LASERS FOR DENTAL APPLICATIONS.

Dr. Zsolt Tóth

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

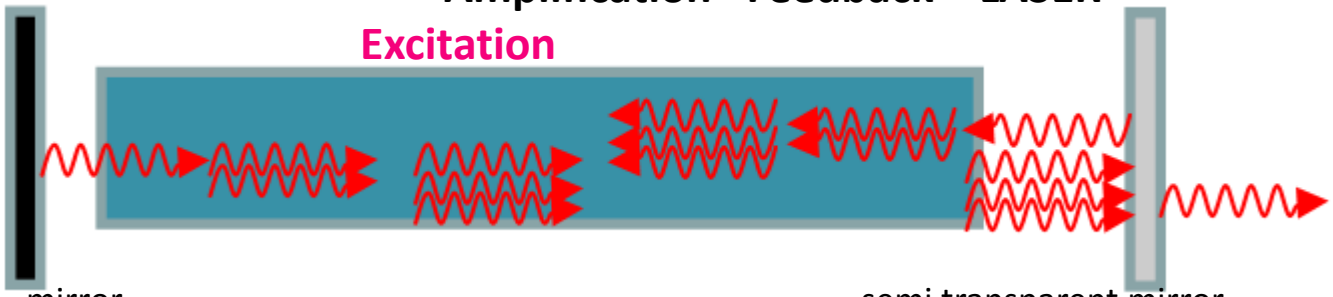
CONTENT:

- **Laser - material interactions**
- **What do lasers with teeth?**
  Examples for dental applications:
  - **oral surgery**
  - **tooth whitening**
  - **fissure sealing**
  - **treatment of hypersensitivity**
  - **root canal treatment**
- **Future possibilities**
- **Summary**

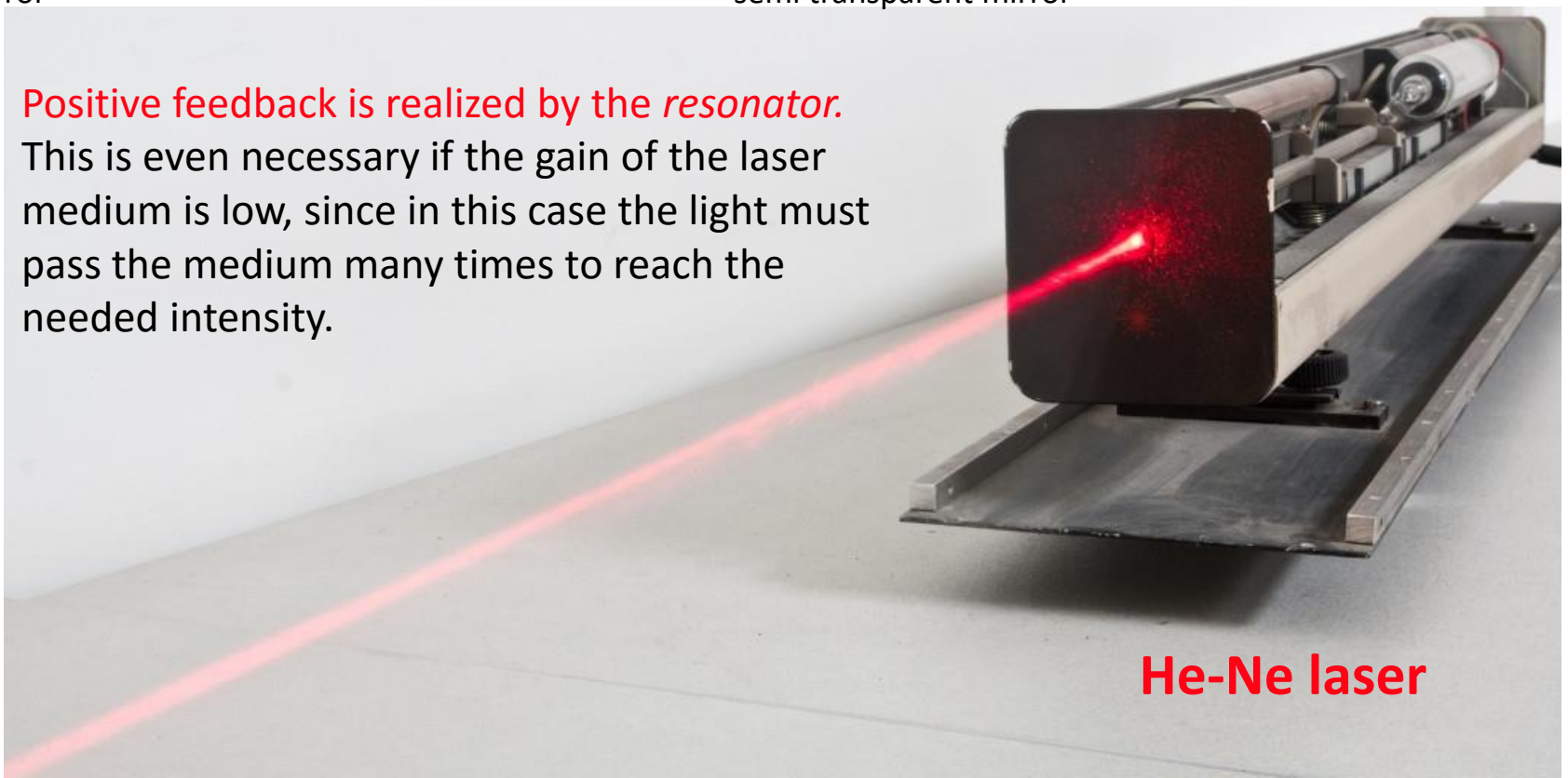
Laser - material interactions

Operation of Lasers

Amplification +Feedback = LASER

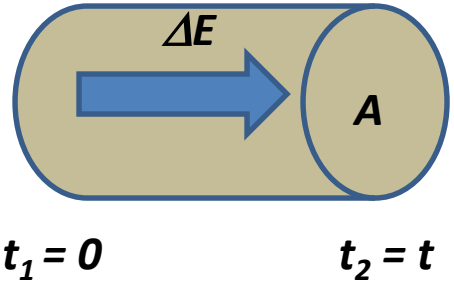


Positive feedback is realized by the *resonator.*
This is even necessary if the gain of the laser medium is low, since in this case the light must pass the medium many times to reach the needed intensity.



The power of radiation

Suppose that in a time interval between *zero* and *t* some energy in an amount of *E* is transported through a given cross-sectional area *A* .



$$P = \frac{dE}{dt}$$

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

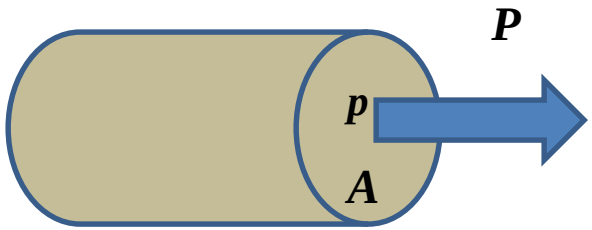
CURRENT DENSITY, OR INTENSITY

Let A be an area in the 3D space containing point p which is perpendicular to the direction of flow!

Denote P the power (energy current) flowing through A!

- The definition of current density or intensity I, at point p is:

$$I = \frac{dP}{dA}$$



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.

AVERAGE intensity can be easily calculated:

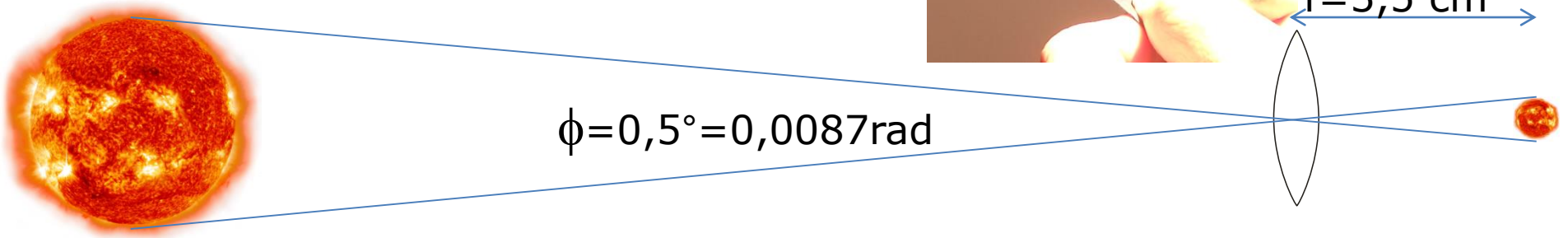
$$I = \frac{E}{A\ t}$$

What intensity can be reached by lasers?

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

Example: focusing the sunlight by a lens:

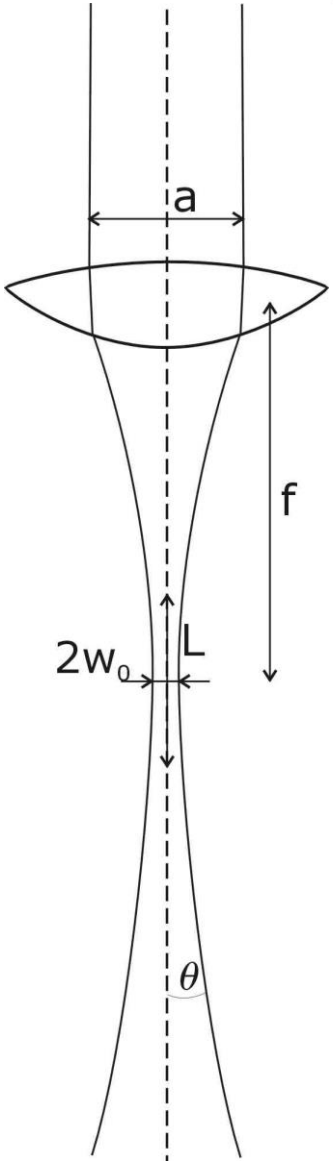
d_{lens}=3 cm, → P~0.7 W



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

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

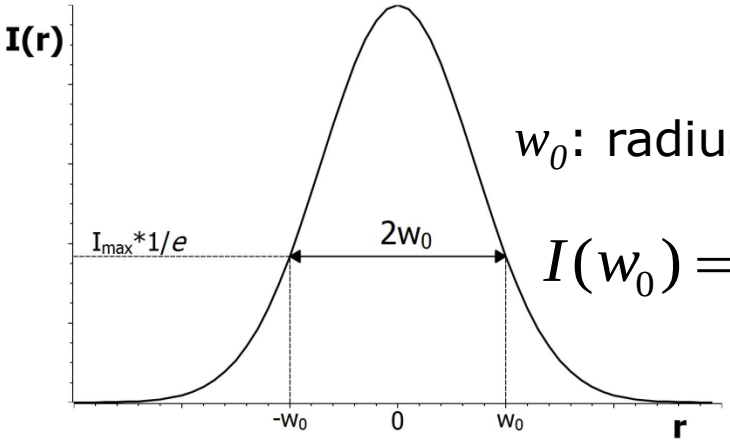
What intensity can be reached by lasers?



