Laser

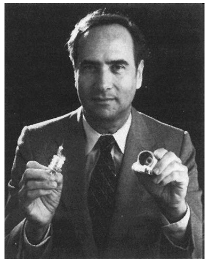
light amplification by stimulated emission of radiation

Brief laser history

1917 - ***Albert Einstein:*** theoretical prediction of stimulated emission

1954 - ***N.G. Basow, A.M. Prochorow, C. Townes:*** ammonia maser*

1960 - ***Theodore Maiman:*** first laser
(ruby laser)



***M**icrowave **A**mplification by **S**timulated **E**mission of **R**adiation

Brief laser history

Alexander Prokhorov

Charles H. Townes

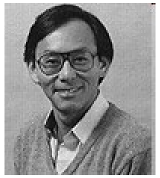
Nicolay Basov

Nobel prize in Physics 1964
for work in quantum electronics leading to lasers and masers

Denes Gabor

Nobel prize in Physics 1971
for invention of holography

Brief laser history



Steven Chu

William D. Phillips

Claude Cohen-Tannoudji

Nobel prize in Physics 1997
for development of methods to cool and trap atoms with laser light.

Zhores Ivanovich Alferov

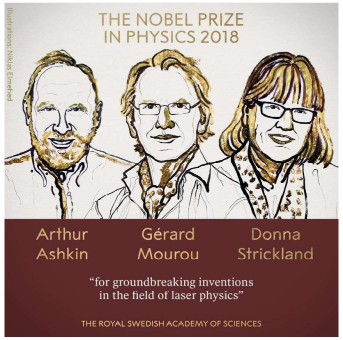
Herbert Kroemer

Nobel prize in Physics 2000
Semiconducting laser dynode

Nobel prize in Physics 2018

"for groundbreaking inventions in the field of laser physics"

with one half to **<u>Arthur Ashkin</u>** "for the optical tweezers and their application to biological systems"



the other half jointly to **<u>Gérard Mourou and Donna Strickland</u>** "for their method of generating high-intensity, ultra-short optical pulses."

Fundamentals of Laser Operation

Special electronic energy states - precondition for laser action

E_1
excited state

E_2
long lifetime
excited stationary state

E_0
ground state

Metastable state

Occupancy in energy levels

Thermal equilibrium

according to Boltzmann distribution:

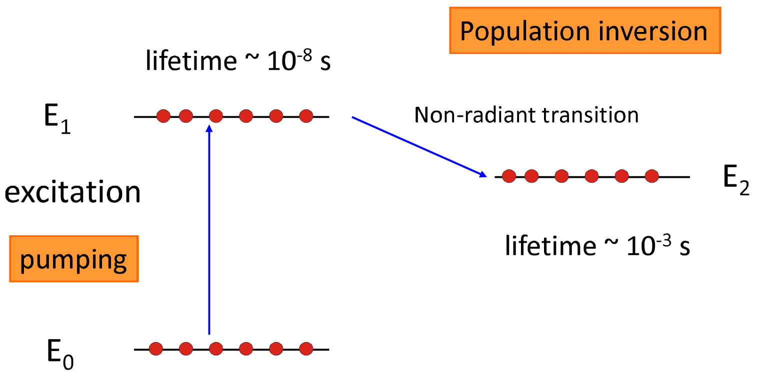
$$N_2 = N_1 e^{-\frac{\Delta E}{RT}}$$

The relative number of atoms N_1 and N_2 in two energy levels separated by the energy difference

