Lasers
: Applications and Safety

2009. 4. 20.

LASER, Laser, laser

LIGHT

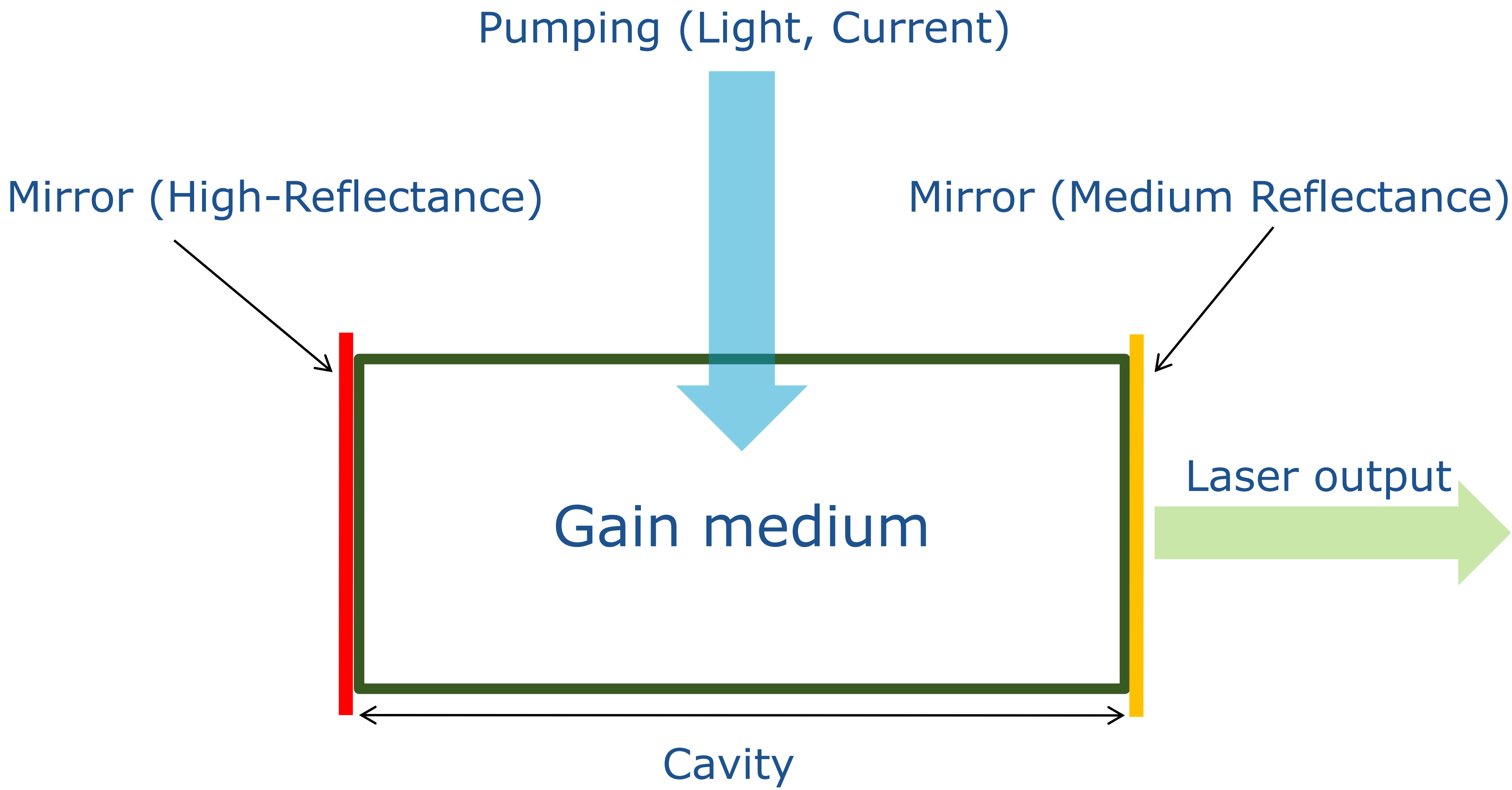
AMPLIFICATION BY

STIMULATED

EMISSION OF

RADIATION

Let's make a laser



History of laser

http://en.wikipedia.org/wiki/Laser

Foundations

In 1917 **Albert Einstein**, in his paper *Zur Quantentheorie der Strahlung (On the Quantum Theory of Radiation)*, laid the foundation for the invention of the laser and its predecessor, the maser, in a ground-breaking rederivation of Max Planck's law of radiation based on the concepts of probability coefficients (later to be termed 'Einstein coefficients') for the absorption, spontaneous emission, and stimulated emission of electromagnetic radiation.

In 1928, Rudolf W. Ladenburg confirmed the existence of stimulated emission and negative absorption, **In 1939**, **Valentin A. Fabrikant** predicted the use of stimulated emission to amplify "short" waves.

In 1947, Willis E. Lamb and R. C. Retherford found apparent stimulated emission in hydrogen spectra and made the first demonstration of stimulated emission.

In 1950, Alfred Kastler (Nobel Prize for Physics 1966) proposed the method of optical pumping, which was experimentally confirmed by Brossel, Kastler and Winter two years later.

The first working laser was demonstrated on 16 May **1960** by **Theodore Maiman** at **Hughes Research Laboratories**. Since then, lasers have become a multi-billion dollar industry. By far the largest single application of lasers is in optical storage devices such as compact disc andDVD players, in which a semiconductor laser less than a millimeter wide scans the surface of the disc. The second-largest application is fiber-optic communication. Other common applications of lasers are bar code readers, laser printers and laser pointers.

