Lecture 1, 14.12.2022 - VO10

High resolution spectroscopy

The goal is to get narrow bandwidths in the range of natural line widths (so sub-doppler)

Bandbreiten in / für λ=500nm		Laser cw	Laser gep.	Gas M.B.	Natürliche Linienbreite
eV	1			$1 \cdot 10^{-5}$	
cm^{-1}	8065.5	$3 \cdot 10^{-5}$	$2 \cdot 10^{-2}$	$8 \cdot 10^{-2}$	
MHz	$2.4 \cdot 10^{8}$	1	500	3000	10
Å	12399	$8 \cdot 10^{-6}$	$4 \cdot 10^{-3}$	$2 \cdot 10^{-2}$	

Hyperfine splitting ("not annoying but confusing")

Energy levels are split into several sub-levels
Sodium D2 line

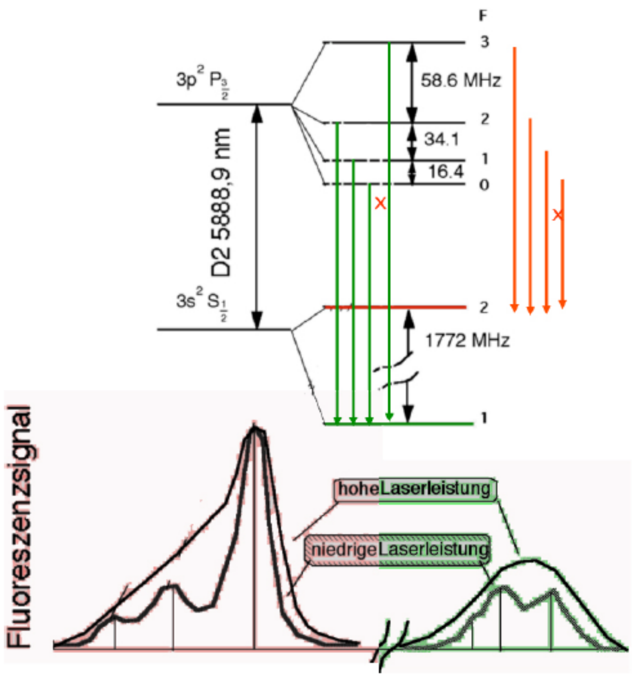
Hyperfine splittings are usually in the order of 1-100MHz → can only be resolved with narrow-band (single mode) lasers.

Sodium atoms in a beam, crossed at 90° by laser (→ no doppler).

Nuclear spin → magnetic moment I

Electron spin → moment J
Total moment F = I+J

Ground state s1/2
Upper state p3/2



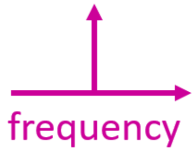
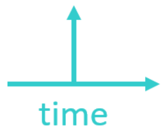
Only the left 3 green lines will be observed because? (something with conservation of momentum)

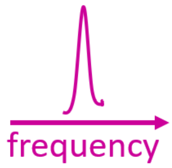
- Left side (Red Fluoreszenzssignal) transitions from higher state to level 2 in lower state.
- At small laser powers the hyperfine lines can be well resolved. Lines get broader with higher intensity: saturation effect. Increased intensity leads to higher FWHM, broader Laser spectrum → individual lines can no longer be observed

Lecture 2, 11.01.2022 - VO11

Continuous Ultrashort Laser Radiation

- A constant and a delta functions are a Fourier-Transform pair

Beam type	Irradiance vs. Time	Spectrum
Continuous	 (signal as long as infinity)	
Ultrashort pulse	 (infinitely short pulse)	 (all frequencies possible)

Pulse type	Irradiance vs. Time	Spectrum
Long		
Short pulse in reality leads to more Gaussian spectra in frequency domain, than a constant function		

- The uncertainty principle says that the product of the temporal and spectral pulse widths is greater than ~1

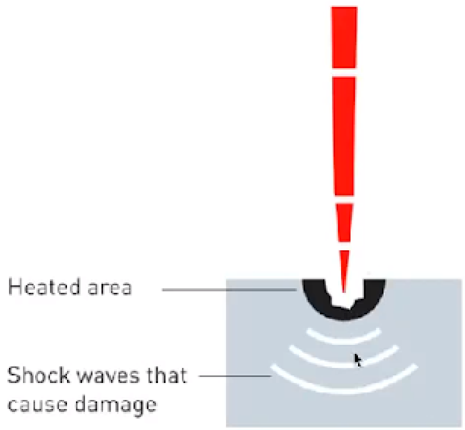
Femtosecond pulses are formed by the superposition of a high number of resonator modes. This technique allows the generation of light signals on much shorter time scales than electrical switches can react ($\sim$ nanoseconds, 1 ns $= 10^{-9}$ s). The higher the number of locked modes the shorter the pulse, see Fig 1. The physical limit of the pulse length is given by the duration of a single optical cycle, i.e. the wavelength of the laser. The pulselength-bandwidth-product (PBP) describes that limit in a mathematical way :

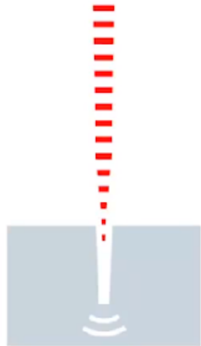
$$\Delta\tau \cdot \Delta\nu \;\geq\; K \qquad (1)$$

$\Delta\tau$ and $\Delta\nu$ represent the temporal and spectral full width at half maximum (FWHM), respectively. The constant K depends on the shape of the given pulse :

$$\text{gaussian}: \quad K = 0.441 \quad , \quad \text{sech}^2: \quad K = 0.315$$

Pulse sources   Generate different effects in different materials

<table>
<tr><th colspan="2">TYPE OF LASER</th></tr>
<tr><th>Nanosecond</th><th>Femtosecond</th></tr>
<tr><td>Heat, damage, and shockwaves

</td><td>Soft pulses, light is not dissipated as heat (time pulse is too short)

Small bubbles (small crystals that you can write on, this can be used in surgery)
</td></tr>
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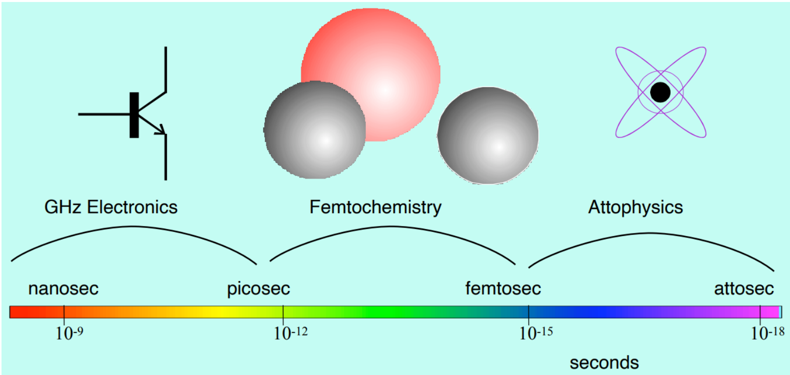
Ultrashort pulsed lasers (USPL)

Characteristics:

- Order of **femtoseconds** (10^{-15}) to ten picoseconds (10^{-12})
- Broad optical bandwidth → Large gain profile → enough frequencies have to be available
- Mostly Ti-Sapphire and Dye LASERS (easy to handle, around 800 nm→ Infrared)
- Relevant physical effects involved:
    - <u>Chromatic dispersion</u>: Phase velocity and group velocity of light propagating in a transparent medium depend on the optical frequency
    - <u>Kerr Effect</u>: nonlinear optical effect which can occur when light propagates in crystals and glasses, but also in other media such as gases. It can be described as a **change in refractive index** caused by electric fields, and being proportional to the square of the electric field strength
    - <u>Raman Scattering:</u> The nonlinear response of a transparent optical medium to the optical intensity of light propagating through the medium is very fast, but not instantaneous. In particular, a delayed nonlinear response is caused by vibrations of the crystal (or glass) lattice → as long as it is associated with photons
    - <u>Gian Saturation:</u> An amplifier device such as a laser gain medium cannot maintain a fixed gain for arbitrarily high input powers, because this would require adding arbitrary amounts of power to the amplified signal. → Gain must be reduced for high input powers
- The importance of ultrashort lasers relies on its applications:
    - GHz → Electronics
    - Femtochemistry
    - Attophysics



Attosecond Physics:

- Possible with short-pulse lasers   very small type of movement is observable.
- Small lasers produce high intensity levels at a small amount of time. The goal is to eventually be able to generate ELI (petawatt).
- Very doubtful results

Drawbacks:

- Dealing with high optical powers
- Nonlinear optical phenomena → Chromatic aberrations of the focusing optics unless special correction techniques are employed

Creation of ultrashort pulses

1. Requirements: Large gain profile (large frequency spectra given by the resonator modes)
2. All the intensities must be added (superimposed → added overall intensity)
    a. This is a consequence of a non phase-relation:
    $E_{total} = E_1 + E_2 + cos\delta(phase\ shift\ -->\ interference)$
3. Mode coupling/locking: Passive or active
    + **Self-phase modulation is used to increase the number of frequencies**
4. Pulse compression

Consideration: Population inversion lasts for a definite amount of time. Pulse time of pulse lasers is given by finite time characteristic of population inversion. However it has NOTHING TO DO WITH ULTRASHORT PULSES.

