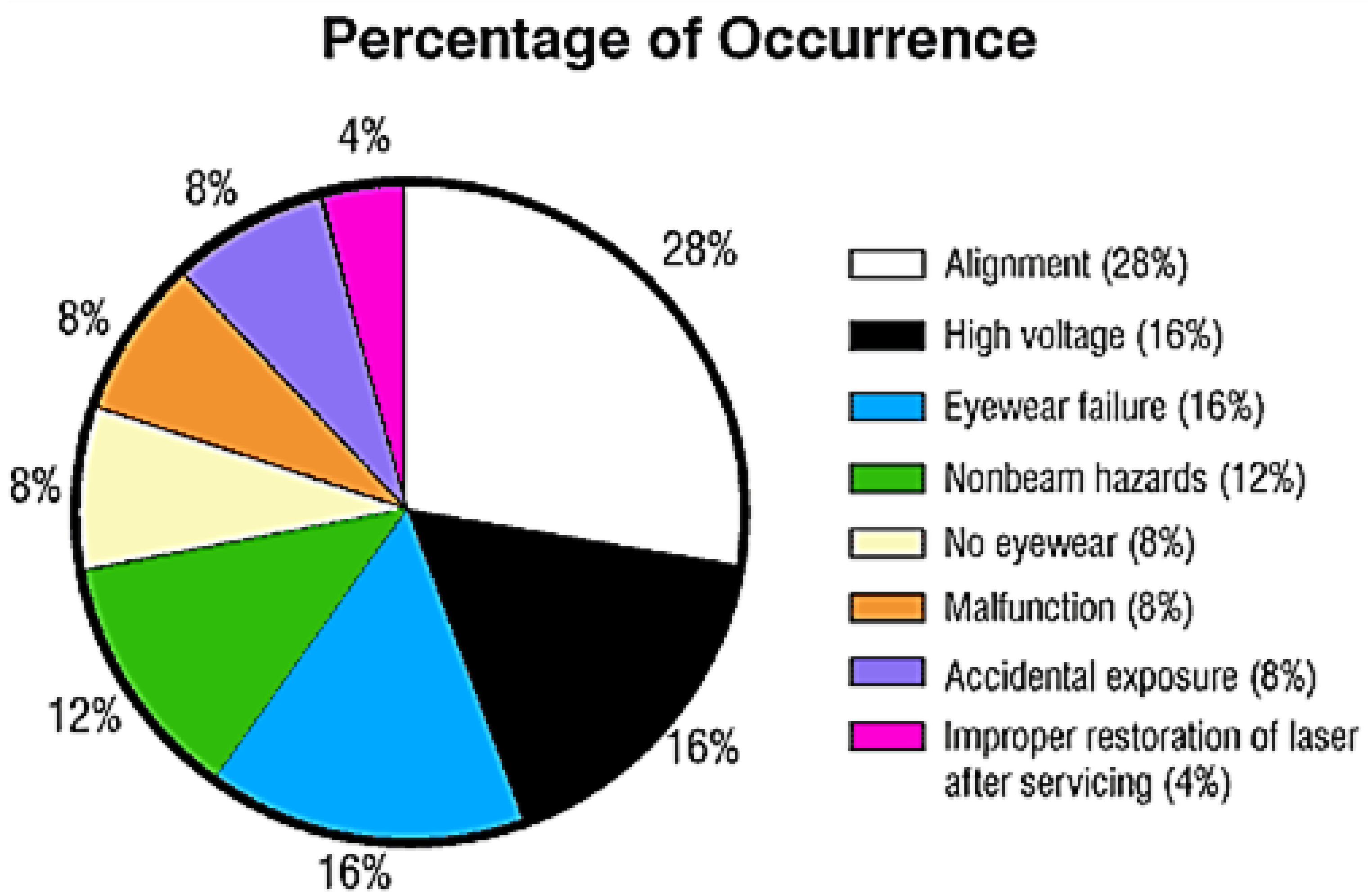
Patrik Hoffmann

Content

- Laser dangers & hazards
- Insight into the eye physiology
- Classification of Lasers
- Protective measures
  - awareness
  - personal protection
  - protection of people around

Laser Dangers & Hazards

Causes of Laser Accidents



Non-eye Dangers

- Skin Burns
- Fire
- Electrical shock
- Chemicals required for operation of the laser:
  - liquid organic dyes
  - excimer gasses (F_2, Cl_2,..)
- Dangerous gases due to decomposition/burning of irradiated material
- High pressure lamp explosion (for flash lamp pumped lasers during maintenance)

Laser is an Electric Device

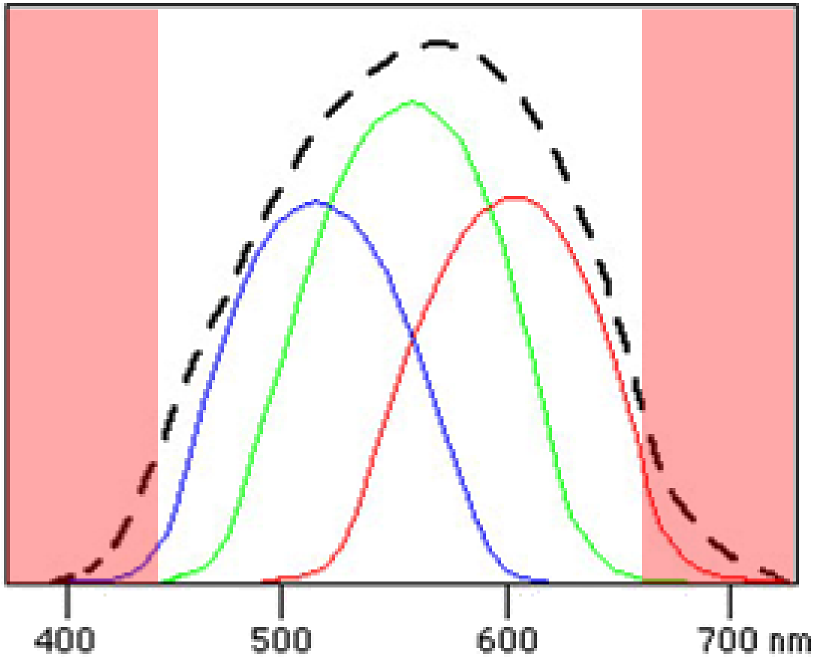
- High-voltage can be present in the laser – apply general safety measures
  - the operation area must be DRY (be careful with cooling water)
  - disconnect equipment the power supply before openning the housing