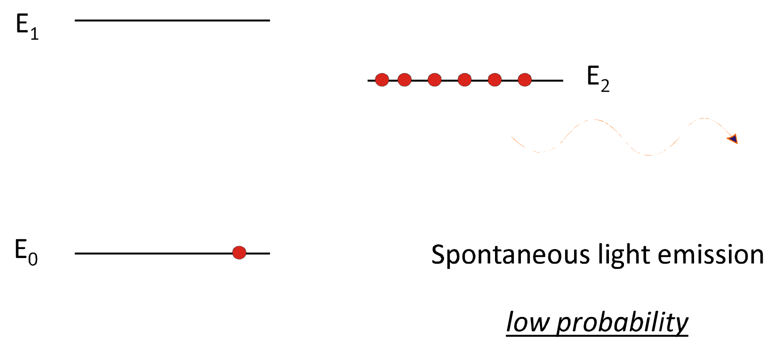
Population inversion

"opposite" distribution – more electrons in excited than in ground state

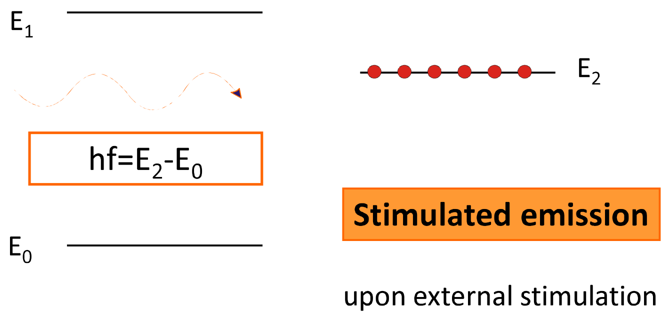
Elementary radiative processes:



Spontaneous photon emission

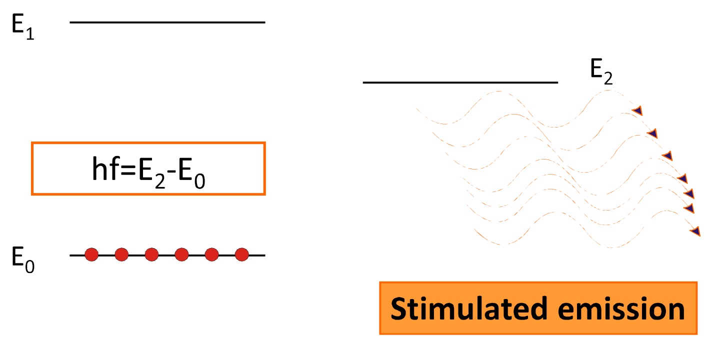


Induction of atomic transition – relaxation of electrons in metastable state



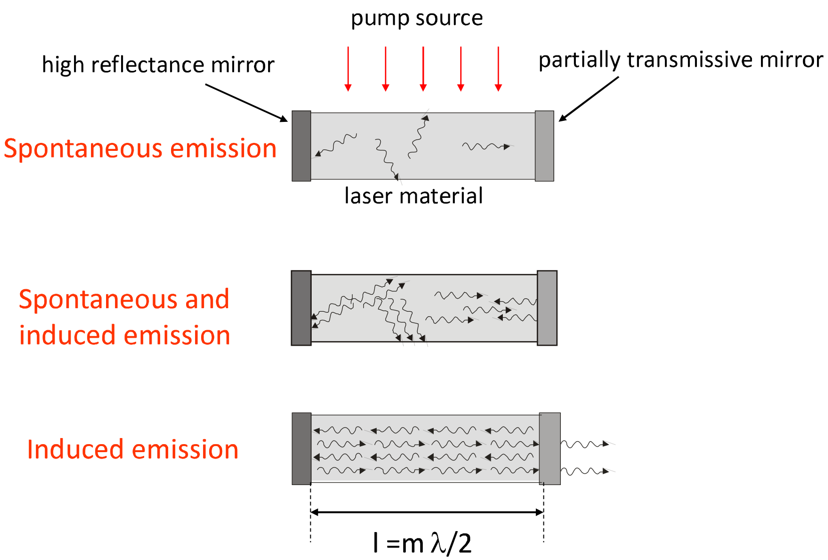
Electron interacting with an electromagnetic wave, may drop to a lower energy level.