History of laser-Continued

http://en.wikipedia.org/wiki/Laser

Maser

In 1953, **Charles H. Townes** and graduate students James **P. Gordon** and **Herbert J. Zeiger** produced the first microwave amplifier, a device operating on similar principles to the laser, but amplifying microwave rather than infrared or visible radiation. Townes's maser was incapable of continuous output. **Nikolay Basov** and **Aleksandr Prokhorov** of the Soviet Union worked independently on the quantum oscillator and solved the problem of continuous output systems by using more than two energy levels and produced the first maser. These systems could release stimulated emission without falling to the ground state, thus maintaining a population inversion. In 1955 Prokhorov and Basov suggested an optical pumping of multilevel system as a method for obtaining the population inversion, which later became one of the main methods of laser pumping.

Townes reports that he encountered opposition from a number of eminent colleagues who thought the maser was theoretically impossible -- including Niels Bohr, John von Neumann, Isidor Rabi, Polykarp Kusch, and Llewellyn H. Thomas.

Townes, Basov, and Prokhorov shared the Nobel Prize in Physics in 1964 "For fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle."

History of laser-Continued

http://en.wikipedia.org/wiki/Laser

Laser (1)

In 1957, **Charles Hard Townes and Arthur Leonard Schawlow**, then at Bell Labs, began a serious study of the infrared laser. As ideas were developed, infrared frequencies were abandoned with focus on visible light instead. The concept was originally known as an "optical maser." Bell Labs filed a patent application for their proposed optical maser a year later. Schawlow and Townes sent a manuscript of their theoretical calculations to Physical Review, which published their paper that year (Volume 112, Issue 6).

The first page of **Gordon Gould**'s laser notebook in which he coined the acronym LASER and described the essential elements for constructing one.

At the same time Gordon Gould, a graduate student at Columbia University, was working on a doctoral thesis on the energy levels of excited thallium. Gould and Townes met and had conversations on the general subject of radiation emission. Afterwards Gould made notes about his ideas for a "laser" in November **1957**, including suggesting using an open resonator, which became an important ingredient of future lasers.

In 1958, **Prokhorov** independently proposed using an open resonator, the first published appearance of this idea. **Schawlow and Townes** also settled on an open resonator design, apparently unaware of both the published work of Prokhorov and the unpublished work of Gould.

History of laser-Continued

http://en.wikipedia.org/wiki/Laser

Laser (2)

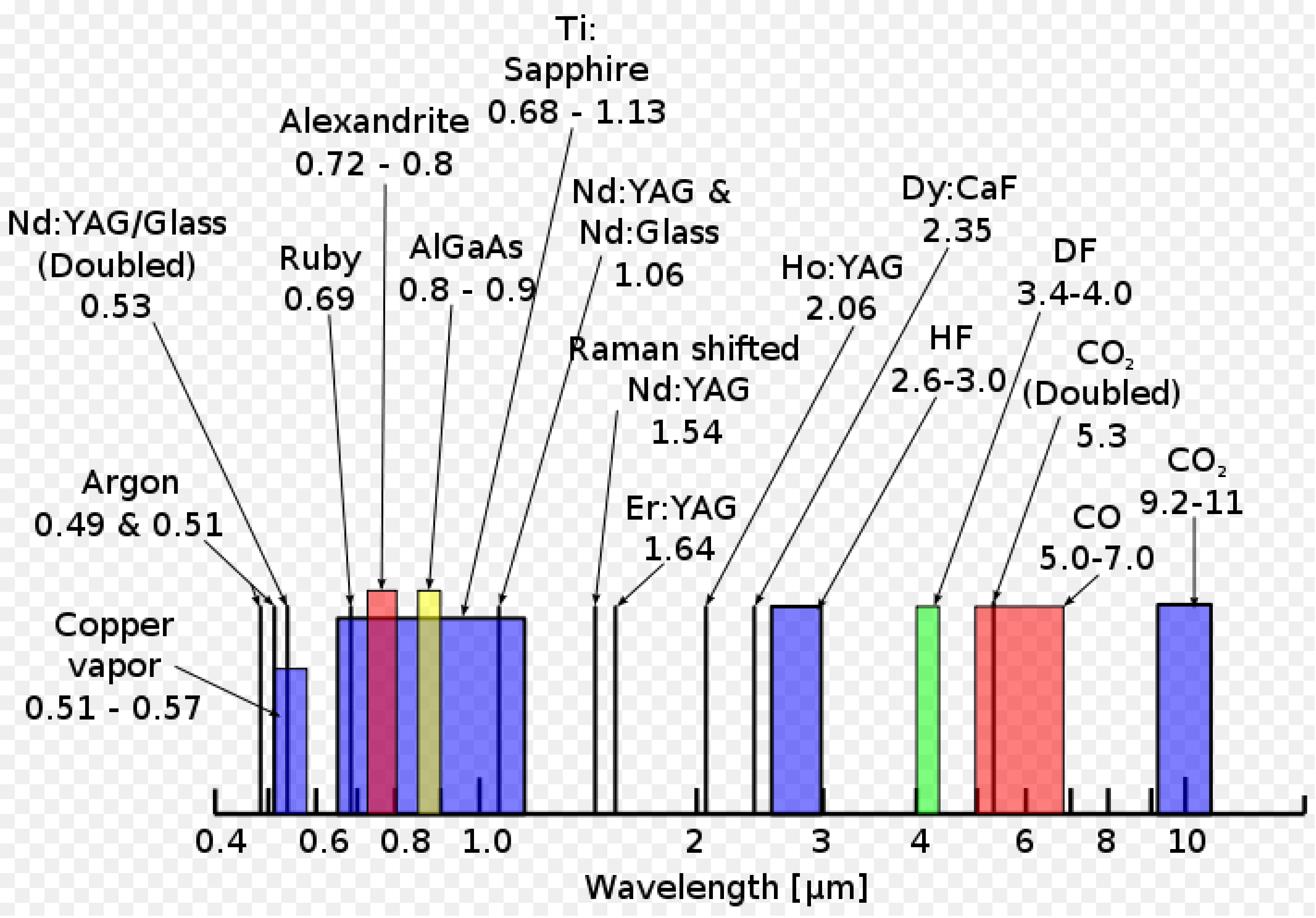
Gould's notes included possible applications for a laser, such as spectrometry, interferometry, radar, andnuclear fusion. He continued working on his idea and filed a **patent application in April 1959**. The U.S. Patent Office **denied** his application and **awarded a patent to Bell Labs in 1960**. This sparked a legal battle that ran 28 years, with scientific prestige and much money at stake. Gould won his first minor patent in 1977, but it was not until 1987 that he could claim his first significant patent victory when a Federal judge ordered the government to issue patents to him for the optically pumped laser and the gas discharge laser.