Dangers to the Skin

- Burns
  - 1W laser can cause burns, but protective reaction can be fast enough
  - for 5W laser reaction time is not enough
- UV lasers can have cancerogenic effect on skin (especially 248 nm – KrF excimer)

Eye Physiology

Spectral Sensitivity of the Eye



Spectral sensitivity of cones and rods in the human eye

Visible range: ~400 – ~750 nm

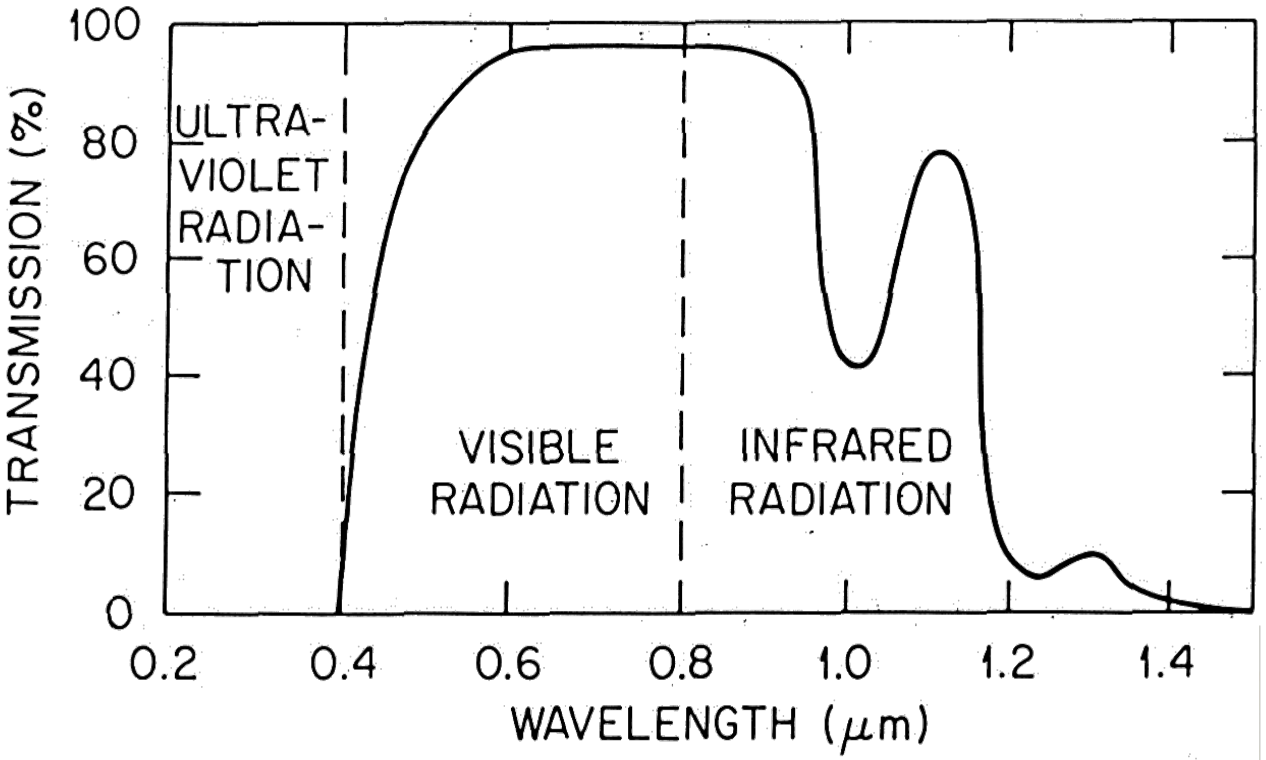
Laser in the range close to the visibility regions (350- 400 nm and 700-850 nm) are very dangerous.

The beam is visible and appear to be very weak - though in reality the power may be very high.

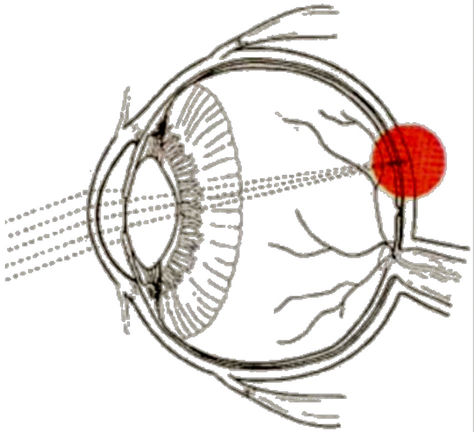
Typical examples:

pumping diodes for Nd:YAG (808 nm, P > 20-50 W)

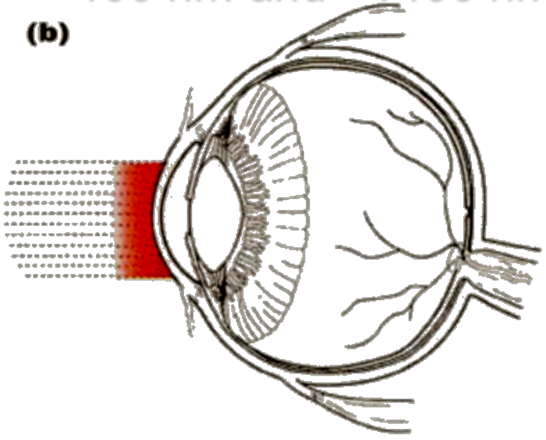
Transmission of the Eyes Tissues



Retinal hazard region:
400 – 1400 nm



Cornea/lens hazard:
<400 nm and >1400 nm



Transmitted wavelength range is significantly broader than visible range → retinal hazard !!!!

