LAMELIS 2017
Lasers in Medicine and Life Sciences

Lasers for dental applications

Dr. Zsolt Tóth

University of Szeged, Faculty of Dentistry
Department of Oral Biology and Experimental Dental Research

University of Szeged
Where knowledge and challenge meet

Laserlab Europe

eli attosecond

HUNGARIAN BIOPHYSICAL SOCIETY

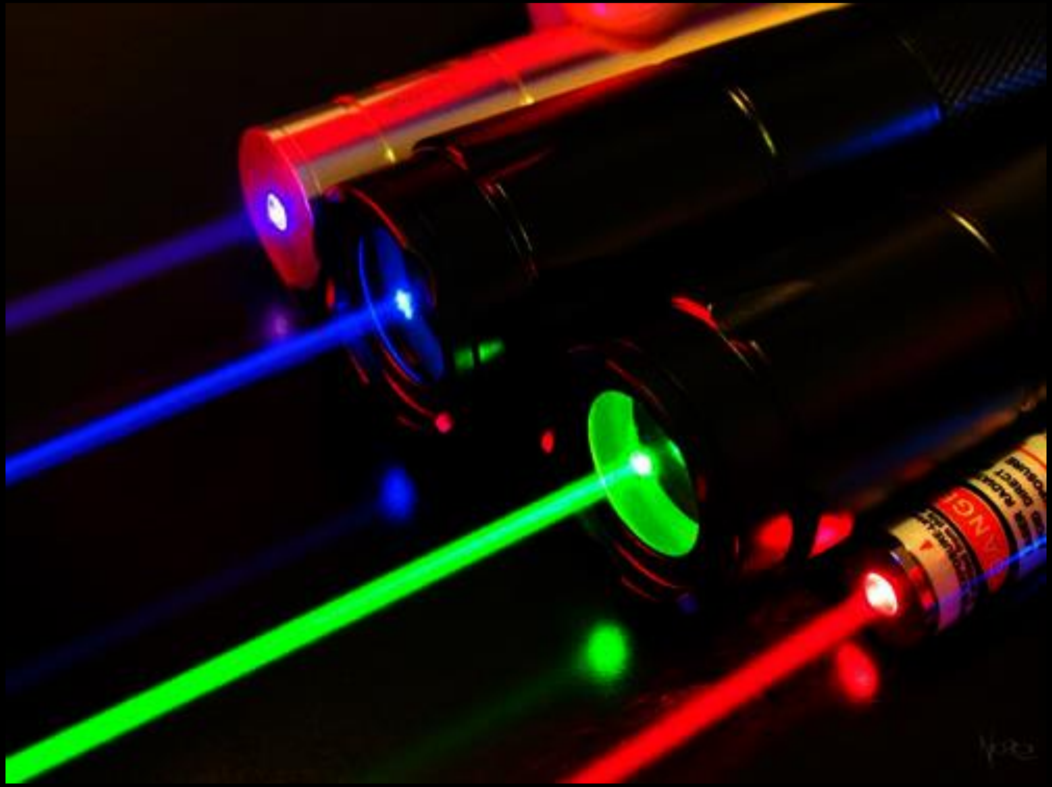
Outline:

- Laser sources
- Laser safety
- Laser (dental) material interactions
- Teeth…
- Laser applications in dentistry
- Summary

LASER SOURCES

Lasers

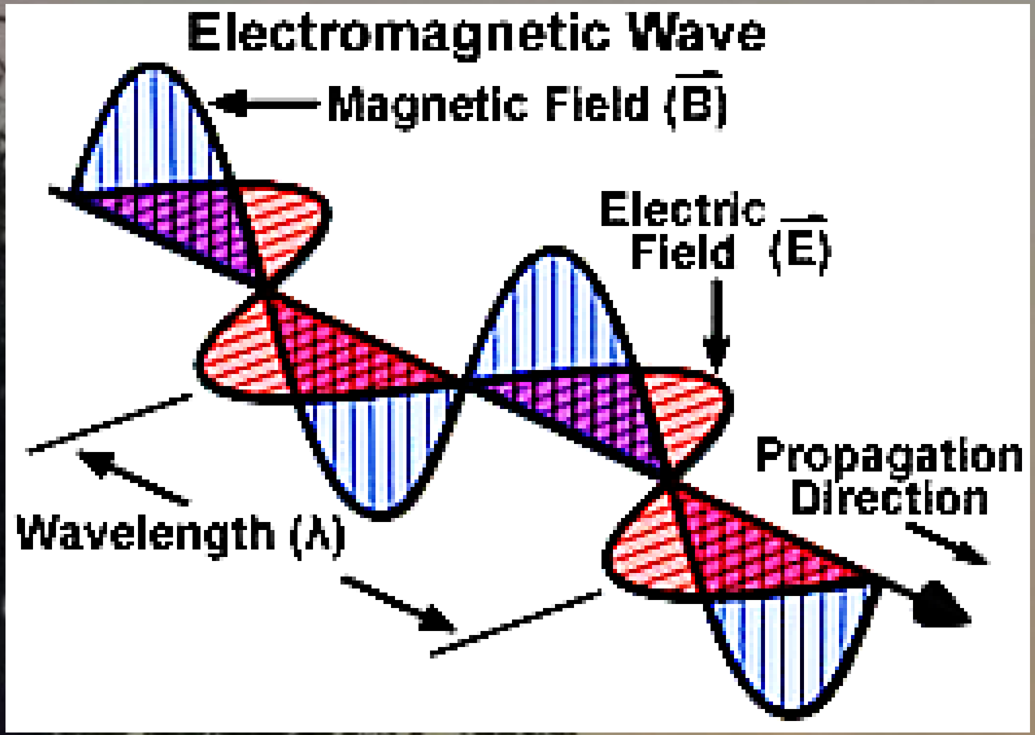
Light Amplification by Stimulated Emission of Radiation



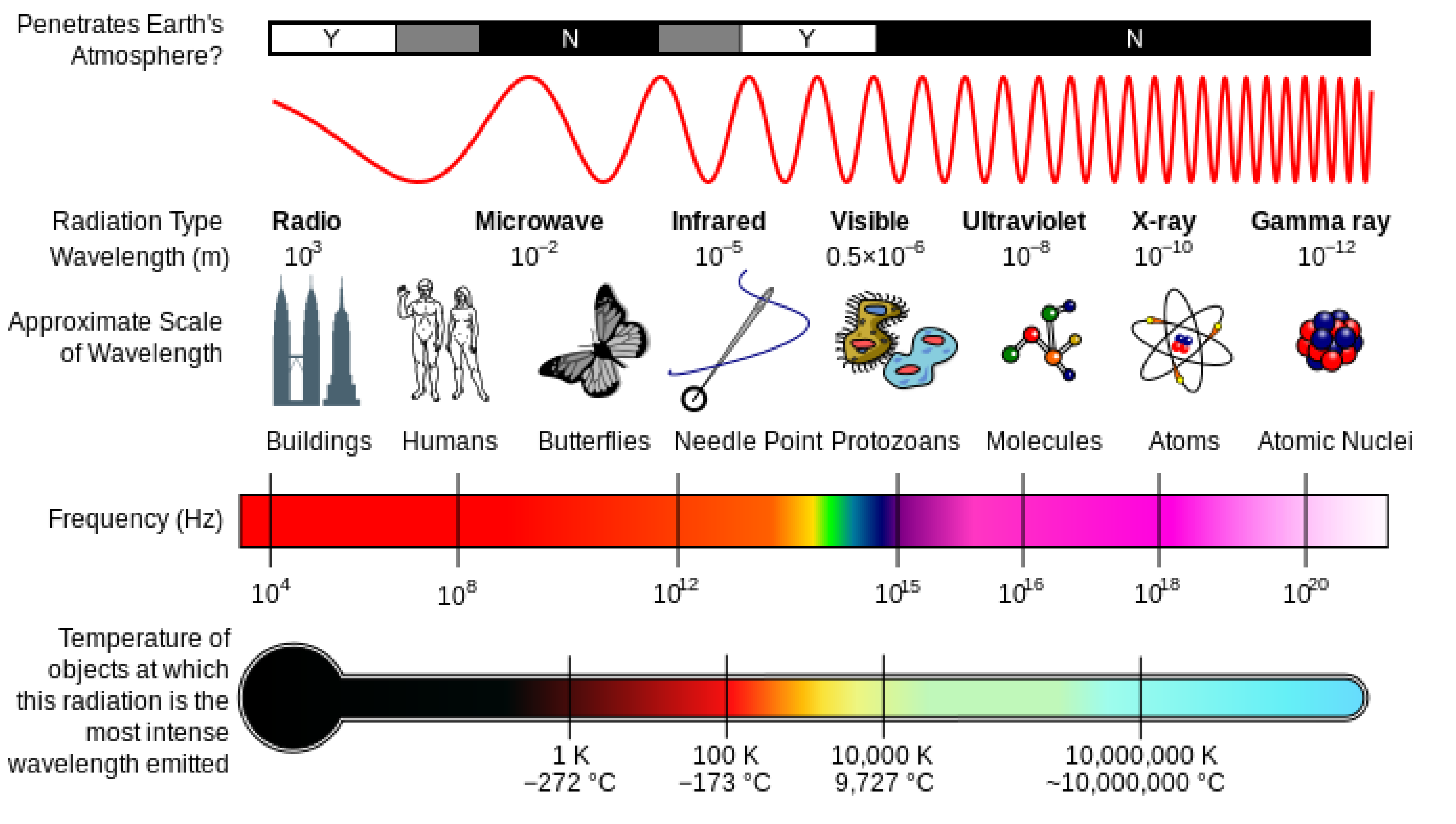
Lasers are unique light sources. Many important parameters of laser light are substantially different from those of the light emitted by classical (thermal or fluorescent) light sources

Light

- Light is electromagnetic wave
- velocity: $c=3\cdot10^{8}$ m/s
- Radiation is a transport process, energy is transported



Full electromagnetic spectrum

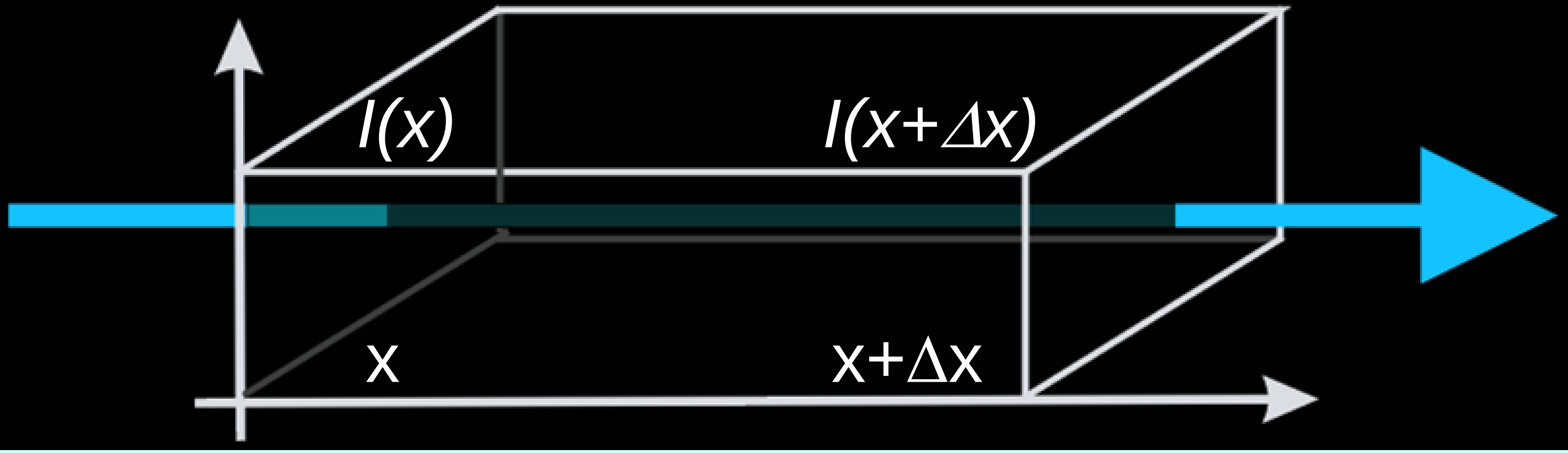


Optical spectrum

range name, sign	subrange name, sign		λ (nm)	ν [1/cm]	f (THz)	E (eV)
Ultraviolet (UV)	Vacuum UV VUV	UV-C	100 - 200	$5\cdot10^4$-10^5	1498-2997	6,2 - 12,4
	Far UV FUV		200 - 280	35700-$5\cdot10^4$	1070-1498	4,43 - 6,2
	UV-B		280 - 315	31700-35700	951-1070	3,94 - 4,43
	UV-A		315 - 400	25000-31700	749 -951	3,1 - 3,94
Visible (VIS)	VIS		400 - 800	12500-25000	375-749	1,55 - 3,1
Infrared (IR)	Near IR NIR	IR-A	800 - 1400	7100-12500	214-375	0,89 - 1,55
		IR-B	1400 - 3000	3300-7100	99-214	0,41 - 0,89
	Mid IR MIR	IR-C	3000 – $5\cdot10^4$	200-3300	6-99	0,025 - 0,41
	Far IR FIR		$5\cdot10^4$ - 10^6	10-200	0,3-6	0,00124-0,025

Different spectral ranges, and the associated λ wavelengths, ν wave numbers, f frequencies, and E photon energy values.

Einstein coefficients, absorption and emission phenomena



$$\Delta I \equiv I(x+\Delta x) - I(x) \propto \left(N_2 - N_1\right) \cdot B_{21} \cdot I \cdot \Delta x$$

The solution of this equation:

$$I(x) = I_0 \cdot e^{c \cdot (N_2 - N_1) \cdot B_{12} \cdot x}$$

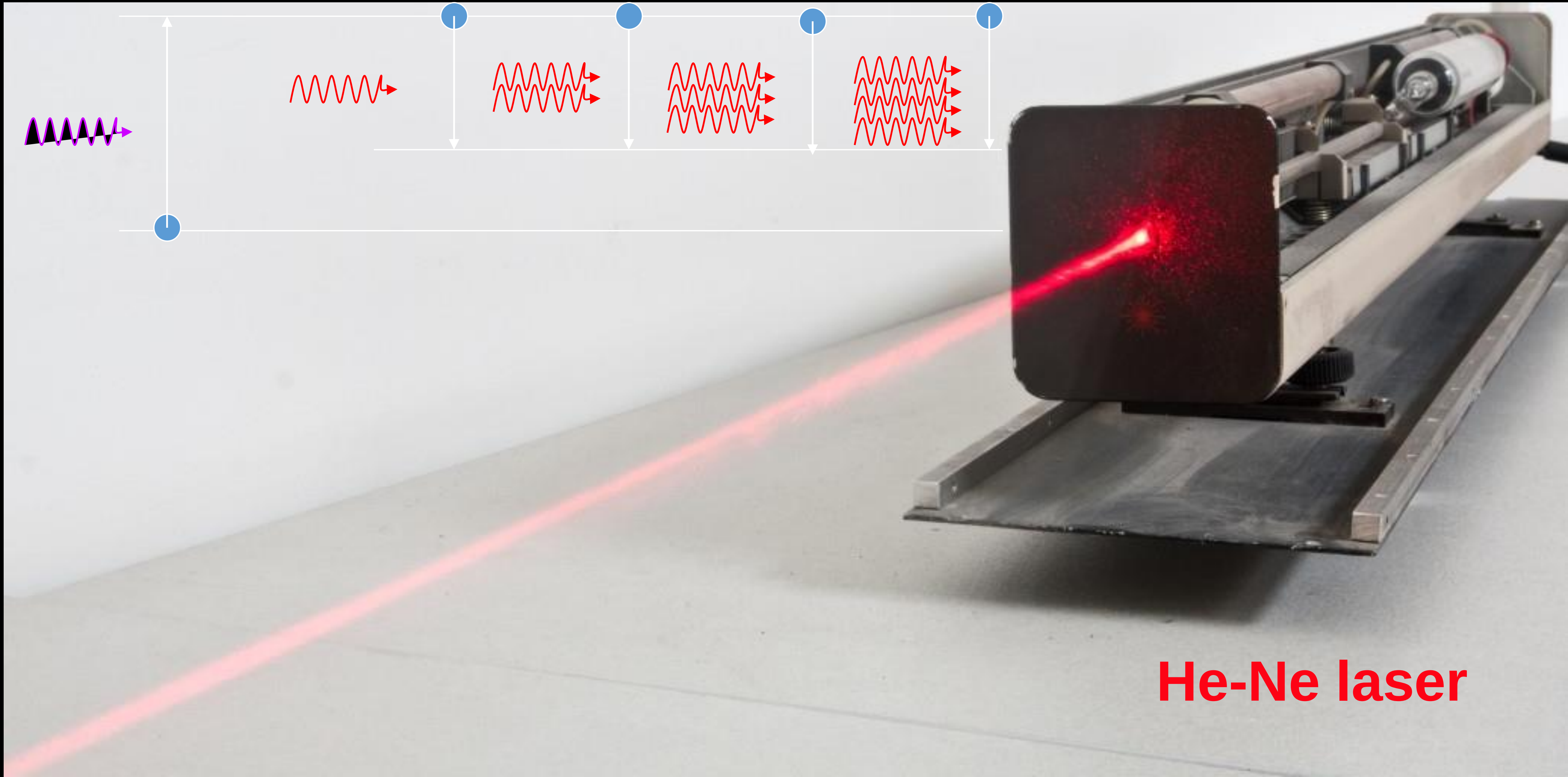
c: constant

If $N_1 > N_2$ then the light wave weakens (as in case of Lambert law!)

