

# Laser

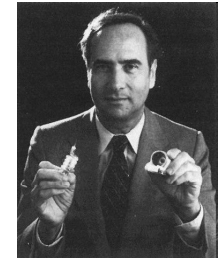
light amplification by stimulated emission of radiation

## 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)



\*Microwave Amplification by Stimulated Emission of Radiation

## 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



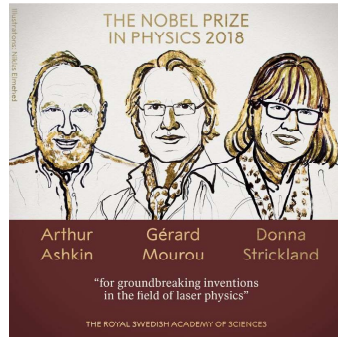
Herbert Kroemer

Nobel prize in Physics 2000  
Semiconducting laser dynode

## Nobel prize in Physics 2018

"for groundbreaking inventions in the field of laser physics"

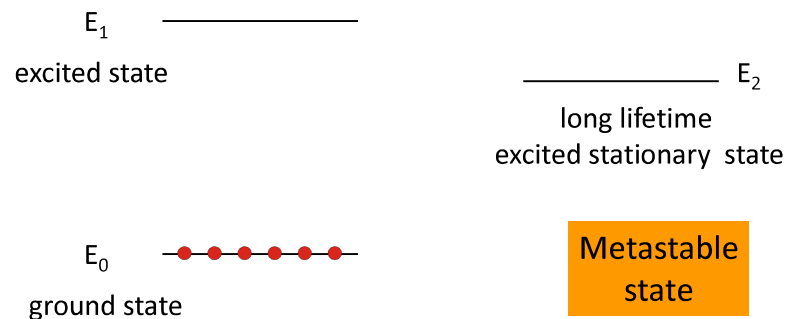
with one half to **Arthur Ashkin** "for the optical tweezers and their application to biological systems"



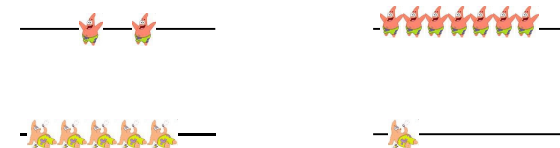
the other half jointly to **Gérard Mourou and Donna Strickland** "for their method of generating high-intensity, ultra-short optical pulses."

## Fundamentals of Laser Operation

**Special electronic energy states** - precondition for laser action



Occupancy in energy levels



*Thermal equilibrium*

*Population inversion*

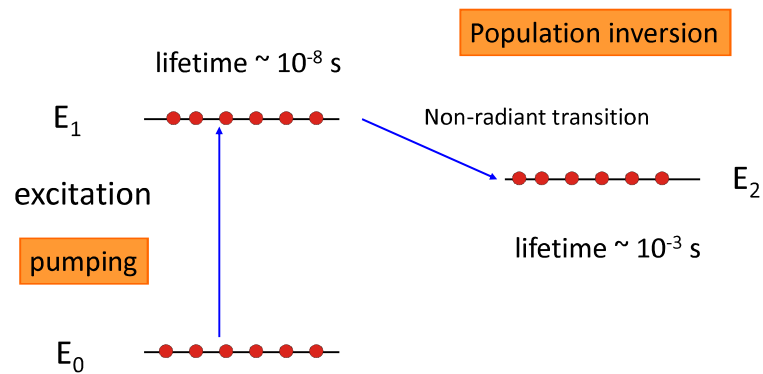
according to Boltzmann distribution:

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

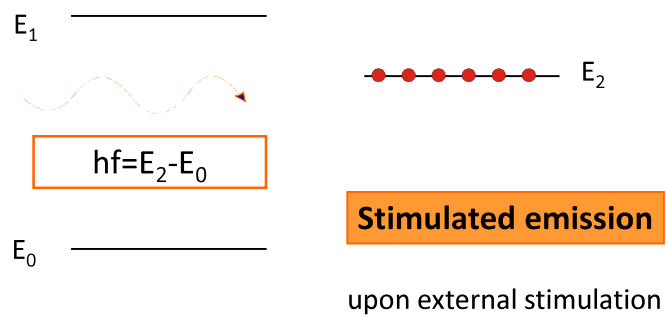
"opposite" distribution – more electrons in excited than in ground state

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

## Elementary radiative processes:

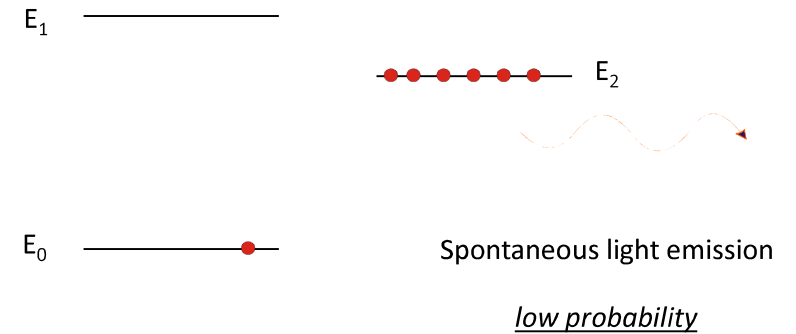


## Induction of atomic transition – relaxation of electrons in metastable state

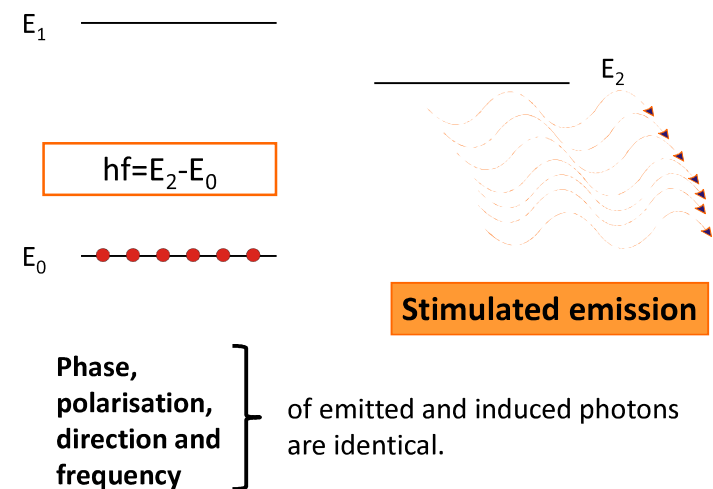


Electron interacting with an electromagnetic wave, may drop to a lower energy level.