Do not get injured!

Followed safety rules

Cornea Damage

BAD

Retina Damage

WORSE

What to do in case

In case of injury optician should be visited immediately !!!!

Experience has demonstrated that most laser injuries go unreported by the injured person for 24–48 hours.

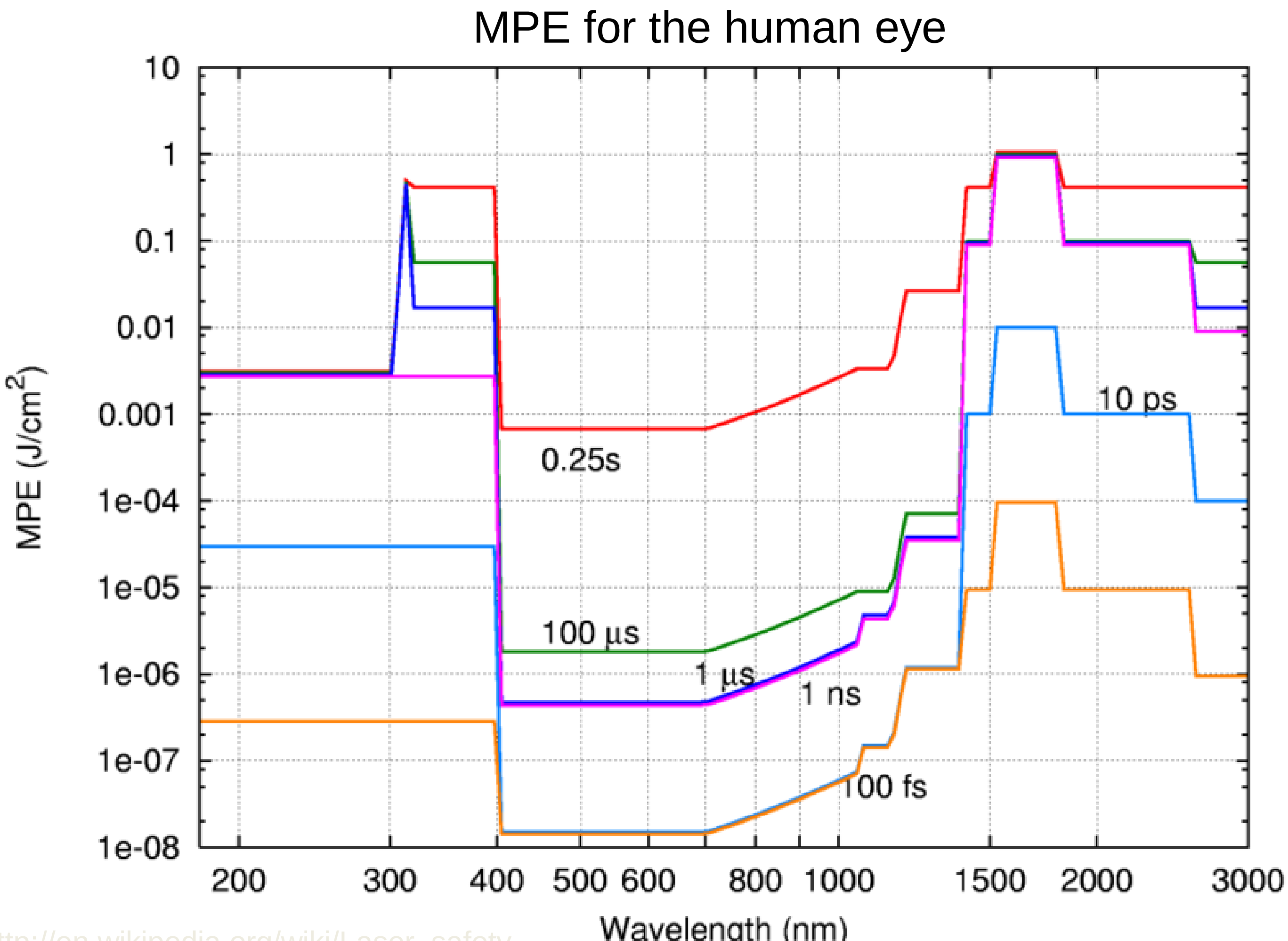
This is a critical time for treatment of the injury!

How do you know if you have an eye injury?

- Exposure to infrared high-power laser causes a burning pain in the eye (to the cornea or sclera)
- Exposure to visible lasers causes a bright color flash of the emitted wavelength and afterwards an image of the complementary color
- Exposure to short pulsed infrared lasers may go undetected or may cause a popping sound followed by visual disorientation

Maximum Permissible Exposure

MPE: highest power or energy density (in W/cm_2 or J/cm_2) of a light source that is considered safe – depends on the exposure duration