If $N_2 > N_1$ then the ***light wave is amplified***

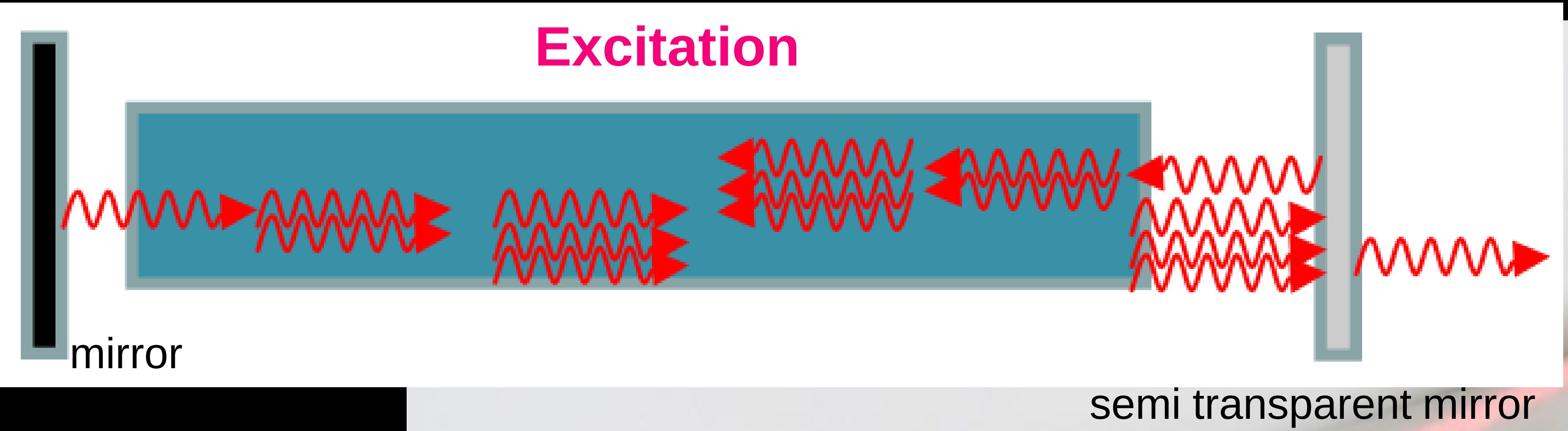
Operation of lasers

Stimulated emission + Population inversion = Amplification



Operation of lasers

Amplification +Feedback = LASER



Positive feedback is realised by the *resonator.*

Properties of laser light

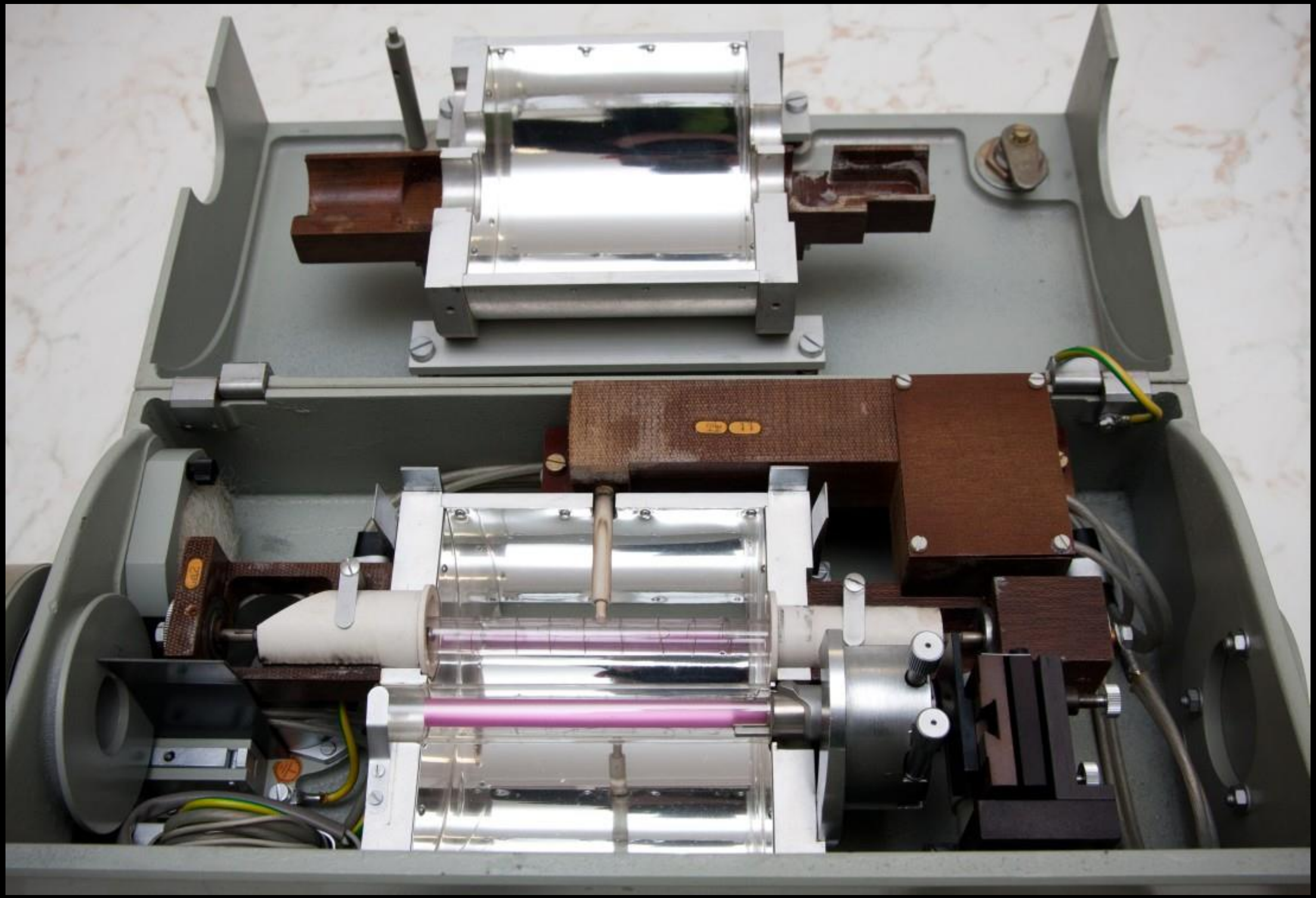
- **Wavelength:** it depends on the energy difference of the electronic transitions
- **Monochromaticity:** laser radiation consists of one single color or wavelength
- **Divergence:** the laser radiation is directional (collimated)
- **Coherence:** it characterizes the phase relation of the waves. Coherent light rays are able to produce interference
- **Energy and oputput power**: The output power is defined by several laser parameters (pumping, amplification, feedback, outcoupling)
- The laser radiation can be continuous (CW laser means Continuous Wave laser)in time or pulsed.

Lasers, power densities, pulse lengths

Laser type	Process time	Power density [W/cm^2]	wavelength
ion lasers (He-Ne, Ar+, Kr+)	ms-min	10^3-10^6	VIS
CO_2 lasers	ms-s	10^5-10^7	10,6 μm
Diode lasers	μs-s	10^3-10^6	UV-VIS-NIR
Q-switched solid state lasers	ns	10^6-10^{13}	UV-VIS-NIR
excimer lasers	ns	10^6-10^{11}	UV
Dye excimer laser	fs-ps	10^{10}-10^{14}	UV
CPA solid state lasers	fs	10^{10}-10^{17}	700-800 nm

Classification of lasers

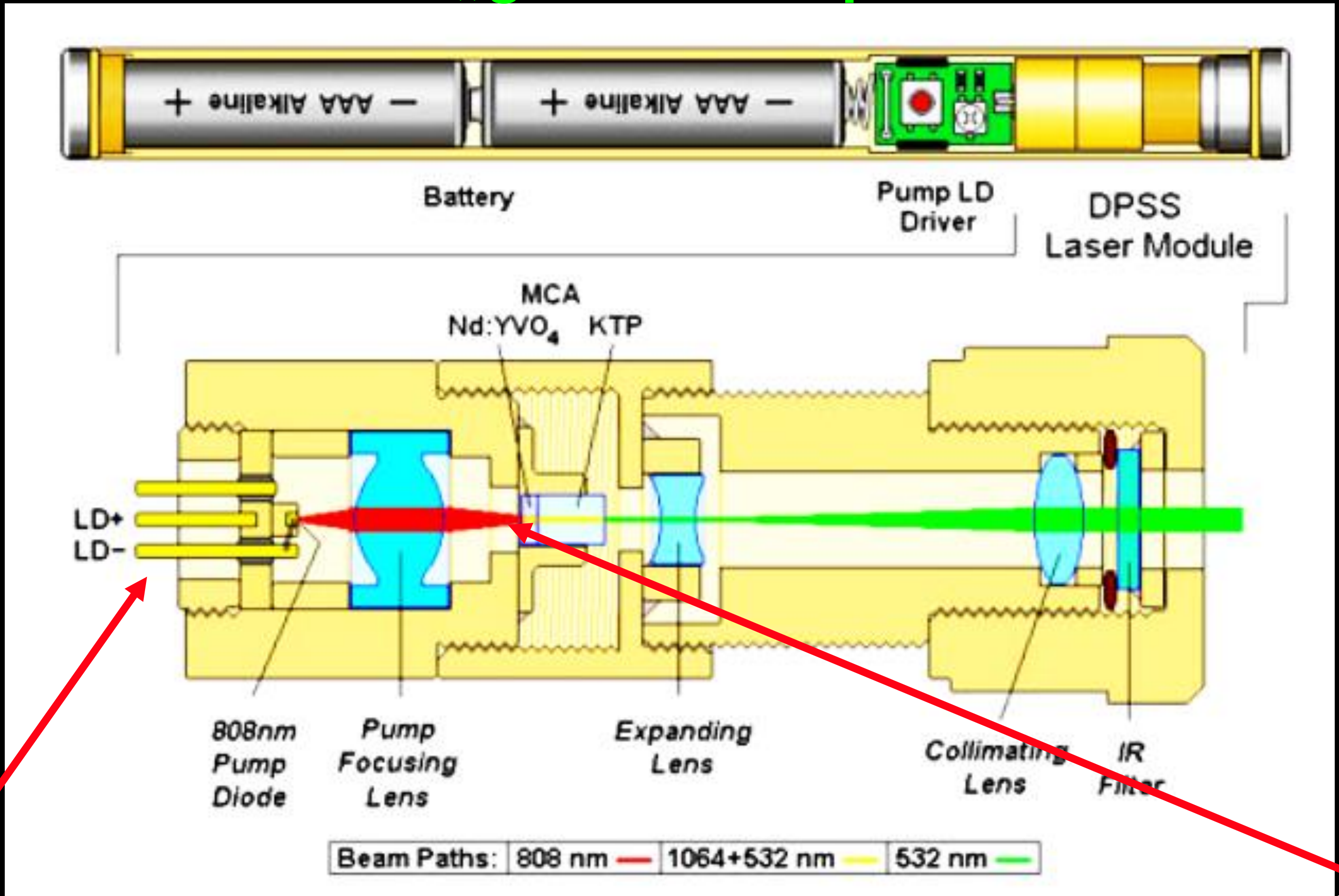
Based upon the radiation intensity high and low power lasers are distinguished. A laser is taken as a high power laser if intensity of $I=10^6$ W/cm^2 can be overcome.



Classification of lasers

According to the pumping: electric pumping, pumping with light, micro- or radio waves, chemical pumping.

„green" laserpointer



electric pumping

pumping by light

Classification of lasers

Lasers can be classified by the physical state of the active medium:

solid state- , liquid- and gas lasers.

Dye lasers

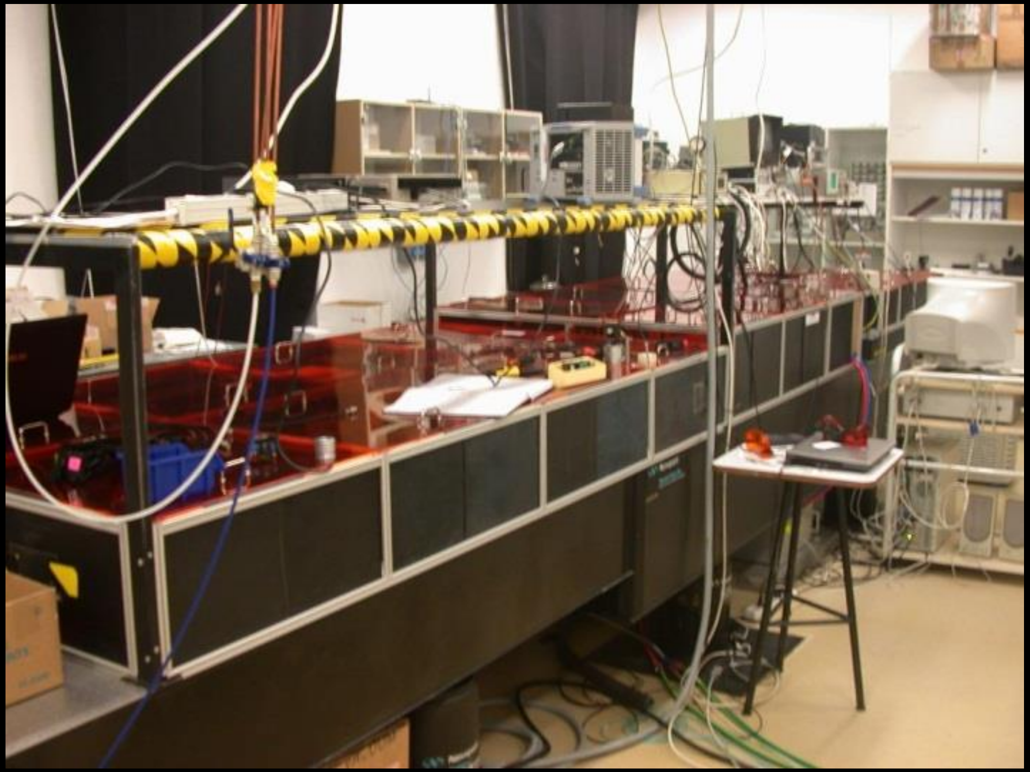
KrF excimer laser

Kr, F and He gas mixture

Classification of lasers

Lasers can be classified by the physical state of the active medium:

solid state- , liquid- and gas lasers.



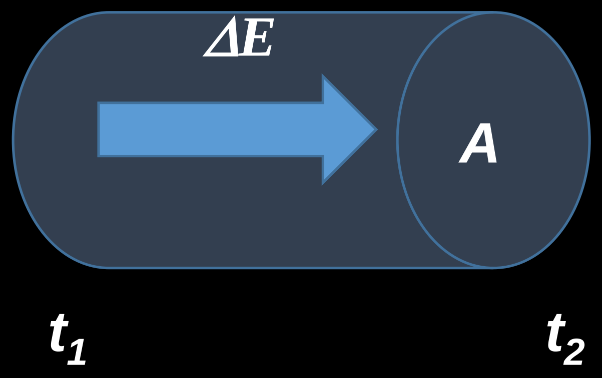
Titanium-sapphire laser system
medium: sapphire crystal

Definition of power of radiation

The quantity of energy reaching the surface during a unit time gives the current of light or power of light.

In a time interval Δt

energy in an amount of ΔE is transported through an area A



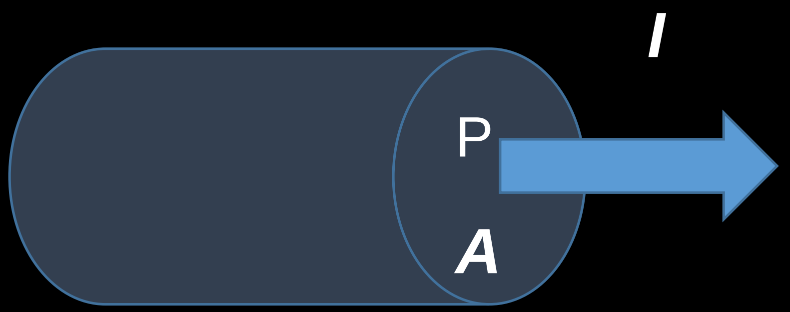
$$P = \frac{\Delta E}{\Delta t}$$

unit: J/s=W

$\Delta t = t_2 - t_1$

Intensity

The strength of phototermal, or photochemical effects depends on the *I* **intensity, or power density** of the light. This is the light power which falls to a unit area:



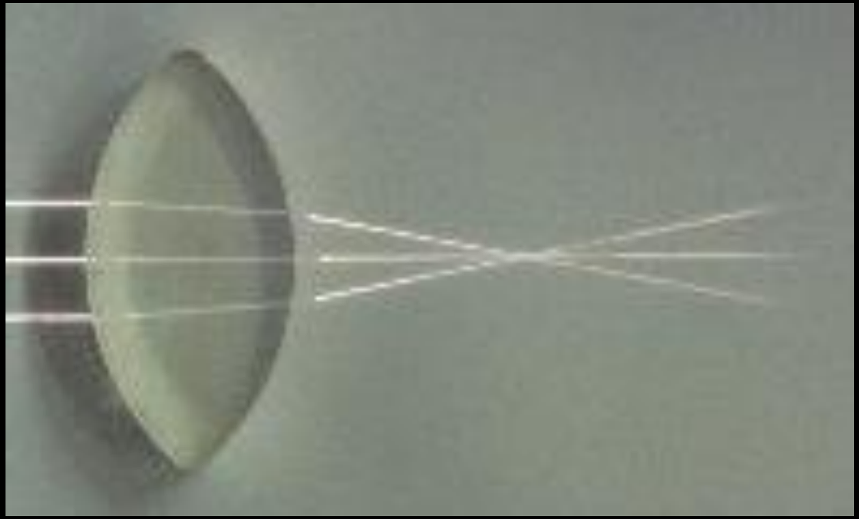
$$I = \frac{\Delta P}{\Delta A}$$

unit: W/m^2

Focusing with lenses

- Concave lens

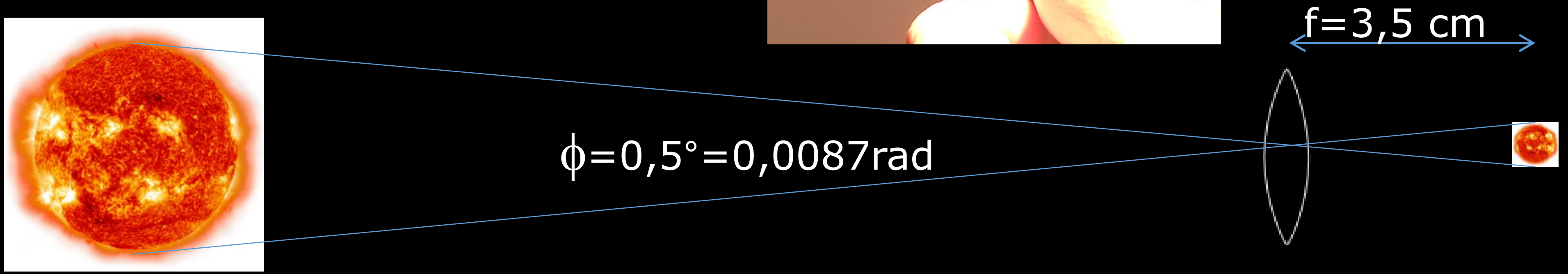
Convex lens



The intensity of the sunlight upon normal incidence is: **0.1 W/cm²**.

