The Effect of Laser Radiation on Tissue

Dr. Karl Stock from ILM at the University of Ulm. If you want to describe the biological and physical effect of light on tissue, you must first understand light dispersion in tissue to consequently understand the different interactions between light and tissue.

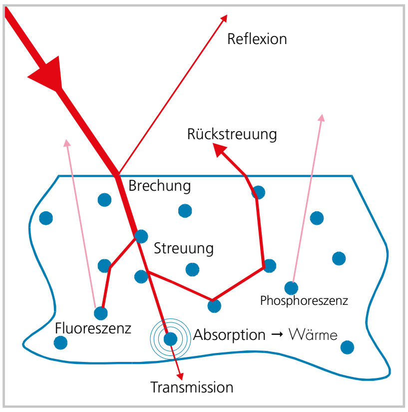

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Fig. 1: Light Propagation in Tissue

Light Dispersion in Tissue

The majority of light that meets tissue is reflected, transmitted, scattered, or absorbed. If light is absorbed, the absorbed light energy is either transmitted in the form of heat, fluorescence, or phosphorescence. Depending on the wavelength of the incoming light and the tissue type, the aforementioned effects occur in different amounts.

The **percentage of reflected light** largely depends on the refractive difference between air and tissue, as well as on the angle of incidence. Light that penetrates tissue is either absorbed or scattered by microscopic structures such as, for example, cell components.

This **scattering** is responsible, for example, for the fact that a laser beam cannot be focused as needed in the tissue but rather that the spot diameter increases in size.

Absorption is the crucial mechanism in being able to use the applied laser energy in therapeutics. The probability at which radiated light is absorbed is described by the absorption coefficient μa. The reciprocal of μa is the mean free path that a photon travels in the tissue until it is absorbed. [1].

Important absorbers in tissue include:

- In the UV range:
  Peptide bonds and nucleic acids
- In the VIS range:
  Bilirubin, carotene, melamine, and hemoglobin
- In the IR range:
  Water and hydroxyl apatite

[1] Lasertherapie der Haut, S. 26, R. Steiner, Springer-Verlag Berlin Heidelberg, 2013
[Laser Therapy of the Skin, p. 26, R. Steiner, Springer Publishing House Berlin Heidelberg, 2013]

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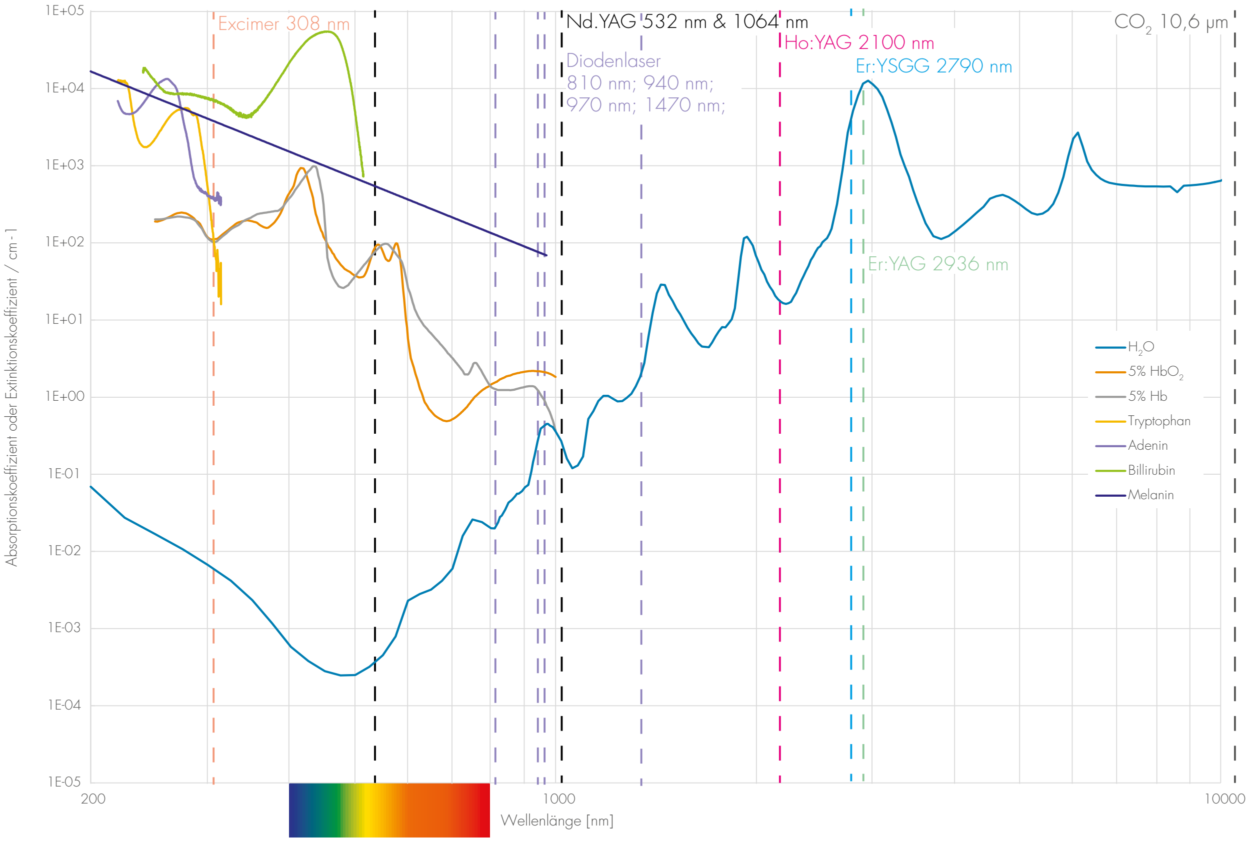
As the blue curve shows in Fig. 2, the absorption in water in the infrared spectral range is particularly high (a depth of penetration of only 1 µm at a wavelength of 3 µm). This is why the 2.94 µm Er:YAG laser and the 10.6 µm CO_2 laser are particularly well suited for cutting and removing soft tissue as it consists largely of water.