Reference: http://en.wikipedia.org/wiki/Laser_safety

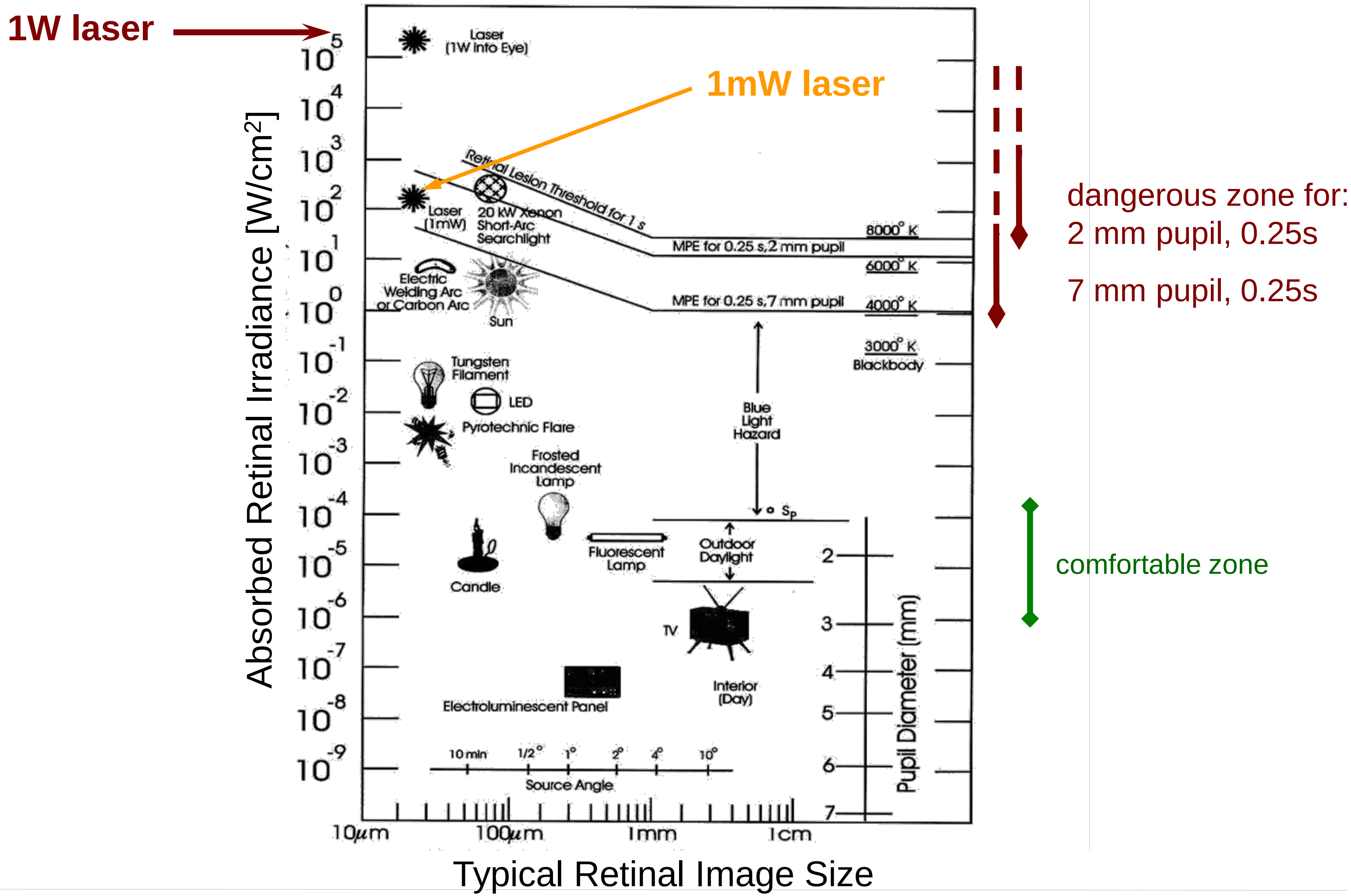
MPE and Exposure Duration

$\Delta\tau$=0.25s is a typical reaction time to close the eye lid (blinking)

For visible lasers this is considered a critical period during which MPE should not be reached.

For invisible (e.g. infrared laser) 10s exposure is usually taken as the critical period – so the protection need to be stronger.

Retinal Irradiance for Various Sources



Classification of Lasers

Laser Safety Standards

There are two principle international laser safety standards:

- International Electrotechnical Commission
  IEC 60825
- American National Standards Institute
  ANSI Z136

There are also European Norms for Safety Eyewear:

- EN 207 and EN 208

Old and New System

Revised system (introduced in 2002) - IEC 60825-1

- Class 1
- Class 1M
- Class 2
- Class 2M
- Class 3R
- Class 3B
- Class 4

new classification takes into account knowledge about the lasers and laser safety accumulated since introduction of the first classification

↑

Arabic numerals

"Old" classification system (developed in early 1970s), still used in US (ANSI Z136)

- Class I
- Class II
- Class IIa
- Class IIIa
- Class IIIb
- Class IV

How to differentiate?