Example: focusing the sunlight by a lens:

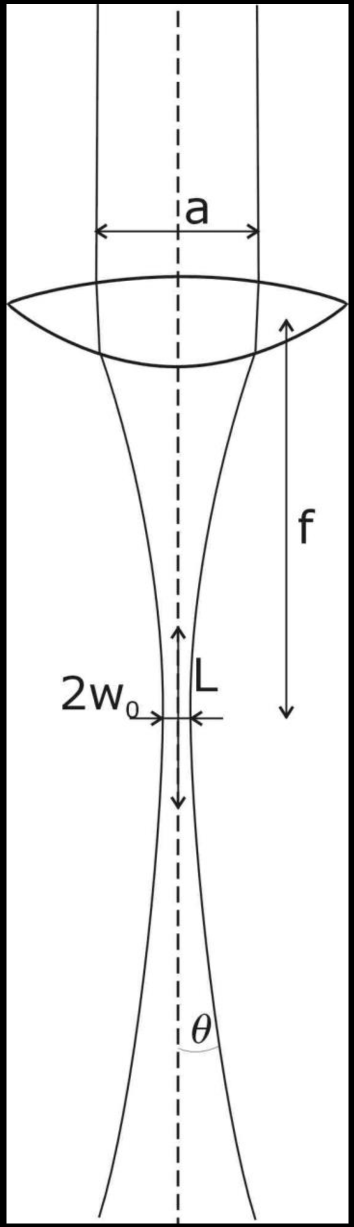
d_{lens}=3 cm, → *P*~0.7 W



f=3.5 cm → the image of the Sun is ~0.03 cm diameter circle.

$I = P/A = 0.7\ W / 0{,}015^2\ \pi\ cm^2 = 0.7\ W / 0{,}0007\ cm^2 = 1000\ W/cm^2$

What intensity can be reached by lasers?

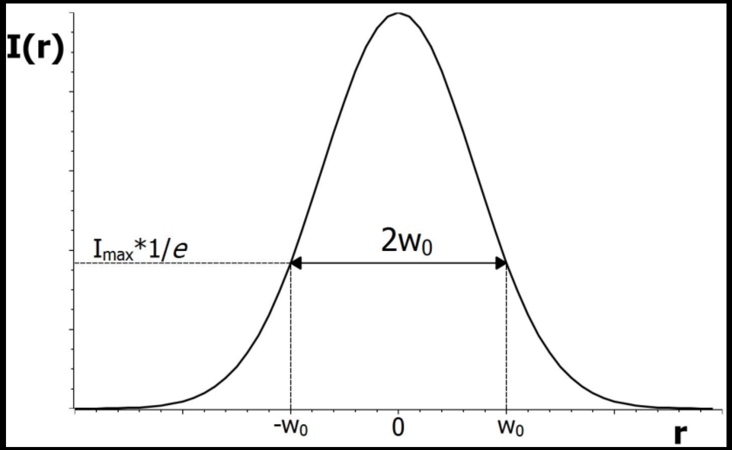


Lasers have Gaussian distribution: $I(r) = I_0 \exp\left(-\frac{r^2}{w_0^2}\right)$

I_0: central intensity

w_0: beam waist

$I(w_0) = I_0 / e \quad w_0 = \frac{f\,\lambda}{\pi\, a}$



Power of Gauss beam:

$P = 2\pi \int_0^{\infty} r I(r) dr = \pi w_0^2 I_0$, thus $I_0 = \frac{P}{\pi\, w_0^2}$

What intensity can be reached by lasers?

Example: focusing a stronger laser pointer

Laser power: P=0,15 W,

a=1 mm,

f=10 cm,

λ=532 nm.

The spot size: $$2w_0 = \frac{2f\lambda}{\pi a} \approx 34\mu m$$.

Maximum intensity: $$I_0 = \frac{P}{\pi w_0^2} \approx 16{,}5\,\mathrm{kW/cm^2}$$.

This intensity is 16.5 X of the focused sunlight!!!
The „high laser intensity" domain has even 2 orders of magnitude higher intensities.

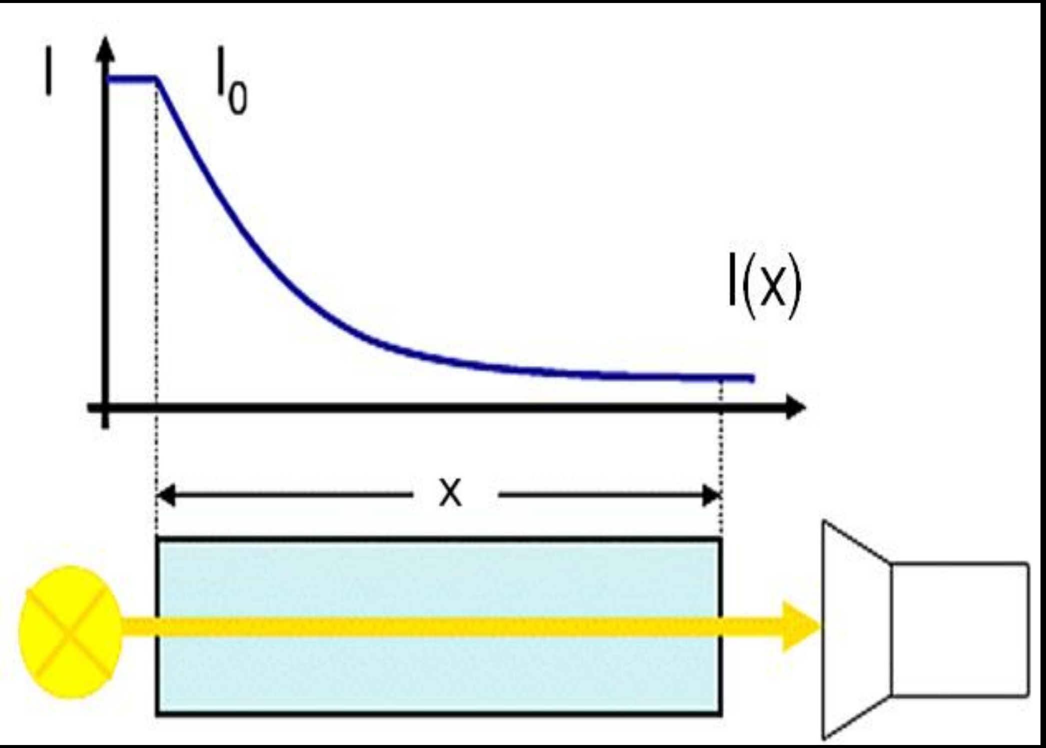
Not only intensity or energy matters: the role of absorption

Light is absorbed in the material:

Due to absorbtion the light intensity is exponentially decreasing as a function of the position.

- The *Lambert-law.*

$$I(x) = I_0 \cdot e^{-\alpha(\lambda)\cdot x}$$



Taking into account the absorption: the volumetric intensity

- To interpret laser material interaction energy density or intensity is not enough: materials behave differently to the same laser conditions.
- A parameter is needed which determines the effects of the laser pulses having different wavelength and pulse durations.
- The wavelength determines the absorption penetration depth ($1/\alpha$) therefore the heating rate and the temperature of the surface region.
- The characteristics of the different laser treatments can be described by introducing the volumetric intensity, which takes into account the different absorption coefficient values at different laser wavelengths.

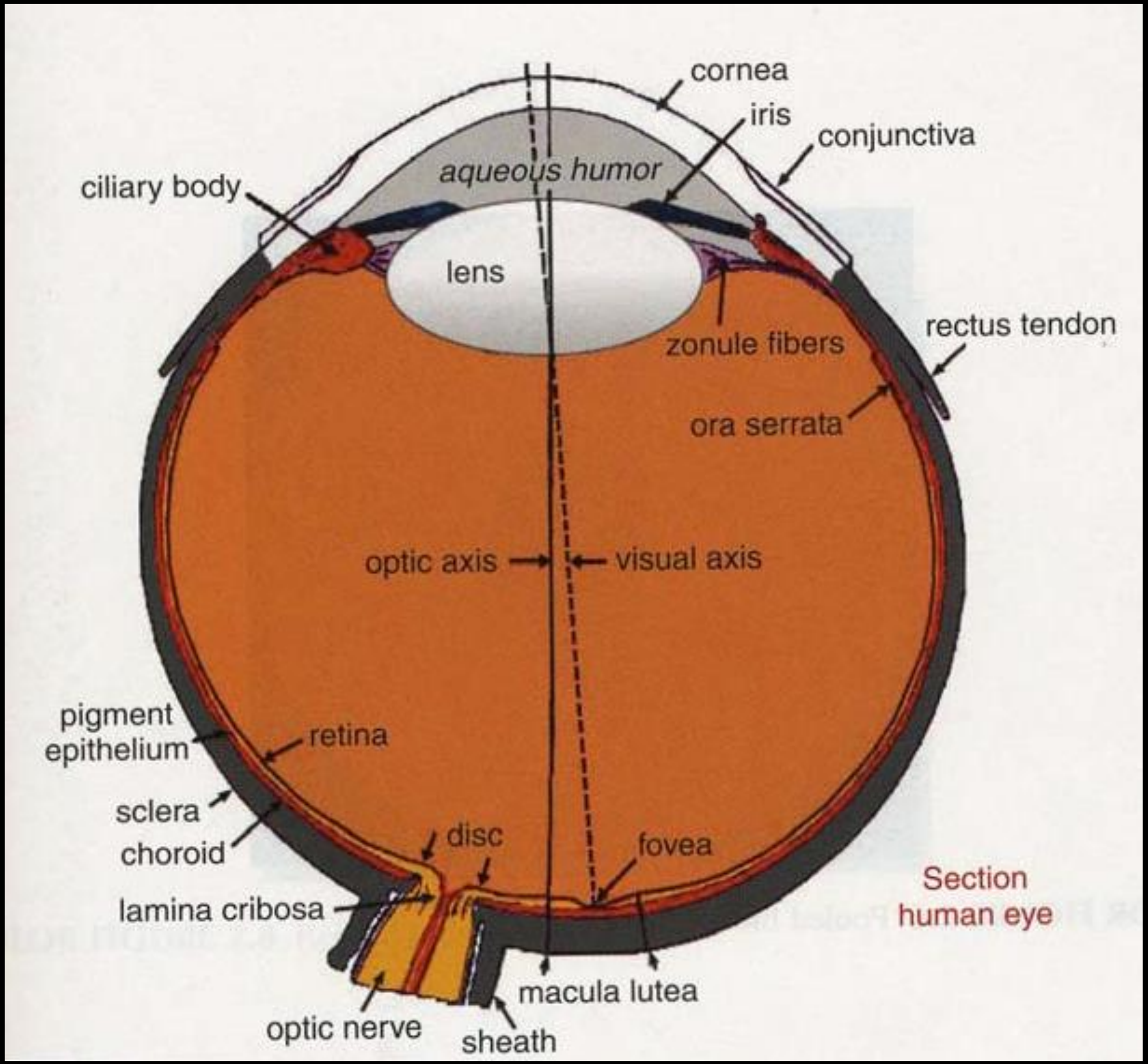
$$I_{vol} = \alpha(\lambda) \cdot I$$

- When calculating an average effect, it describes the intensity value absorbed in a unit volume near to the surface:

$$I_{vol} = \frac{E}{A\,t} \cdot \frac{1}{1/\alpha}$$

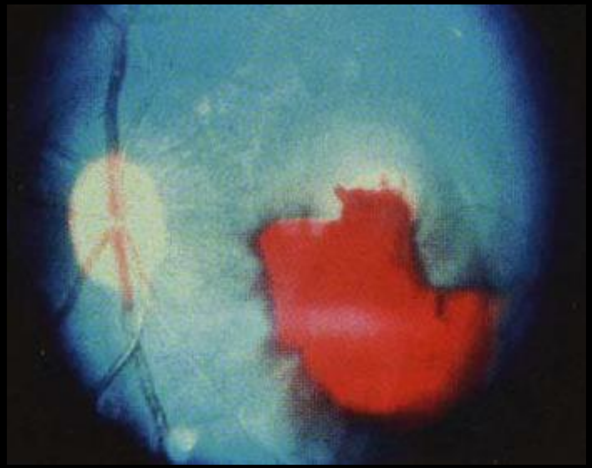
Laser safety

- Cornea, lens, and retina are susceptible to damage by laser light.
- Parallel laser light is focused by the lens onto the retina!
- The eye in essence intensifies light intensity, particularly the visible and the near-infrared wavelengths, in some cases as much as 100,000 times.

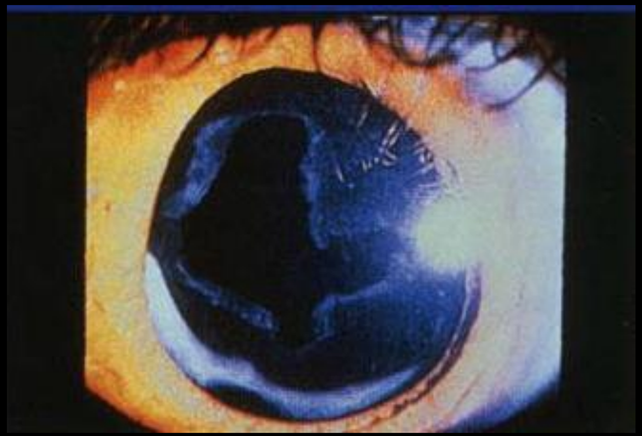


Eye injury by laser light

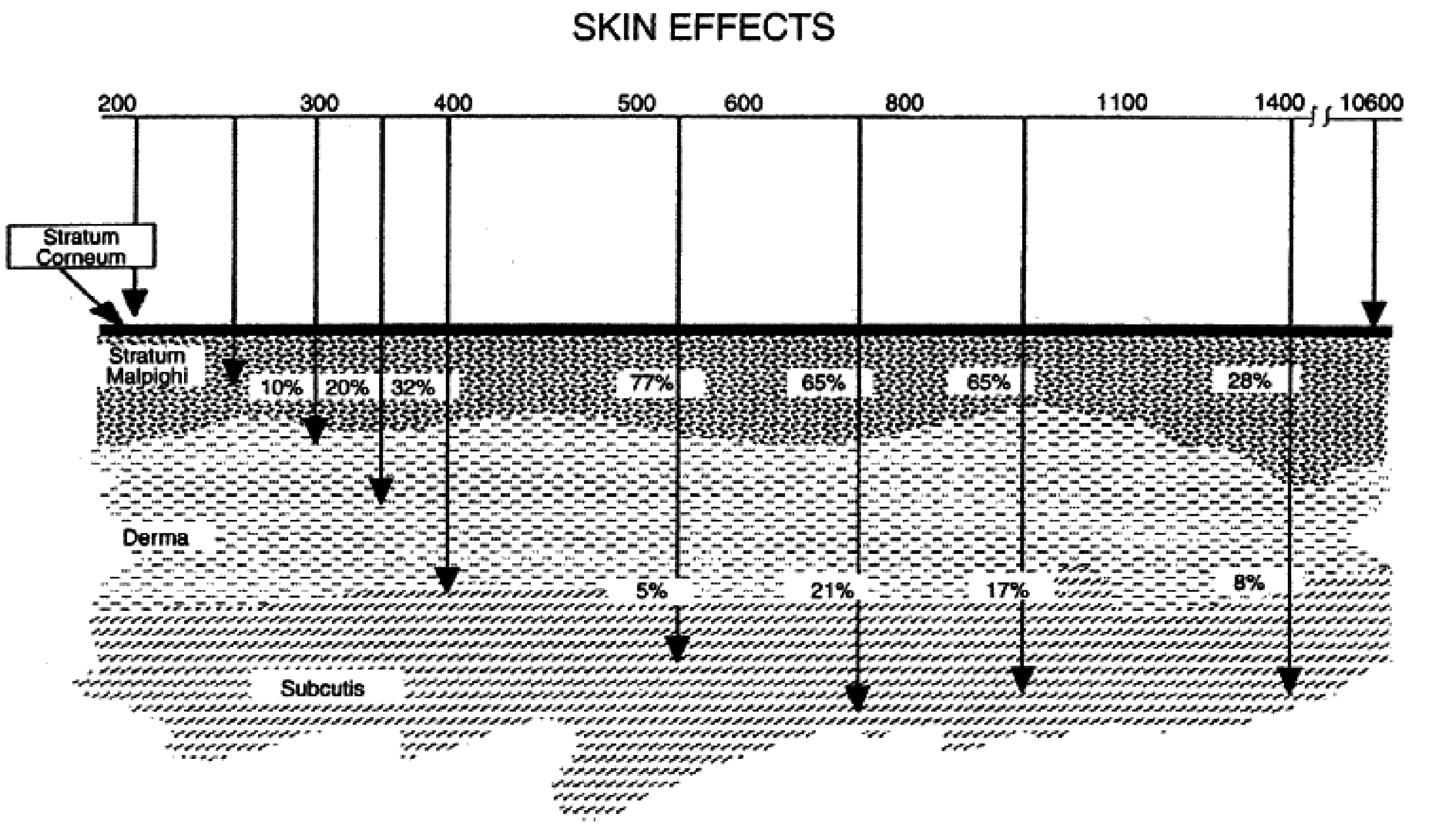
- **Symptoms of Exposure:** If the eye has been damaged by laser light the first symptoms can be a bright flash of light (if a visible wavelength) followed by watering of the eye, headache, and **floaters**.
- Floaters are actually dead cells that have detached from the retina and choroid.