Mode-locking

- Related to the creation of "many frequencies", but also to the medium and how the laser is designed/built
- Important to avoid mode competition
- Different modes are forced to oscillate in phase (max of each mode is at the same location)
- Intensities of modes are summed via a phase relation between these modes, resulting in superposition electric field:

$$E_{aus} = \sum_{-(N-1)/2}^{(N+1)/2} E_n e^{i2\pi[V_0 t + \Delta V_{Mode} n t + \phi_n]}$$

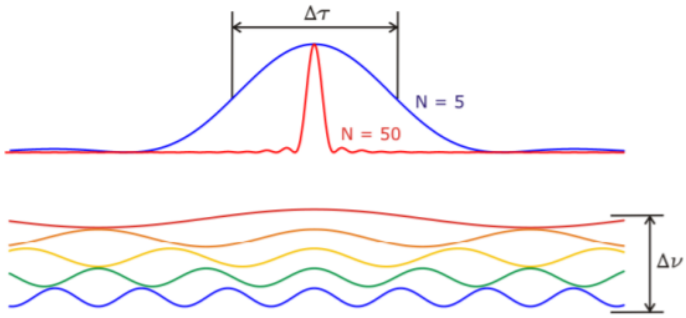
Where: En = amplitude of n-mode (= monochromatic oscillator), V0 = central frequency, ΔVmode = distance between modes defined by resonator length, ϕ_n = individual phase of each mode

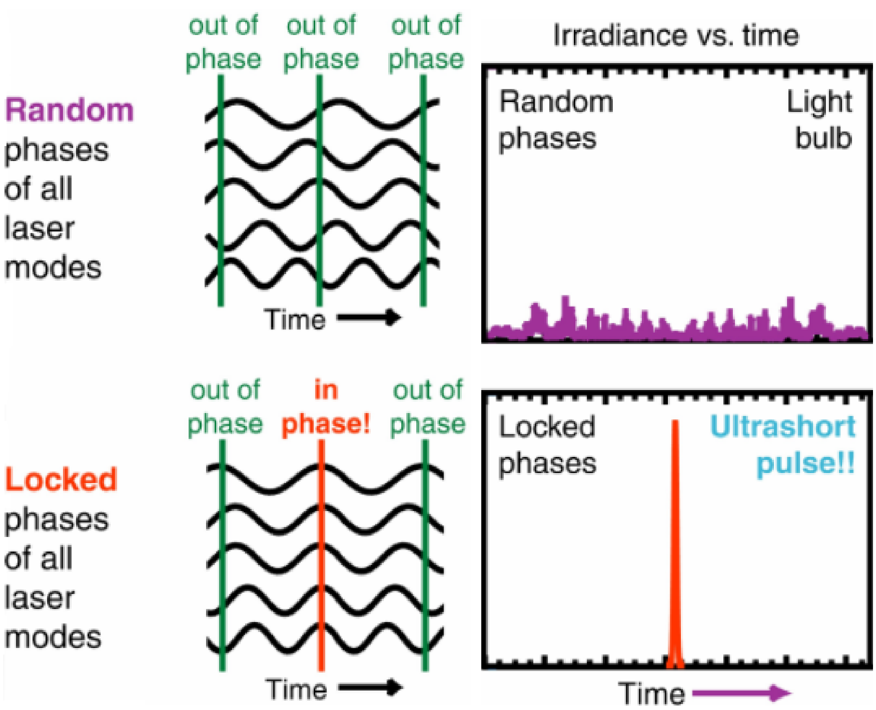
When ϕ_n is constant: $E_{aus} = E_0 e^{i2\pi V_0 t} \frac{sin\,[\Delta\nu_{Mode} Nt]/2}{sin\,[\Delta\nu_{Mode} t]/2}$

Time between pulse maximas: $T = \frac{2d}{c} = \frac{1}{\Delta\nu_{Cavity}}$, where d - length of the resonator, c - speed of light

Pulse broadness: $\Delta T = \frac{2\pi}{N \cdot \Delta\nu}$, where N = total number of modes, Δν = frequency range

More resonator modes are used in mode-locking, better the superposition, shorter the resulting pulse!



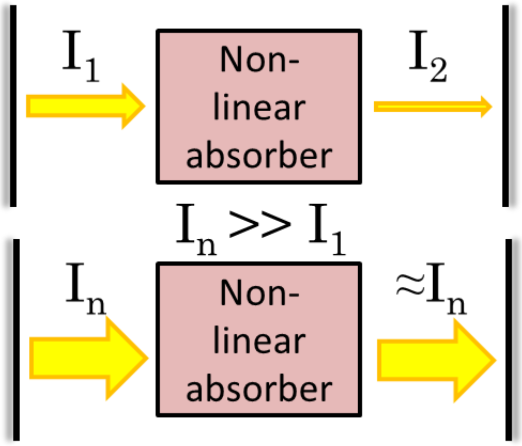


Passive mode-locking

Non-linear absorber means that at some high value of intensity I, **absorption will go to saturation (doesn't increase any more)**, so the medium becomes **transparent** for the beam of light.

Almost all the intensity is transmitted (lower picture on the right) and one **strong mode will create a "transparency window".**

The **other modes** will see this "window" and they will adapt to it (= **become in phase**) because for them it is the path with **lower losses**.



High intensities = small losses due to the optimal pathway

Requirements:

- LASER is in CW mode and Linear resonator
- Non-linear absorber (it must absorb the same frequencies that are produced by the resonator)

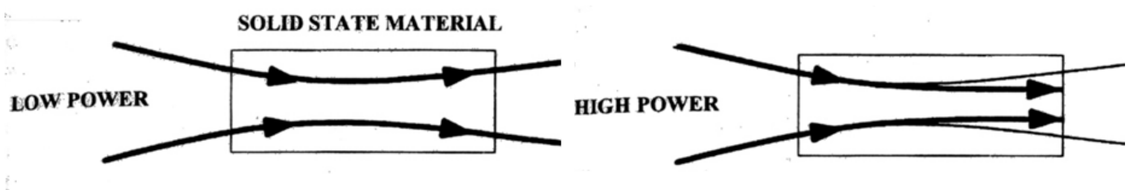
Active mode-locking

We introduce actively opening and closing in a crystal with a modulator. It is performed by an electro optic modulator, leading to periodic transmission or no transmission regimes of the crystal. Now, this technique is not popular.

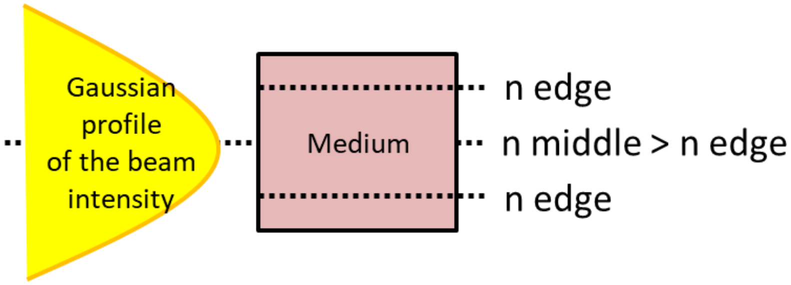
Kerr-lensing

- Refractive index of the medium is dependant on the light intensity

$$n(I) = n_0 + n_2 I$$

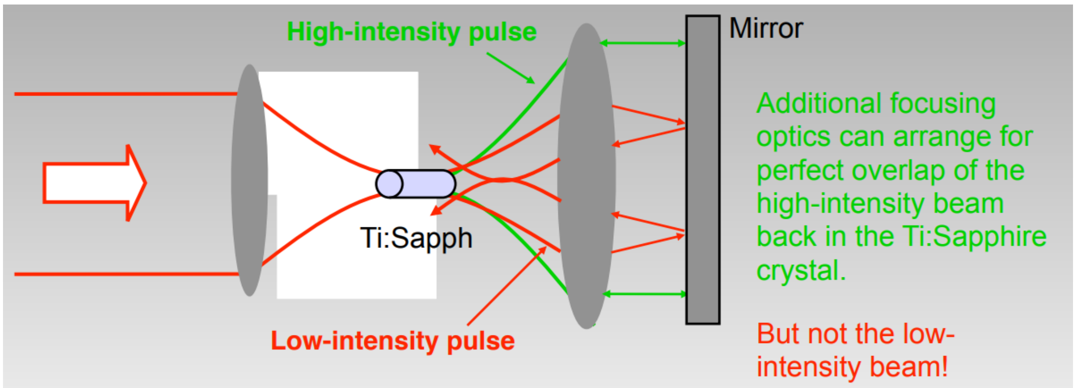


- In the case of Gaussian profile of the beam, refractive index n is higher in the middle (higher intensity of the beam passing the medium) than at the edges, so the medium operates as a lens
- It is called Kerr-lensing, when the medium starts focusing the beam = acting like a lens due to difference in the profile intensities



Saturable absorber (Kerr-Lensing Effect)

If a pulse experiences additional focusing due to high intensity and the nonlinear refractive index, and we align the laser for this extra focusing, then a high-intensity beam will have better overlap with the gain medium.