Roman numerals →

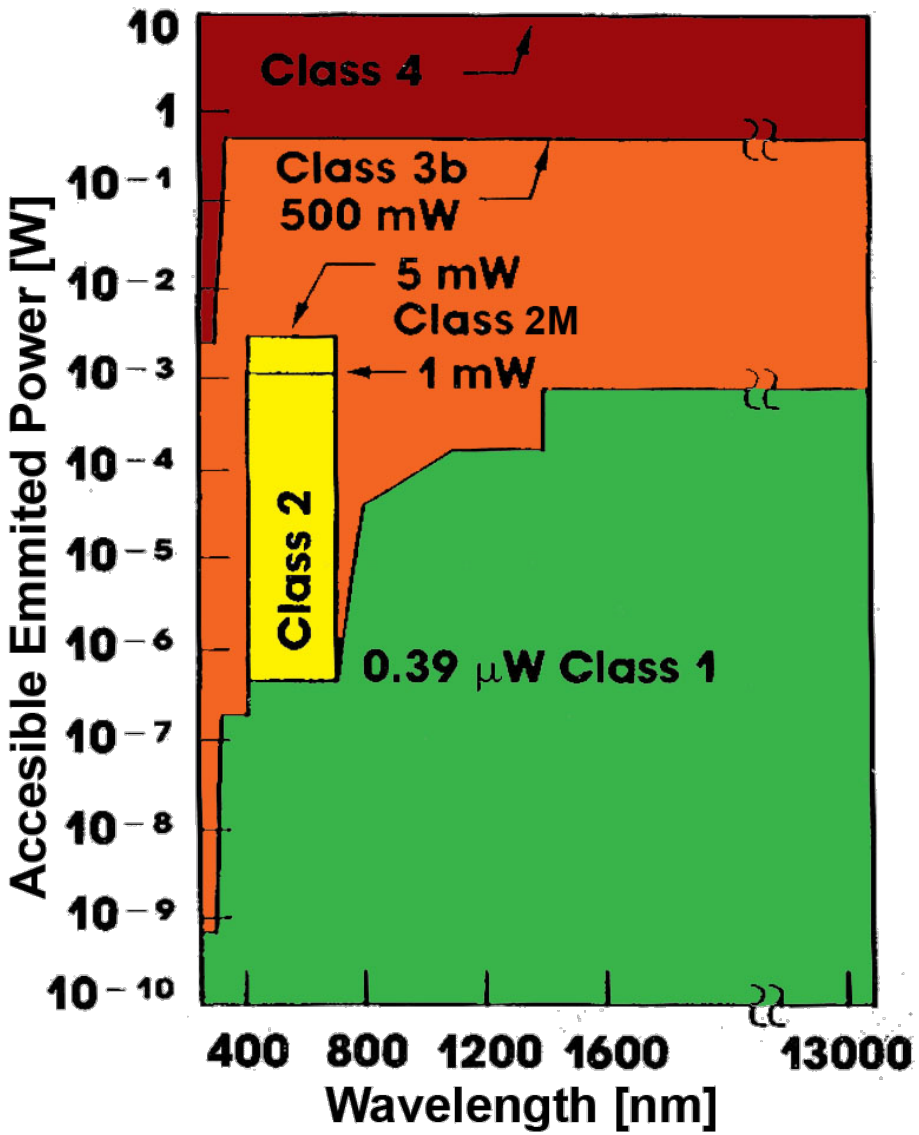
Laser Classes

Class	Hazard	Comments
1	without danger	if view not intentional
1M	retinal burn	dangerous if viewed **through magnifying optics** (microscope, telescope, etc.)
2	retinal burn	danger if exposure **>0.25s** (reaction time)
2M	retinal burn	danger if exposure **>0.25s** and **viewed** through the **optical device**
3R	retinal burn	direct view is dangerous (5mW limit for visible lasers)
3B	retinal burn & other biological effects	direct view is dangerous, diffuse reflections could be dangerous (0.5W limit for visible lasers)
4	retinal burn & other biological effects & skin burn	**direct** view **and diffuse** reflections are **dangerous**. Extreme care!

Laser Classes

Approximate assignment of the laser classes for continuous wave lasers

Depend on laser power, emitted wavelength, pulse duration.



Maximum Emission Limits for Class 1

Accessible emission limits for Class 1 laser products

←pulse length

Wavelength λ (nm) \ Emission duration t(s)	$<10^{-9}$	10^{-9} to 10^{-7}	10^{-7} to 10^{-6}	10^{-6} to 1.8×10^{-5}	1.8×10^{-5} to 5×10^{-5}	5×10^{-5} to 10	10 to 10^{3}	10^{3} to 10^{4}	10^{4} to 3×10^{4}
180 to 302.5	2.4×10^{4} W	2.4×10^{-5} J							
302.5 to 315		$7.9 \times 10^{-7} C_1 J (t < T_1)$ / $7.9 \times 10^{-7} C_2 J (t > T_1)$					$7.9 \times 10^{-7} C_2 J$		
315 to 400		$7.9 \times 10^{-7} C_1 J$					7.9×10^{-3} J	7.9×10^{-6} W	
400 to 550	200 W	2×10^{-7} J			$7 \times 10^{-4} t^{0.75}$ J		3.9×10^{-3} J		3.9×10^{-7} W
or	$10^{11} W.m^{-2} sr^{-1}$	$10^{5} t^{0.33} J.m^{-2} sr^{-1}$					$2.1 \times 10^{5} J.m^{-2} sr^{-1}$		$21 W.m^{-2} sr^{-1}$
550 to 700	200 W	2×10^{-7} J			$7 \times 10^{-4} t^{0.75} J. (t < T_2)$ / $3.9 \times 10^{-3} C_3 J (t > T_2)$				$3.9 \times 10^{-7} C_3 W$
or	$10^{11} W.m^{-2} sr^{-1}$	$10^{5} t^{0.33} J.m^{-2} sr^{-1}$					$(t < T_2)$ $3.9 \times 10^{4} t^{0.75} J.m^{-2} sr^{-1}$ / $2.1\ 10^{5} C_3 J.m^{-2} sr^{-1}$ $(t > T_2)$		$21 C_3 W.m^{-2} sr^{-1}$
700 to 1050	$200 C_4 W$	$2 \times 10^{-7} C_4 J$			$7 \times 10^{-4} t^{0.75} C_4 J$			$1.2 \times 10^{-4} C_4 W$	
or	$10^{11} C_4 W.m^{-2} sr^{-1}$	$10^{5} t^{0.33} C_4 J.m^{-2} sr^{-1}$					$3.9 \times 10^{4} t^{0.75} C_4 J.m^{-2} sr^{-1}$	$6.4 \times 10^{3} C_4 W.m^{-2} sr^{-1}$	
1050 to 1400	2×10^{3} W	2×10^{-6} J				$3.5 \times 10^{-3} \times t^{0.75}$ J		6×10^{-4} W	
or	$5 \times 10^{11} W.m^{-2} sr^{-1}$	$5 \times 10^{5} t^{0.33} J.m^{-2} sr^{-1}$					$1.9 \times 10^{5} t^{0.75} J.m^{-2} sr^{-1}$	$3.2 \times 10^{4} W.m^{-2} sr^{-1}$	
1400 to 1530	8×10^{4} W	8×10^{-5} J	$4.4 \times 10^{-3} t^{0.25}$ J				8×10^{-4} W		
1530 to 1550		8×10^{-3} J		$4.4 \times 10^{-3} t^{0.25}$ J					
1550 to 10^{5}		8×10^{-5} J	$4.4 \times 10^{-3} t^{0.25}$ J						
10^{5} to 10^{6}	10^{7} W	10^{-2} J	$0.56 t^{0.25}$ J				0.1 W		

(See notes page 36)

↑ wavelength

complexity of the real world !!! (meant mainly for manufacturers)

Prevention & Protection

Protection Measures

- Warning signs and flashing lights
- Interlocks
- Exposed areas restriction
- Eye protection: goggles/glasses
- Skin protection: gloves, full face mask (for UV lasers)
- Most important: think about consequences before you act !!!