The **first working laser** was made by **Theodore H. Maiman** in **1960** at Hughes Research Laboratories in Malibu, California, beating several research teams including those of Townes at Columbia University, Arthur Schawlow at Bell Labs, and Gould at a company called TRG (Technical Research Group). Maiman used a solid-state flashlamp-pumped synthetic ruby crystal to produce red laser light at 694 nanometres wavelength. Maiman's laser, however, was only capable of pulsed operation due to its three-level pumping scheme.

Later in 1960 the Iranian physicist **Ali Javan**, working with **William R. Bennett** and **Donald Herriot**, made the first gas laser using helium and neon (first CW laser). Javan later received the Albert Einstein Award in 1993.

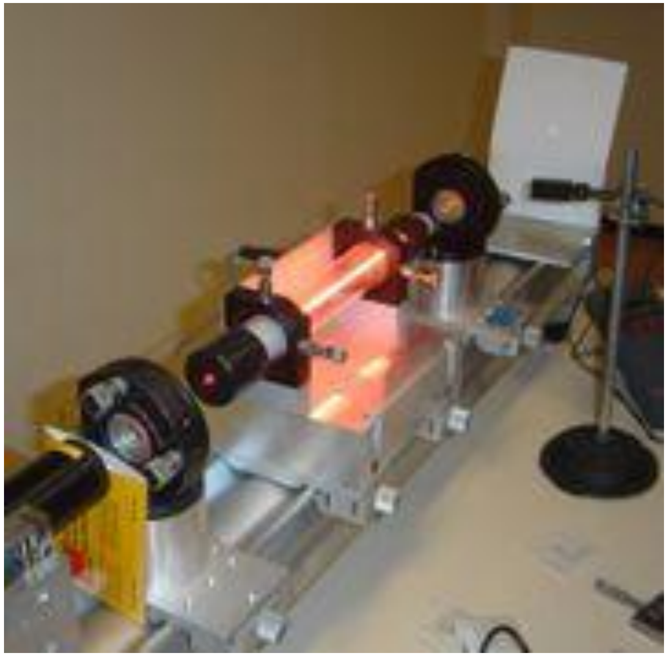
Laser spectral lines

http://en.wikipedia.org/wiki/File:Laser_spectral_lines.svg

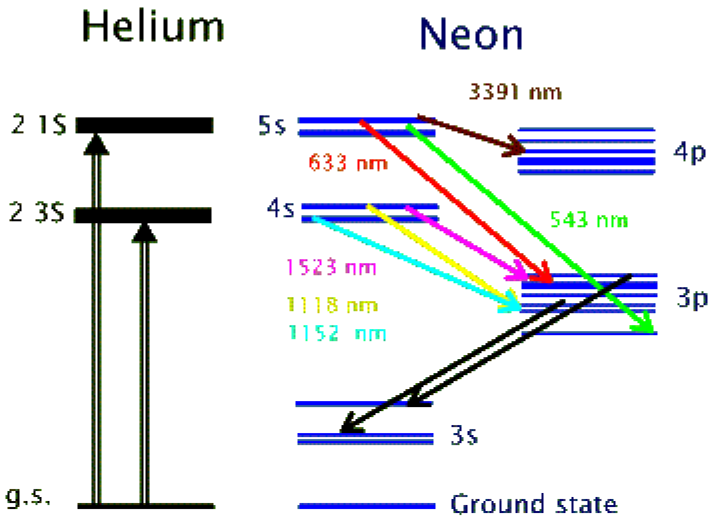


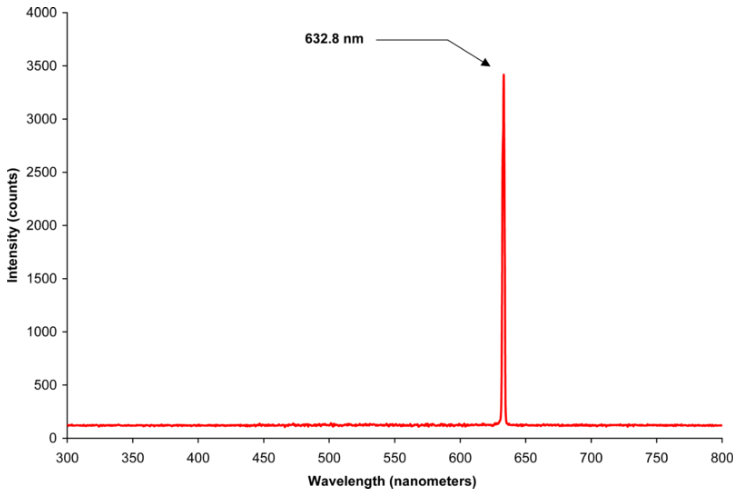
Types of lasers-Gas lasers

He-Ne laser



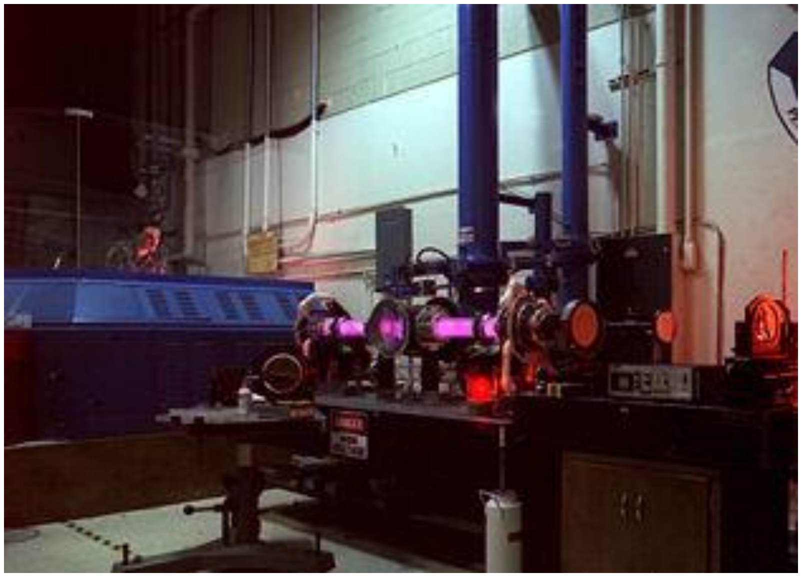
- Wavelength = 632.8nm
- Output power = 1mW~100mW
- Very high spectral purity intrinsic

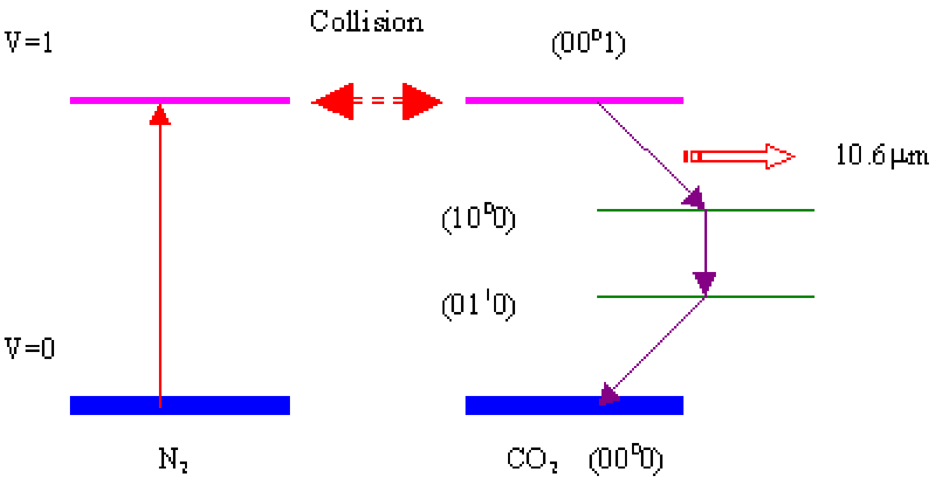




Types of lasers-Gas lasers

CO_2 laser

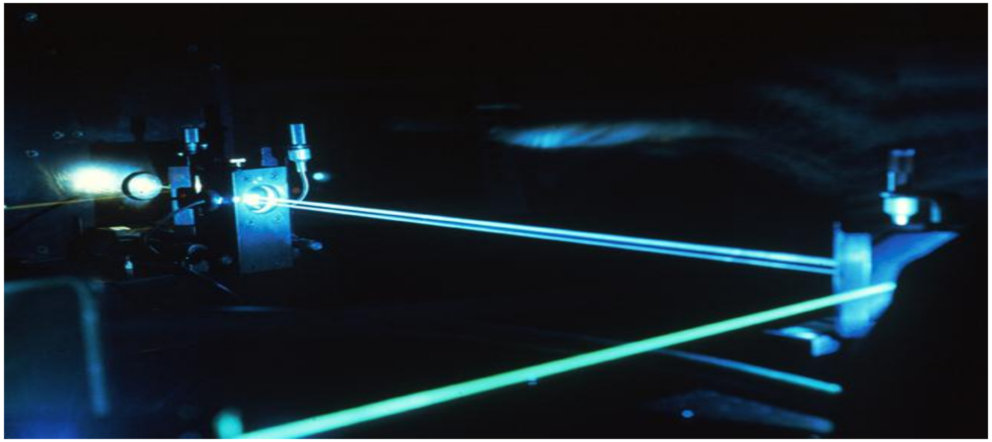


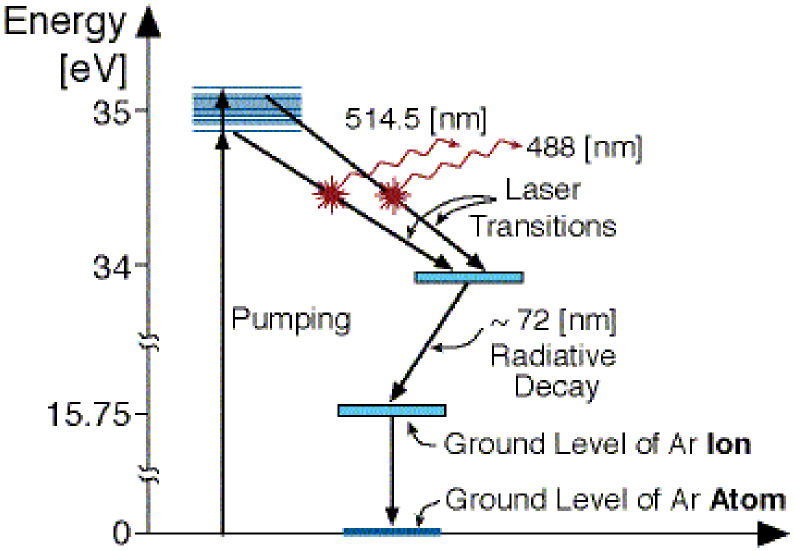


- Wavelength = 9.6 μm and 10.6μm
- Output power = mW~kW
- Used in industry for cutting and welding