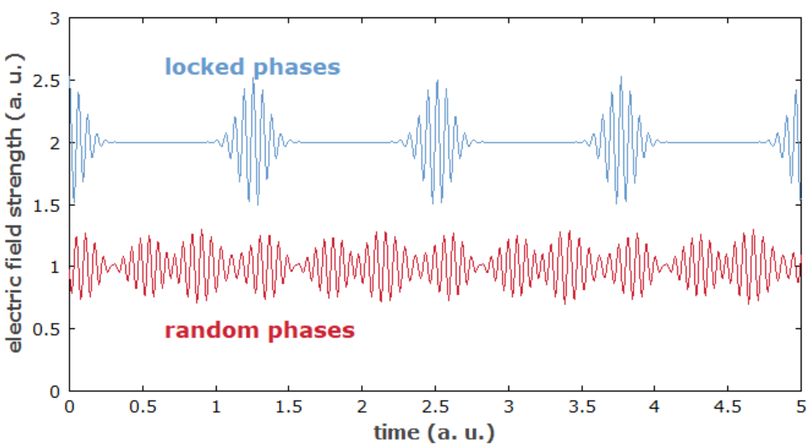


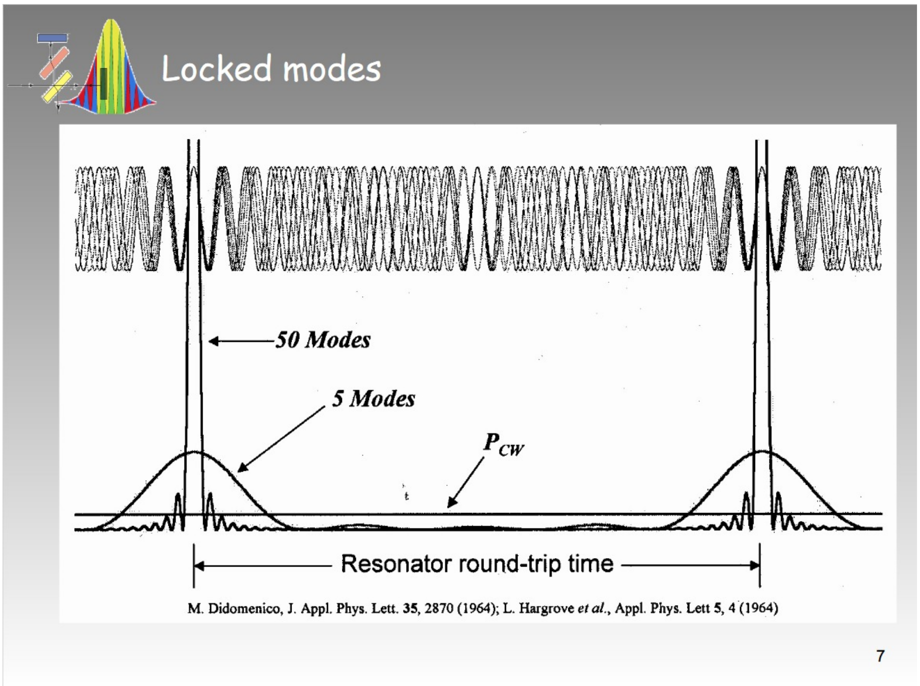
★ Placing an aperture at the focus favours a short pulse.

★ Losses too high for a low-intensity cw mode to lase, but not for high-intensity fs pulse.

How to know if the LASER is mode locked?

To know if a LASER is mode locked or not, one has to measure the output spectrum.

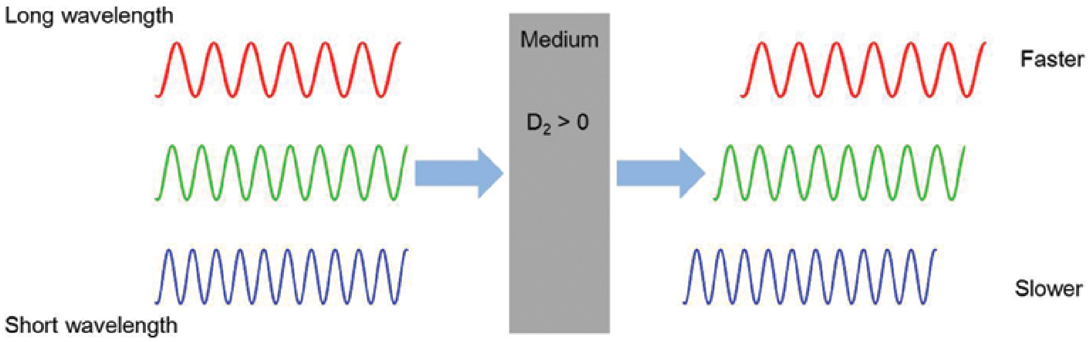




Ultrashort Pulse in a Medium: Chirping

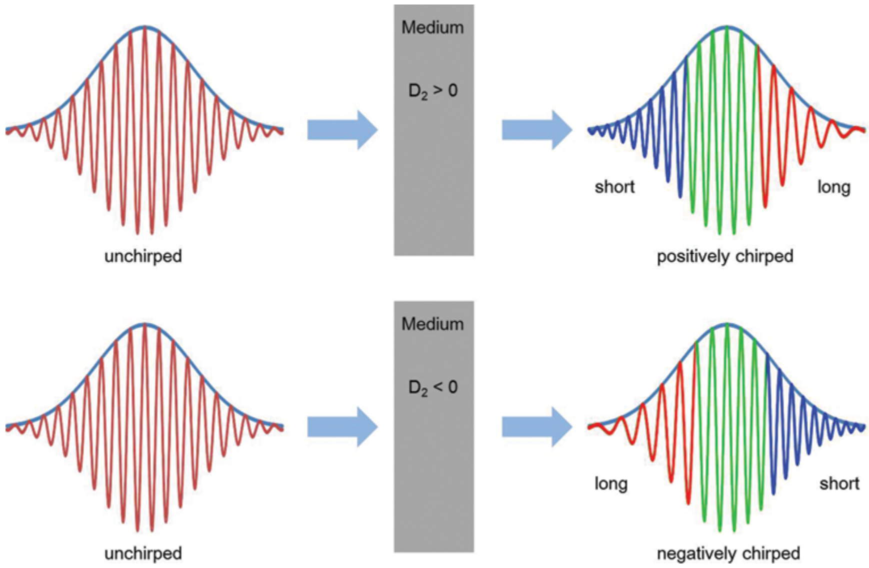
Ultra-short pulse has a lot of different frequencies (Δt*Δf = 1). When the pulse passes a dispersive medium each frequency gets a different velocity due to the differences in refraction index. For example, low frequency components travel faster than high frequency components (up-chirp phase modulation). So the pulse **broadens in TIME domain**. At each moment of time different frequency components are presented.

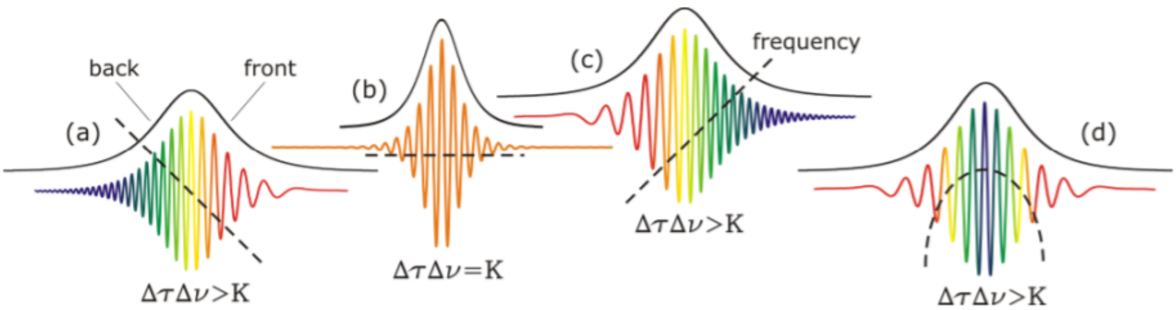
- The **refractive index n(w)** has a severe consequence = group velocity dispersion
    - Group velocity $V_s = dw/dk$, where w - angular frequency, k - wave vector
    - Group velocity dispersion $dV_s/dw = 1/V_s * d^2w/dk^2$
- **Group velocity dispersion** = frequency components of the beam speeding up differently resulting in the broadening of the beam at z-axis = **Chirp**



- However, the frequency spectrum is not broadened (in contrast to self modulation) but stays the same. So the amount of frequencies before obtaining the chirp is the same as after.

- Phenomena responsible for the acquisition of a chirp (= temporal broadening of pulse):
  - Group delay dispersion
  - Chromatic dispersion and nonlinearities (Kerr effect) in a transparent medium.





- All pulses (a-d) have the same spectral width Δv but different duration Δt.
- The shortest pulse (b) is not chirped:
  - the pulse duration is at minimum
  - instantaneous frequency is constant
  - Proper phase between modes
- In (a) blue components are delayed with respect to the red ones, vice versa (c)
- Up-chirp means that the instantaneous frequency rises with time (c), and a down-chirp means that the instantaneous frequency decreases with time (a)
- Case (d) is quadratically chirped

Ultrashort Pulse in a Medium: Self phase modulation

It happens due to non-linear refractive index of the medium (if you take a look to the formula of refractive index, you will see that the refractive index depends on intensity I)

If intensity is large, we see the contribution of the non-linear effects.

Outcome: spectral broadening = **additional frequency components** are presented in the e/m wave, they depend on the derivation of the intensity dI/dt (increase/decrease).