- If the cornea has been damaged there will be a sensation of grittiness, as if sand were in the eye. In some cases there may be immediate pain at the site of exposure.



Skin transmission by wavelength

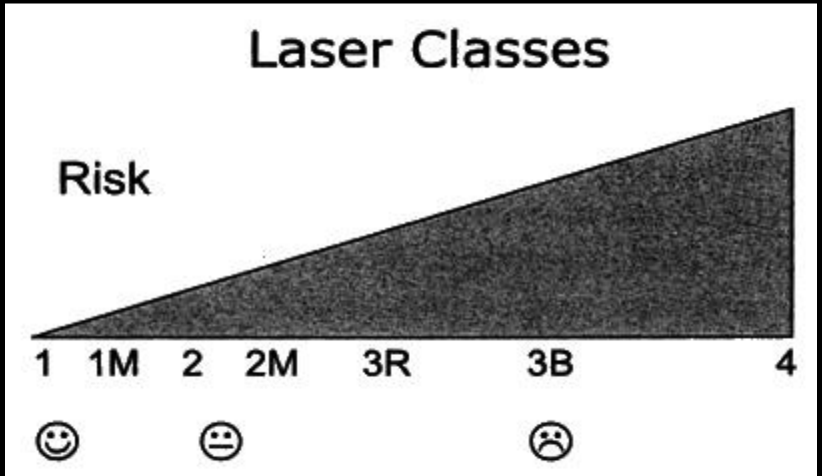


Hazards caused by various light wavelengths

Wavelength Range	Effect on Eye	Effect on Skin
Ultraviolet C 200–280 nm	Photokeratitis	Erthema (sunburn) Skin cancer Accelerated skin aging
Ultraviolet B 280–315 nm	Photokeratitis	Increased pigmentation
Ultraviolet A 315–400 nm	Photochemical cataract	Pigment darkening Skin burn
Visible 400–700 nm	Photochemical Thermal retinal injury	Pigment darkening Skin burn
Near-infrared 700–1,400 nm	Cataract and retinal burn	Skin burn
Mid-infrared 1,400–3,000 nm	Corneal burn Aqueous flare, cataract	Skin burn
Far-infrared 3,000–100,000 nm	Corneal burn	Skin burn

Laser hazard classification

Class	Basis for Classification
Class 1: Safe Visible and nonvisible	Lasers that are safe under reasonably foreseeable conditions of operation; generally a product that contains a higher-class laser system but access to the beam is controlled by engineering means.
Class 2: Low power Visible only	For CW lasers, protection of the eyes is normally provided by the natural aversion response, including the blink reflex, which takes approximately 0.25 sec. (These lasers are not *intrinsically* safe.) AEL = 1 mW for a CW laser.
Class 1M: Safe without viewing aids 302.5 to 4000 nm	Safe under reasonably foreseeable conditions of operation. Beams are either highly divergent or collimated but with a large diameter. May be hazardous if user employs optics within the beam.
Class 2M: Safe without viewing aids Visible only	Protection of the eyes is normally provided by the natural aversion response, including the blink reflex, which takes approximately 0.25 sec. Beams are either highly divergent or collimated but with a large diameter. May be hazardous if user employs optics within the beam.
Class 3R: Low and medium power 302.5 nm to 1 mm	Risk of injury is greater than for the lower classes but not as high as for class 3B. Up to 5 times the AEL for class 1 or class 2.
Class 3B: Medium and high power Visible and nonvisible	Direct intrabeam viewing of these devices is always hazardous. Viewing diffuse reflections is normally safe provided the eye is no closer than 13 cm from the diffusing surface and the exposure duration is less than 10 sec. AEL = 500 mW for a CW laser
Class 4: High power Visible and nonvisible	Direct intrabeam viewing is hazardous. Specular and diffuse reflections are hazardous. Eye, skin and fire hazard. Treat class 4 lasers with caution.



How to protect?

- Take seriously the labels:

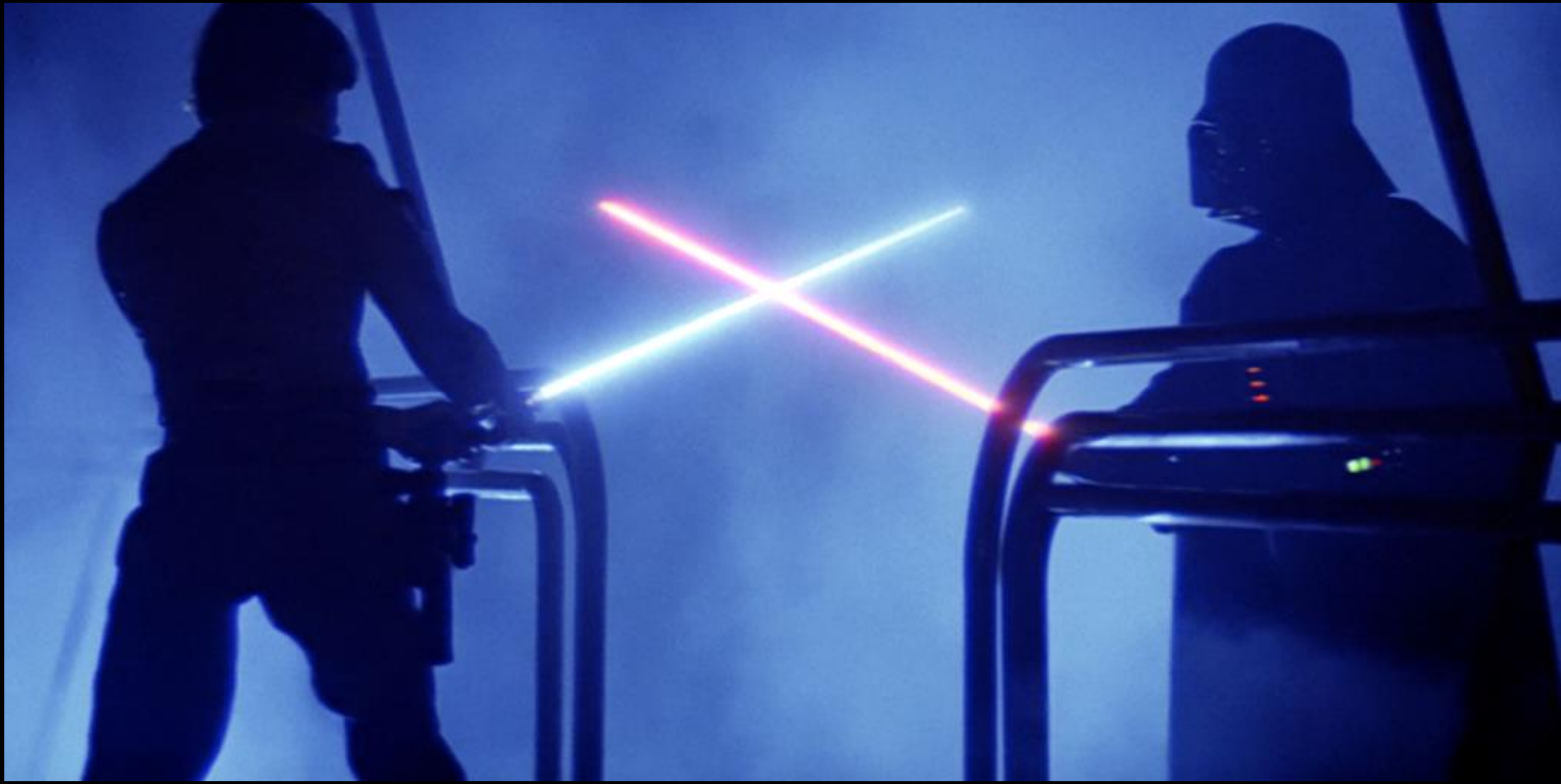
How to protect?

- Do not look to laser light directly!
- Use the appropriate protecting glasses for your patient and YOURSELF!

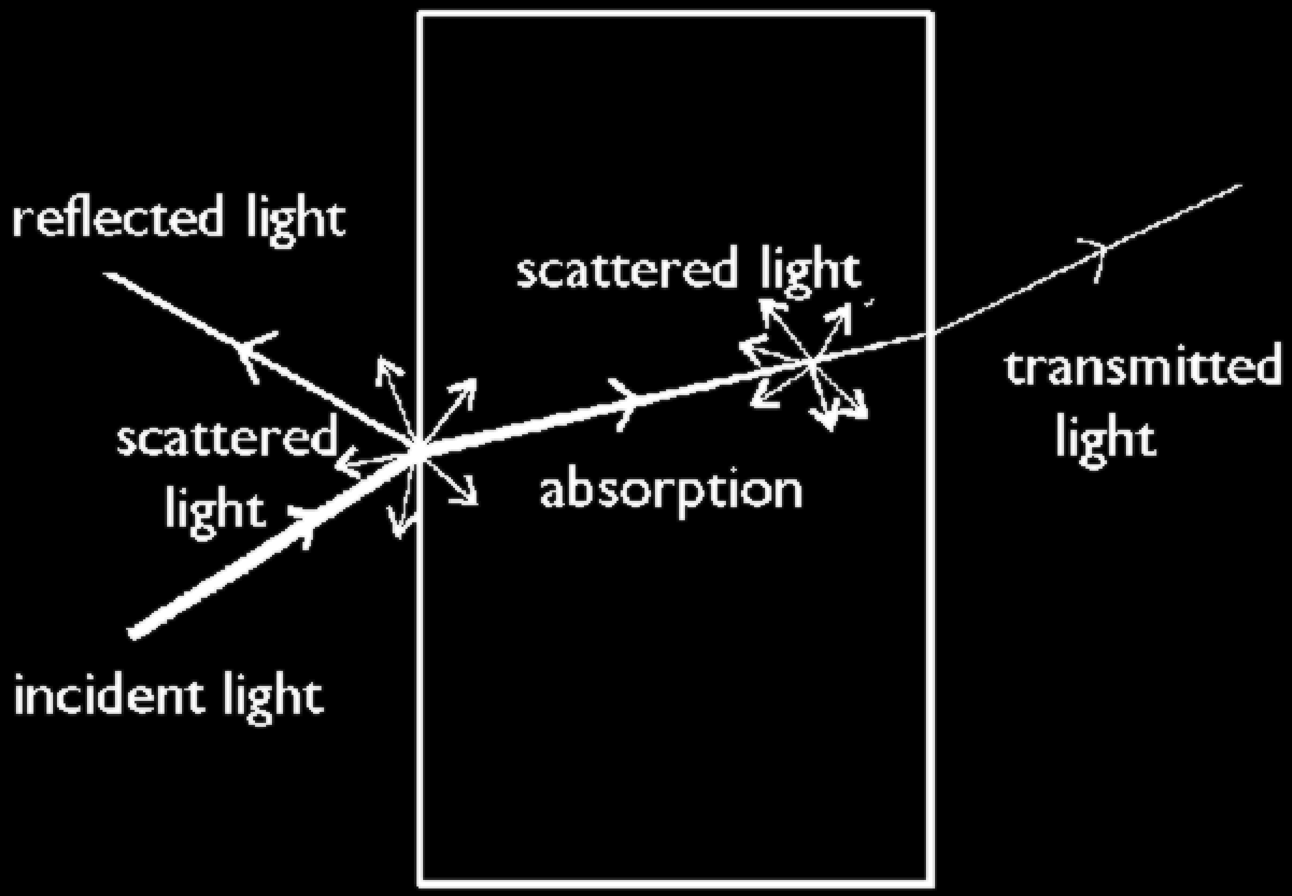
How to protect?

- Cover the skin with clothes, use protecting glass:

Who is better protected?



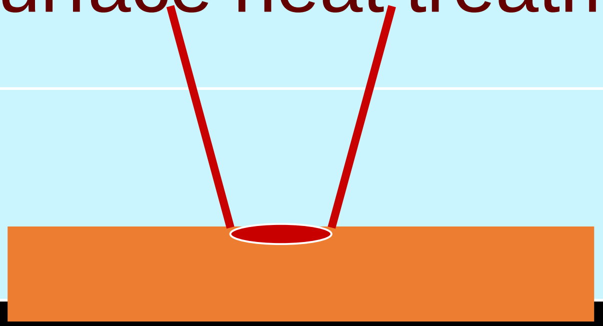
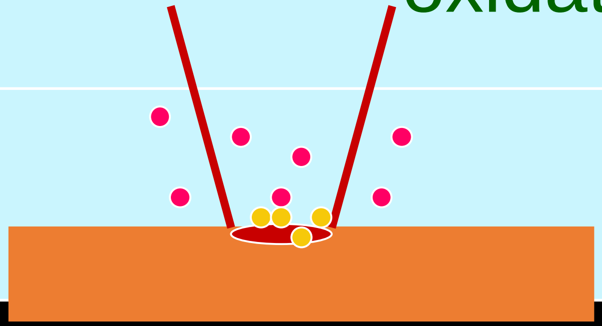
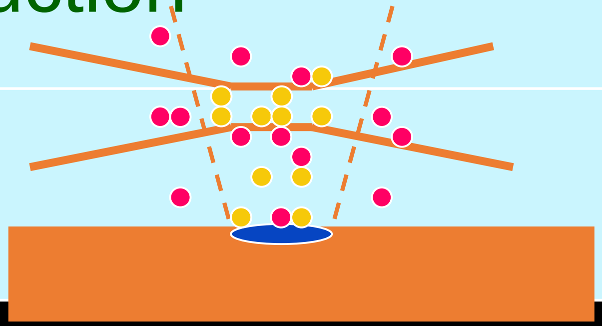
Laser (dental) material interactions



Material processing by lasers

Physical (phase changes)	Chemical: thermal / photolytic
plasma formation (layer deposition, fusion...)	reactive plasma chemistry
evaporation, (engraving, drilling)	etching
melting (soldering,welding, crystallization, alloying)	material synthesis
surface heat treatment	oxidation, reduction

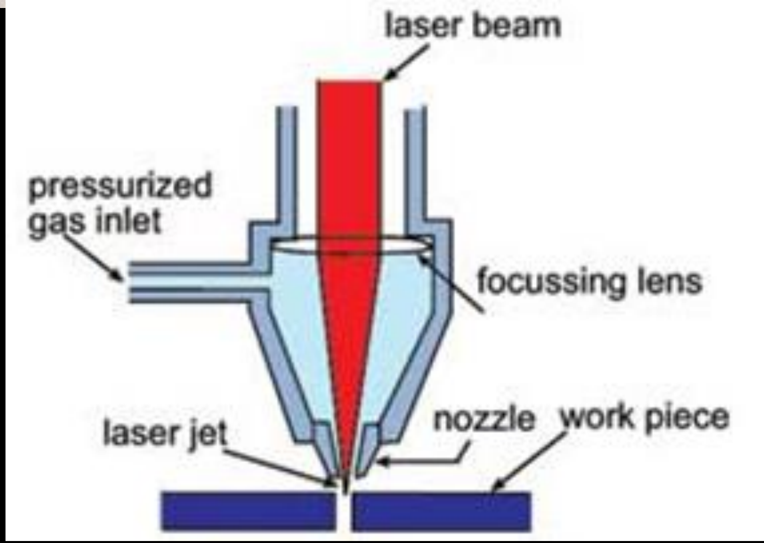
intensity ↑

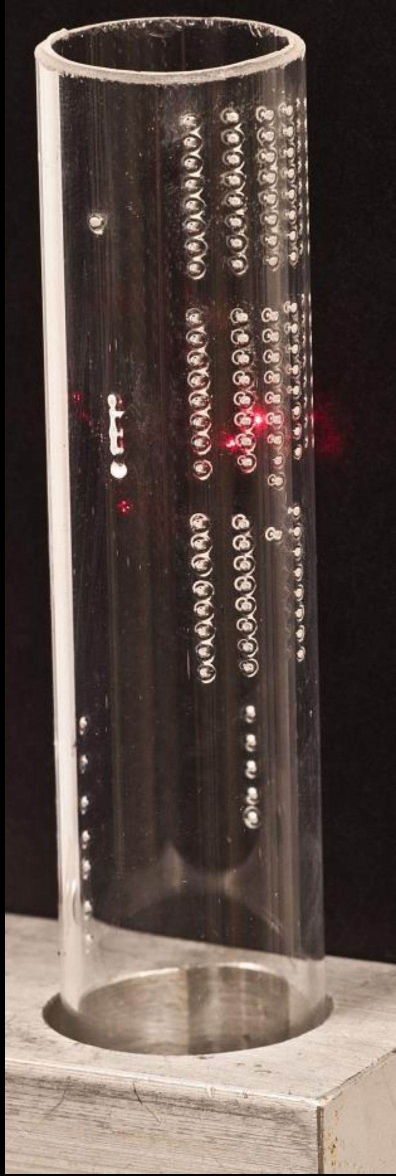
Material processing by lasers

By increasing the energy of a laser high intensity can be reached. The kW power CO_2 lasers drill or cut plates, e.g. steel plates of some cm thickness.