Types of lasers-Gas lasers

Argon laser

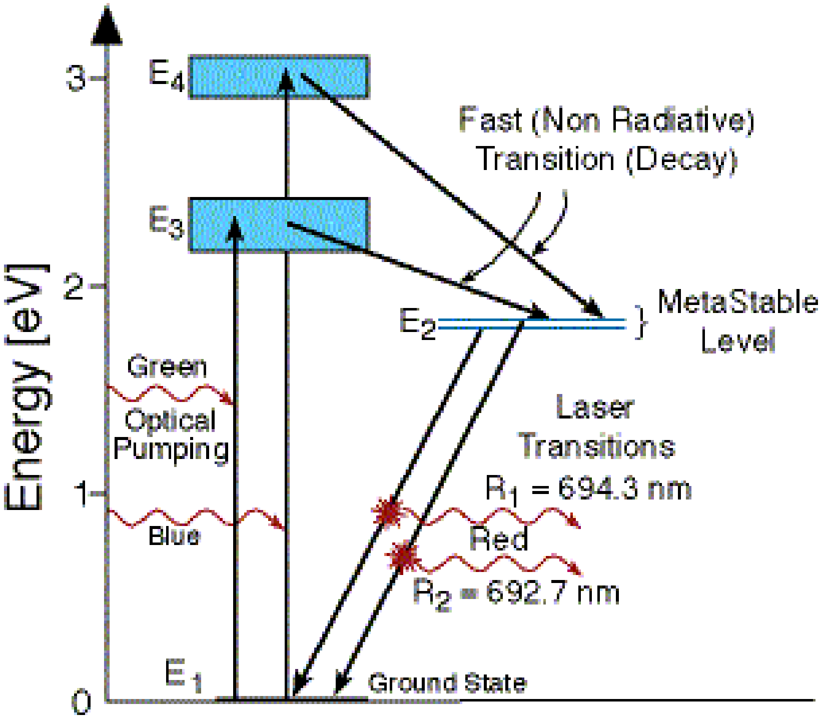




- Wavelength = 351nm~528.7nm
- Most used line = 458nm, 488nm, and 514nm
- Used for retinal phototherapy,
  lithography, and pumping other lasers

Types of lasers-Solid state lasers

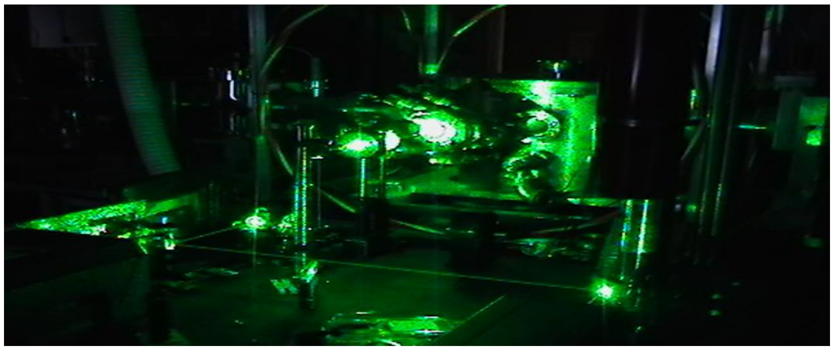
Ruby laser

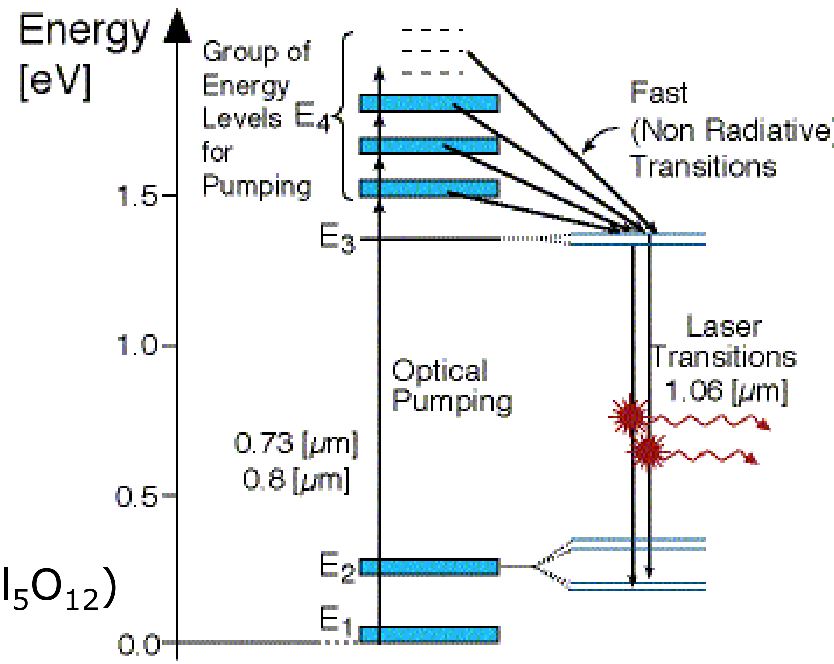


- Wavelength = 694.3nm
- The first working laser
- Three level laser
- Used in a number of applications where short pulses of red light