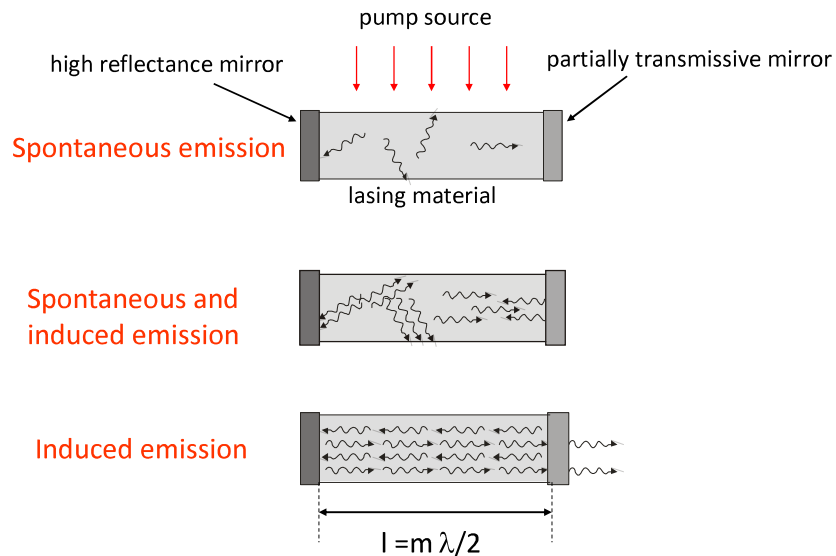
## Spontaneous photon emission



## Induction of atomic transition – relaxation of electrons in metastable state

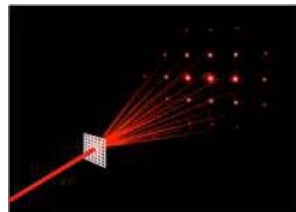


## Operating a laser – optical resonator



### 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). CO<sub>2</sub> laser: CO<sub>2</sub>-N<sub>2</sub>-He mixture;

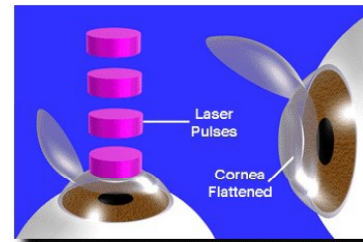
dye lasers – Dilute solution of organic dyes (e.g., rhodamine, coumarine); pumped with another laser  
Large power (in Q-switched mode); Tunable

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

## Excimer laser – **excited dimer**

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

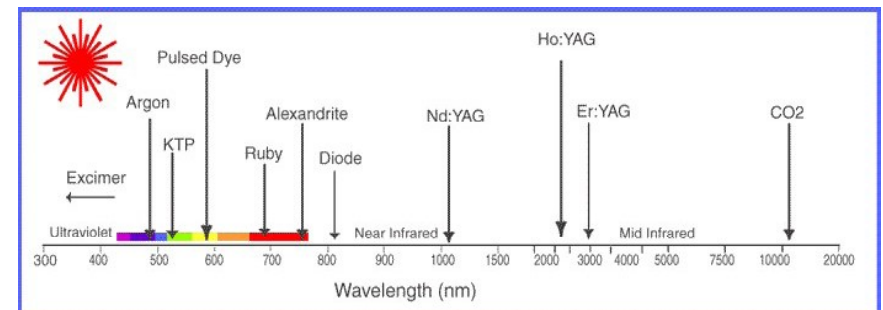
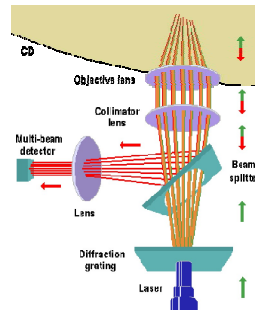


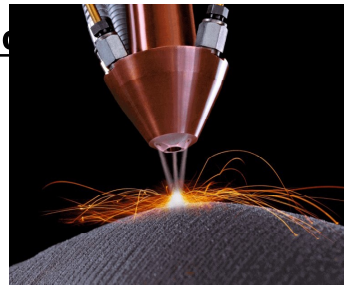
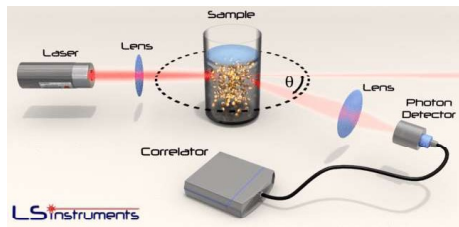
Ar <sub>2</sub>	126 nm
Kr <sub>2</sub>	146 nm
F <sub>2</sub>	157 nm
Xe <sub>2</sub> <sup>*</sup>	172 & 175 nm
ArF	193 nm
KrF	248 nm
XeBr	282 nm
XeCl	308 nm
XeF	351 nm
CaF <sub>2</sub>	193 nm
KrCl	222 nm
Cl <sub>2</sub>	259 nm

## 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<sub>2</sub> surgical lasers
- 100–3000 W (peak output 1.5 kW) – typical sealed CO<sub>2</sub> lasers used in industrial laser cutting