$$J = \frac{E}{A\,t}$$



Laser cutting

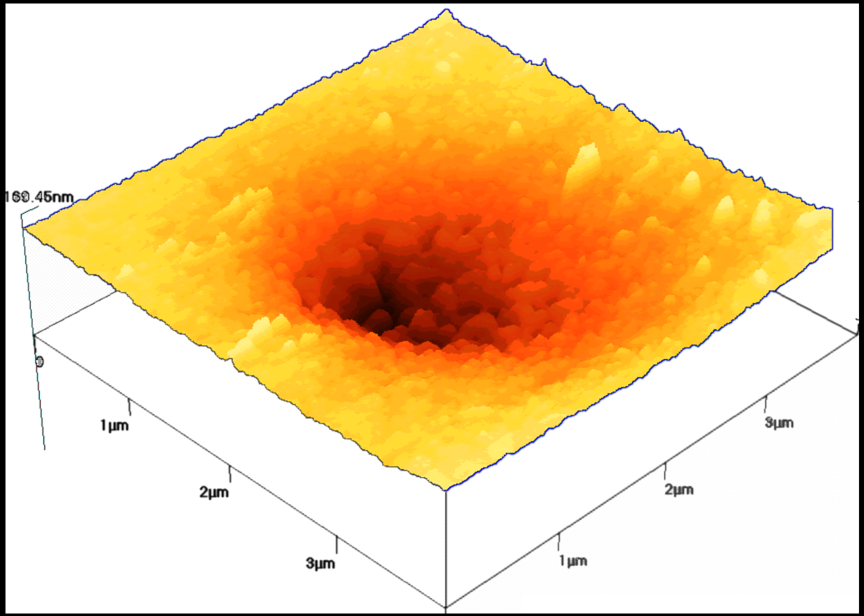


Holes drilled by CO_2 laser (wavelength: 10,6 μm) into a glass tube

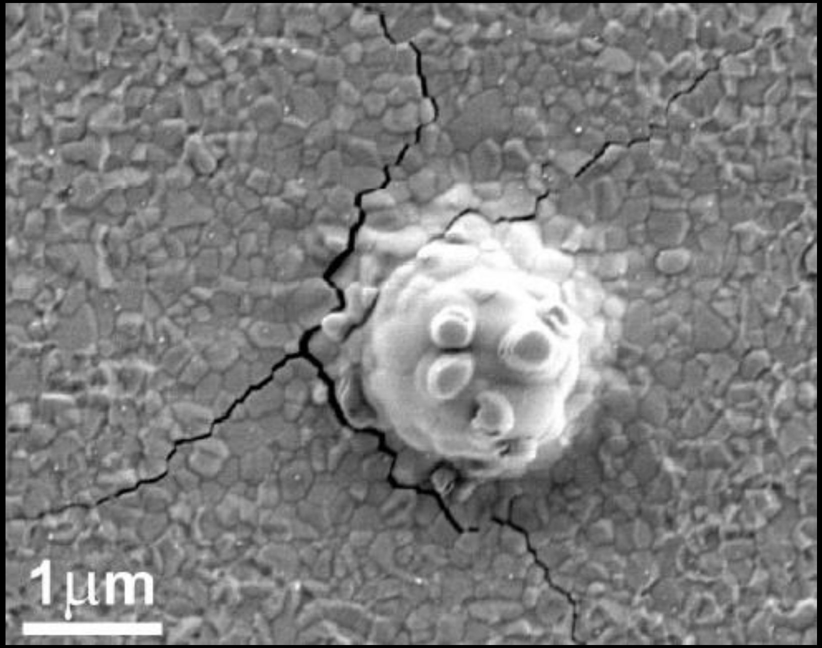
Material processing by lasers

$$J = \frac{E}{A\,t}$$

Decreasing the irradiated surface laser micromachining is possible.



CW Ar^+ ion laser light (wavelength: 512 nm) was focused onto a tungsten layer. AFM image shows the hole, which was drilled into the tungsten layer



Scanning electron microscope image from laser induced chemical deposition of a tungsten dot.

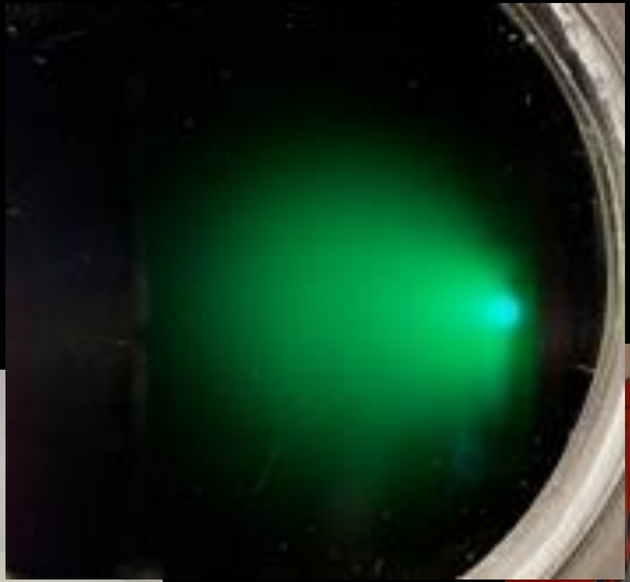
$WF_6 + 3H_2 \rightarrow W + 6HF$

Material processing by lasers

$$J = \frac{E}{A\,t}$$

By decreasing the duration of the laser pulses (into a nano-, pico-, femto-, and soon attosecond regime) ultrahigh laser intensity can be reached, which is capable to form plasma on surfaces

Plasma formed on a text by the infrared pulse of a Nd:YAG laser (wavelength 1064 nm)



Ultraviolet pulses from KrF excimer laser (wavelength 248 nm) can easily form plasma in vacuum. Target: copper

Laser processing of biological materials

- production of high energy particles,
  - hadron therapy
- drilling of teeth
- evaporation of hard tissues
- evaporation of soft tissues
  - laser surgery
- coagulation
- selective heat treatment
  - local heating of tumors
  - treatment of skin deseases (e.g. psoriasis)
  - treatment of allergic reactions of mucosa
- wound healing

Plasma formation
- generation of shock waves
- plasmachemical reactions

Evaporation
- drilling
- cutting

High temperature treatment

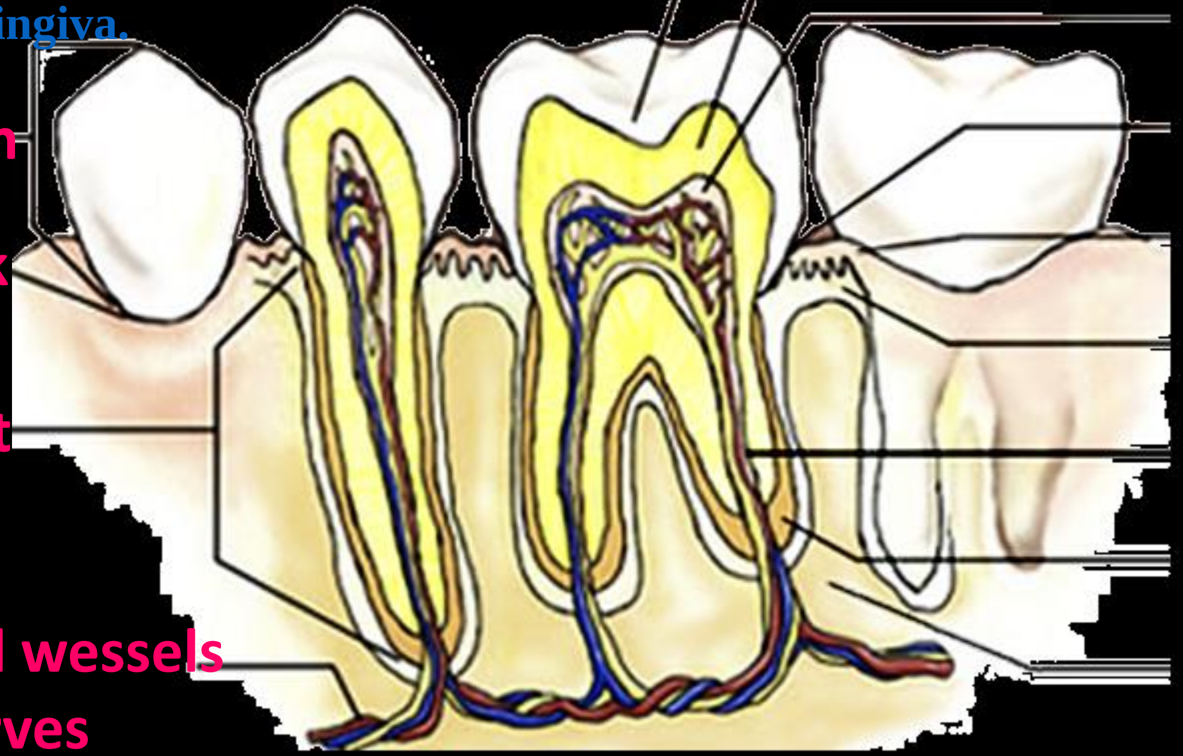
Heat treatment

- Stimulation without significant heating

$$I = \frac{E}{A\ t}$$

Teeth and their structure

In general only the crown of the tooth is visible above the gingiva.



Each tooth has 3 mineralized portions:

Enamel / substantia Adamantina

98% inorganic components
(Calcium phosphate)
2% organic material
(soluble and insoluble proteins)
The enamel is made of enamel-prisms and is cell-free!

Dentin / substantia eburnea

70% inorganic components
(primarily calcium and phosphate
in the form of hydroxyapatite crystals).
20% organic matrix
90% of them - Type I collagen,
10% proteoglycans).

10% water

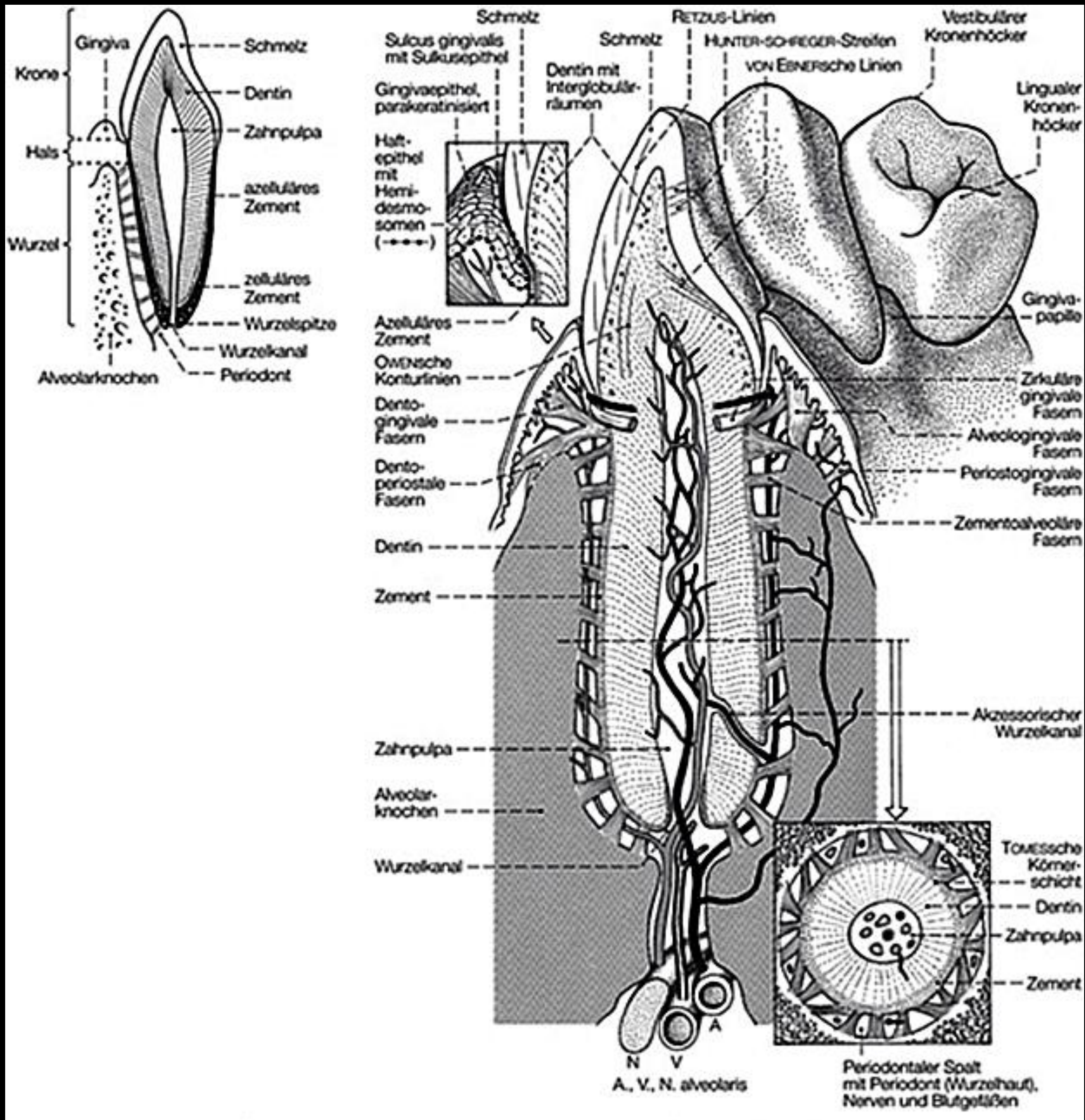
Cement / substantia ossea

Covers the dentin of the root;

Formed by the cementoblasts; they are already surrounded by the matrix - cementocytes;

50% inorganic material - amorphous calcium phosphate, hydroxyapatite crystals;

50% organic material: collagen fibers;



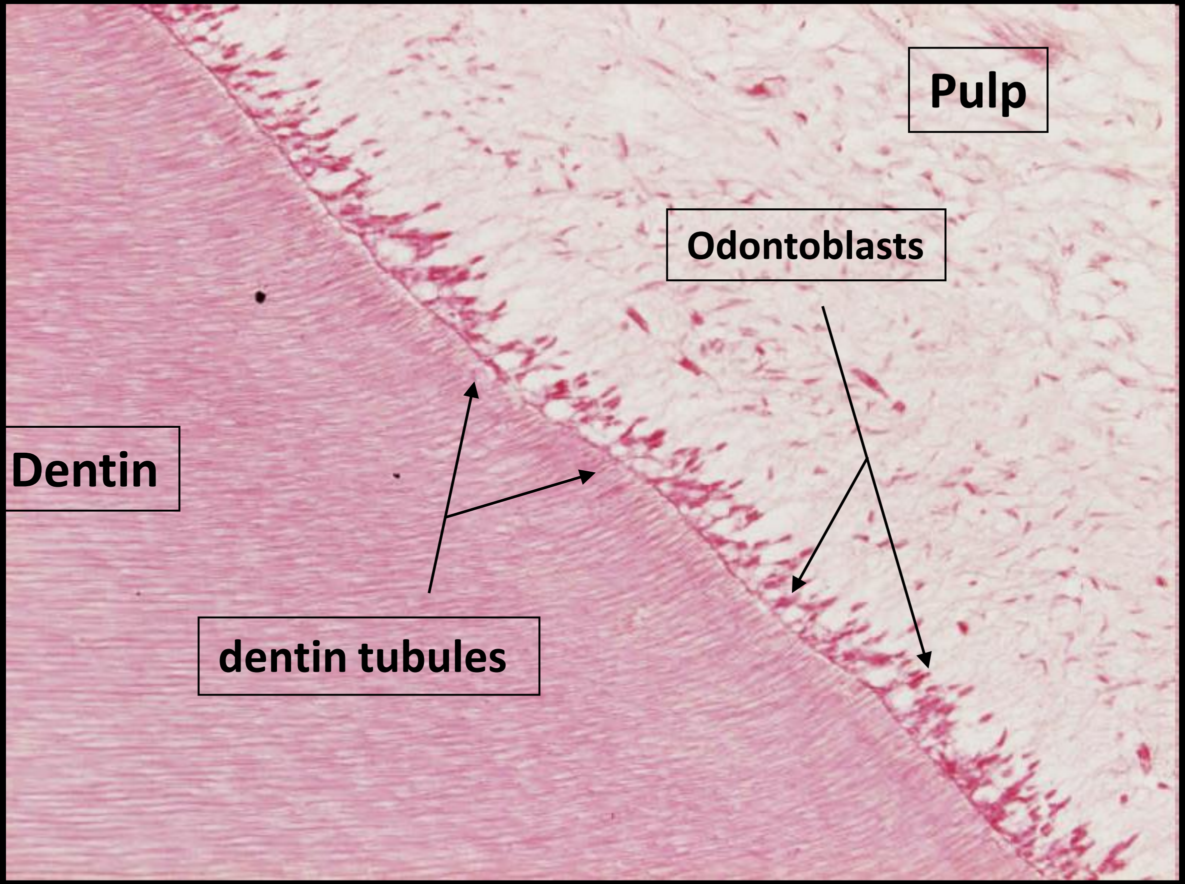
Benninghoff / Drenckhahn: Anatomie 1, 17.A. © Elsevier GmbH. www.studentconsult.de

Dental pulp

Loose connective tissue rich in blood vessels and nerves.