Types of lasers-Solid state lasers

Nd(Neodymium) laser

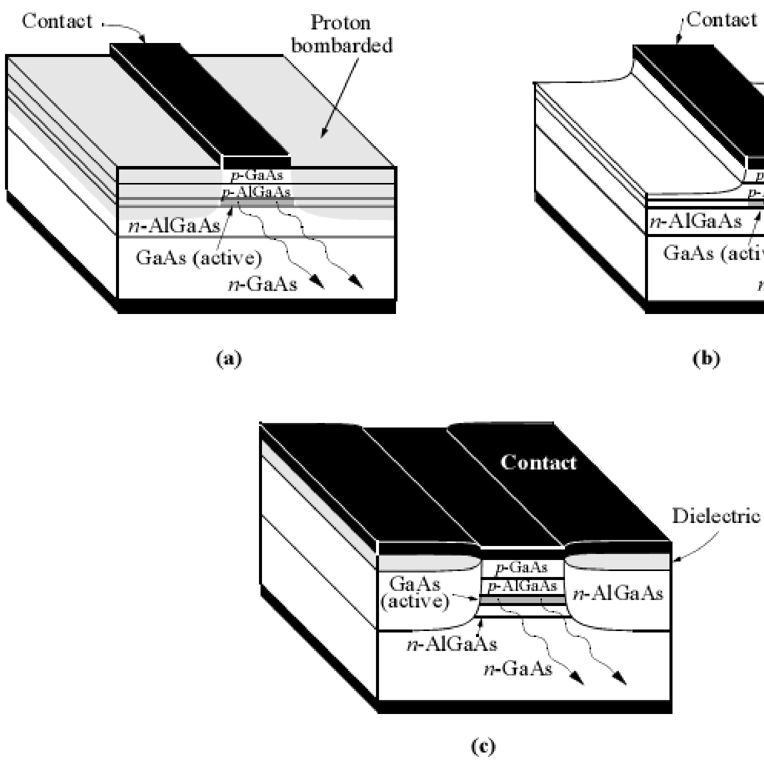




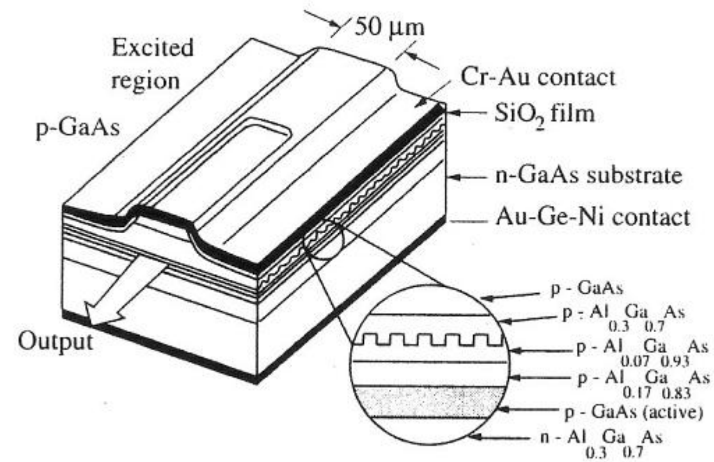
- Neodymium : common dopant
- Nd:YAG - Yttrium aluminium garnet ($Y_3Al_5O_{12}$)
- Nd:YVO_4 - Yttrium orthovanadate
- Nd:YLF - yttrium lithium fluoride
- Wavelength = 1064nm
- Can produce high powers in the infrared spectrum
- Cutting, welding and marking of metals and other materials, and also in spectroscopy and for pumping dye lasers