Induction of atomic transition – relaxation of electrons in metastable state



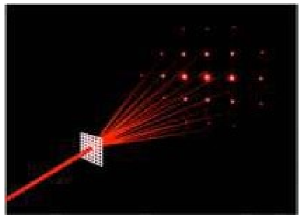
Phase, polarisation, direction and frequency of emitted and induced photons are identical.

Operating a laser – optical resonator



Light generated by stimulated emission:

- monochromatic – small spectral width
- coherent – phase equivalency in space
- and in time → ability for interference



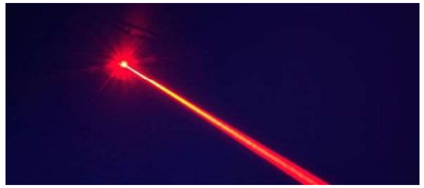
polarized → can provide large spatial density due to small divergence.

Possibility of very short pulses – *ps, fs*

Possibility of high power – *kW - GW*

Photons emitted by stimulated emission and inducing photons are identical:

- frequency
- phase,
- polarization
- and direction.



Consequently laser light is

- monochromatic
- coherent
- polarized
- parallel, collimated beam

Conditions of laser light production:

- pumping energy
- population inversion
- induced emission
- optical resonance

Properties of laser light:

- Monochromatic
- Coherent
- Polarized
- Collimated
- Facilitate a high power density

Types of laser

Based on active medium:

solid state lasers – Crystals or glasses doped with metal ions;
Ruby, Nd-YAG, Ti-sapphire
Red - infrared spectral range; possibility of high power

gas lasers – He-Ne laser (10 He/Ne). CO2 laser: CO2-N2-He mixture;

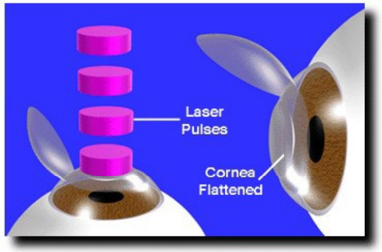
dye lasers – Dilute solution of organic dyes (e.g., rhodamine, coumarine); pumped with another laser
Large power (in Q-switched mode); Tunable

semiconductor lasers – At the junction of p- and n-type, doped semiconductors.
No need for resonator mirrors (internal reflection)

Excimer laser – **exci**ted di**mer**

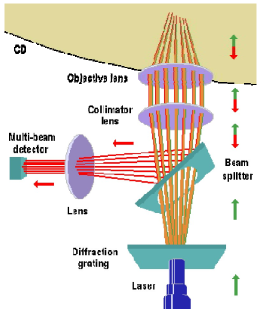
In ground state they are monomers, but in excited state they form stable complexes or dimers

For example: noble gases or the mixture of noble gas and halogen



Ar_2	126 nm
Kr_2	146 nm
F_2	157 nm
Xe_2*	172 & 175 nm
ArF	193 nm
KrF	248 nm
XeBr	282 nm
XeCl	308 nm
XeF	351 nm
CaF_2	193 nm
KrCl	222 nm
Cl_2	259 nm