Focusing the TEM_{00} mode: The intensity distribution of a Gauss-beam :

$$I(r) = I_0 \exp\left(-\frac{r^2}{w_0^2}\right)$$

I_0: maximum intensity



w_0: radius at the beam waist

$$I(w_0) = I_0 / e$$

$$w_0 = \frac{f\ \lambda}{\pi\ a}$$

The power of the Gauss-beam:

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

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:

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

Maximum intensity:

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

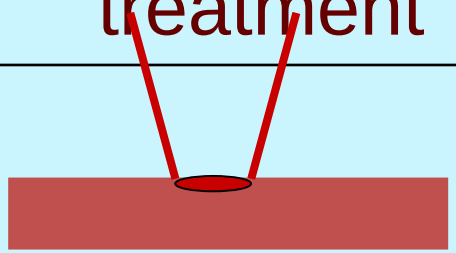
This intensity is 16.5 X of the focused sunlight!!!
The „high laser intensity” domain has even 2 orders of magnitude higher intensities.

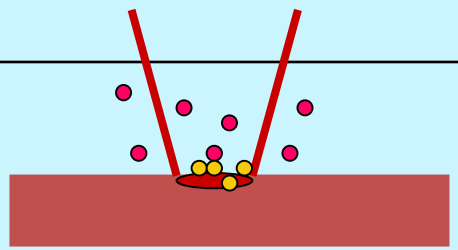
Material processing by lasers

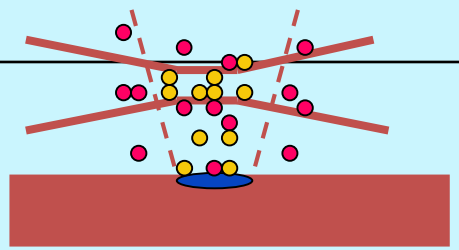
Laser - material interactions

intensity

Physical (phase changes)	Chemical: thermal	Chemical: 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	

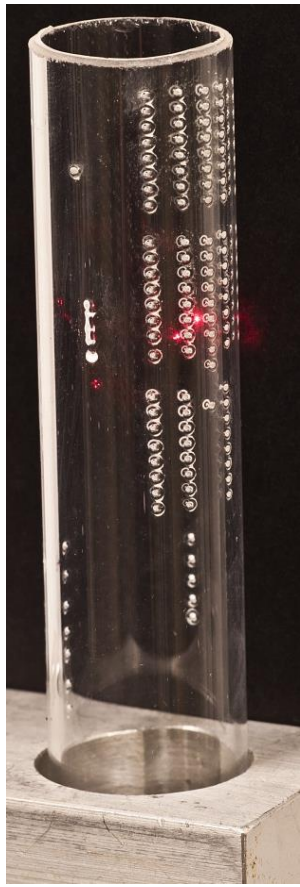




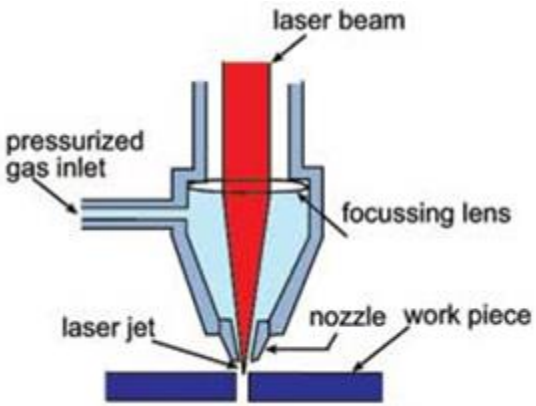


Material processing by lasers

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.



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



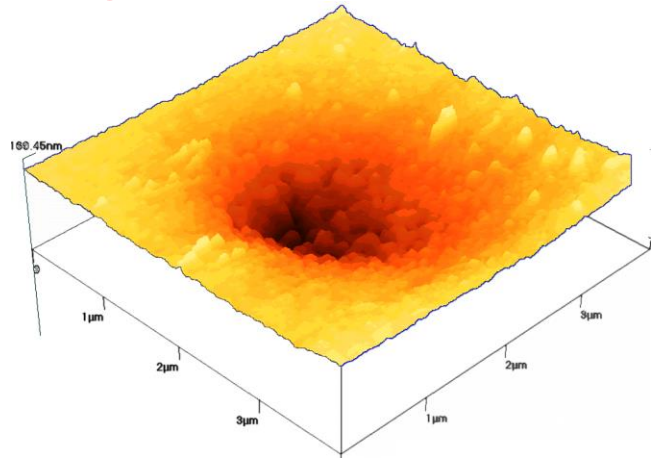
Laser cutting

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

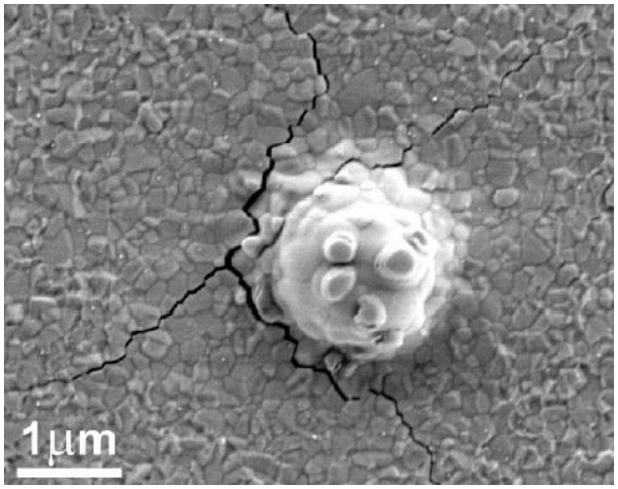
Material processing by lasers

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

By 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.

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

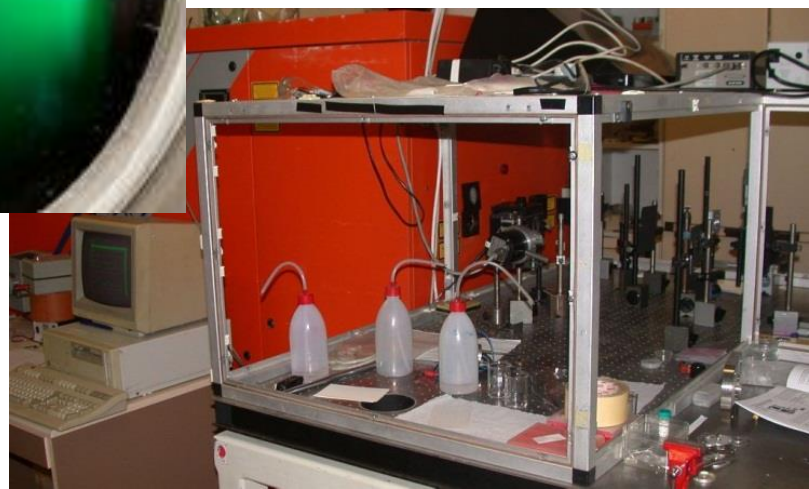
Material processing by lasers

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

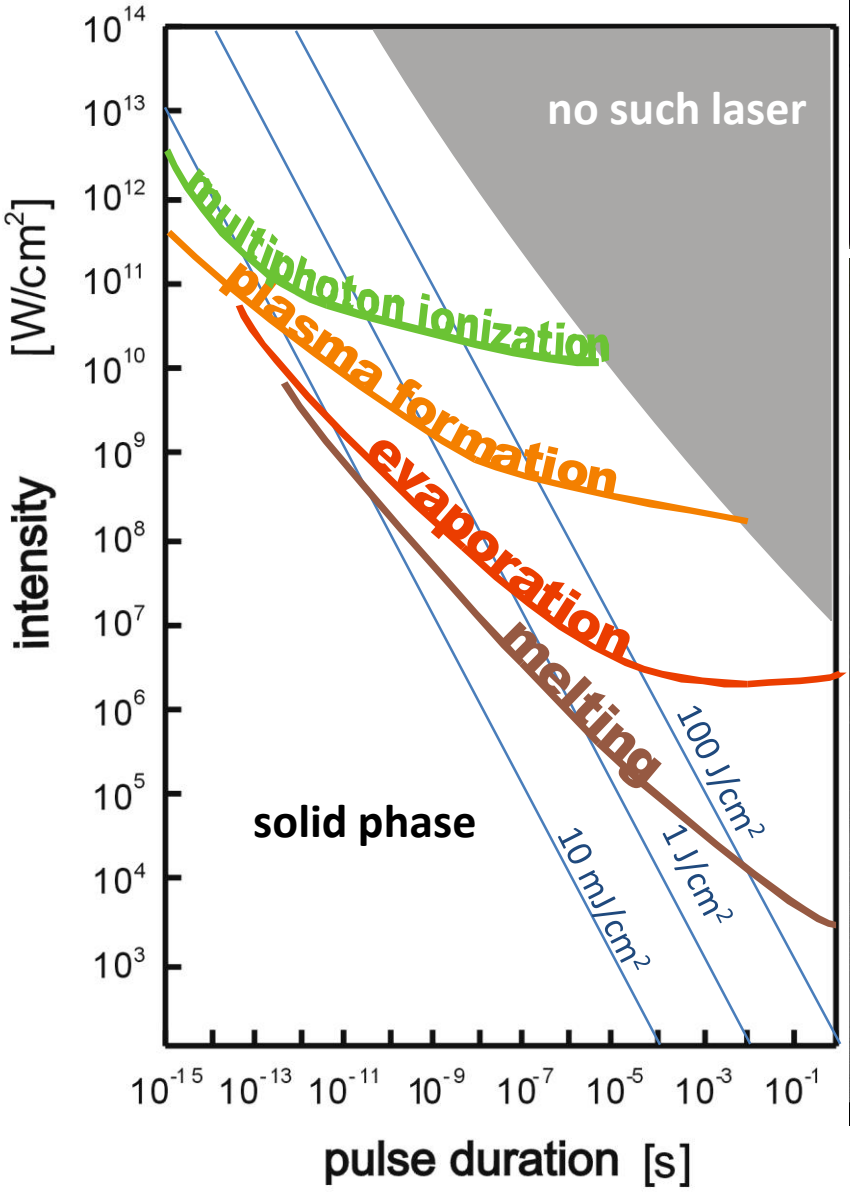
By decreasing the duration of the laser pulses (into a nano-, pico-, femto-, and soon attosecond regime) ultrahigh laser intensity can be reached, which is capable to form plasma on surfaces

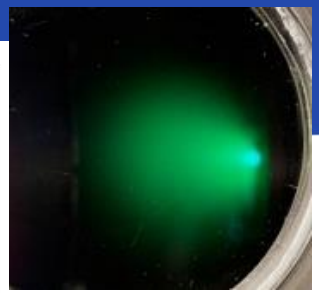
Plasma formed on a text by the infrared pulse of a Nd:YAG laser (wavelength 1064 nm)

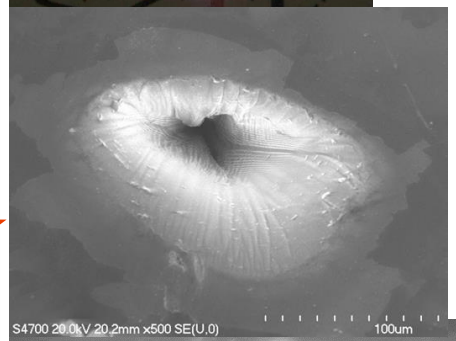
Ultraviolet pulses from KrF excimer laser (wavelength 248 nm) can easily form plasma in vacuum. Target: copper