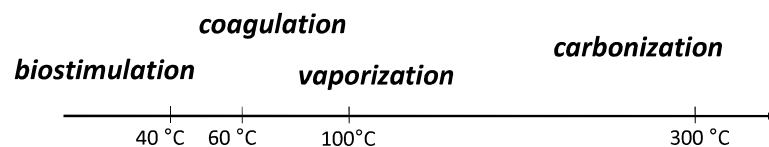




### Fields of application

**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

### Thermal effects

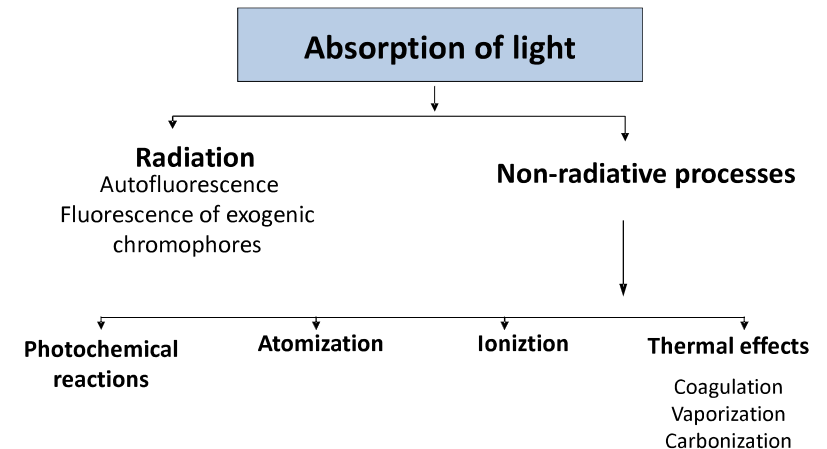


### Light induced processes in tissues:

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.

### Biomedical applications of laser

Light induced processes in tissues

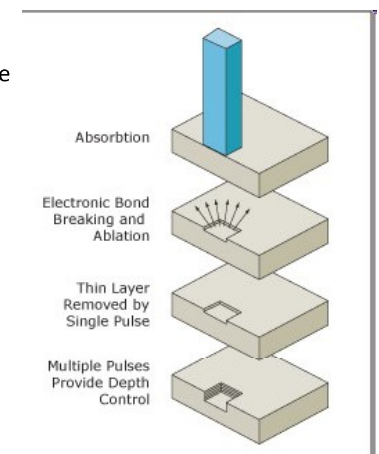
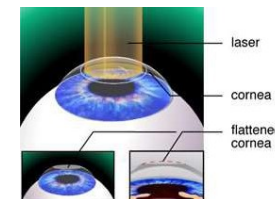


### Photoablation – volatilization of tissue by UV radiation

Mechanism: atomization/vaporization

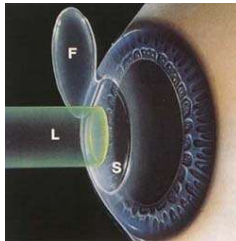
UV laser pulse ( $10 \text{ MW/cm}^2$  -  $10 \text{ GW/cm}^2$ )