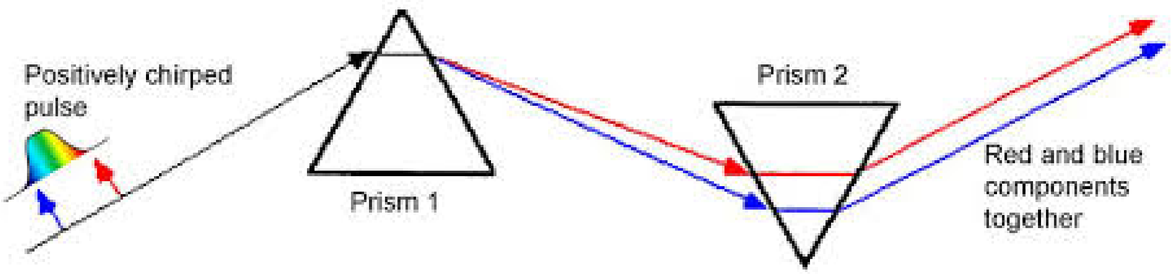
Refractive index: $n(I) = n_0 + n_2 I(t) \quad \Rightarrow \quad w = w_0 - [n_2 w \frac{z}{c}] \cdot dI/dt$

Chirp compensation

Pulse compression to compensate temporally (chirp) and spectrally broadened pulses which can be done in different ways:

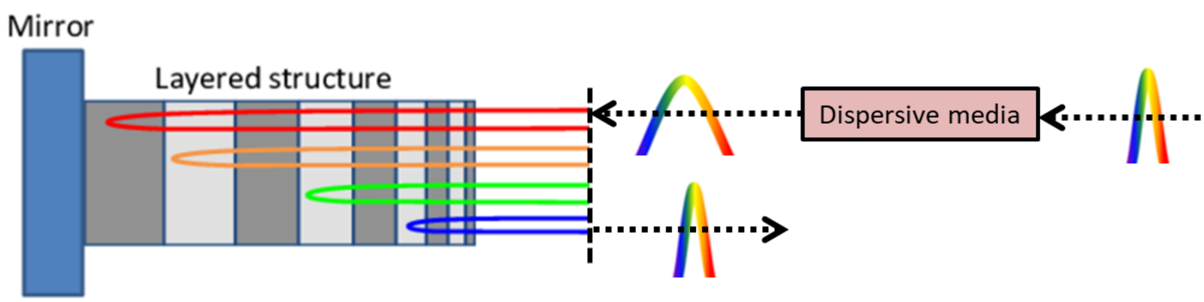
1. Pulse compression with prisms

Rotating inverted and normal prisms and a system of mirrors called **"inverse dispersive" elements** lead to simultaneous arrival of reflected modes and shortening of the signal



2. Pulse compression with chirped mirrors

Chirped mirror has a multilayered structure, which leads to simultaneous arrival of reflected modes and shortening of the signal



Optimising of pulse shape and arbitrary pulses

- The most fascinating thing for Wolfgang Husinsky
- Performed via **genetic procedure** = changing of frequencies and phase shifts

Considerations:

1. How can we choose the best pulse and frequency for a certain experiment?
2. Schrödinger equation describes the systems and it needs potential, then it maybe solved
3. The system itself knows its Hamiltonian **H**, but experimentators don't know it
4. Maybe the system adjusts itself to the best pulse form, which provides the best results

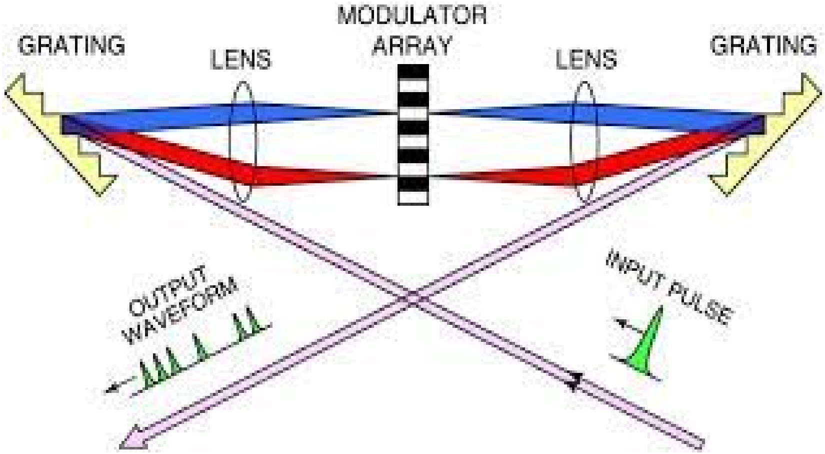
$$i\hbar \frac{\partial}{\partial t} \Psi = \hat{H} \Psi$$

5. Arbitrary pulses can be extended via Taylor series around the main frequency

$$\varphi(w) = \varphi_0 + \varphi_1 * (w - w_0)/1! + \varphi_2 * (w - w_0)^2/2! + \ldots$$

where $\varphi_1 \sim$ group velocity delay, $\varphi_2 \sim$ group delay dispersion, $\varphi_3 \sim$ chirp

Fourier Transform/Fourier-Synthesis pulse shaper



Acousto-optic modulator (AOM), usually a special crystal, allows amplitude and phase modulation

Lecture 3, 18.01.2022 - VO12

Genetic Loop Pulse Generation (Learning Algorithm)

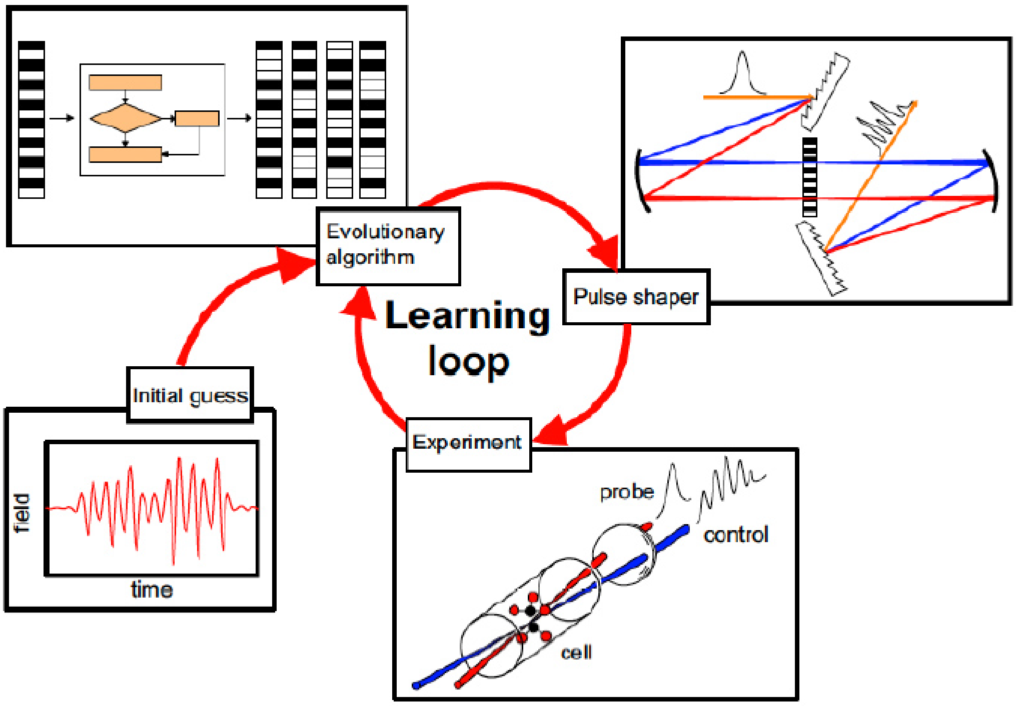
Premise: In complex systems it is not possible to know the following details:
- Dynamics of the system
- The ideal pulse (How can it be determined? How will this influence the output?)
  - Frequency, …

We only have some estimates for the parameters.
But: "The system knows its Hamiltonian"' → similar to recursive functions: new pulses can be generated in a loop and the proper/relevant conditions can be selected by an Evolutionary Algorithm:

Evolutionary Algorithm

- Taken from nature, where species can undergo: cloning, mutations and recombination
  - "Best traits are passed on to the offsprings"
- Experiments should be done "in-situ" and quite fast since this is an adaptive algorithm
  - The experiment is done several times (~100 - 1000 times) with different parameters ("first generation") -> It is analysed how well it worked
  - New experiment ("next generation") with the best pulses from "first generation" -> better outcome
  - New experiment …
- Each generation should show an improvement compared to the previous results
  - BEST PULSE FORM COULD BE FOUND

Laser self-adaptation

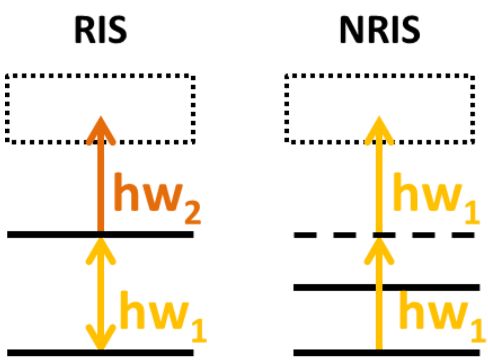


Drawbacks	**Advantages**
In a experimental setting even under the same conditions, results may vary Laser intensity could change (Observed in the phase function) Only makes sense if experiment can be performed very quickly Experiments could become very complex	Pulse adaptation by “fitting” → model becomes better with time In short pulses all adjustable parameters are available

Ionisation Spectroscopy

Molecule is	Photonic Phenomena	Technique	Sensitivity
Excited	Fluorescence takes place Then the photons are detected	Fluorescence spectroscopy	Only 1% can be detected due to the solid angle
Ionised	Electron is in free state Molecule turns to an ion+ Ions are caught by electrodes	Ionisation spectroscopy	All the electrons/ions can be detected

- Intensive lasers are needed
- 1 atom in cm3 can be detected with ionisation spectroscopy
- There is a possibility to fragment a molecule leading to problem with results interpretation
- E (energy between ground and free states) is too large for most of lasers, so two laser beams are used for excitation



Resonant ionisation spectroscopy (RIS):

- Pulse dye laser is used to excite an electron ($h\omega_1$) - resonance process
- The a less selective excimer laser frees the electron ($h\omega_2$) - non-resonance process

Non-resonant ionisation spectroscopy (NRIS):