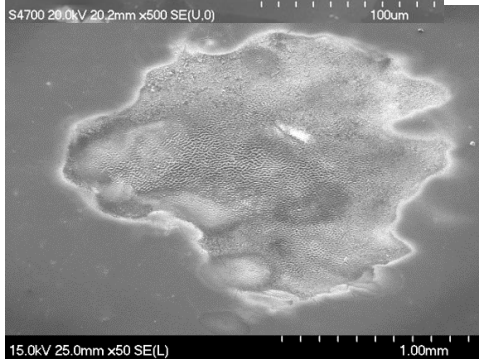


Material processing by lasers









plasma generation
implantation

generation of shock waves
plasma-surface interactions

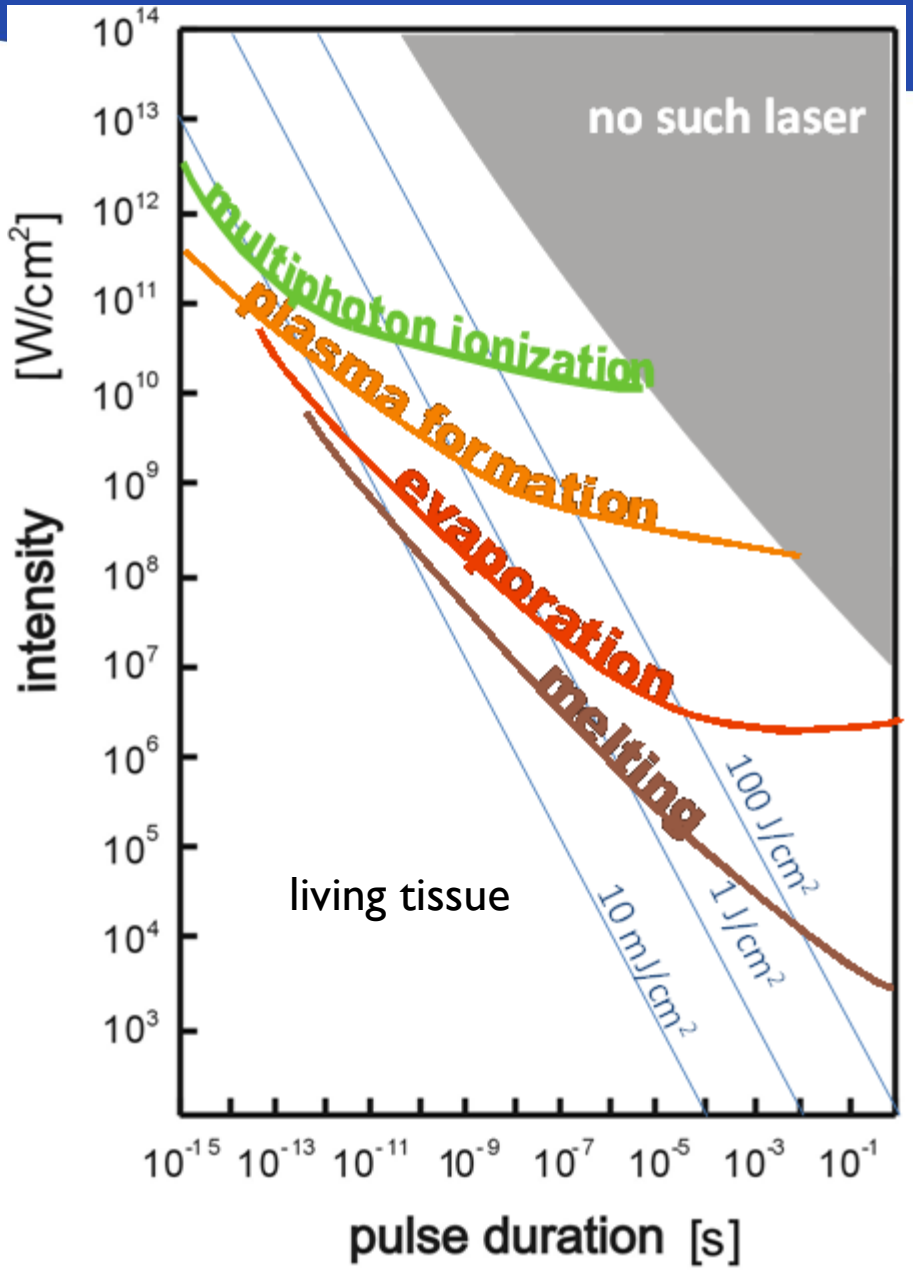
vaporization
drilling
cutting

melting
soldering, welding

remelting surface, alloying

heat treatment
diffusion
recrystallization

Material processing by lasers



- production of energetic particles
  - hadron therapy
- evaporation of hard tissues
  - cavity preparation
- evaporation of soft tissues
  - laser surgery
- selective heat treatment
  - koagulation
  - photodynamic therapy

„soft-laser" therapy
- treatment of allergic symptoms of mucosa
- wound healing

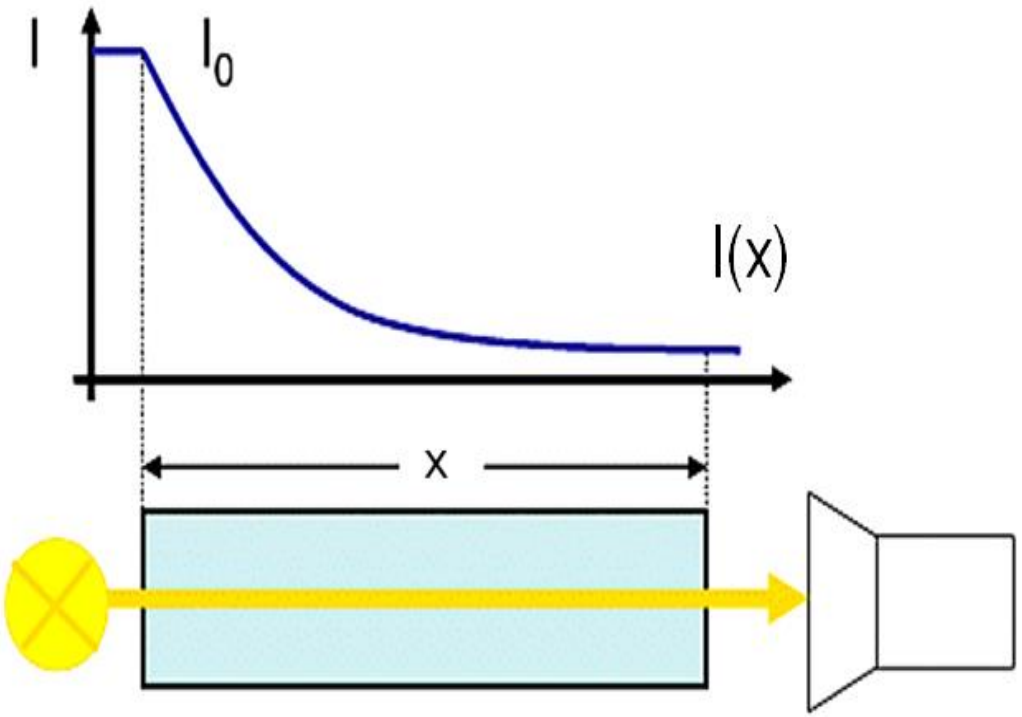
Not only intensity or energy matters: the role of absorption

Light is absorbed in the material: $\Delta I = - \alpha(\lambda) \cdot I \cdot \Delta x$,

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.