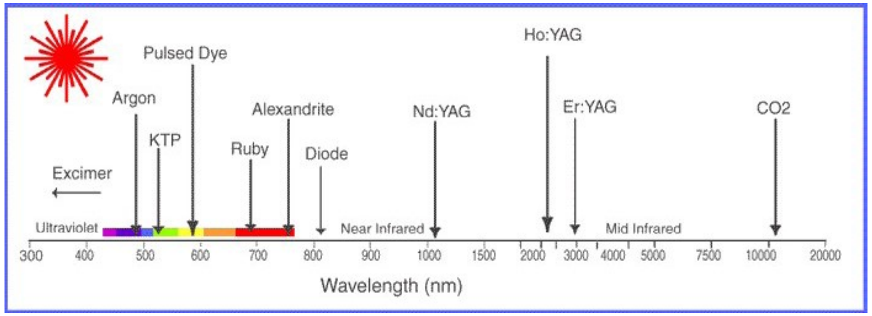
Types of laser

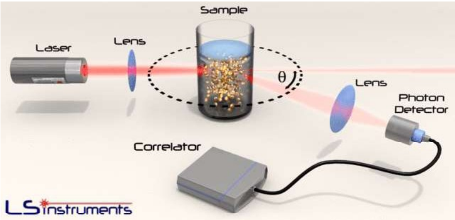


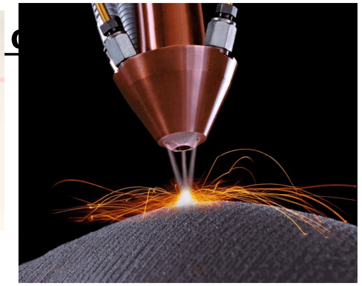
Depending on power:

- 5 mW – CD-ROM drive
- 5–10 mW – DVD player or DVD-ROM drive
- 100 mW – High-speed CD-RW burner
- 250 mW – Consumer DVD-R burner
- 1–20 W – output of the majority of commercially available solid-state
- lasers used for micro machining
- 30–100 W – typical sealed CO_2 surgical lasers
- 100–3000 W (peak output 1.5 kW) – typical sealed

CO_2 lasers used in industrial laser cutting







Fields of application

Medicine (health and beauty) – diagnostic and therapy
Industry: Cutting, welding, material heat treatment, marking parts
Defense: Marking targets, guiding munitions, missile defence, electrooptical countermeasures (EOCM), alternative to radar
Research: spectroscopy, laser ablation, Laser annealing, laser scattering, laser interferometry, LIDAR, Laser capture microdissection
Product development/commercial: laser printers, CDs, barcode scanners, thermometers, laser pointers, holograms.
Laser lighting displays: Laser light shows

Biomedical applications of laser

Light induced processes in tissues

Absorption of light

- **Radiation**
  - Autofluorescence
  - Fluorescence of exogenic chromophores
- **Non-radiative processes**
  - **Photochemical reactions**
  - **Atomization**
  - **Ionization**
  - **Thermal effects**
    - Coagulation
    - Vaporization
    - Carbonization

Thermal effects

biostimulation — 40 °C
coagulation — 60 °C
vaporization — 100°C
carbonization — 300 °C

Light induced processes in tissues:

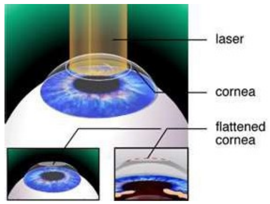
Selectivity of processes: getting the right amount of the right wavelength of laser energy to the right tissue to damage or destroy only that tissue, and nothing else.

Photoablation – volatilization of tissue by UV radiation

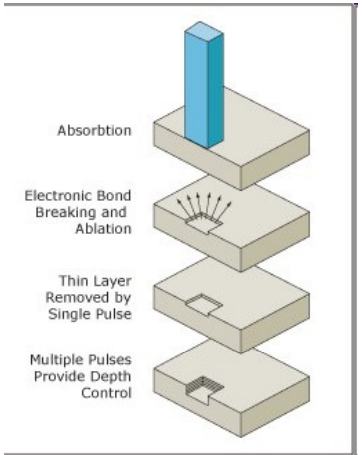
Mechanism: atomization/vaporization

UV laser pulse (10 MW/cm^2 - 10 GW/cm^2)

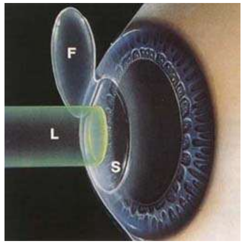
Excimer laser (193 nm-351 nm), 10-20 ns pulse



Photorefractive Keratectomy (PRK): myopic eye is too big compared to the refraction of its lens



Corneal reshaping: LASIK (Laser in situ Keratomileusis)



The epithelium is surgically peeled back and the underlying stroma is ablated. LASIK allows correction of even severe myopia because it is not limited by the finite thickness of the epithelium.