The dentin producing cells: odontoblasts

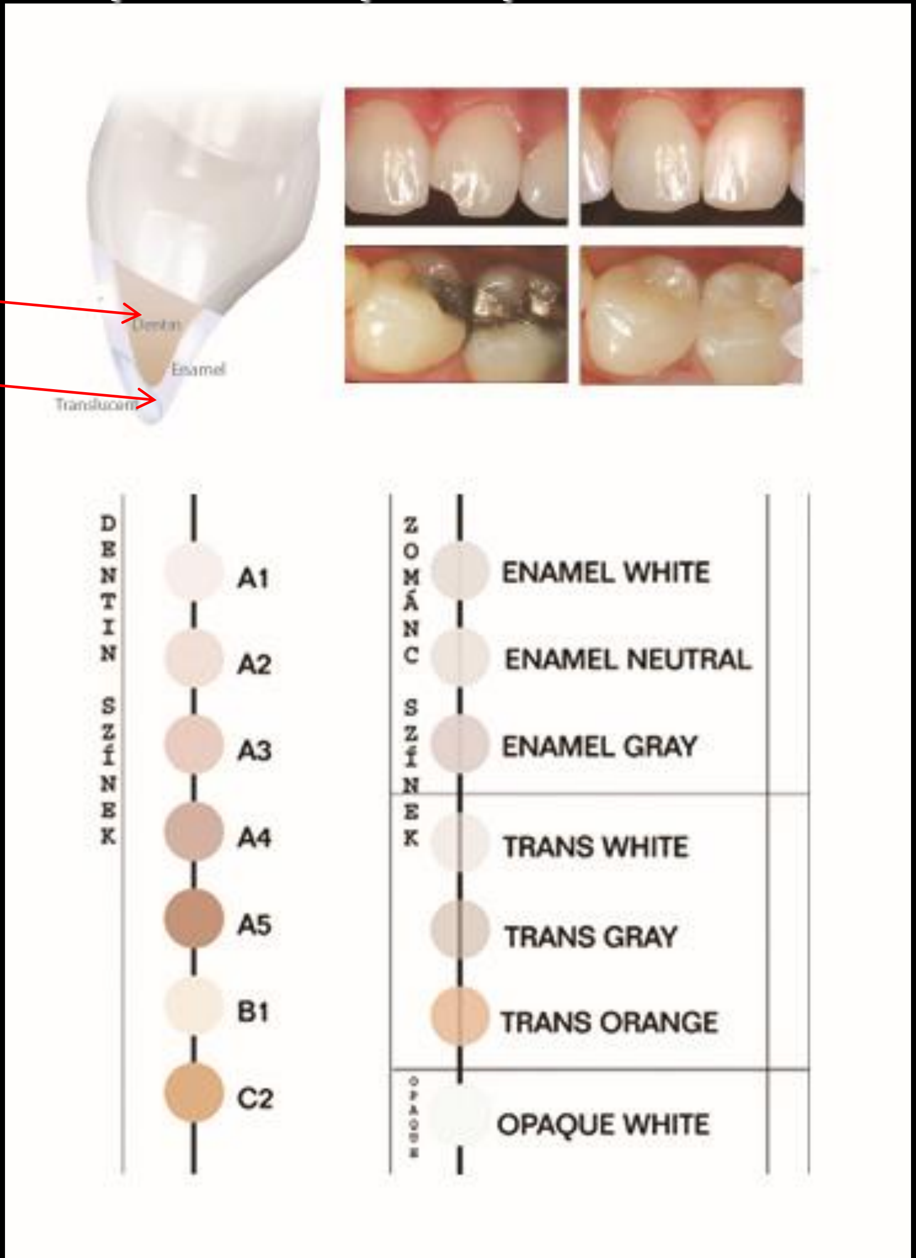
The Tomes fibers of the odontoblasts run into the dentinal tubules.



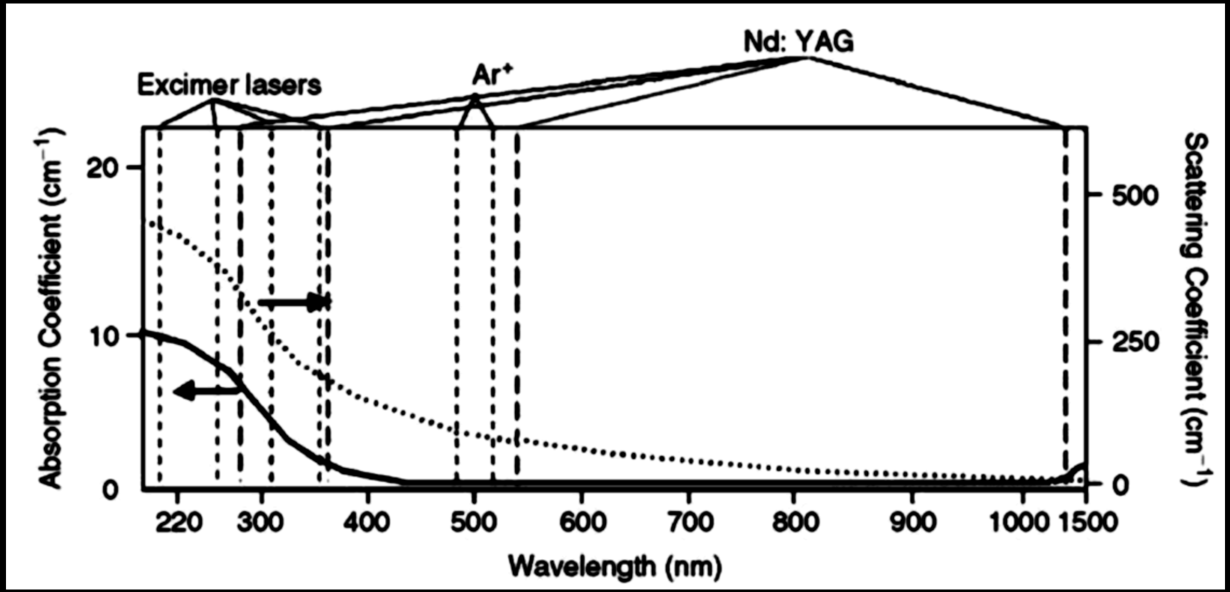
Optical properties: color of teeth

opac

translucent

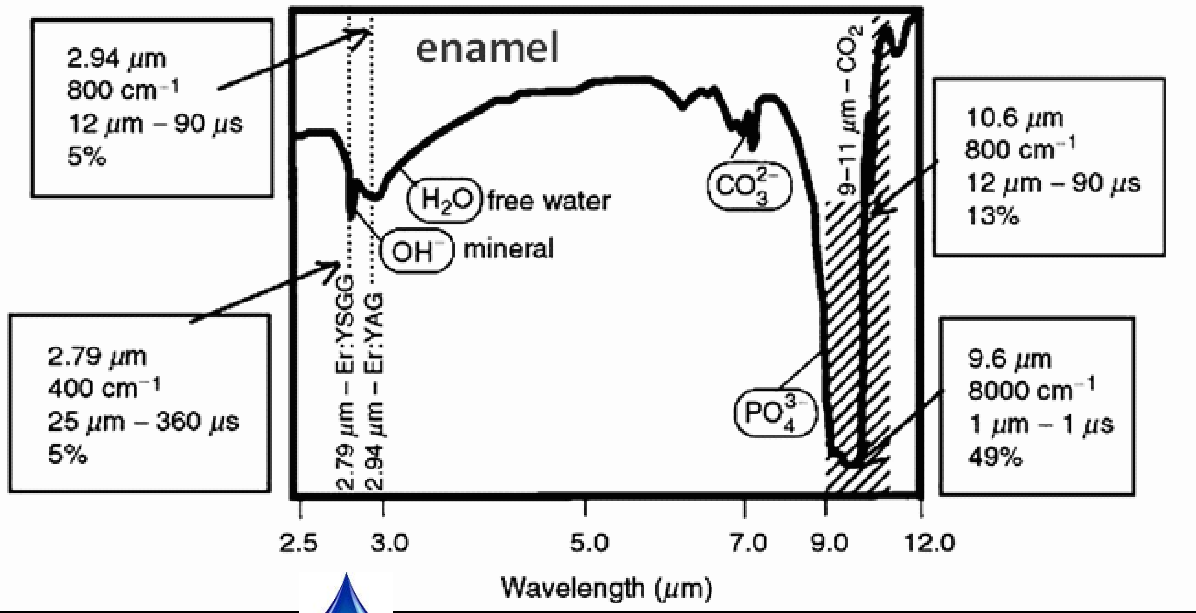


Optical properties: transmission, absorption

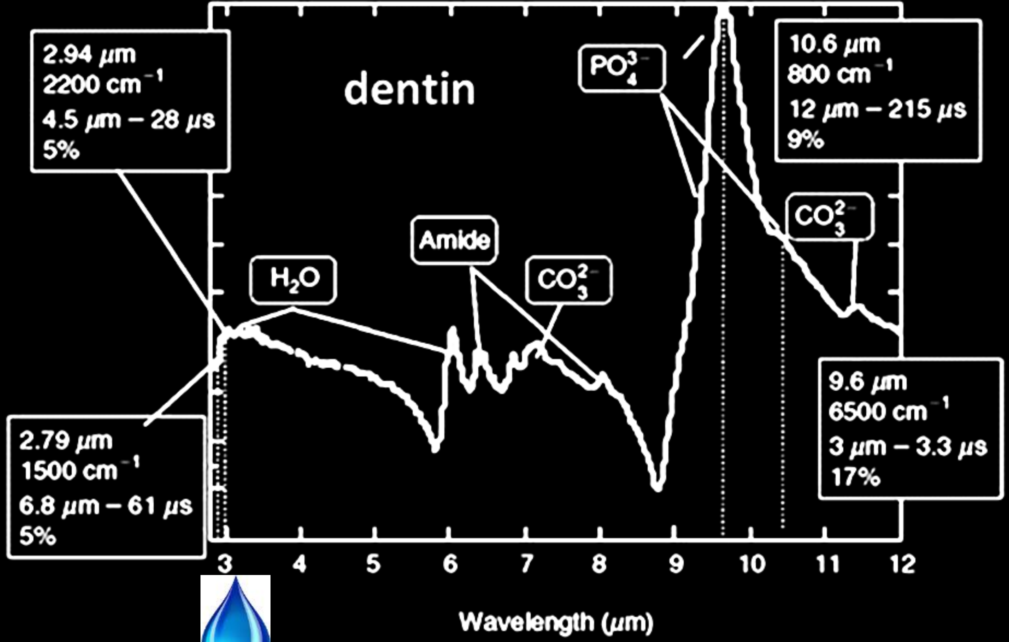


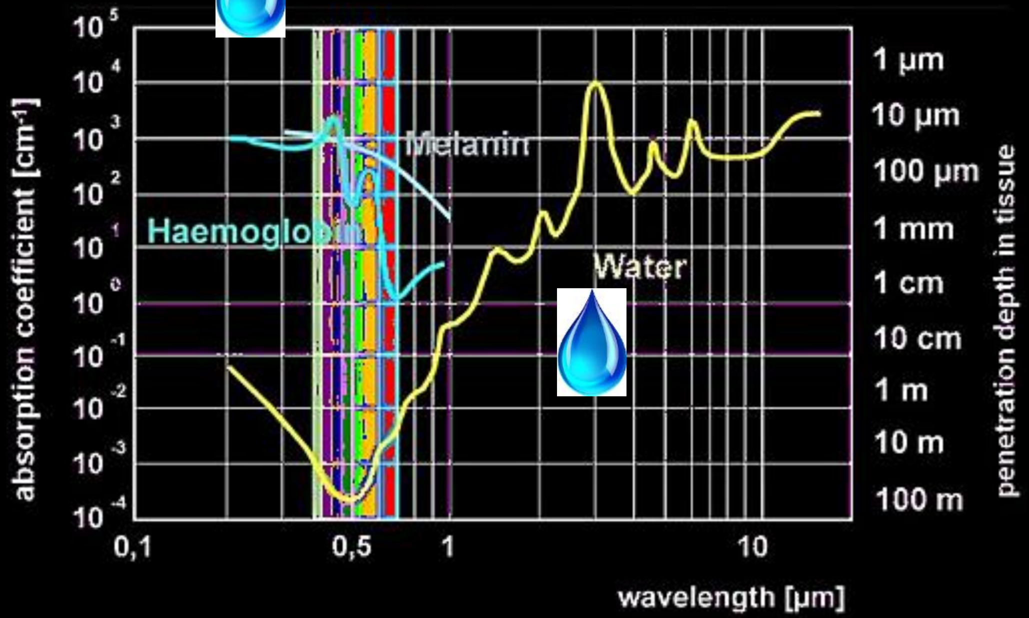
absorption spectrum of enamel in the VIS range

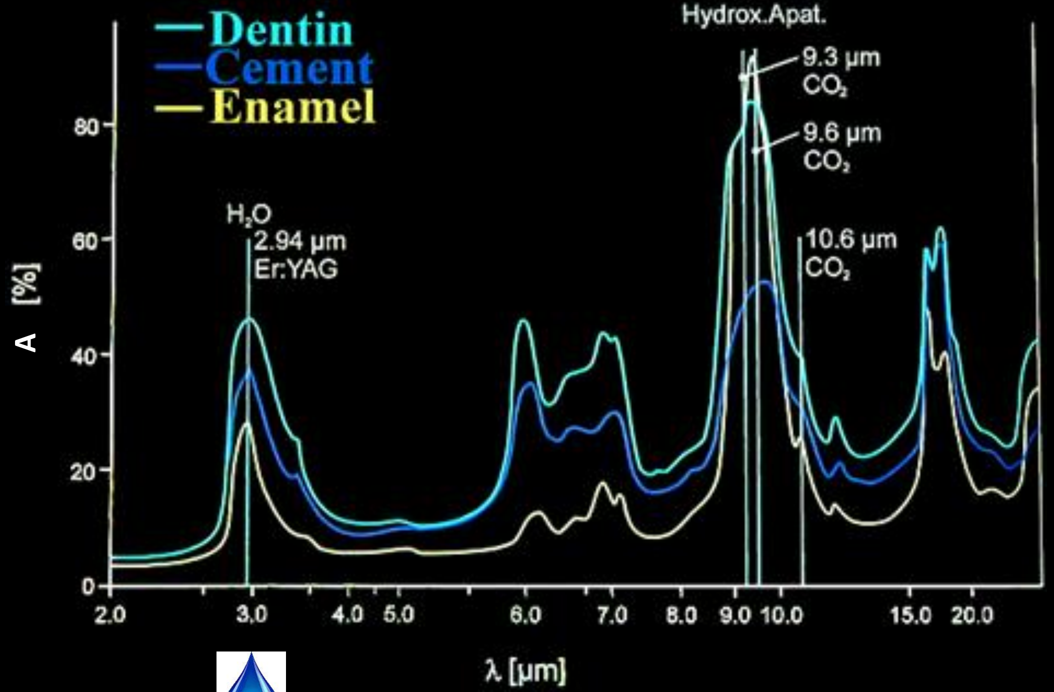
transmission spectra of enamel in the IR



Optical properties: absorption spectra







Laser applications in dentistry

prevention

- treatment of sensitivity by closing tubules
- supplementing fluoride treatment
- preventing tooth decay (UV light germicidal effect)

diagnosis

- caries detection by photoluminescence

therapy

- teeth whitening by oxidative processes (promoting lower drug concentrations, shorter treatment time and higher sufficiency)
- tooth drilling
- root Canal Treatment
- fillings removal
- treatment of oral and periodontal diseases
- laser surgery
- photodynamic therapy
- soft laser therapy: stimulation of wound healing and periodontitis
- and many more...

Oral surgery with CO2 laser

Tooth whitening

- The teeth is treated by with a hydrogen peroxide- or other oxidizing material

- Then illuminated with light from a laser.

- Due to light enhanced reaction the material penetrates deeper into the enamel, even reaching the dentin.