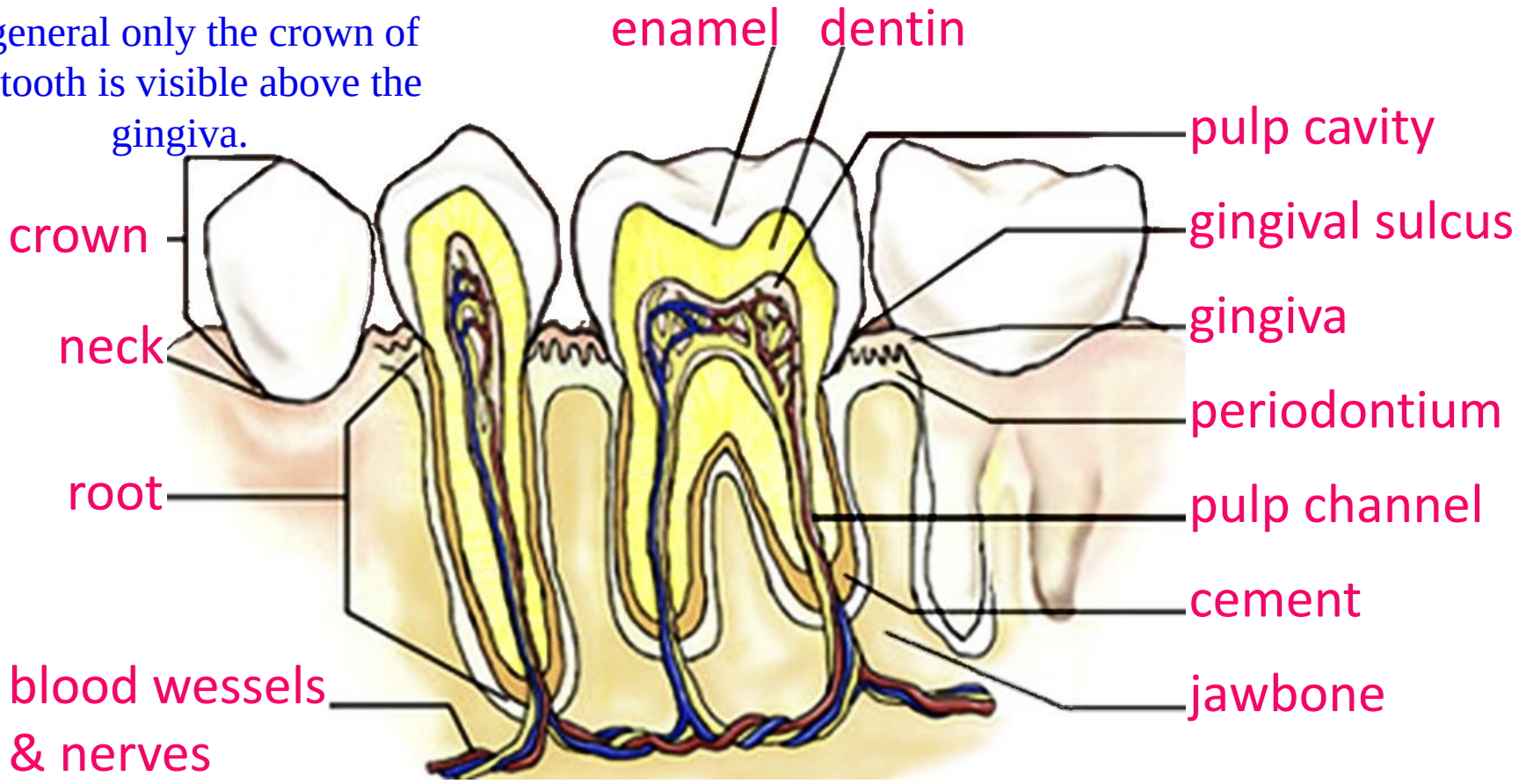
$$I_{vol} = \alpha(\lambda) \cdot I$$

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

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

Teeth… their structure

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



Teeth… their structure

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

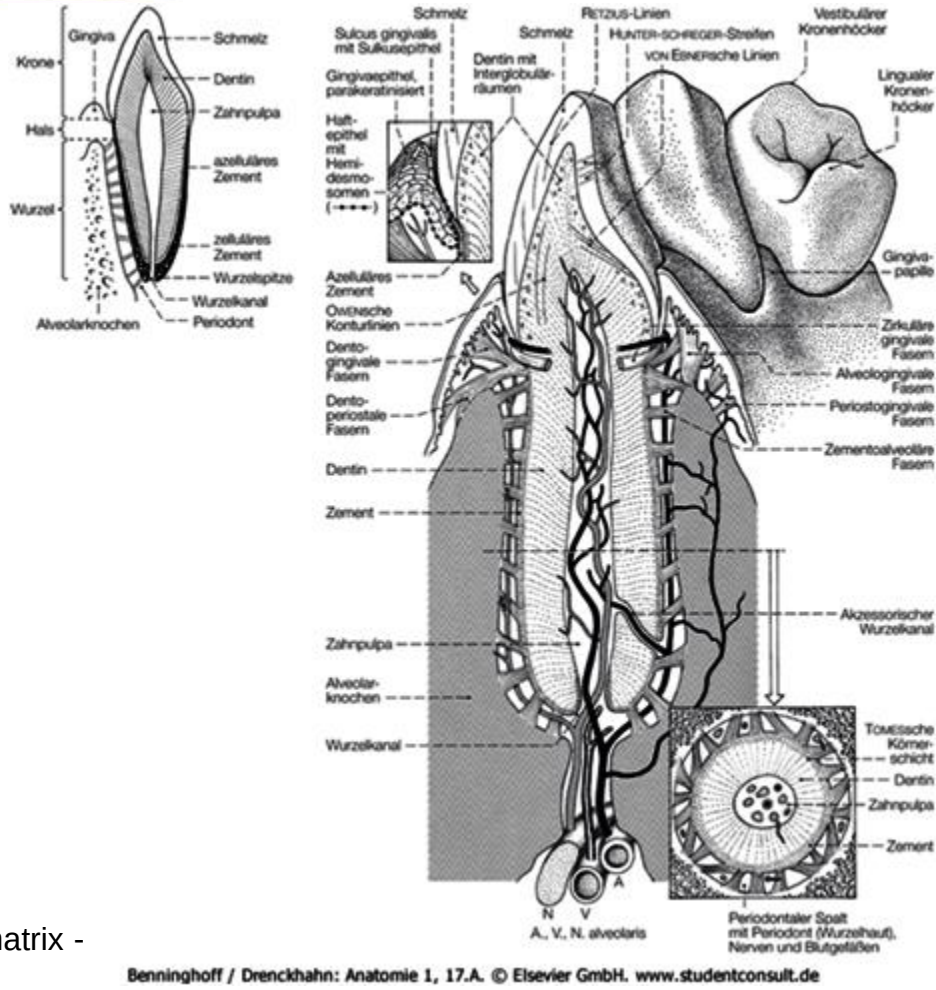
Cement / substantia ossea

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;

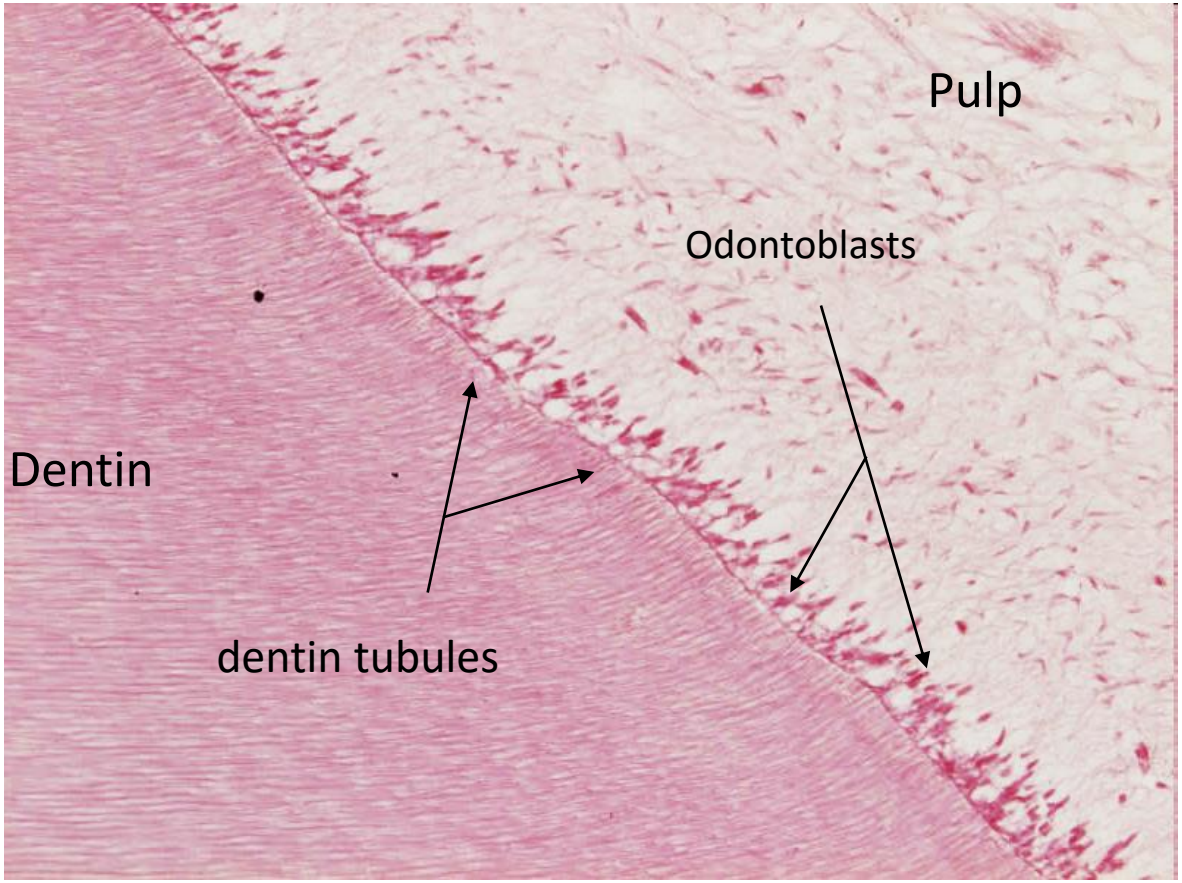


Dental pulp

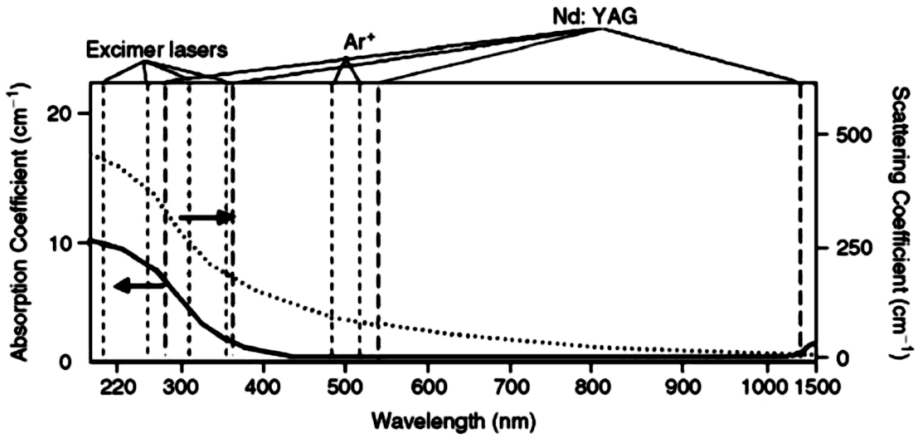
- Loose connective tissue rich in blood vessels and nerves.

  The dentin producing cells: odontoblasts

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

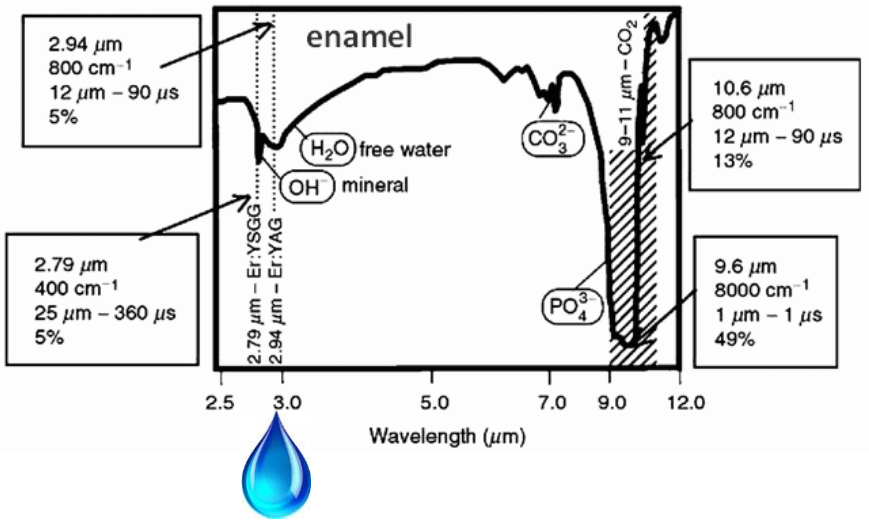


Optical properties: transmission, absorption



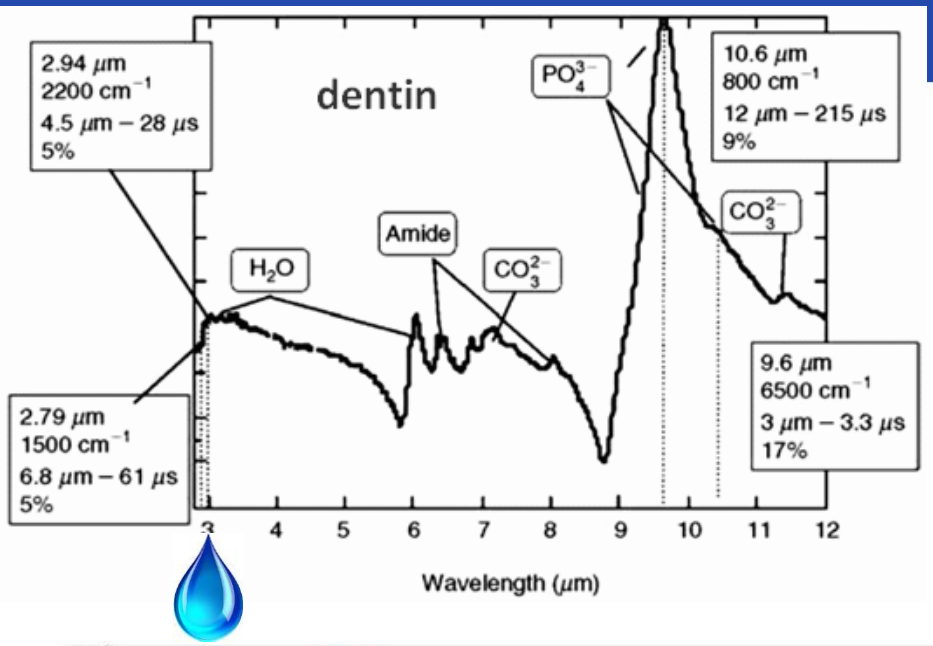
absorption spectrum of enamel in the VIS range