Resposibility

- Operator of the laser has the primary responsibility !!!!
- If you have any concerns, questions or lack of knowledge contact the superior or (laser) safety responsible

Warning Signs

Labels used to mark the lasers

Classes **I** to **IIIa**

Classes **IIIb** to **IV**

Warning Signs

Standard “Laser Hazard” warning sign.

Must be present on lasers starting from Class II

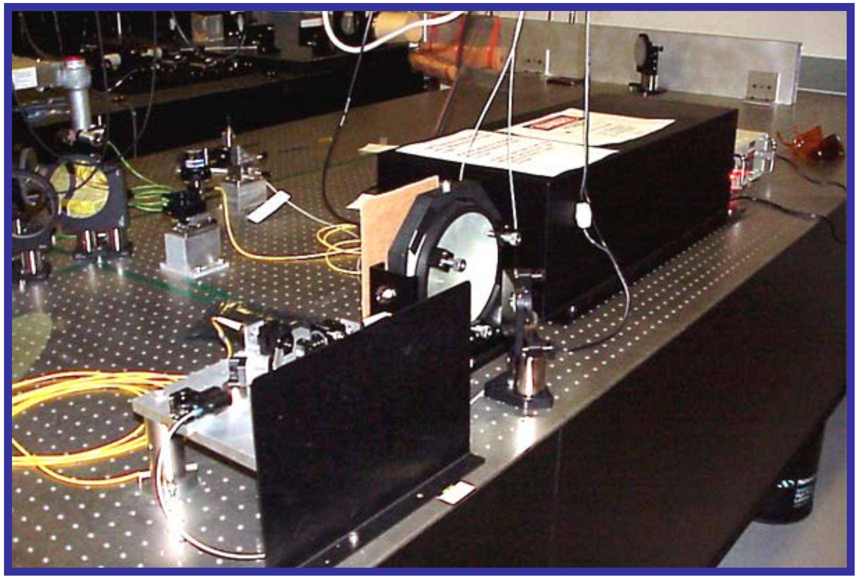
Normally also placed to mark the dangerous area (e.g. at entrance doors, etc.)

Warning sign at the beam exit of the laser body

Precautions

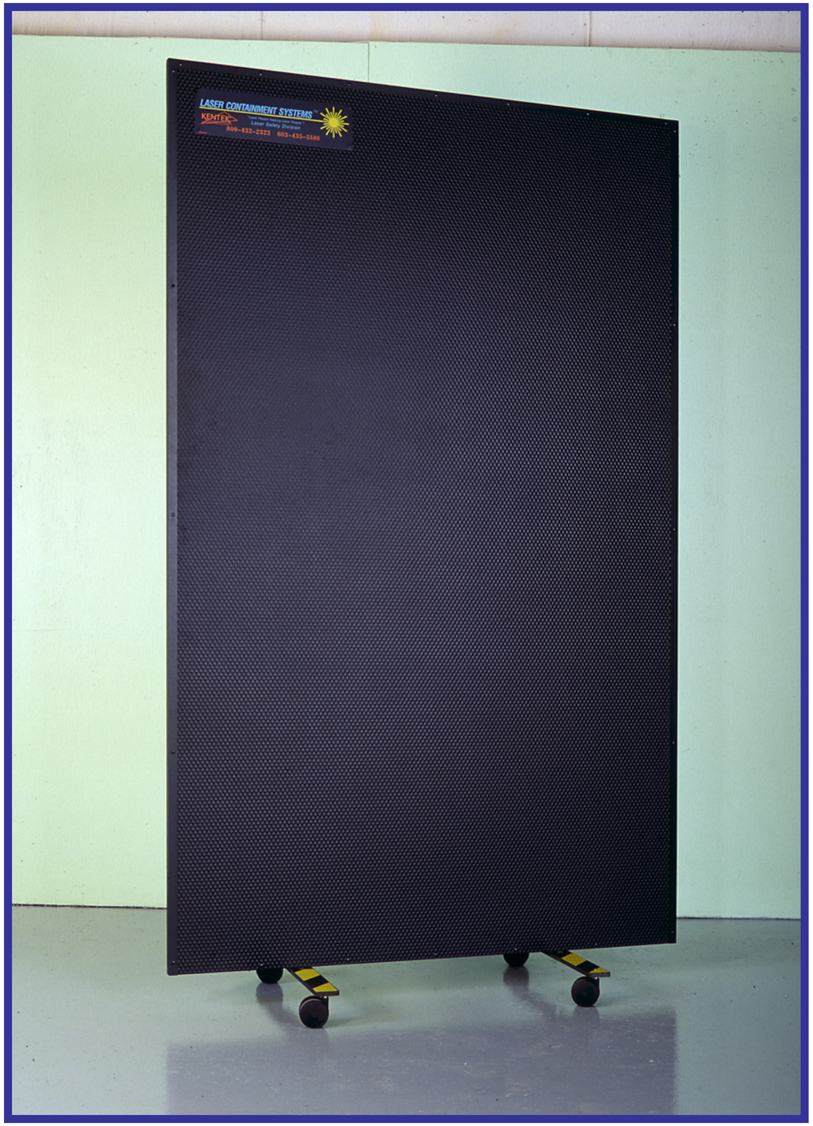
- Avoid reflective materials in the laser lab
  - polished objects
  - glossy paints
  - jewellery; watches
- Use beam barriers
  - beam blockers to absorb unused beams/reflections
  - redundant blocker behind your set-up in case beam passes through
  - curtains/screens to protect the others

Protective Barriers (local)



Laser-Professionals.com

Protective Screens (whole area)



KENTEK®
"Laser People Helping Laser People"®

Precautions

- Never point the beam to somebody
- Never look along the beam axis or at the level of the beam path in general
- Don't install beam axis in eye height
  - laying (unconscious) ca. 0.1 m
  - sitting ca. 1.2 m
  - standing ca. 1.7 m
- PC for data recording / analysis should be placed in the protected area (common risk source!!!)