- The treated teeth will also receive a fluoride brushing, so that the tooth enamel becomes more resistant to subsequent wear

- The process can take up to 1 hour

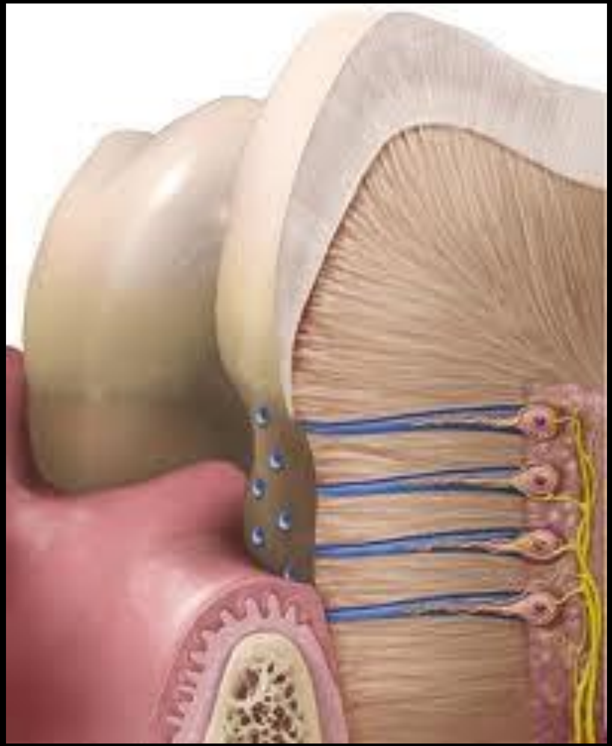
Tooth whitening

Tooth whitening

- Durability 1-2 years
- The bleaching results in 8-12 shades in the color of the teeth

Dentin hypersensitivity treatment

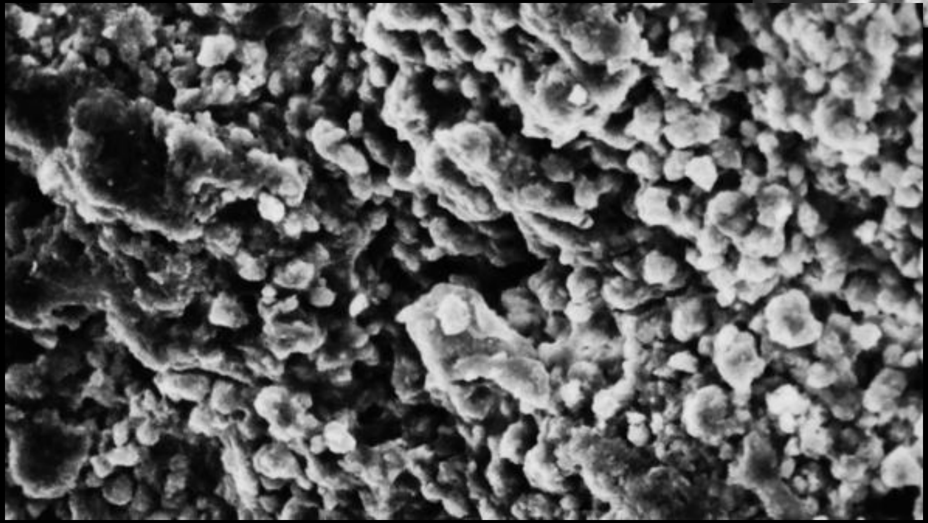
The main cause of DH is gingival recession with exposure of root surfaces, loss of the cementum layer. Through open dentinal tubules hydrodynamic flow can be increased by cold, air pressure, drying, sugar, sour, or forces acting onto the tooth.



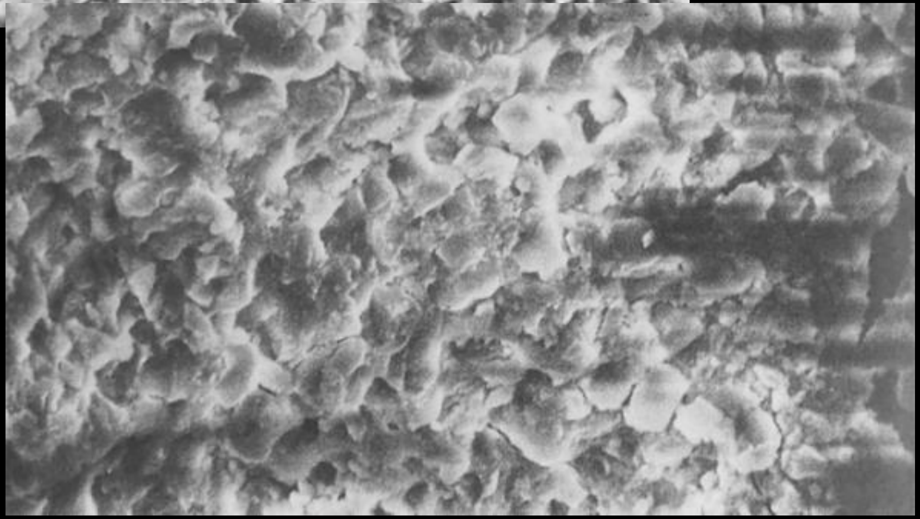
Through open dentinal tubules bacteria can attack the inner pulp, causing inflammation, pain, and dying the pulp.

Dentin hypersensitivity treatment

Open dentinal tubules:



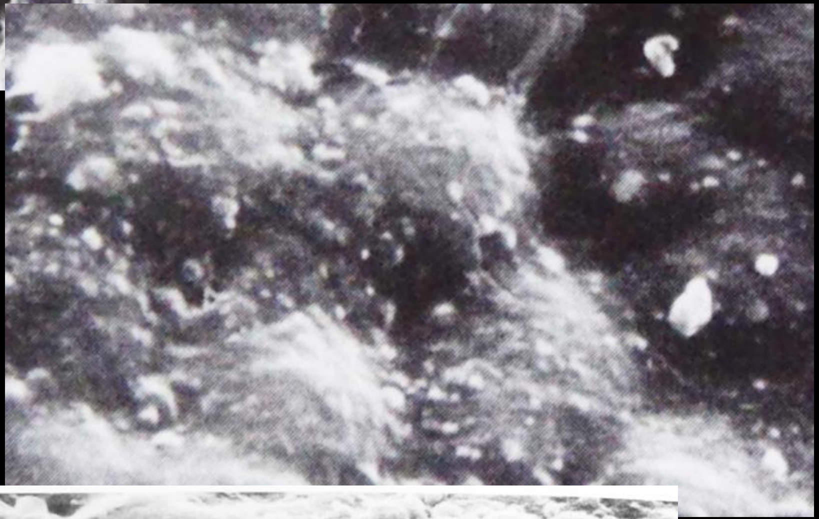
Open dentinal tubules are treated by
0.5 W Nd:YAG laser



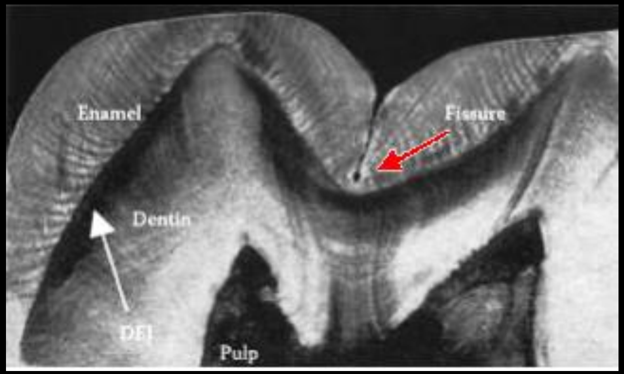
0.5 W Nd:YAG laser and fluoride gel

Dentin hypersensitivity treatment

Open dentinal tubules are treated by cw CO_2 laser and fluoride gel



Fissure sealing – the classic way




Fissures on occlusal surface of molar.


Cleaning with pumice paste.


Etching


Etched occlusal surface.


Application of sealant

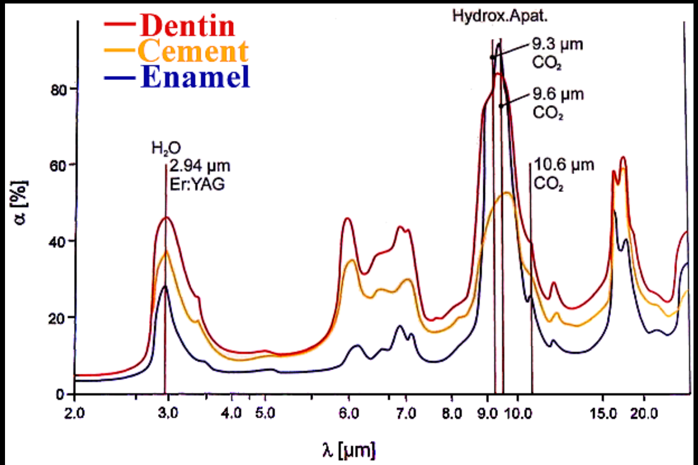

Application of sealant with a microapplicator brush

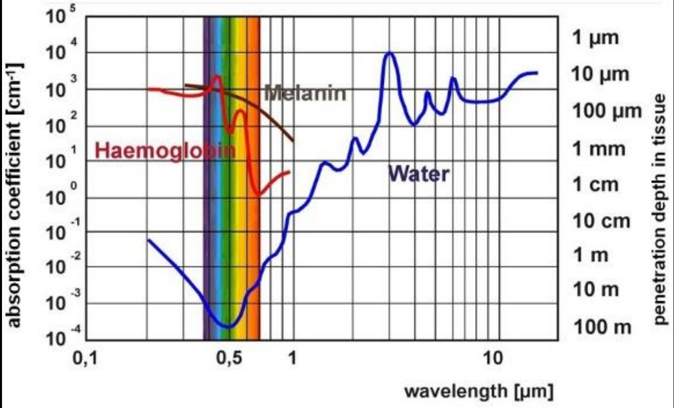

Light curing


Sealant after light curing.

ida.cdeworld.com/courses/4618-Sealants_to_Prevent_Pit_and_Fissure_Occlusal_Caries

Extended fissure sealing

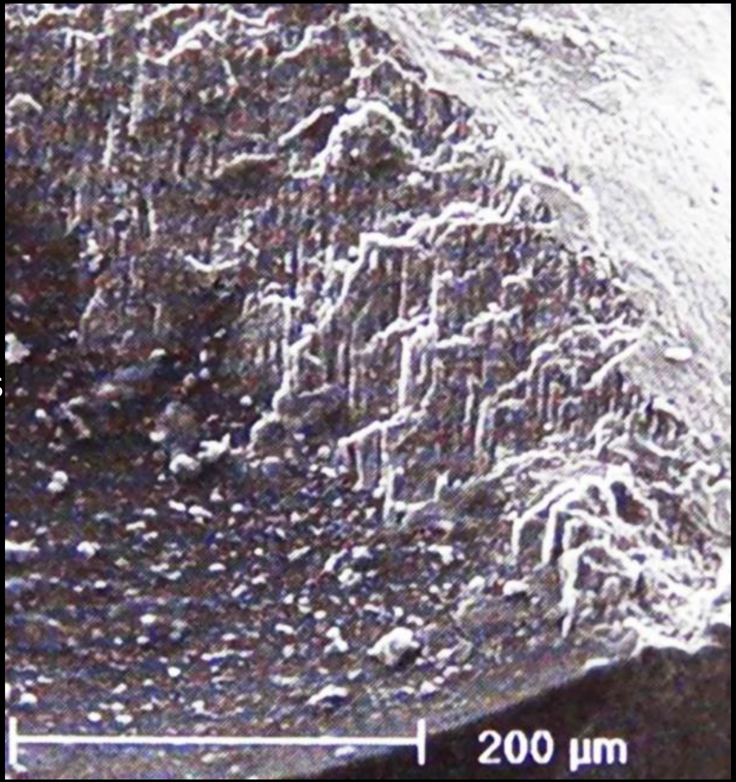




selective removal of water containing contanimations

Er:YAG laser treated fissures

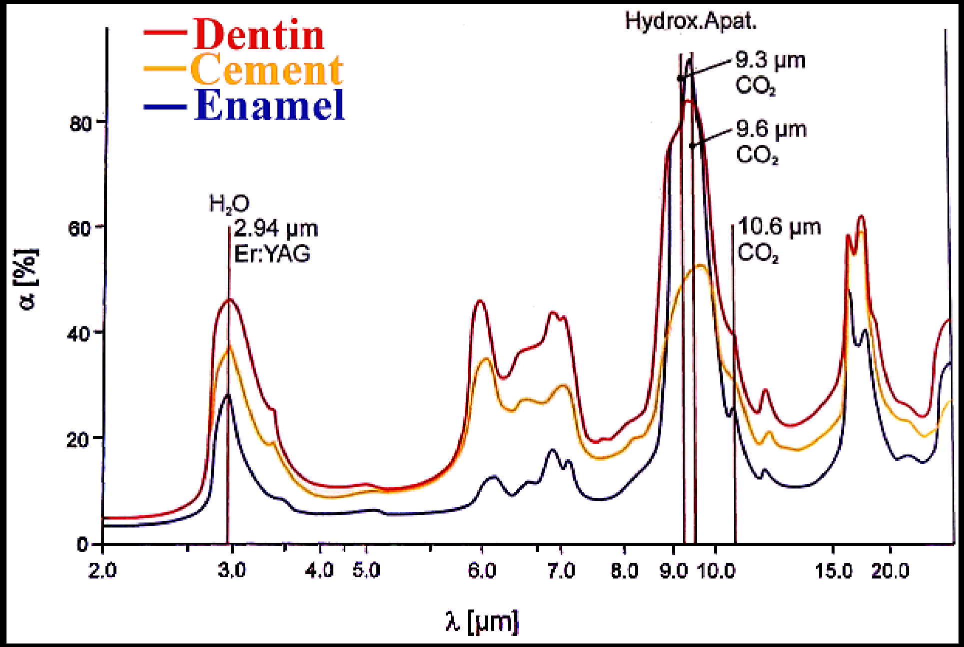
Sealed fissures

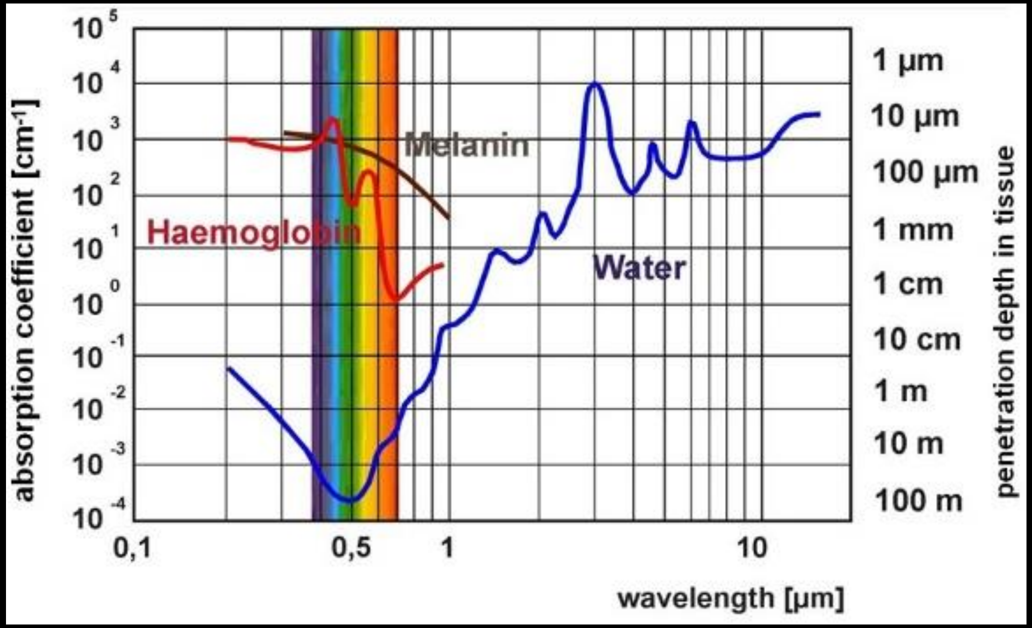


- Roughening of enamel
  - it is applied to elicite acidic roughening.