Data based on:
W. B. Gratzer, Med. Res. Council Labs, Holly Hill, London
N. Kollias, Wellman Laboratories, Harvard Medical School, Boston

Fig. 2:
Wavelength dependent absorption coefficients (water, blood, melanin) or molar extinction coefficients (tryptophan, bilirubin, adenine) of biological tissue components

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Interaction of Light with Tissue

The characteristics of the tissue and the radiation parameters (wavelength, intensity, pulse energy, duration of radiation) lead to different effects:

Low Power Lasers

In low power lasers, **fluorescence**, for one, can be used to diagnose bladder tumors, for example. For another, **photochemical processes** are used in low-level laser therapy (LLLT) and photodynamic therapy (e.g., in combination with methylene blue to kill bacteria).

Higher Power Lasers

In higher power lasers, **thermal effects** play an increasingly important role. In thermotherapy, the tissue does not sustain thermal damage. At approx. 60 °C, the tissue coagulates (e.g., during ablation of the blood vessels) and at approx. 300 °C the tissue **vaporizes** (which is referred to as so-called tissue vaporization). The latter is the effect used, for example, in surgery to cut soft tissue with a CO_2 laser or diode lasers.

Lasers and Their Mechanisms

High-Power Pulsed Lasers

One particularly efficient type of tissue ablation is **thermomechanical ablation**, which is used in connection with pulsed lasers with high absorption in water. The high absorption and high power of the laser pulse causes the tissue to heat up suddenly. At approx. 100 °C, the water vaporizes and the tissue rapidly increases in pressure, which can cause explosive tissue ablation. Due to fast and efficient ablation, the thermal damage of the tissue is significantly lower than with vaporization. In hard tissue, bones, teeth, and bladder and kidney stones, efficient and precise ablation can also be achieved, especially with Er:YAG lasers (see Fig. 3).

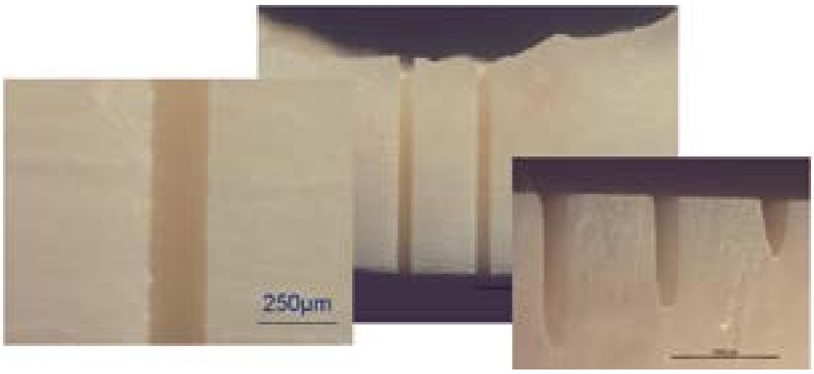

Fig. 3:
High-precision bone sections with diode-pumped Er:YAG laser
(Institute of Laser Technology, Ulm, Germany)

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Excimer Lasers

Excimer lasers are used in the UV range with short pulses and high intensity. Thus, not only the absorption in tissue but also the energy of the single photon is so high that ablation occurs with single atoms. This photoablation is used in particular in ophthalmology to correct corneal curvature.

Ultra-short Pulsed Lasers

In **photo-disruption**, the atoms in focus are ionized with ultra-short pulsed lasers in the nano, pico, or even the femtosecond range. This produces micro-plasma that can expand extremely fast and create an acoustic shock wave. This shock wave leads, for example in LASIK surgery, to high-precision ablation that is also used to correct ametropia. In deeper tissue, plasma and the pigments in tattoos, for example, can also be destroyed.

Author

Karl Stock, a doctor of human biology who also studied engineering, is the associate director of the Institute of Laser Technology in Medicine and Measurement Technology (ILM) at the University of Ulm and head of the equipment development workgroup. This workgroup primarily develops units and applicators for medical and dental applications – most often for industrial partners, such as, for example, laser methods for surgical and diagnostic applications, including those in the specialist areas of otorhinolaryngology (ENT medicine), urology, general surgery, and ophthalmology.

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