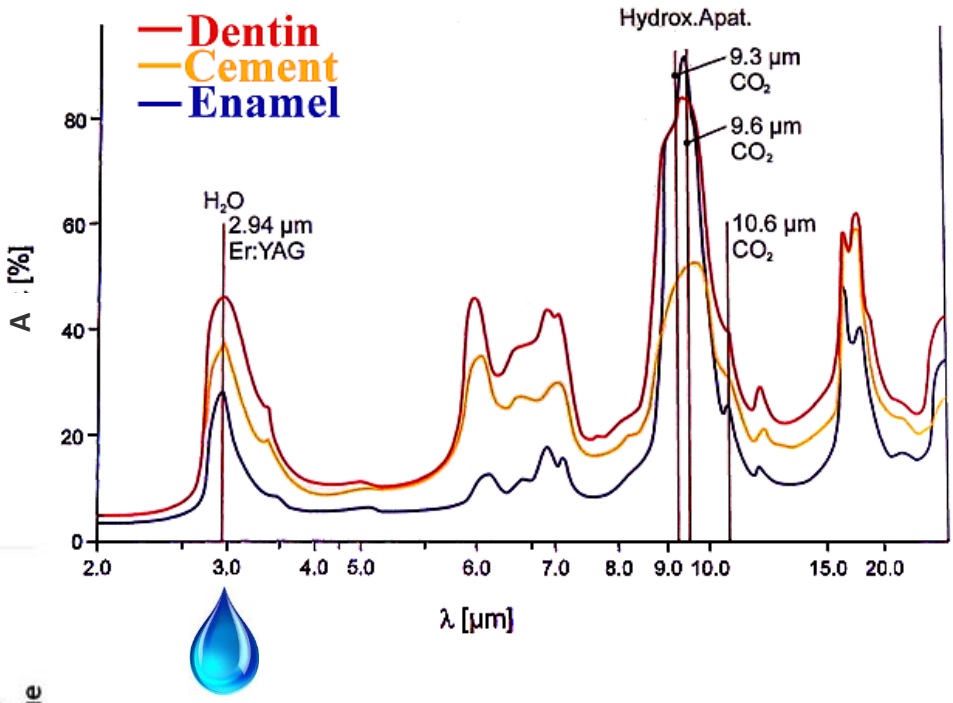
transmission spectra of enamel in the IR

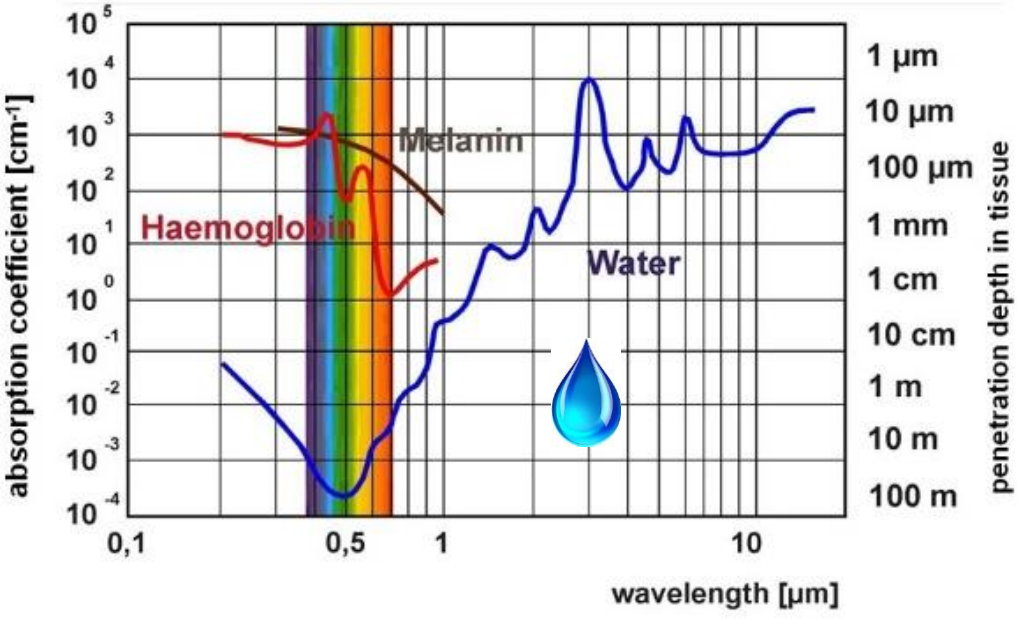


Optical properties: absorption spectra

Dental applications







Areas of laser applications in dentistry

prevention

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

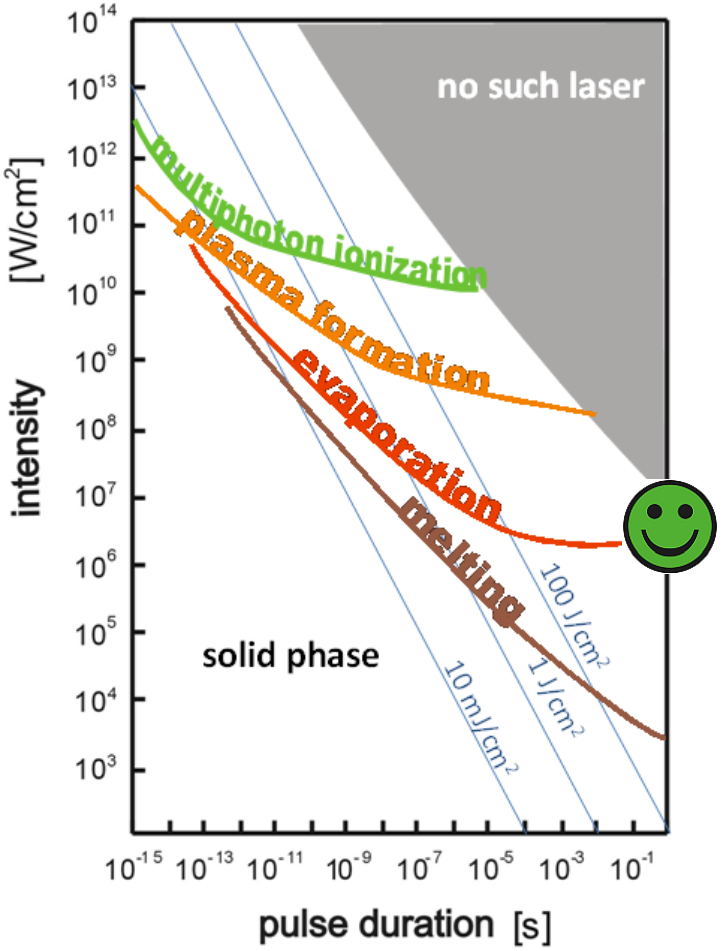
diagnosis

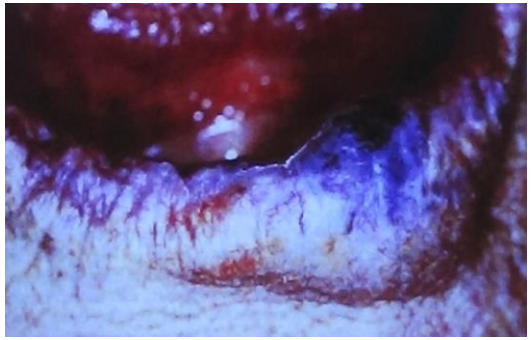
- caries detection by photoluminescence

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 CO_2 laser





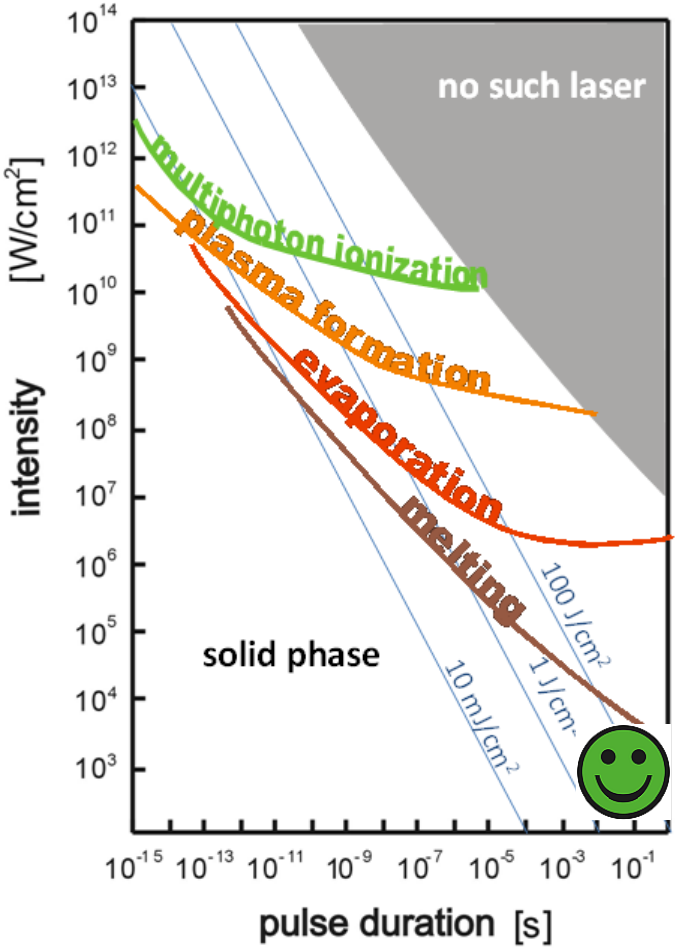
images from Prof. Dr. István Sonkodi
University of Szeged, Faculty of Dentistry