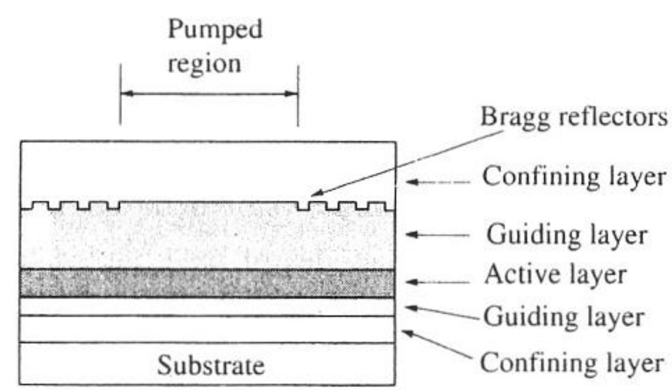
Types of lasers-laser diodes

FP (DH) lasers



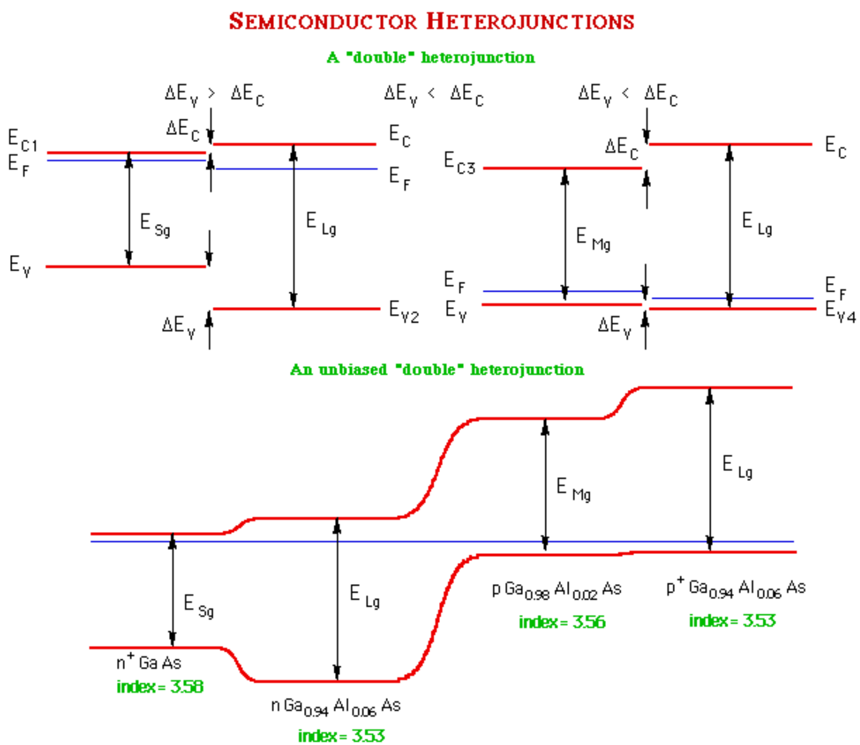
DFB/DBR laser



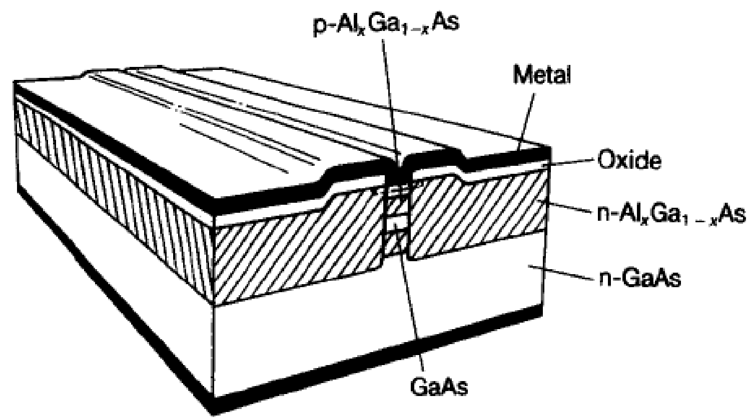


(참고) DH, BH strucutres

DH – Double Hetero



BH – Buried Hetero



Laser hazard classes

Class	Power	Remarks	Typical examples
I	Very low or beam completely enclosed	• Inherently safe, • No possibility of exposure	CD, DVD drives, laser printers…
II	1 mW Visible only	• Staring into the beam is hazardous • Eye protected by aversion response	Supermarket laser scanners, some pointers
IIIa	1-5 mW	• Aversion may not be adequate	Laser pointers
IIIb	5-500 mW	• Direct exposure is a hazard	Ar laser in Birge 123 CF microscope in B219
IV	>500 mW	• Exposure to direct beam and scattered light is eye and skin hazard • Fire hazard	Laser ablation setup in Birge 266

Classes of Lasers adopted from ANSI Z-136.1-2000

Laser safety

Class 1

Class 1 Accessible Emission Limit (AEL)을 넘는 빛을 내지 않음
(Note: AEL's vary by laser wavelength and pulse duration)

Most lasers in this class are lasers which are in an enclosure which prohibits or limits access to the laser radiation.

Not capable of producing damage to the eye (unless disassembled).

Laser safety

Class 2

1 AEL을 넘는 빛을 maximum duration 동안 발하지만, 0.25초 (사람 눈이 깜박이는 시간, 혹은 다른 곳을 보는데 걸리는 시간)이내에는 1AEL을 넘는 빛을 내지 않고, 평균 radiant power가 1mW가 넘지 않는 가시광 영역의 CW 혹은 pulse lasers.

The output of the laser is not intended to be viewed.

An example of a Class 2a laser is a supermarket point-of-sale scanner.

Laser safety

Class 3a

Have output between 1 and 5 times the Class 1 AEL for wavelengths shorter than 0.4 mm or longer than 0.7 mm, or less than 5 times the Class 2 AEL for wavelengths between 0.4 mm and 0.7 mm.

Is only a hazard if collected and focused in the eye.

Most laser pointers are 3a lasers.

Laser safety

Class 3b

UV, IR laser (systems) 으로, maximum duration 동안 Class 3a AEL 이상의 출력을 내지만, 0.25초 혹은 그 이상동안 평균 radiant power가 0.5 W를 넘지 않고, 0.25초 이상의 노출 시간동안 0.125 J 이하의 에너지를 내는 것.

Visible 혹은 near-IR lasers (systems)으로, maximum duration 동안 Class 3a AEL 이상의 출력을 내지만, 0.25초 혹은 그 이상동안 평균 radiant power가 0.5 W를 넘지 않고, 펄스당 0.03 Ca J 이하의 에너지를 내는 것. (Ca는 사람피부의 염색소가 near IR 파장을 흡수하는 정도를 근거로 산출된 correction factor)

Is a hazard if the direct or reflected beam is viewed.

Class 4

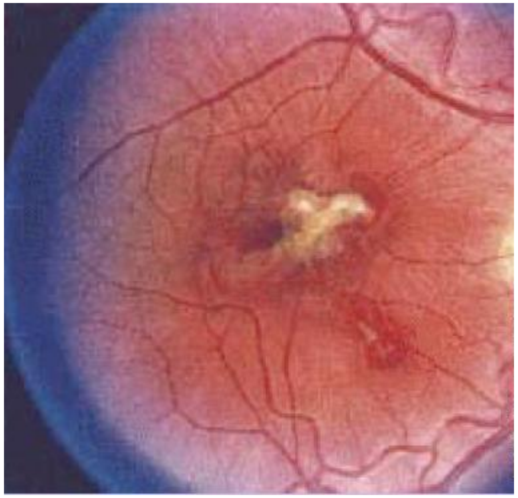
Limits exceed Class 3b limits.