Photodisruption

Focused, high intensity ns pulses

Kavitation

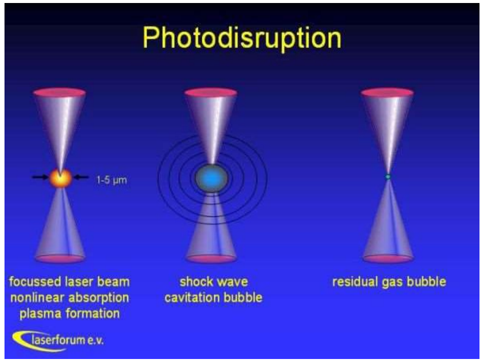
Water evaporation and CO_2

generation in the cavity

Shock wave

Distruction of surrounding

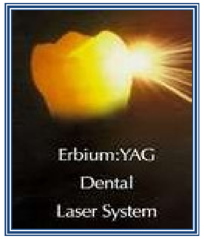
tissues



Applications in dentistry:

Er:YAG laser

2940 nm



Absorption in water and hydroxyapatite

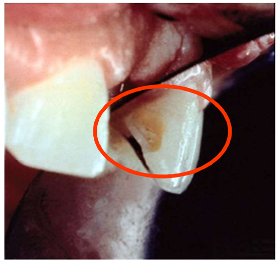
↓

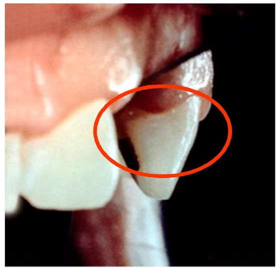
Vaporization and mechanical shockwave

↓

caries removal

caries removal





caries removal

Argon laser

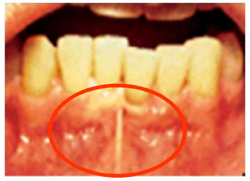
A rubber dam is put over your teeth to protect the gums

Teeth whitening

https://www.youtube.com/watch?v=NW6XI5JvGsE

Nd: YAP* laser

930, 1080, 1340 nm

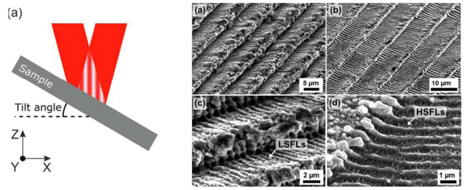


frenectomia

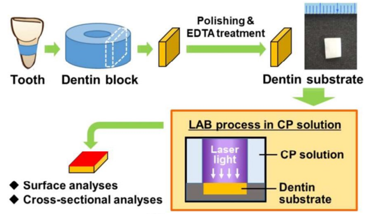
gingivectomia

*$YAlO_3$:Nd

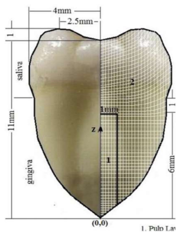
One-step fabrication of asymmetric saw-tooth-like surface structures on stainless steel using Direct Laser Interference Patterning (Materials Letters 245 (2019) 183–187)

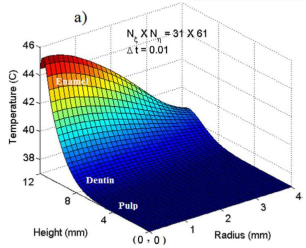


Laser-assisted biomineralization on human dentin for tooth surface functionalization (Materials Science & Engineering C 105 (2019) 110061)



Evaluation of heat conduction in a laser irradiated tooth with the three phase-lag bio-heat transfer model (Thermal Science and Engineering Progress 7 (2018) 203–212)





Heat flux of pulsed laser at top surface: 8times 8 s

Dermatological applications:

„resurfacing” – ablation technic for renewal of epidermis

wrinkles,

damages,

acnes …

Er:YAG laser (2940 nm) or CO_2 laser (10600 nm)