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

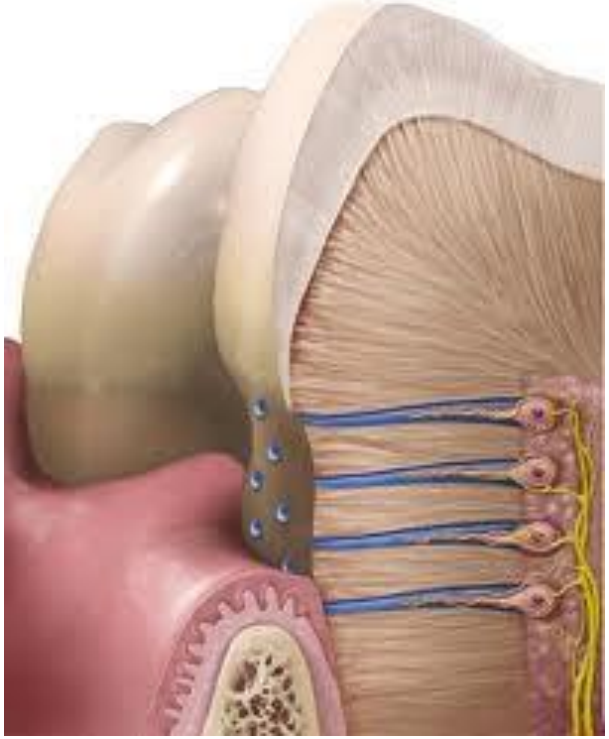
Tooth whitening

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



Dentin hypersensitivity treatment

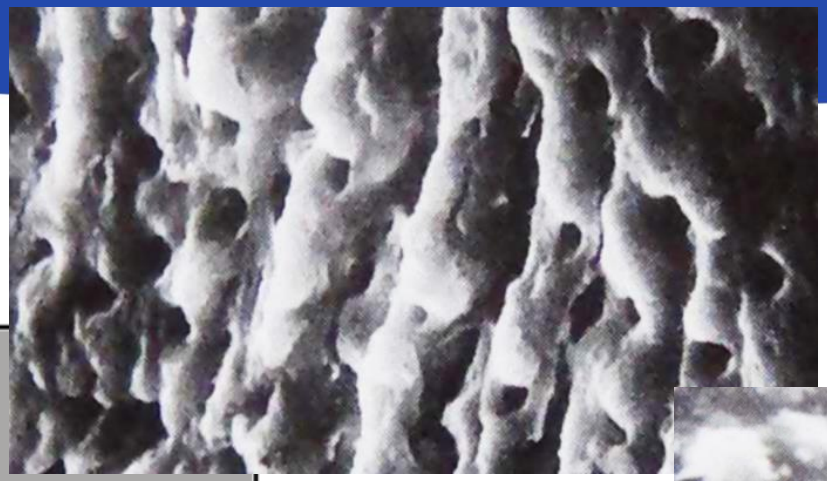
The main cause of DH is gingival recession with exposure of root surfaces, loss of the cementum layer. Through open dentinal tubules hydrodynamic flow can be increased by cold, air pressure, drying, sugar, sour, or forces acting onto the tooth.



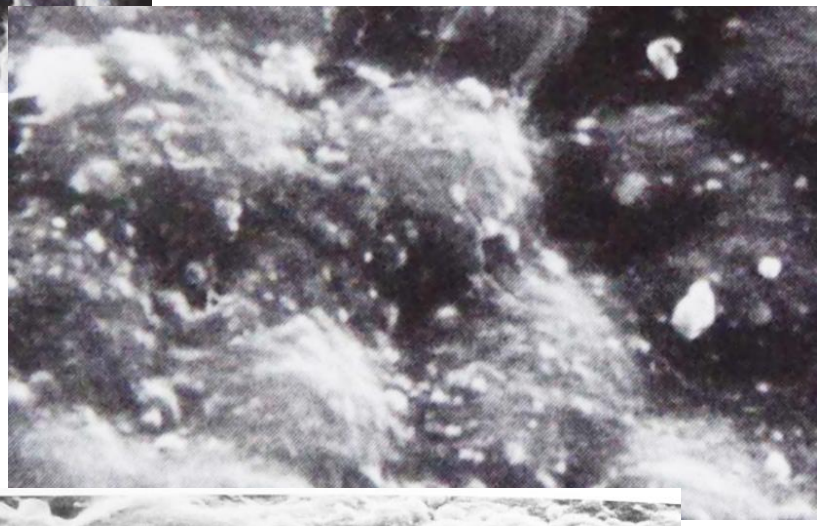
Through open dentinal tubules bacteria can attack the inner pulp, causing inflammation, pain, and dying the pulp.

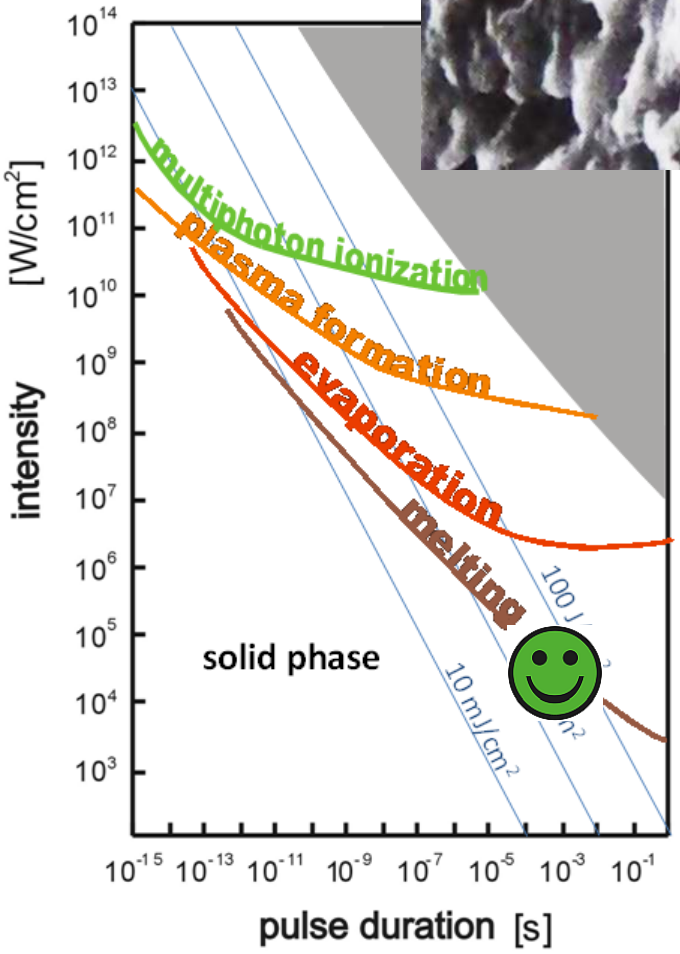
(Andreas Moritz Wienna)

Dentin hypersensitivity treatment

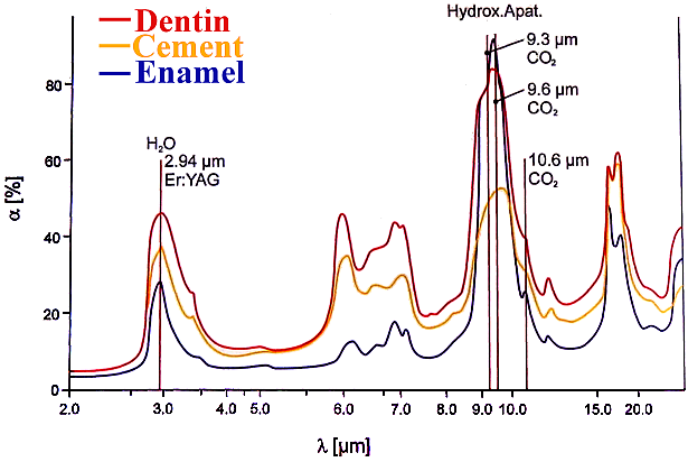


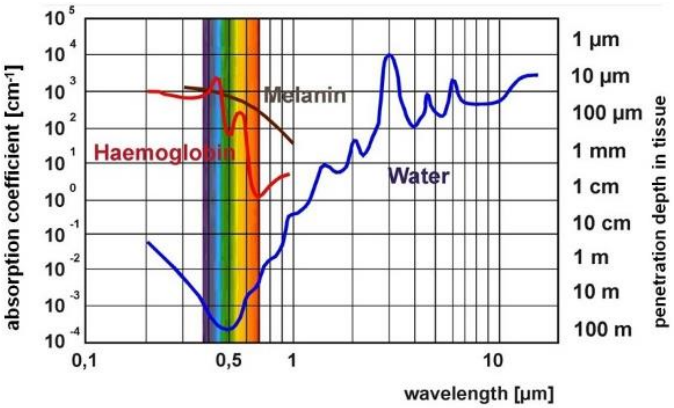
Open dentinal tubules are treated by cw CO_2 laser and fluoride gel