Eyewear

Eyeware

Protective glasses / goggles are laser specific – they are disigned to block certain wavelength and withstand certain power

Pay attention that the glasses are suitable for the laser you use !!!

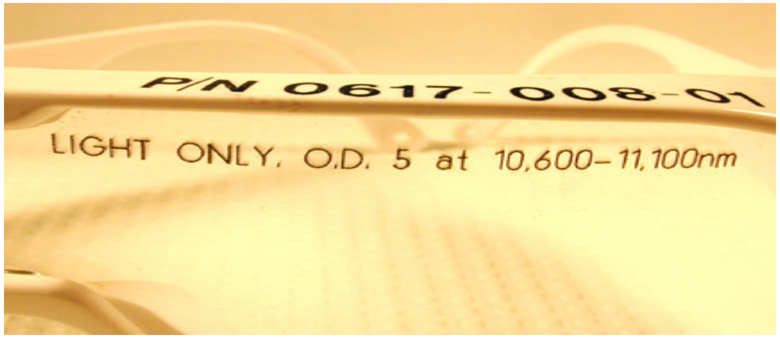
Optical Density

Protective properties of the protective eyewear is typically marked in OD units.

Optical Density (OD) – measure of absorption in logarithmic scale

$$D_\lambda = \log_{10}(I_{incident} / I_{transmitted})$$

OD	% Transmission
0	100%
1	10%
2	1%
3	0.1%
4	0.01%
5	0.001%
6	0.0001%



Selecting Eye Protection

How to determine minimum required Optical Density (OD):

$$\mathbf{D_\lambda = \log_{10}(H_p/MPE)}$$

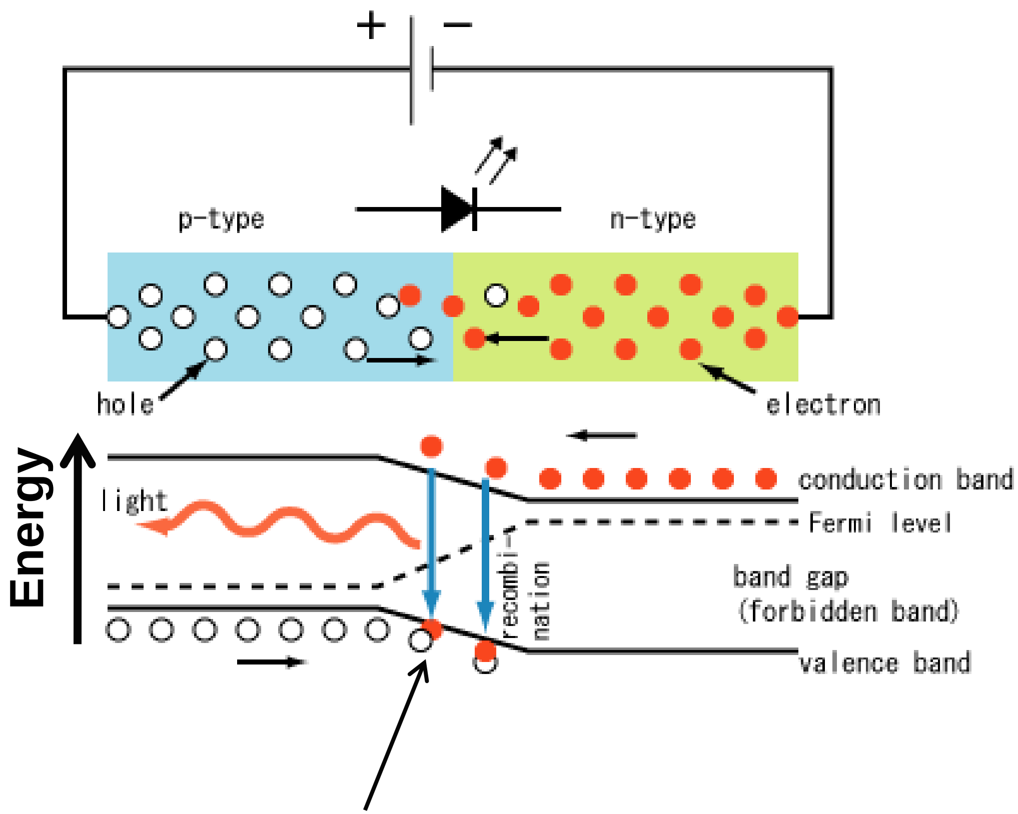
- D_λ = optical density at wavelength λ
- H_p = potential eye exposure (given by laser and set-up)
- MPE = Maximum Permissible Exposure for used laser type (λ, τ)

Eye Protection

- Remember: protective laser glasses are “the last hope” in case of accidental exposure and also might fail (especially for high power lasers)
  - Be sure to take all possible protective measures to avoid such exposures in principle

LEDs

Light Emitting Diodes



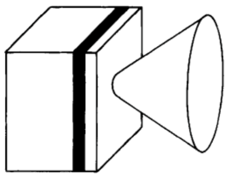
Recombination of electrons and holes in the p-n junction liberates energy, emitted as light.