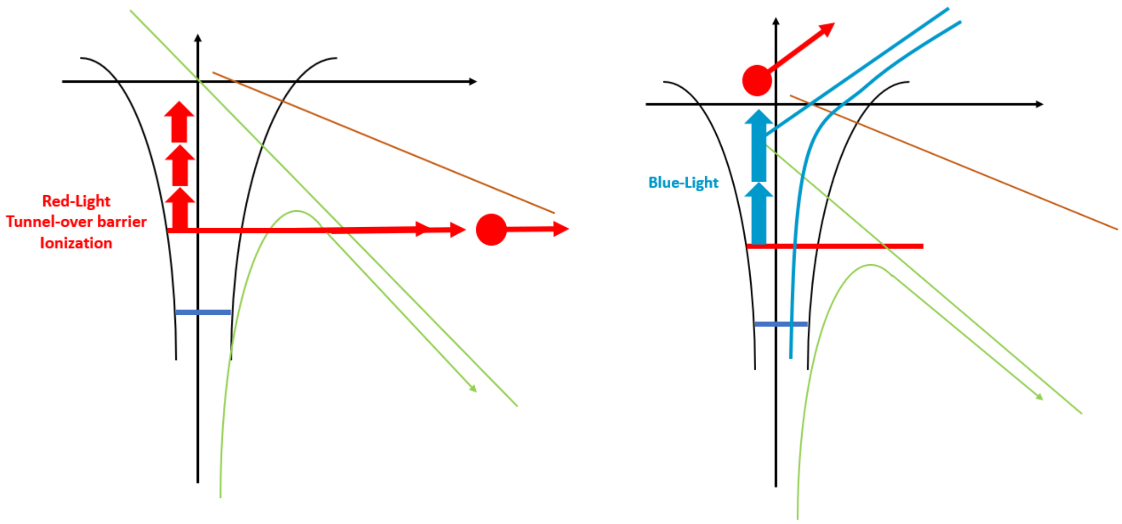
- Two identical excimer lasers are used to move an electron ($h\omega_1$) to a non-stable level and then to the free state ($h\omega_1$) - non-resonance process
- Simultaneous arrival of both photons from these two lasers is required (hard alignment of electronics)
- Quasi-resonance process can happen, when the non-stable level is close energetically to a real level of the molecule

Ionisation Spectroscopy + Mass spectroscopy = distinguishing ions

Advantages	Disadvantages
Everything contained inside a volume can be ionised Alignment in time and space → electronic adjustment and overlapping	Quantitative interpretation can be very difficult → different isotopes have distinct hyperfine structures

Ionisation with Ultrashort Pulses

- **Keldysh parameter ɣ <1** → When the Rate Equations (assume stability) are no longer applicable, we move to the non-equilibrium state in Quantum Mechanics
- In other words Keldysh parameter describes quantum mechanical evolution of a non-equilibrium state
    - This parameter describes the evolution of a system subject to time varying external e/m field
    - Quick and strong change of E creates a certain Δt for tunnelling
    - Observed effect: Tunnel Over Barrier Ionisation → Before we used to observe the changes in electron population within the energy levels



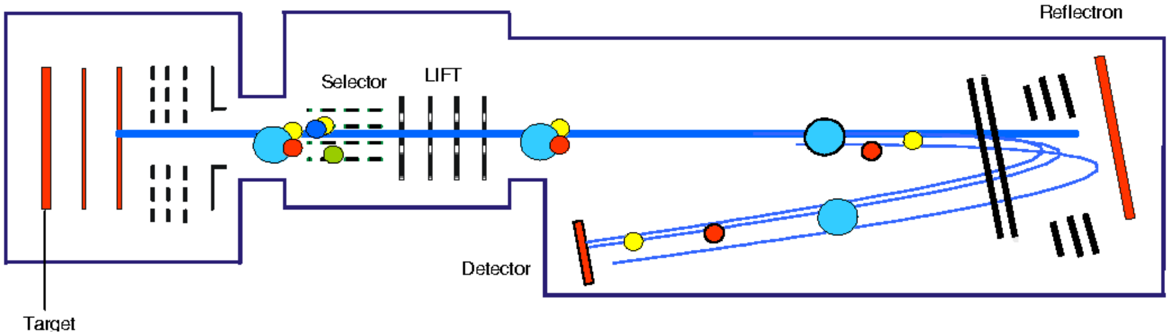
γ > 1: Resonance effect, multiphoton absorption, material dependent
γ < 1: Field ionisation and tunnelling, material independent (high E field leading to excitation of electrons. At very high intensities may lead to plasma formation)

Time of Flight Spectrometer

- Target may be rotatable
- Several laser beams may be used to ionise the molecules of target
    - First laser beam to extract particles/molecules from target (ablation)
    - Second laser beam to ionise particles
        - This second beam can also be used to measure the initial velocity of the particles extracted from the target. The second laser makes short

pulses at specific timepoints -> only particles that pass the beam at this moment get ionised.

- Ions are accelerated by high voltage into the chamber with refletron
- Reflectron (analog to chirped mirror) allows distribution of ions, so that their arrival time to the detector depends on their masses
- Uncertainty of the arrival time: initial velocity of the ions before being accelerated by high voltage and their origin (place) of ionisation -> reflectron counteracts this uncertainty



Applications of Lasers in Medicine

Very rough classification in 3 different ablation types. In reality these types often overlap.

Characteristics	Effects
Thermal Laser Ablation Example: CO_2, Nd:YAG	
Relatively low laser intensity Long pulses (slow process) Threshold heat conduction	Energy is absorbed, molecules are excited to vibrational states = increase in temperature due to friction Heat will be conducted through some area The place, where the temperature of evaporation is reached, flies away The remaining part, where the heat was conducted, will be damaged Result: damaged tissue
Explosive Laser Ablation Example: Ultra-short laser, IR, Er:YAG	
High laser intensities Short pulses (fast process) Threshold heat conduction	Energy absorption will result in a fast excitation to vibrational levels -> excited tissue flies off in an explosive way Very fast process, so no time for heat conduction Result: less damaged tissue

Photochemical Laser Ablation (Cold) Laser example: ArF excimer laser for cornea, dye laser	
UV light is required to excite a molecule to unbinding state The laser type and its characteristics should be specifically chosen for aiming target Intensity function has no threshold Long or short pulses can be used	When material is excited to unbinding state, the molecules will break Particles removed without reaching vibrational state (cold ablation) Only thin surface layer is influenced Very precise and slow Result: almost no damaged tissue

Lecture 4, 25.01.2022 - VO13

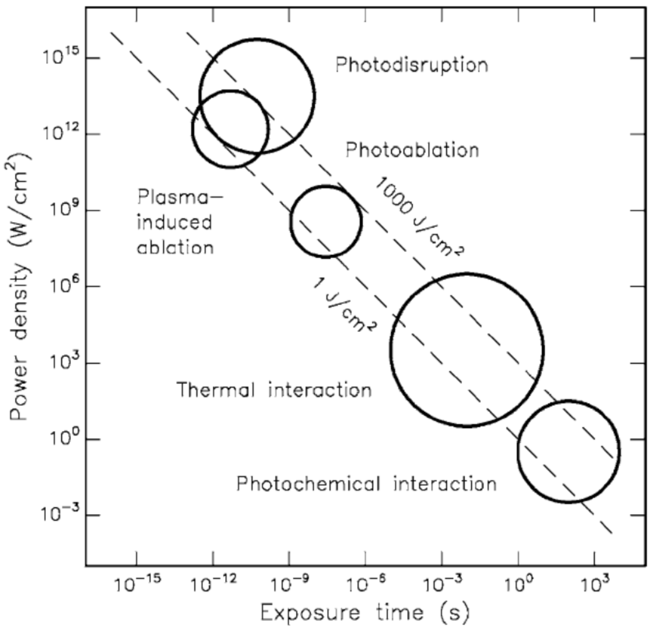
At high intensities the overlap of ablations happens: **Optical breakdown**, leading to Tissue Ablation
It includes:

- Plasma formation (dielectric breakthrough)
- Shock wave generation
- Cavitation (leading to Jet formation)

Power density and exposure time correlation leading to different processes

For medical applications we need lasers with:

- Small bandwidth
- Small beam divergence
- High spectral density



Laser Thermotherapy Modelling (Comsol)

Helmholz equation: Heat diffusion (propagation through some tissue)

$$\frac{1}{c'}\frac{d}{dt}\Phi(r,t) - \nabla D(r,t)\nabla\Phi(r,t) + \mu_a\Phi(r,t) = S(r,t)$$

Multi-photon imaging

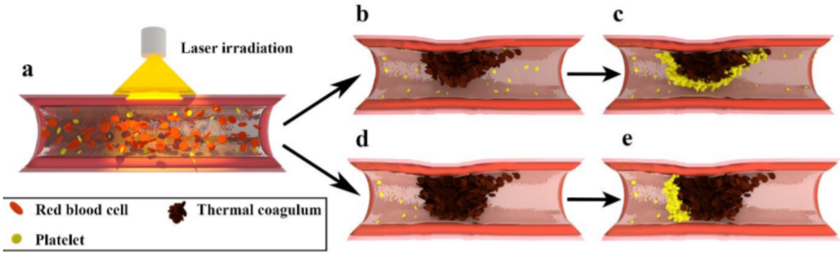
- Femto laser is used to excite a matter being microscoped
- Two photons are used for excitation
- The probability of two-photon absorption increase with intensity squared (I^2)
- This method is used to achieve **higher resolution** because the Gaussian profile gets sharper
- P.S. Resolution is proportional to the half-width of the Gaussian spectra of the light intensity (cannot be smaller than the order of the wavelength)