Extended fissure sealing

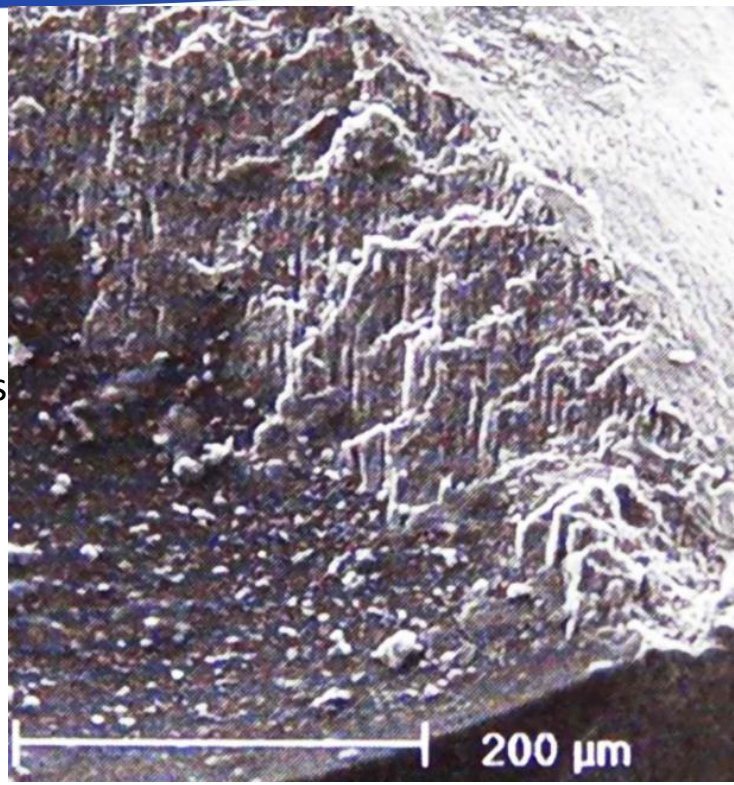




selective removal of water containing contanimations

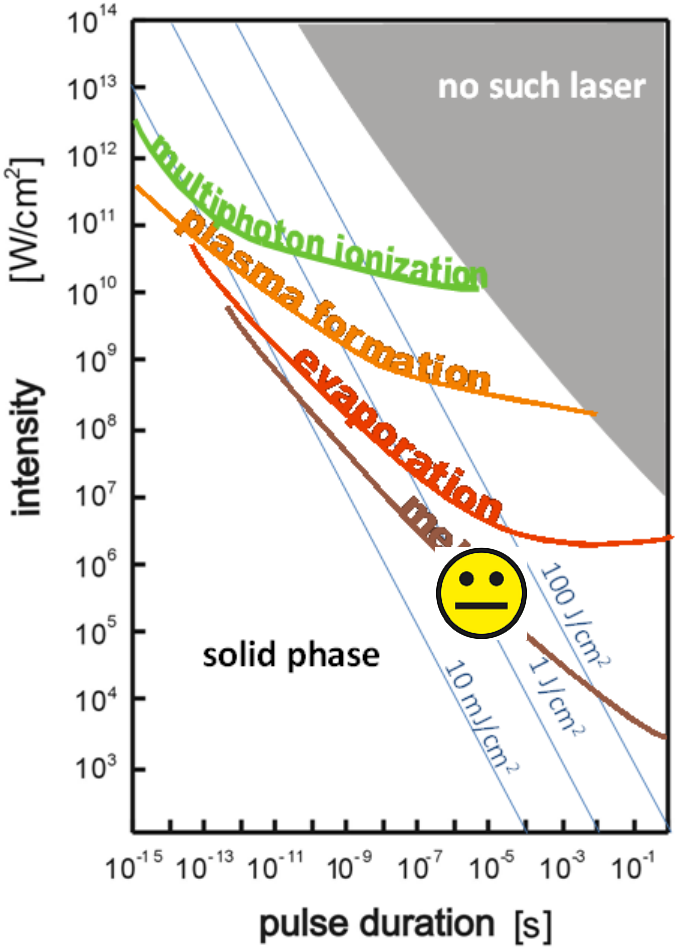
Er:YAG laser treated fissures

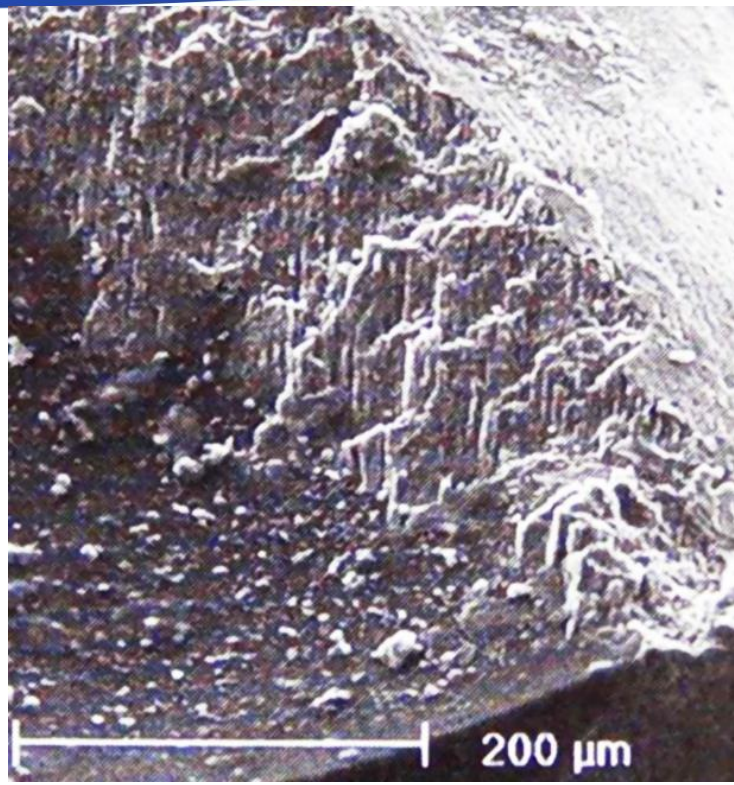
Sealed fissures



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

Extended fissure sealing





- Roughening of enamel
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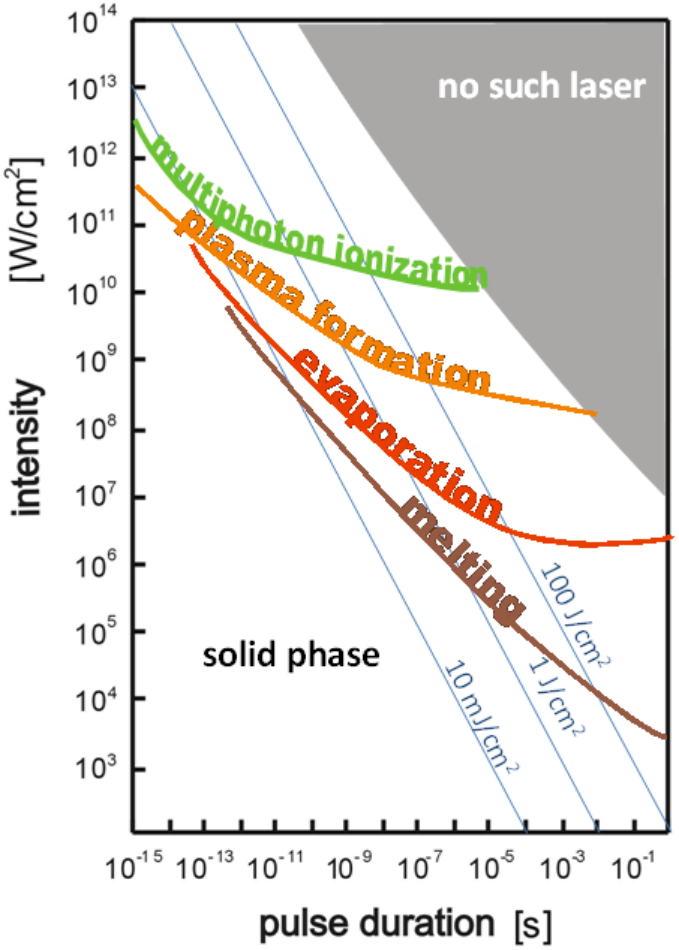
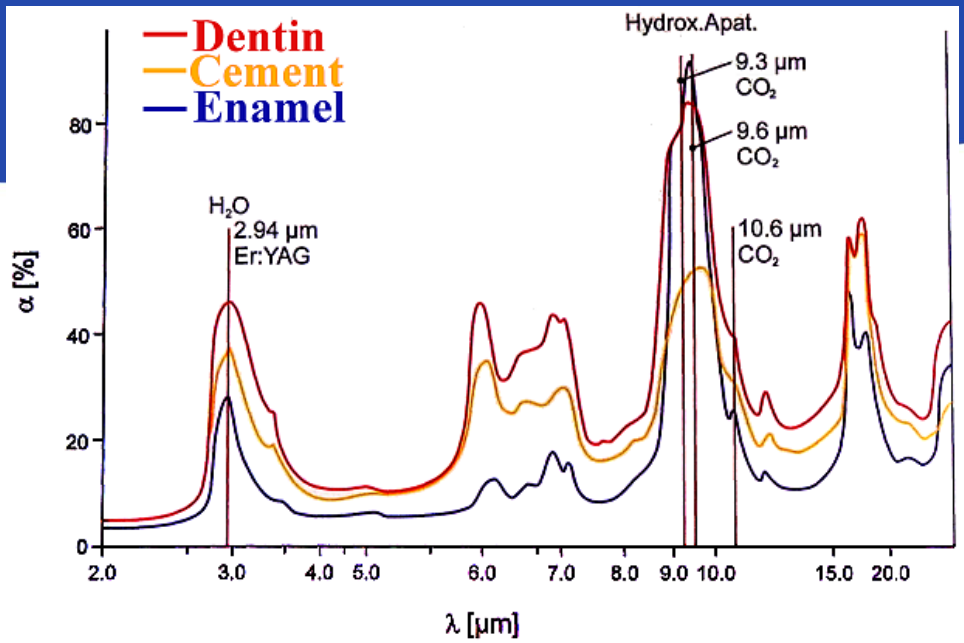
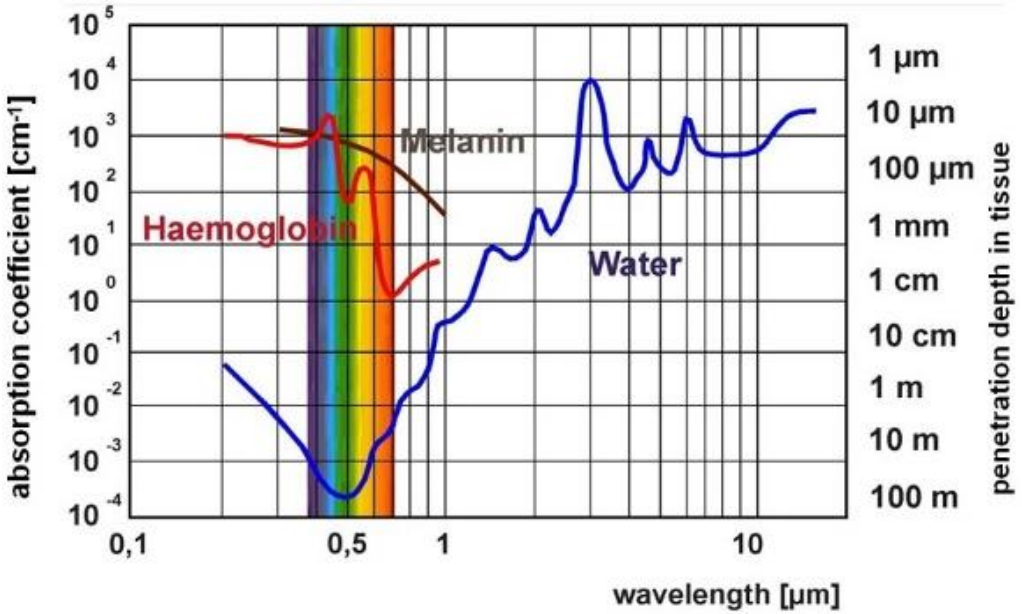
Cavity preparation