Cavity preparation

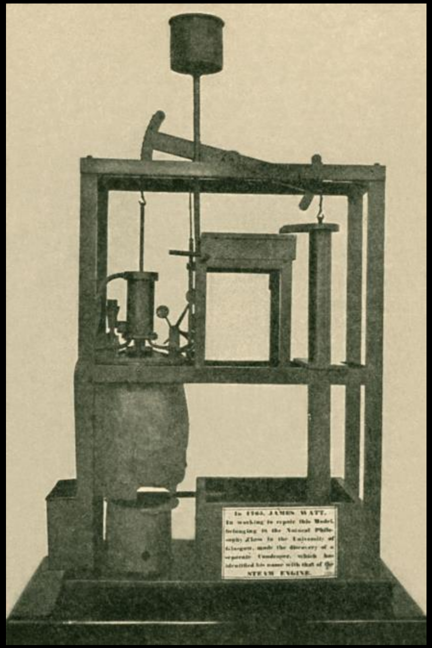
Dental applications





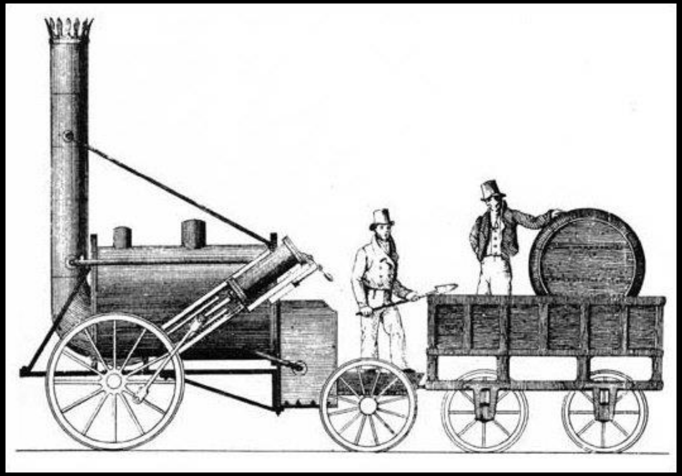
Cavity preparation

Some historic points of steam power applications:

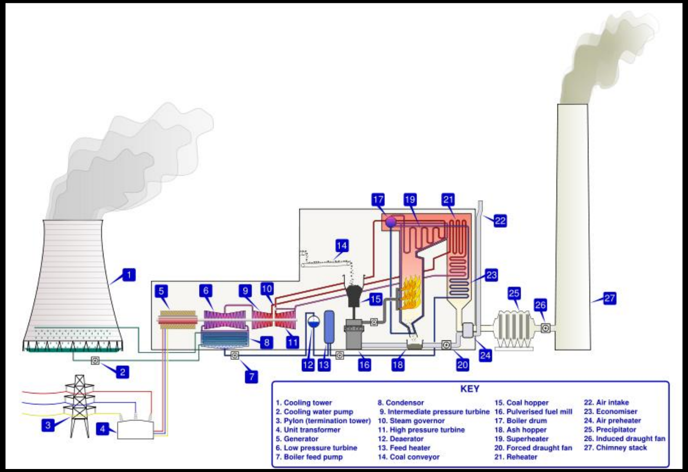


James Watt used this model (1764) to test his separat condensor, inventing the *modern* steam engine

1793, Fulton proposed plans for steam-powered vessels

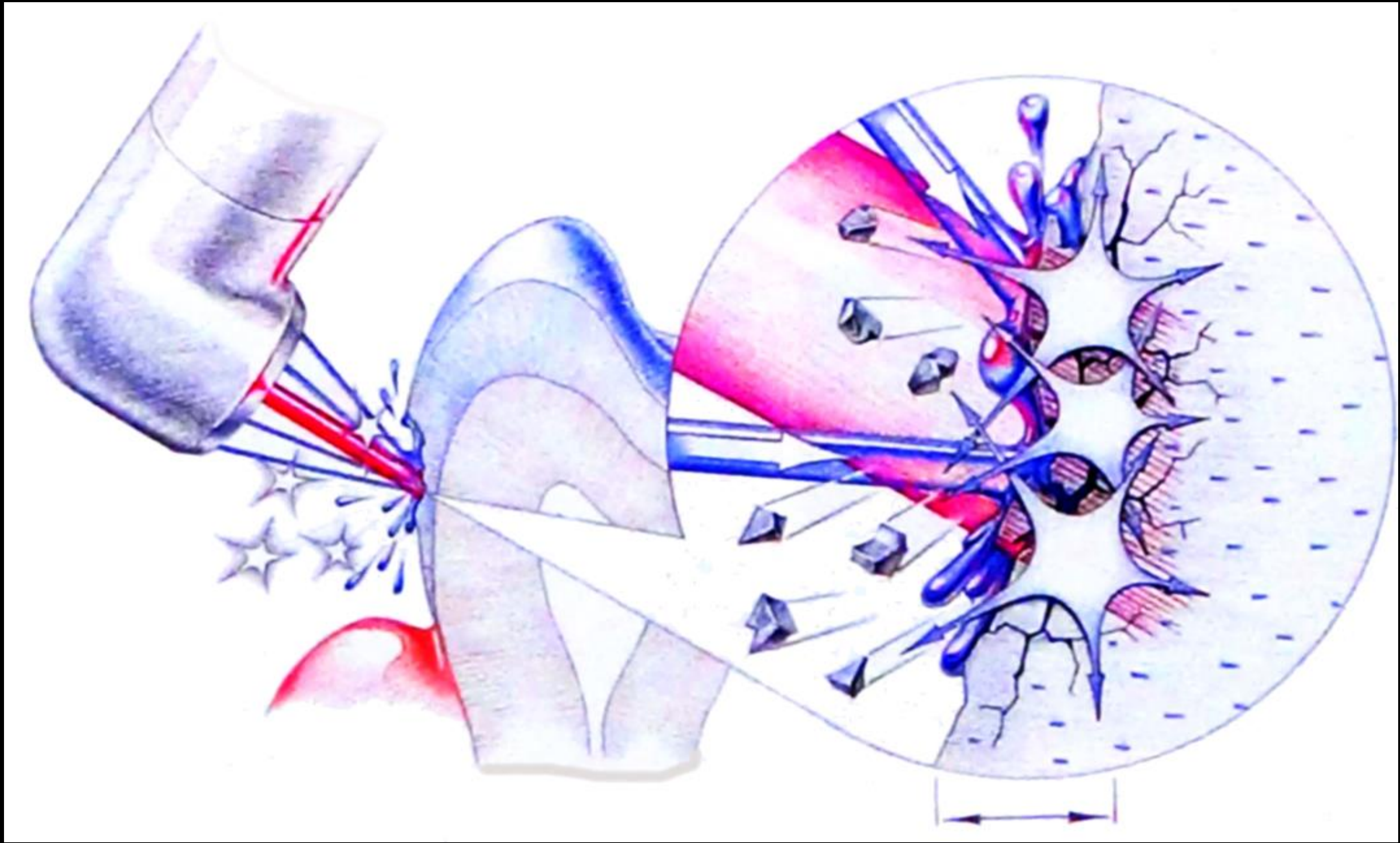


Stephenson's Rocket 1829, the winner of the Rainhill Trials



Power generation by steam power

Cavity preparation by Er:YAG laser uses steam power, too!

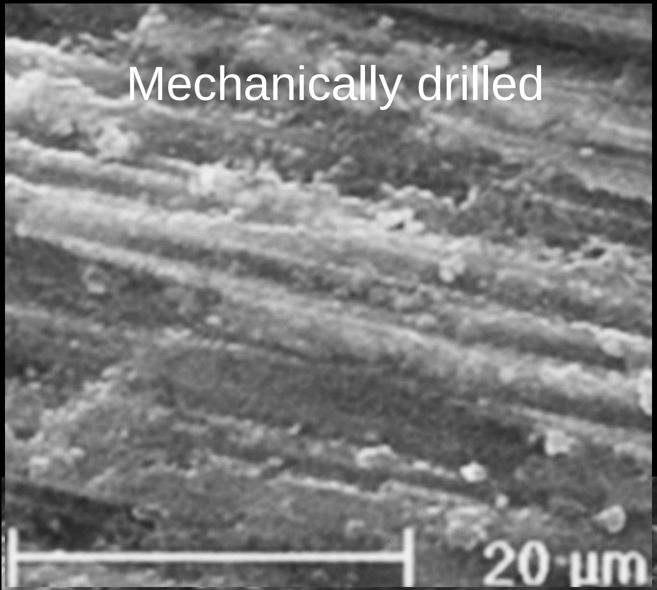


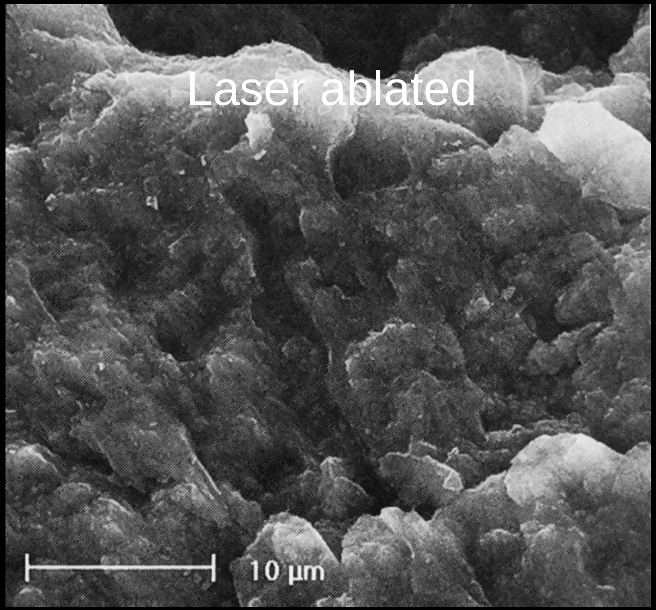
Cavity preparation

Mechanically drilled

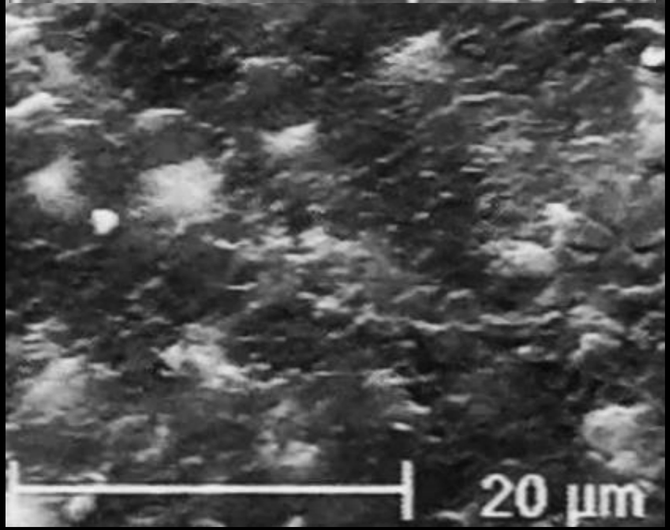
Laser ablated

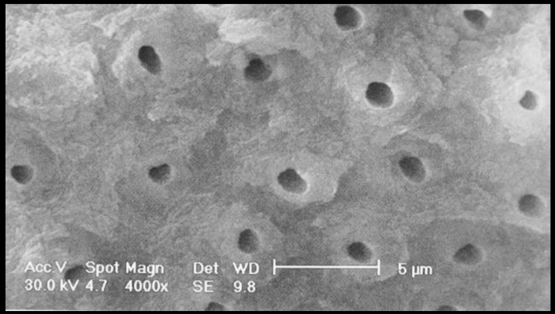
Enamel





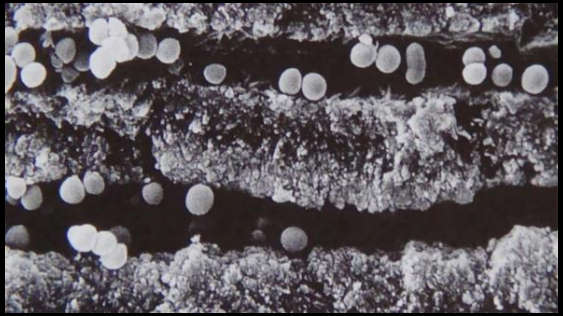
Dentin





No smear layer!

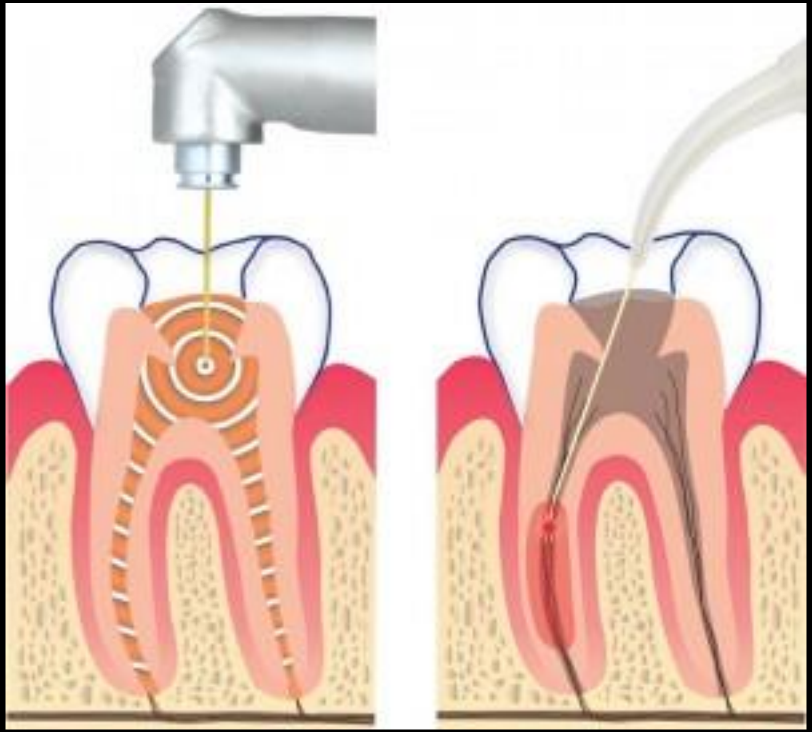
Root canal treatment



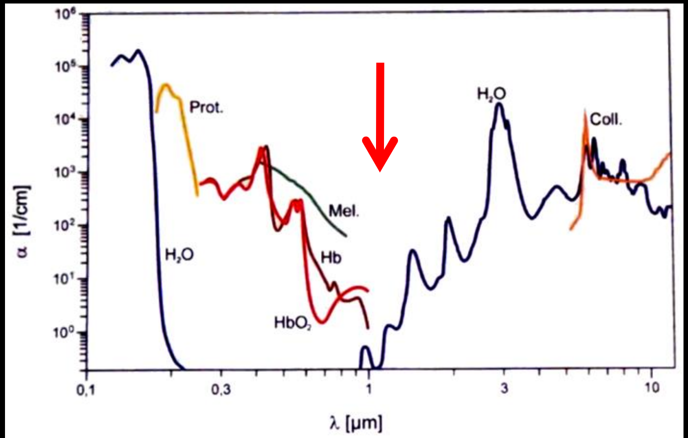
ENDODONTIC Treatments

The laser disinfection complements conventional treatment.

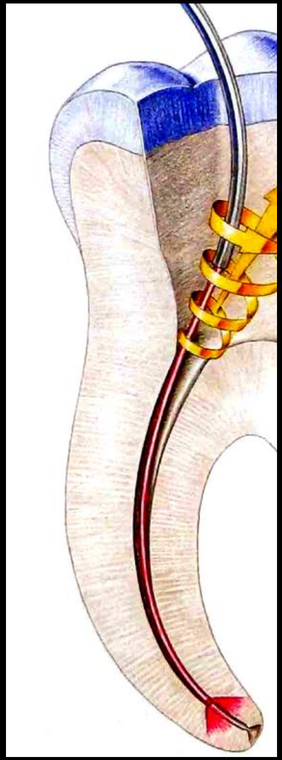
- **The high energy laser light is capable to destroy bacteria in the root canal and in dentinal channels.**
- **Approx. 500 µm in depth of the dentin tubules is also effective in addition to the canal walls.**
- **Greater security can be the sterilized running inside the tooth root canal.**
- **Using the laser success, rate of endodontic treatments increases.**

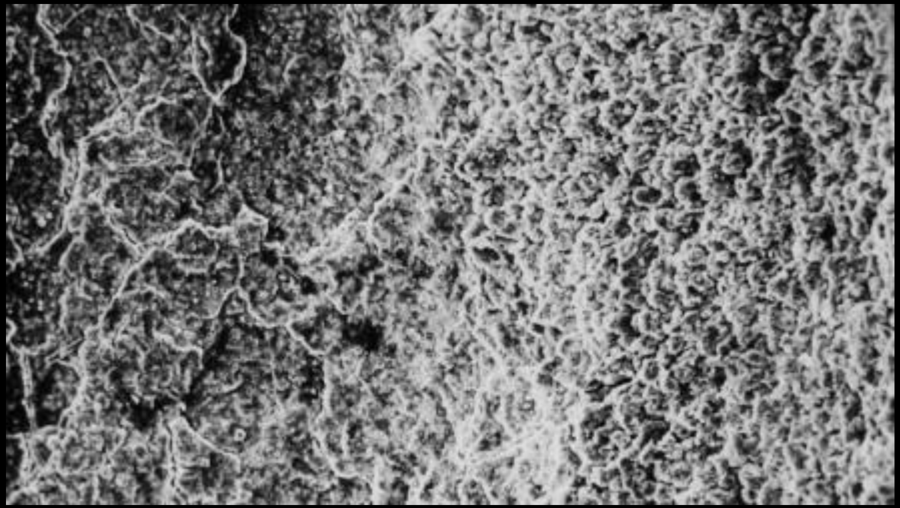


Er YAG laser for the first time clears the channels and root canals. Nd-YAG laser is then deeply disinfects the dentin walls.



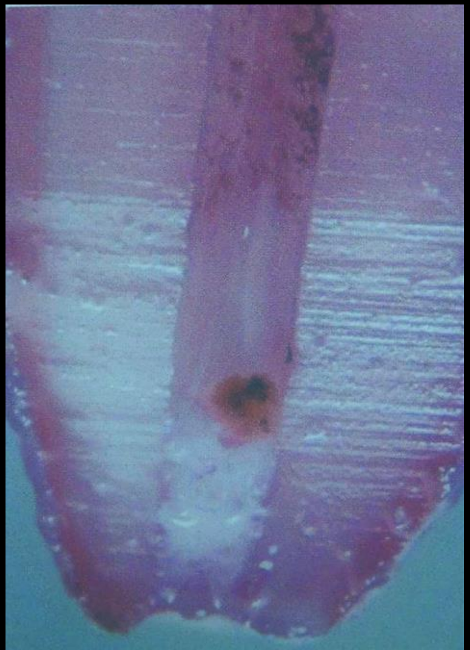
Root canal treatment





Er YAG laser shaped rooot canal

apical sealing,
irradiation with
1.5 W Nd:YAG
laser



Root canal treatment

Effect of laser desinfection:

Nd:YAG laser treated dentinal channels

Summary

- Using lasers sources high power in a small volume can be delivered. → High volumetric intensity can be reached

- The machining processes occur due to the LASER excitation. It results in:
  - biological responses,
  - temperatures rise, melting, evaporation, plasma formation, ablation of material,
  - photochemical reactions and
  - Ionization processes.

- These all can be applied in dental medicine. E.g.:
  - Treatment of sensitiveness
  - closing of tubules
  - supplement of fluoride treatment
  - prevention from caries
  - UV light has a sterilization effect
  - Tooth whitening
  - promoting oxidative processes
  - decreases the concentrations of agents, shorter treatment time is enough
  - Treatment of periodontal diseases
  - Surgical treatments
  - Photodynamic or soft therapy

Thank you for your attention!