Laser-Thermotherapy

- Laser is used to heat the tissue to the critical temperatures which enables coagulation (denaturation) of proteins in the treated tissue.
- Denaturation of proteins causes the death of cells
- We should avoid surpassing the critical temperature for the areas surrounding the treated tissue

Treatments:

- Laser thermotherapy of port-wine stains: destroying blood vessels causing the stain



“Non-thermal” ablation

Corneal surgery: Correction of Myopia or Hyperopia (changing cornea thickness)

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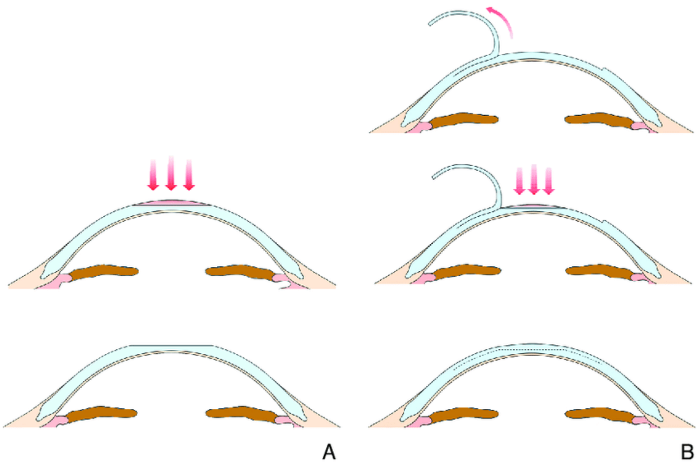
<tr><td colspan="2">
</td></tr>
<tr><td>A: Reducing thickness of cornea in the central region to treat Myopia

Disadvantage:
Removal of top layer leads to pain and complicated healing procedures</td><td>B: Firstly, cut and flip the top layer. Secondly, reduce the thickness of cornea in the central region to treat Myopia. Then flip the top layer back.

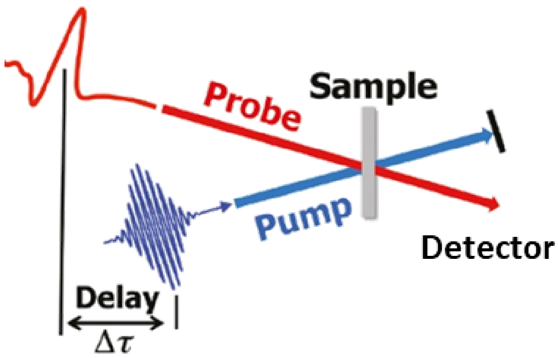
The top layer can be cut using:
Microkeratome or by Nd YAG laser</td></tr>
</table>

Skin resurfacing (Dermatology)

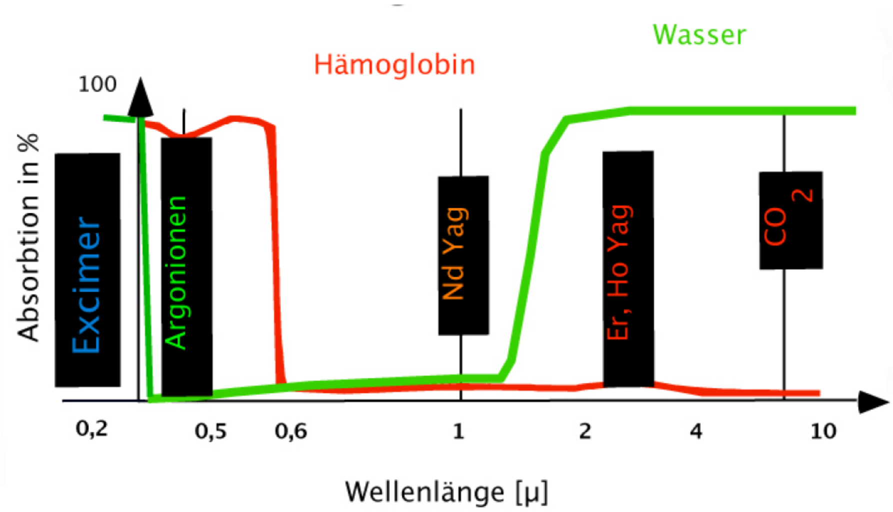
1. At 51 °C collagen shrinks (tightens the skin -> wrinkles are removed)
2. And the top layer of tissue is removed (new skin is generated -> less stains)

Michelson interferometer

- Splits the pulse into two and the time delay between them can vary
- These two pulses are used for analysing the system development
- In other words second pulse (probe) brings the data about the behaviour of system+1st pulse (pump)
- Used in Pump-probe Spectroscopy



Using solid state lasers



Water absorbs the light in the range of 0,6 - 1 micrometre poorly. So the Nd Yag laser with 1000 nm = 1 micron (infrared) seems useless in dermatology (skin contains a lot of water). But why is it still used?

We can use frequency doubling technique, which includes laser power (=intensity) increase, and we get a 500 nm light beam, but still water doesn't absorb it well due to the graph. However, **the intensity increase** results in:

- Multiphoton absorption probability increases
- Damaging of the material leads to new energy levels, which will start absorbing
- Also high e/m field (Keldish parameter $\gamma<1$) changes the configuration of the levels. It facilitates tunnelling and ionisation (=absorption).

We may increase intensity by focusing Nd YAG lasers in the spot

Advantage: We can focus it below the top layer of the material and cut the top layer like it is used in eye surgery. Miracle!

Cuts or ablation are performed at the surface. Therefore, there is no direct contact. But the LASERS can also cut beneath and within the tissue. :)

Alt Tests

1. For warm-up check in the Antwortbogen, which "items" are required for producing ultra-short radiation [Discussion].

Short light pulse needs a high number of interfering modes and/or a wide laser gain profile.
→ active or passive mode locking
Active: shutter (AOM, pockels cell) in resonator closes roughly in same frequency as mode spacing of resonator. Modulation frequency and its harmonics are phase-locked.
Passive: mostly used.
non-linear absorber (e.g. dye) inserted into the resonator → works as an absorber at low laser powers. In Ti:Sapph laser Kerr-lensing is used for mode locking: The high intensity beam is focused so that there is a better overlap with the gain medium than for the low-intensity beam.
Very fast increase of intensity when threshold value of absorber is reached, non-linear curve. Again, the harmonics are phase-locked and add to the intensity.

Self phase modulation: in dispersive media (refractive index n dependent on ω and Intensity) the pulse is delayed, broadened and a frequency chirp is imprinted. If n depends on intensity also the frequency spectrum broadens → n(ω,I) has a non-linear component!
$n(\omega, I) = n0(\omega) + n2I(t)$--> omega is Intensity dependent.
The spectral broadening is needed to create the ultra-short pulses in the first place, the broadening in the time domain hast to be compensated by Pulse compression:
Send pulse through two parallel gratings to compensate for the widening through different optical path-lengths for different wavelengths.

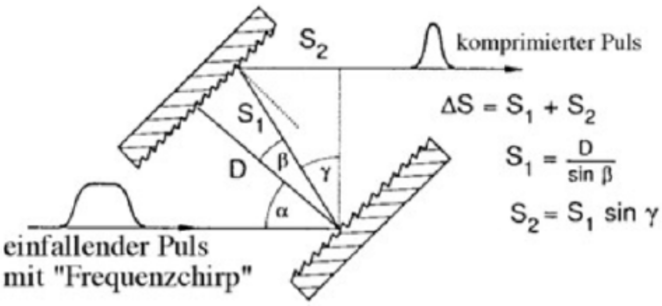


Figure 3.30. Pulse compression with a pair of grids.

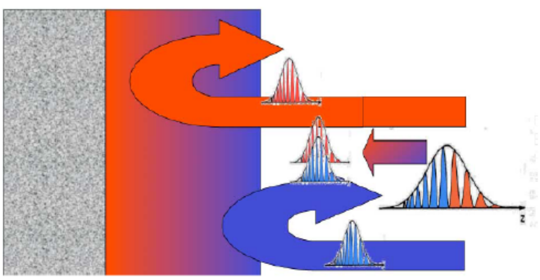


Figure 3.33. Chirped Mirror.

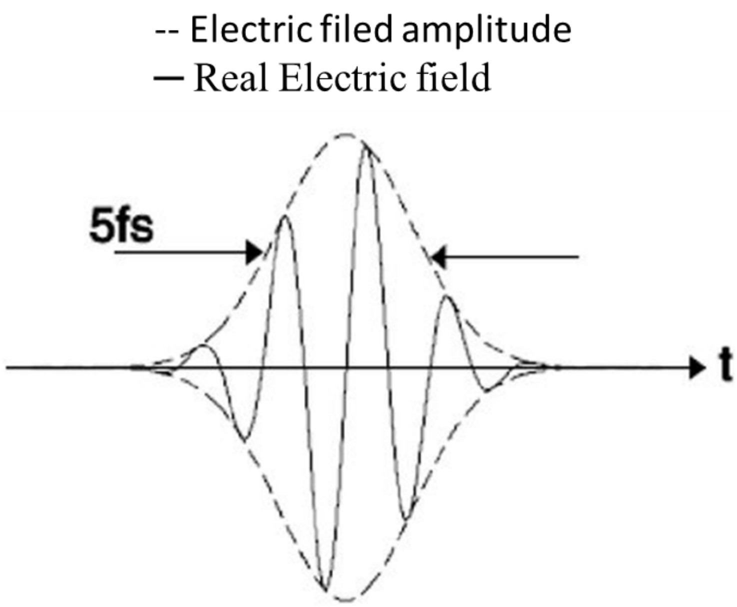
Other way to compensate for Self phase modulation: Chirped mirrors
Different spectral components are reflected in different depths of the mirror causing frequency dependent group-speed delay.