Dental applications





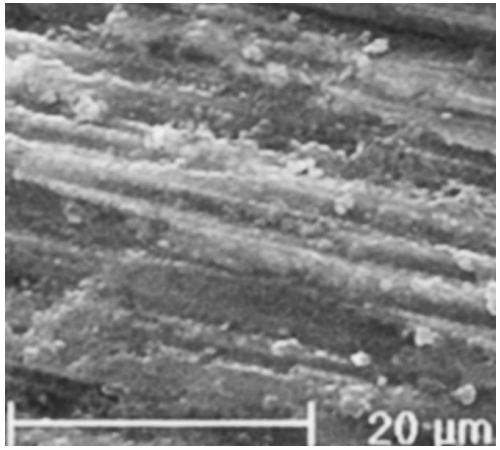


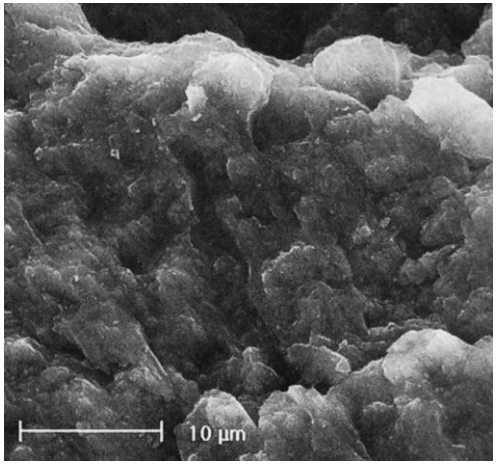
Cavity preparation

Mechanically drilled

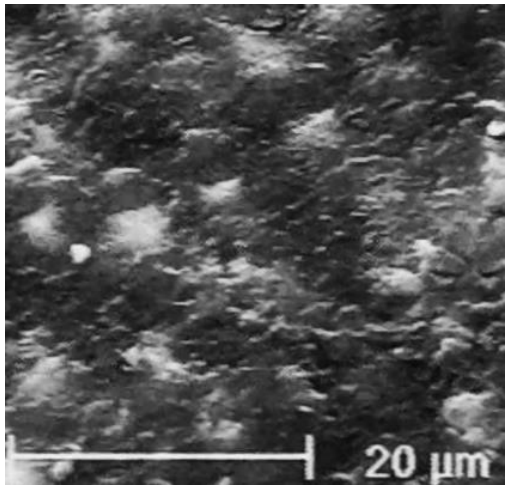
Laser ablated

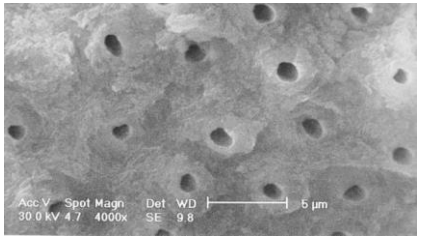
Enamel





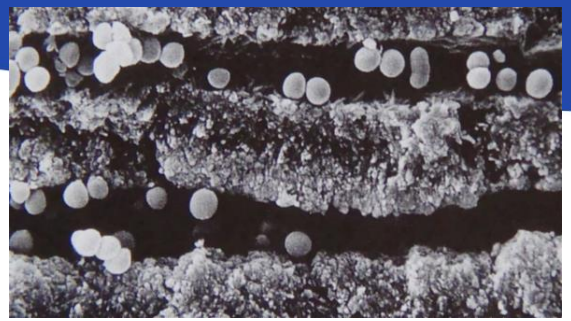
Dentin

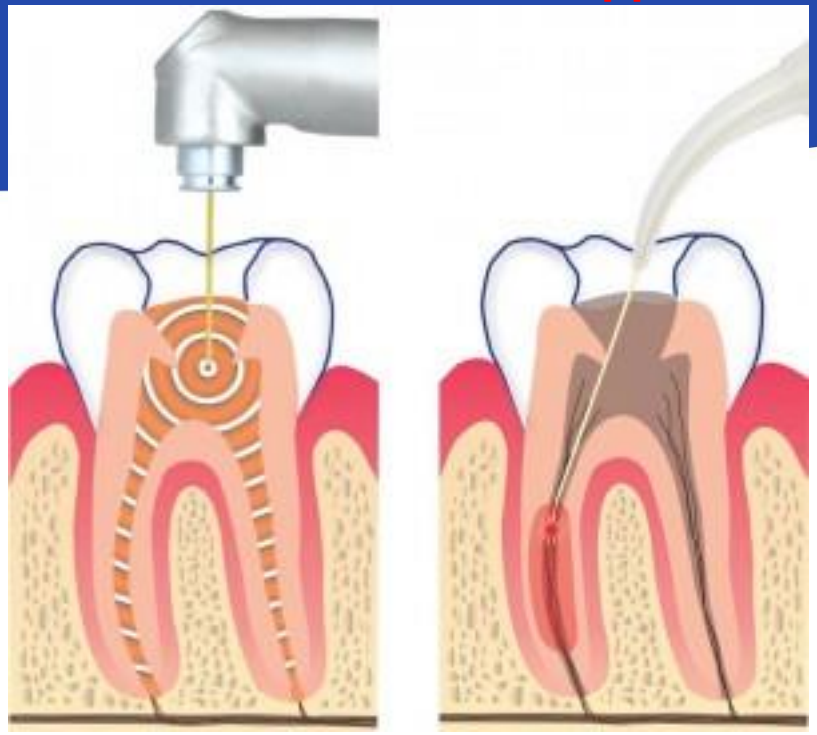




No smear layer!

Root canal treatment



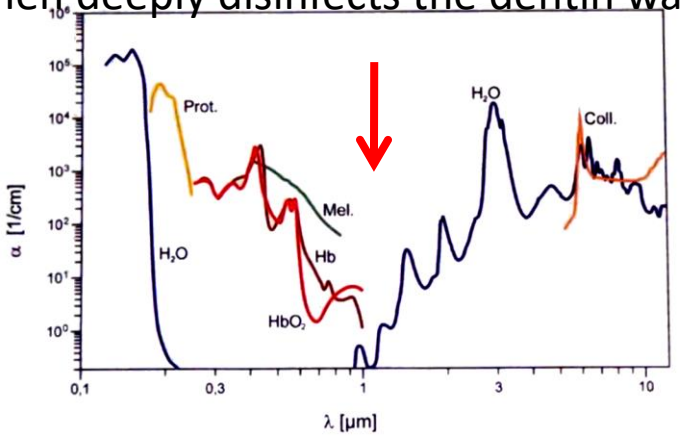


ENDODONTIC Treatments

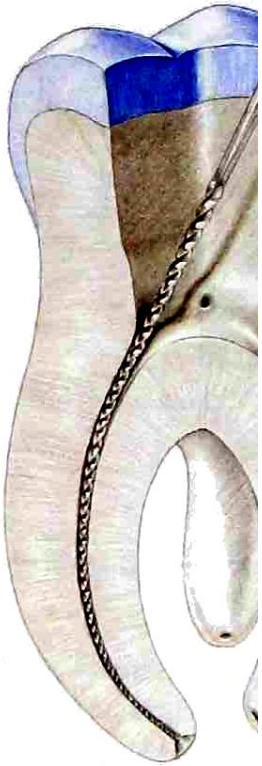
The laser disinfection complements conventional treatment.

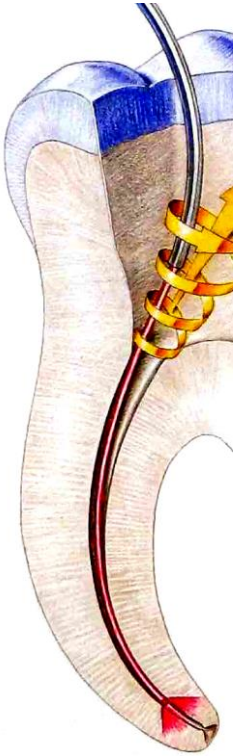
- **The high energy laser light is capable to destroy bacteria in the root canal and in dentinal channels.**
- **Approx. 500 μm in depth of the dentin tubules is also effective in addition to the canal walls.**
- **Greater security can be the sterilized running inside the tooth root canal.**
- **Using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

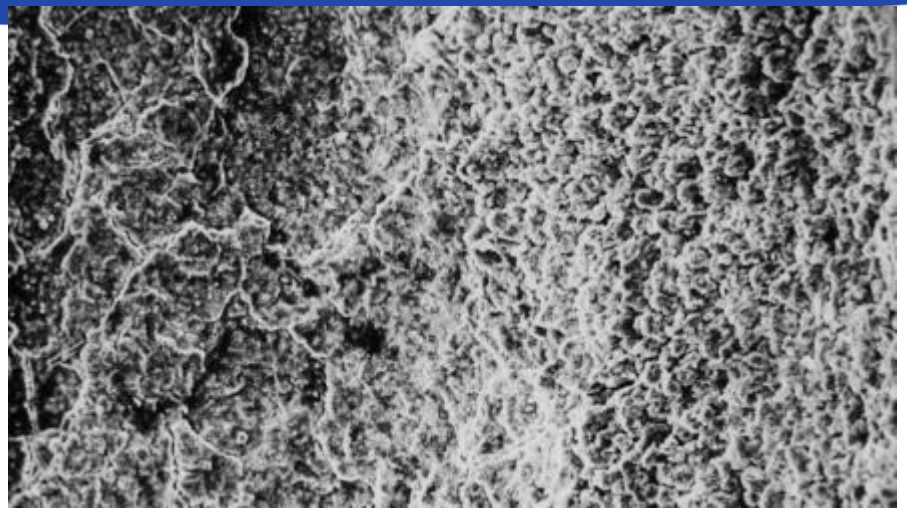
Er YAG laser for the first time clears the channels and root canals. Nd-YAG laser is then deeply disinfects the dentin walls.



Root canal treatment

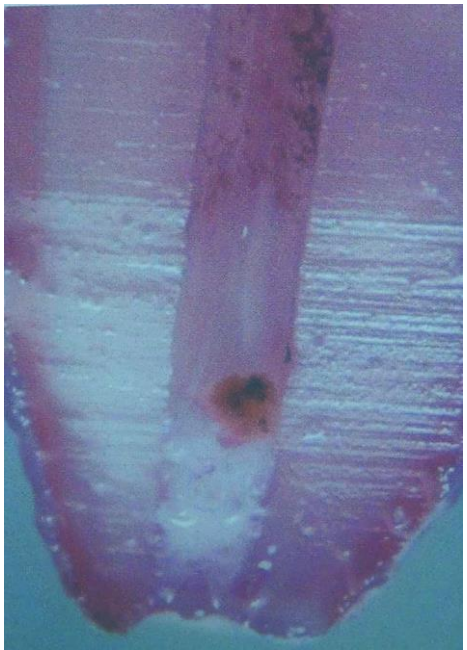




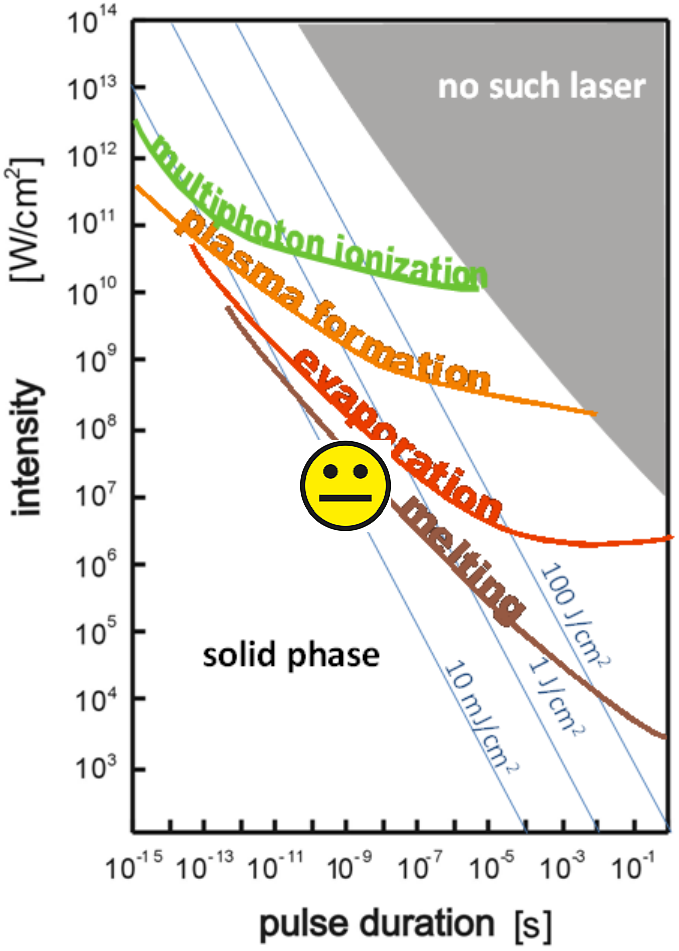


Er YAG laser shaped rooot canal

apical sealing, irradiation with 1.5 W Nd:YAG laser



Root canal treatment



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!