Differences between
LED and LD (laser diode):

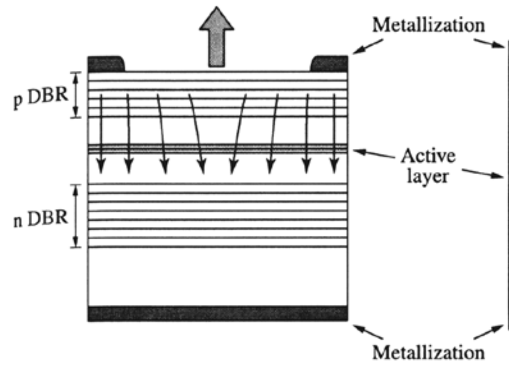
- LED devices do not reach light amplification condition
- LD have designed resonator (feedback) to promote stimulated emittion
- LED are spontanous emission devices
- LD emission is more directed

Light Emitting Diodes

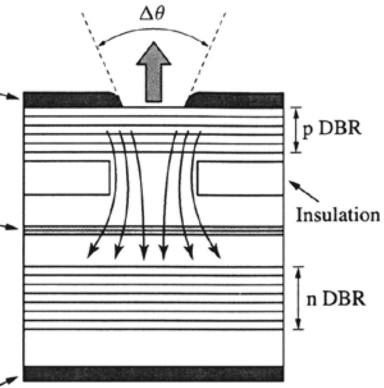
Surface emitting LEDs



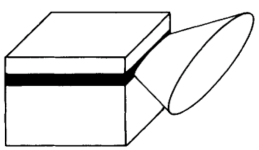
Broad area surface emission



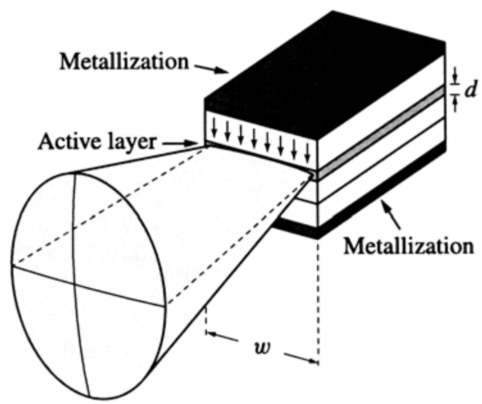
small area surface emission



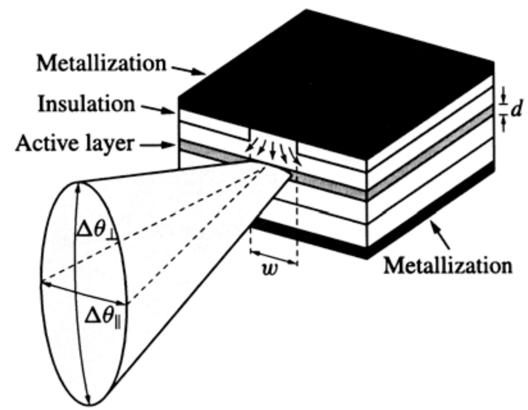
Edge emitting LEDs



Broad area edge emission



Strip geometry edge emission



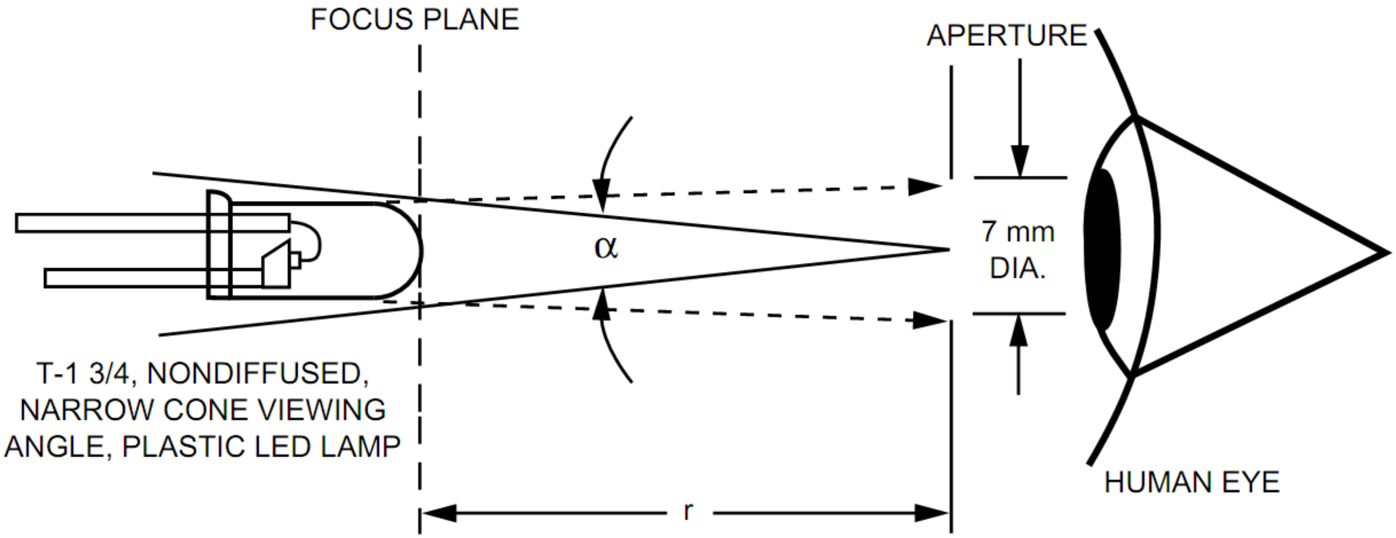
Emitting surface of the LED can be quite small:

dia.~10 µm – for surface emission

1 µm x 10 µm – for egde emitting LED

LED Safety Considerations

- Modern illumination LEDs can reach multi-watt light output.
- Combined with small source area this may result in very high brightness light source.



European CENELEC EN60825-1 Standard specifies LED evaluation method based on source luminous intensity (lm/sr) and viewing angle of the LED

Some brigth LEDs are classified as Class 2 devices (can cause retinal burn!!!)

The END