2. Describe the principle of ultrashort laser system and what you need for realising an ultrashort laser system (include sketch) [Discussion].

The same as question 1

3. In particular also comment on the formula shown, which gives the output electric field of an ultra-short laser oscillator (make a plot that contains pulse and length) [Correct choices]:

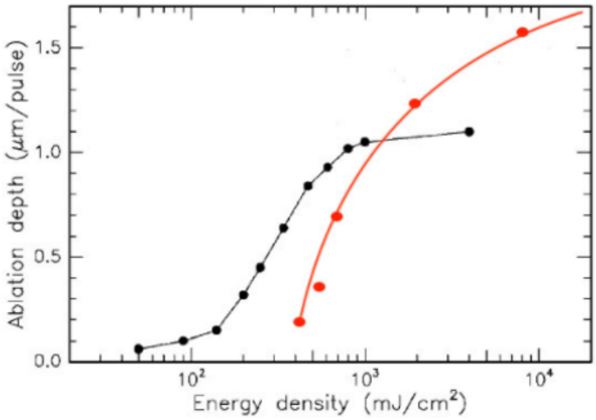
$$E_{aus} = E_0 e^{i2\pi V_0 t} \frac{\sin\,[\Delta\nu_{Mode} N t]/2}{\sin\,[\Delta\nu_{Mode} t]/2}$$



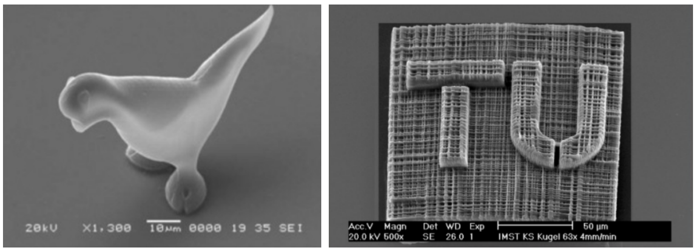
- Pump laser for population inversion of media
- Laser resonator
- Mode locking
- Self phase modulation

4. The following figure shows the ablation curve of a rabbit cornea obtained with 2 different laser types (Laser (a) black and Laser (b) red). Which of the following statements are correct [Correct choices]:

- Laser (a) will allow more precise modification of the tissue (cornea)
- The ablation dependence on laser intensity for laser (a) shows a very low threshold
- The best working condition for laser (a) according to the ablation curve is around $10^2 mJ/cm^2$

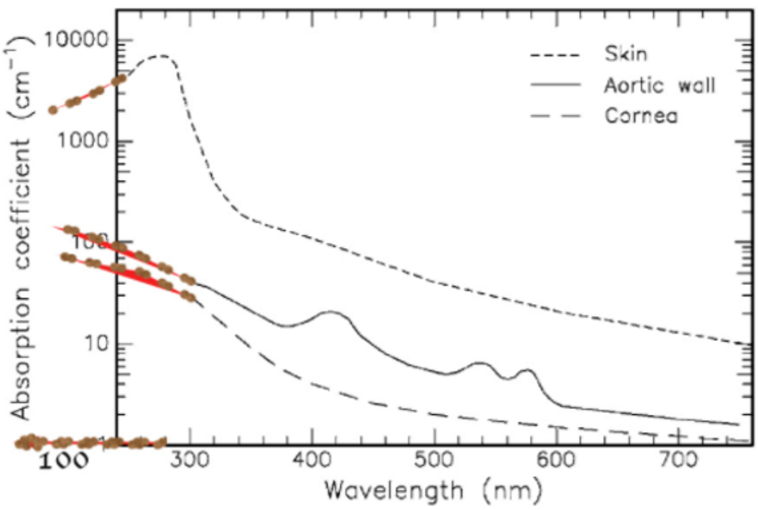


5. The 3D object shown in the figure has been produced with two-photon polymerization (TPP).Two-photon as well as other multiphoton polymerization processes can, in principle, take place in materials. Check all the correct statements [Correct choices]:



- Two photon polymerization represents a special case of nonlinear effects happening when lasers interacts with materials
- Realistically ultra short lasers are required for two-photon polymerization
- Realistically ultra short lasers are required for three photon polymerization
- Traditional one photon polymerization can be realised with more types of lasers or even powerful lamps

6. In the following figure the absorption dependencies on wavelengths for some human "materials" are shown [Discussion].



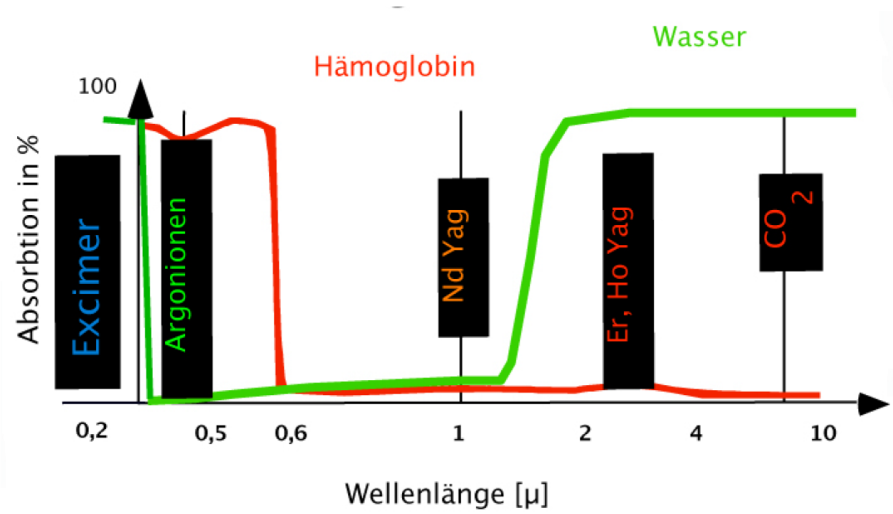
134.154 Laser in Physics, Chemistry, Biology and Medicine, Test 3

a. **Fill (mark) into the figure below useful lasers at the appropriate wavelengths (Type of laser and its wavelength must be given) [Discussion]:**

Skin (a lot of water): CO2 laser (10,600 nm), Er (erbium) Yag laser (2940 nm) + Excimer Laser (UV-light)

Aortic Wall: Argon-Ion, blood vessels closed through burning
Oxygenated haemoglobin: max absorption around 400 nm (Argon-ion laser)

Cornea (a lot of water): Excimer Laser, photochemical ablation, 193/248/308 nm (UV)



b. **Which can be used for treatment at least one of three tissue types are shown. You must also indicate for which tissues it can be used [Discussion]:**

7. For surgical applications what kind of "burning" can be realised with a LASER? Explain the underlying processes and by which lasers they might be "effectively" performed. Also explain how the different processes might be identified experimentally in a laboratory setup. [Discussion].

Explosive, Thermal, Photoablation

Additionally mark the correct statements below [Correct choices]:

- A pulsed laser is required for surgical applications in basically all realistic cases
- Excitation (by the laser) of electrons into antibonding electronic states of the molecular substances of a tissue helps to avoid thermal heating

<table>
<tr><th>Interaction ("Burning")</th><th>Power Density (W/cm2)</th><th>Exposure time</th><th>Pulse duration</th><th>Physical effect</th><th>Application</th></tr>
<tr><td rowspan="2">Photochemical: absorption (in the UV region) of light with wavelengths in the order of electron wavelengths of π-orbitals of organic molecules.</td><td>0.01-50 (~ 1)</td><td>> 1 s</td><td>1-CW</td><td>Excitation</td><td>PDT</td></tr>
<tr><td colspan="5">Examples: Photosynthesis, vitamin D synthesis, skin cancer, photochemotherapy, photodynamic therapy.</td></tr>
<tr><td rowspan="2">Photothermal: light absorption by vibrational- and rotational- bands.

**Extension of burn zone (duration of healing time) is dependent on penetration depth of radiation.</td><td>~ 1 to 10^6</td><td>~ 10^- 6 to 1 min</td><td>1µs-1min</td><td>Excitation +internal conversion</td><td>Coagulation, Vaporisation, Decomposition</td></tr>
<tr><td colspan="5">Examples: Coagulation, Vaporisation, Carbonization, Melting, Pyrolysis.</td></tr>
<tr><td rowspan="2">Photo Spallation: hydrodynamic process that enables ablation of tissue even below vaporisation.

Thin surface layer heated rapidly such that no "normal" thermal expansion is possible</td><td>10-10^6</td><td>< 1 µs</td><td><1µs</td><td>fast expansion</td><td>Refractive surgery</td></tr>
<tr><td colspan="5">Example: Ablating corneal tissue</td></tr>
<tr><td rowspan="2">Photo ablation: UV-light induced explosive removal of tissue</td><td>10^7-10^10</td><td>< 1 µs</td><td>10-100ns</td><td>Excitation + dissociation</td><td>Refractive surgery</td></tr>
<tr><td colspan="5">Example: Application: Refractive corneal surgery (excimer laser (e.g. ArF) with pulse durations of 10 – 100ns)</td></tr>
<tr><td rowspan="2">Plasma induced ablation: local electric field (plasma ionisation) strength of the light exceeds 10^7 V/cm</td><td>10^11-10^13</td><td>~ps</td><td>100 fs-500 ps</td><td>Ionisation</td><td>Refractive surgery caries therapy</td></tr>
<tr><td colspan="5">Examples: refractive corneal surgery, caries therapy</td></tr>
<tr><td rowspan="2">Photo disruption: optical breakdown within soft tissue or fluids that generates cavitation and shock waves.</td><td>10^11-10^16</td><td>~ns</td><td>100 fs-100 ns</td><td>Ionisation Creation of cavities Shockwaves</td><td>Minimal invasive surgery</td></tr>
<tr><td colspan="5">Application: Non-invasive surgery</td></tr>
</table>

8. Read the following 4 paragraphs from a "lasers in medicine" book. On a separate sheet comment on the text, in particular give reasons for the underlined sentences [Discussion].