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

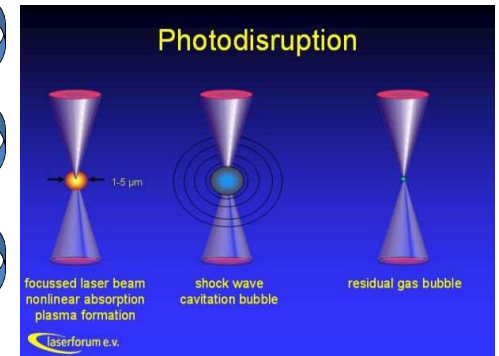
Water evaporation and CO<sub>2</sub>

generation in the cavity

Shock wave

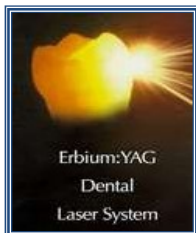
Distruction of surrounding

tissues



## Applications in dentistry:

Er:YAG laser  
2940 nm



Absorption in water and  
hydroxyapatite

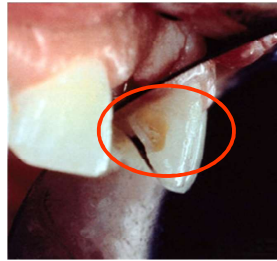
Vaporization and mechanical  
shockwave

caries removal

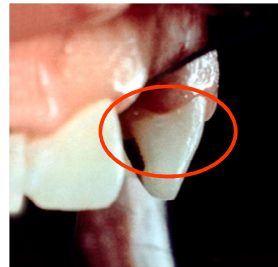


caries removal





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



frenectomy

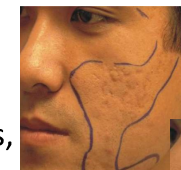


gingivectomy

\*YAlO<sub>3</sub>:Nd

## Dermatological applications:

„resurfacing” – ablation technic for renewal of epidermis



wrinkles,  
damages,  
acnes ...

Er:YAG laser (2940 nm) or CO<sub>2</sub> laser (10600 nm)



## Nd:YAG laser

1064 nm

Removal of superficial blood vessels, veins



## Photocoagulation based correction of veins



## Hair removal

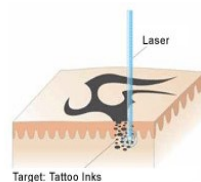
DOES YOUR CAT NEED LASER HAIR REMOVAL?



## Tattoo removal

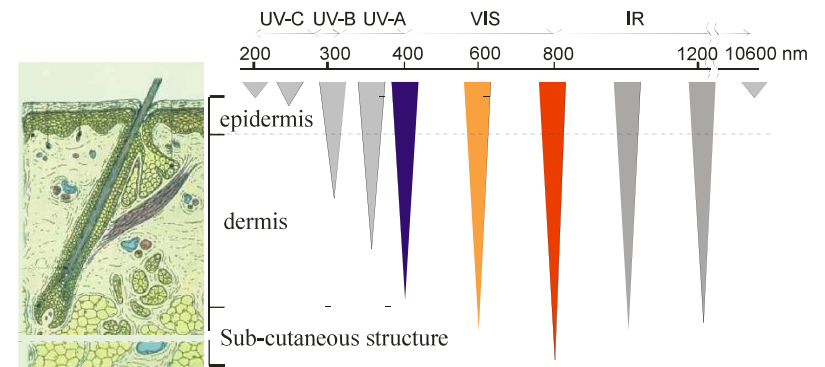


before after



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

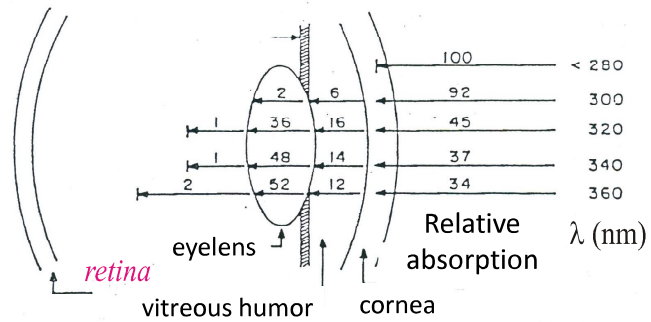
## Penetration of light into the skin



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

Penetration depth depends on the wavelength.

## Penetration of light into the skin



*Question of the week*

What does induced emission mean?

*Damjanovich, Fidy, Szöllősi: Medical Biophysics*

II. 2.2

2.2.5

2.2.7

2.2.8

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

IX. 1.1

IX. 1.2

<https://www.youtube.com/watch?v=KXkqlr7YFU4>

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

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

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