Nd:YAG laser

1064 nm

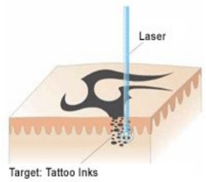
Removal of superficial blood vessels, veins

Photocoagulation based correction of veins

Hair removal

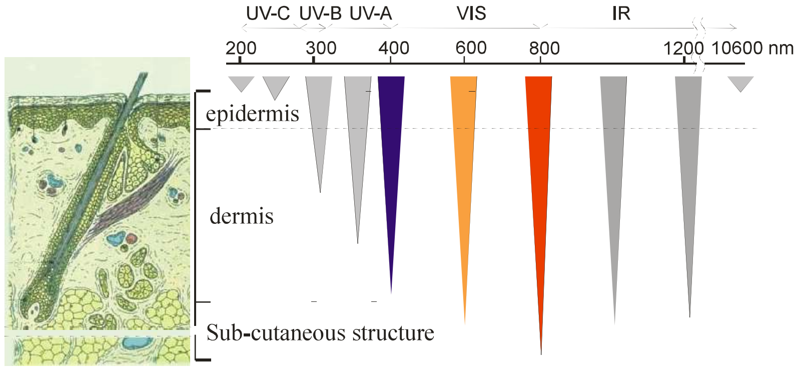
Tattoo removal

before after



ruby laser (694 nm) is specifically absorbed by the color pigments in the tattoo

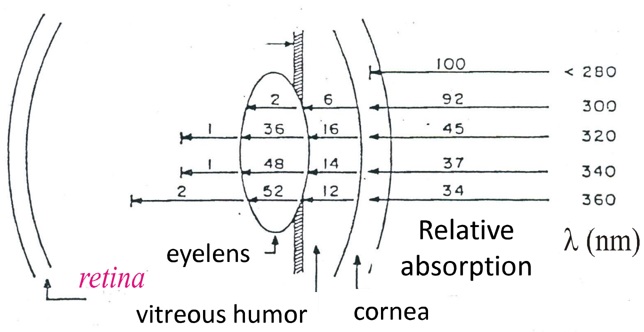
Penetration of light into the skin



Light intensity is attenuated due to absorption, reflection, refraction.

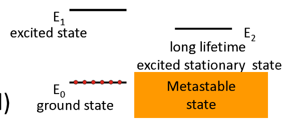
Penetration depth depends on the wavelength.

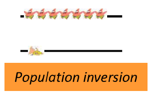
Penetration of light into the skin

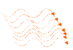


Checklist for the semifinal

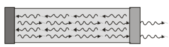
- ❑ Fundamentals of Laser Operation
  - ❑ Special electronic energy states (3 energy level)
  - ❑ Population Inversion (pumping)
  - ❑ Stimulated emission



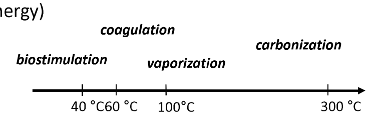


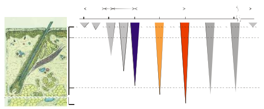


- ❑ Optical resonator



- ❑ Properties of laser light (coherent, polarized, monochromatic, high energy, collimated)
- ❑ Type of the laser lights (material, energy)
- ❑ Biomedical applications
  - ❑ Absorption of the light
  - ❑ Thermal effect
  - ❑ Penetration through the skin





Damjanovich, Fidy, Szöllősi: Medical Biophysics

II. 2.2
2.2.5
2.2.7
2.2.8
IX. 1.1
IX. 1.2

https://www.youtube.com/watch?v=ztkT9tOryAw

https://www.youtube.com/watch?v=KXkqIr7YFU4

https://www.youtube.com/watch?v=j0T8Fd9iQqs

https://www.youtube.com/watch?v=4SCzwOdg4mc

https://www.youtube.com/watch?v=NW6XI5JvGsE