Dermatology is one of the few medical disciplines where biosimulative effects of laser radiation have been reported. Positive stimulation on wound healing is one of the current topics of controversy. A considerable number of papers has been published, but most of the results could not be reproduced, and initial claims could thus not be verified. Moreover, the principal mechanisms of biostimulation have not yet been understood. In general one should be very careful when using laser radiation for such purposes, especially when applying so called “soft lasers” with extremely low output powers which most probably do not evoke any effect at all other than additional expenses according to Alora and Anderson (2000)

COMMENT:
High power, short pulsed lasers, are used in medicine to cut through or simply destroy certain tissue. Low power lasers are advertised as healing devices that help “stimulate” cells. (Alternative medicine alarm)

Radiation from the Nd:YAG laser is significantly less scattered and absorbed in skin than radiation from the argon laser. The optical penetration depth of Nd:YAG laser radiation is thus much larger. According to Seipp et al. (1989), major indicators for Nd:YAG laser treatments in dermatology are given by deeply located hemangiomas or semi malignant skin tumours. However, argon ion and CO2 lasers should never be replaced by Nd:YAG lasers when treating skin surfaces.

COMMENT:
In the range of 0,6 - 1 micrometer absorption of Nd Yag laser is very low, so it penetrates more. However we can reduce penetration by increasing intensity (=increasing absorption by water in the tissue).

Treatment of port wine stains with argon ion lasers is usually performed in several sessions. First a small test area of 4mm2 is irradiated. During this test a suitable power is determined by gradually increasing it until the skin visibly pales. According to Dixon and Gilbertson (1986), laser powers of 2-5 W are applied during an exposure time of 0.02-0.1 s. Immediately after laser exposure, inflammation of the skin frequently occurs. After four weeks…laser radiation is usually applied by means of a flexible handpiece. In the treatment of facial stains, the eyes of both patient and surgeon must be properly protected. One disadvantage of treating port wine stains with argon ion lasers is that it is rather painful to the patient. Depending on the location and spatial extent of the stain, treatment is performed during either local or complete anesthetization.

Less painful and probably even more efficient is the treatment of port wine stains with dye lasers. Although quite expensive, these machines have recently gained increasing significance in dermatology, especially in the treatment of port wine stains and capillary hemangiomas. Detailed studies were reported by Morelli et. al (1986), Garden et. al. (1988) and Tan et. al. (1989). Frequently, Rhodamine dye lasers are used which emit radiation at wave-lengths in the range of 570-590 nm. Typical pulse durations of 0.5ms and energy densities of 4-10 J/cm2 have been recommended.

COMMENT:
Ar-ion laser = 488 - 514 nm (shorter wavelength)
Rhodamine dye laser = 570-590 nm
https://www.semanticscholar.org/paper/Dye-laser-treatment-of-port-wine-stains-Bandoh-Yanai/5d8bd4095869a5997b6e7558ee7050813d39be6b
“The dye laser can achieve selective injury to abnormal vessels of port-wine stains while inflicting less damage to the overlying dermis than the argon laser. “

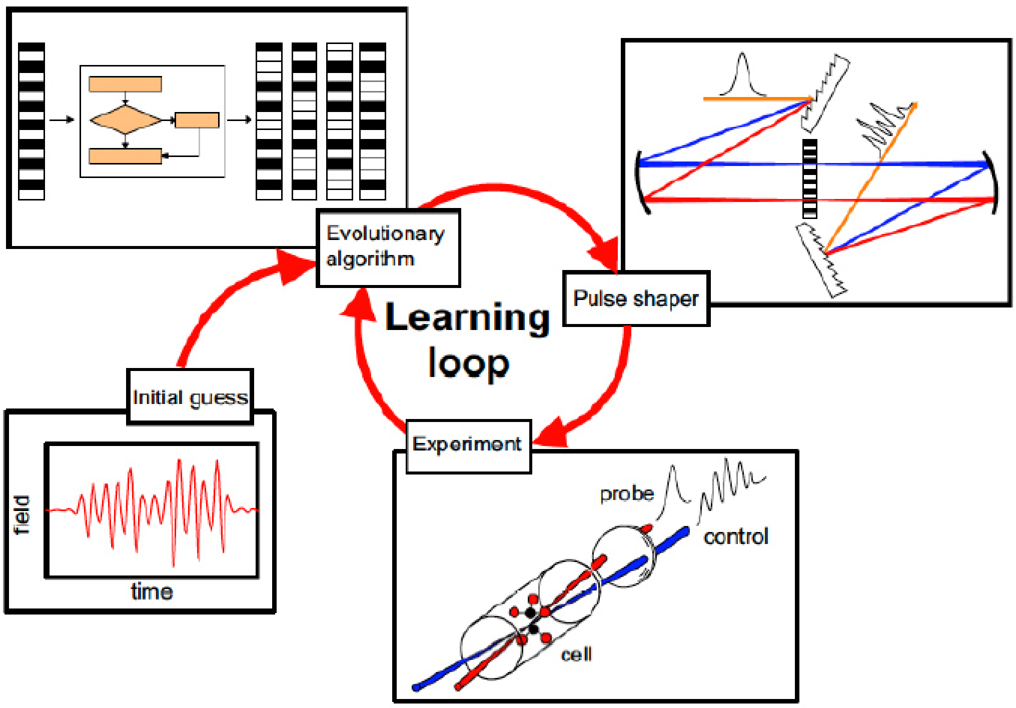
Mark the correct statement [Correct choices]:

- Temperature control of the treated and untreated area can be influenced by the laser intensity, wavelength, pulse length and other boundary conditions.
- The statement "However, argon ion and CO2 lasers should never be replaced by Nd:YAG lasers" is based on the different wavelengths used in lasers.

9. Mark the correct answers on the "Antwortbogen" [Correct choices]:

- Self learning genetic loops can be performed for all kinds of different experimental situations (physical problems, set-ups)
- Experimental pulse shaping is performed in the frequency Fourier domain
- If the phase function of the pulse is modified according to its Taylor-series $\varphi_{(\omega)} = \varphi_0 + \varphi_1 \frac{\omega-\omega_0}{1!} + \varphi_2 \frac{(\omega-\omega_0)^2}{2!} + \varphi_3 \frac{(\omega-\omega_0)^3}{3!}$...around the central frequency $\omega_0$only with respect to $\varphi_2 = \frac{d^2\phi}{dw^2}|_{\omega=\omega0}$, then the pulse will be broadened in time

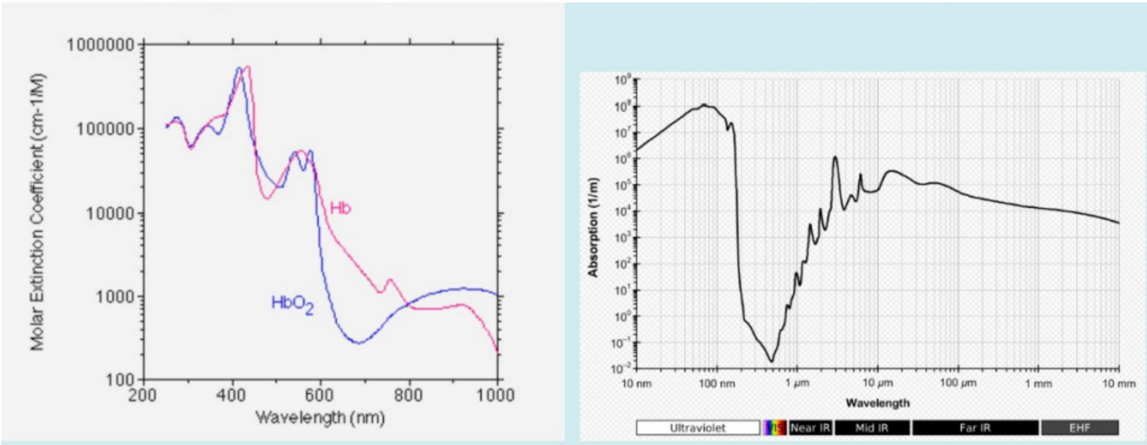
10. Explain the principle of a genetic loop algorithm. How does it work (add sketch) and discuss which lasers are needed and why [Discussion].



maybe just laser systems that are actually capable of changing their pulse shapes / are tuneable / can create short pulses? I'd mention Ti:Sa lasers.

11. Based on the absorption dependencies on wavelength for some human "materials" as shown in the following figures (Haemoglobin, water). Which statements are correct [Correct choices]?

- In order to treat tissue, mainly consisting of haemoglobin as absorber, an excimer laser is well suited.
- Recently a research group reported efficient laser curing using an Er:YAG on a material with high water content.



12. A dentist wants to use a laser for drilling dentin. He obtained the following transmission spectra for high though dentin (different concentrations) from a research lab. He buys a laser system and after his first applications he reports the results of his colleagues. Which ones make sense [Correct choices]?

- I first tried drilling a hole into dental material with a Ti; Sapphire laser at very low intensities and had no success. But at high laser intensities I observed substantial material removal

- Using a CO2 laser with high intensities I could achieve drilling, but observed substantial burning, actually I found carbon deposits on the treated tooth.