Direct and reflected exposure can cause both eye and skin injury.

Class 4 lasers are also a fire hazard.

Laser safety

Eye injury

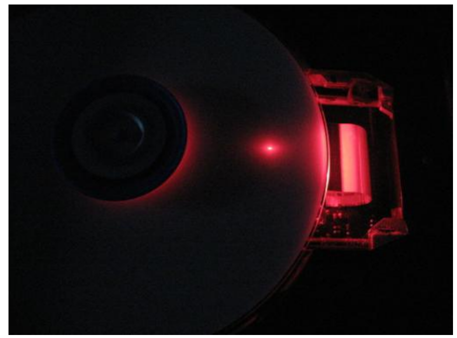


Skin burns

Laser applications: industry

Laser pointer

CD/DVD

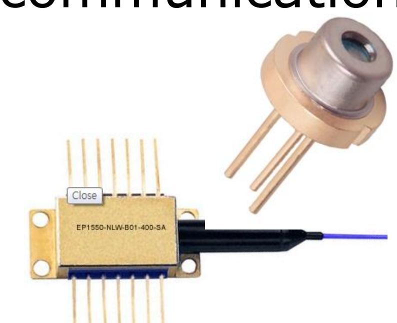


Laser cut

Laser surgery

Laser mark

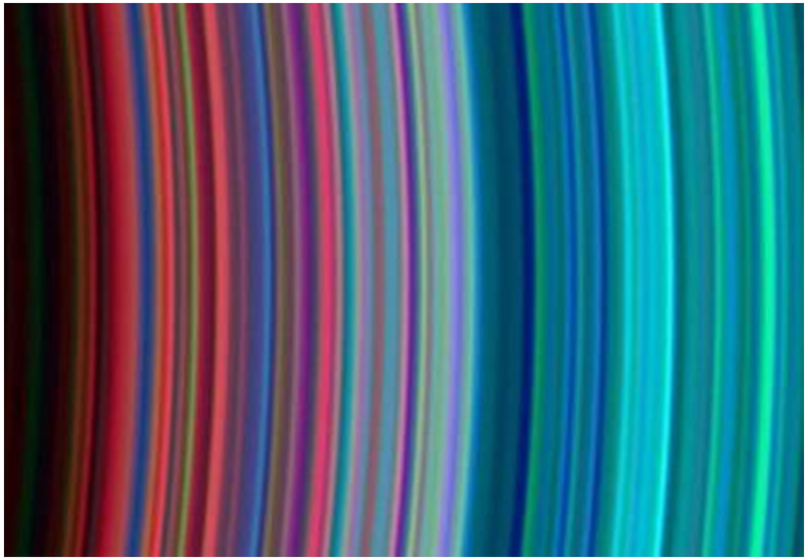
Optical communications



Laser applications: science

Spectroscopy

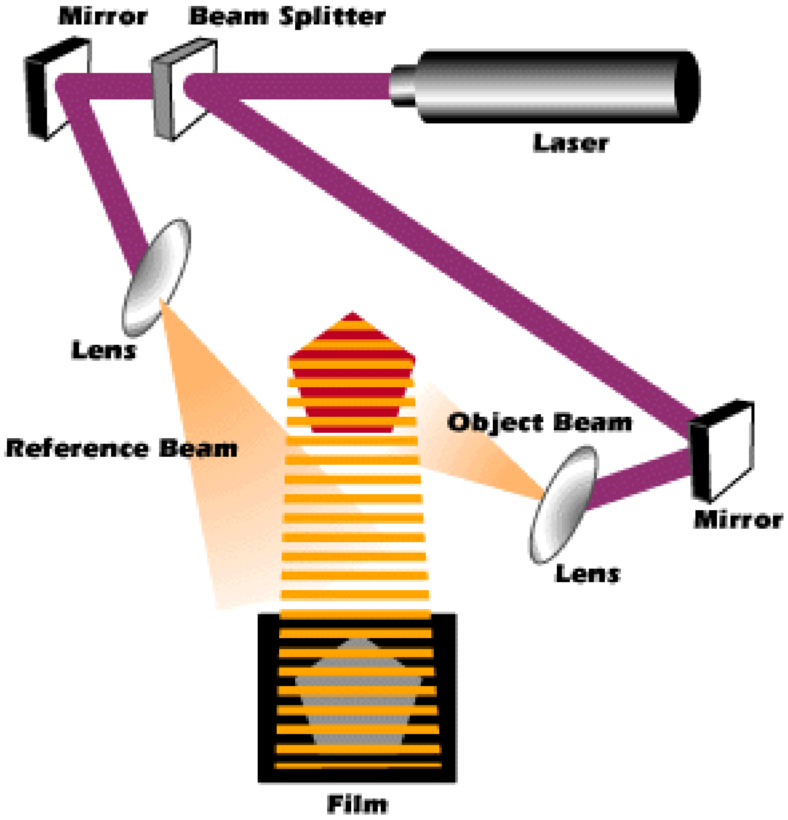
Measures light-matter interactions
(absorptions, emissions, scatterings)



NASA/JPL/University of Colorado
An ultraviolet imaging spectrograph took this picture of Saturn's C rings (left) and B rings (right). The red bands indicate "dirty" particles while cleaner ice particles are shown as turquoise in the outer parts of the rings

Laser applications: science

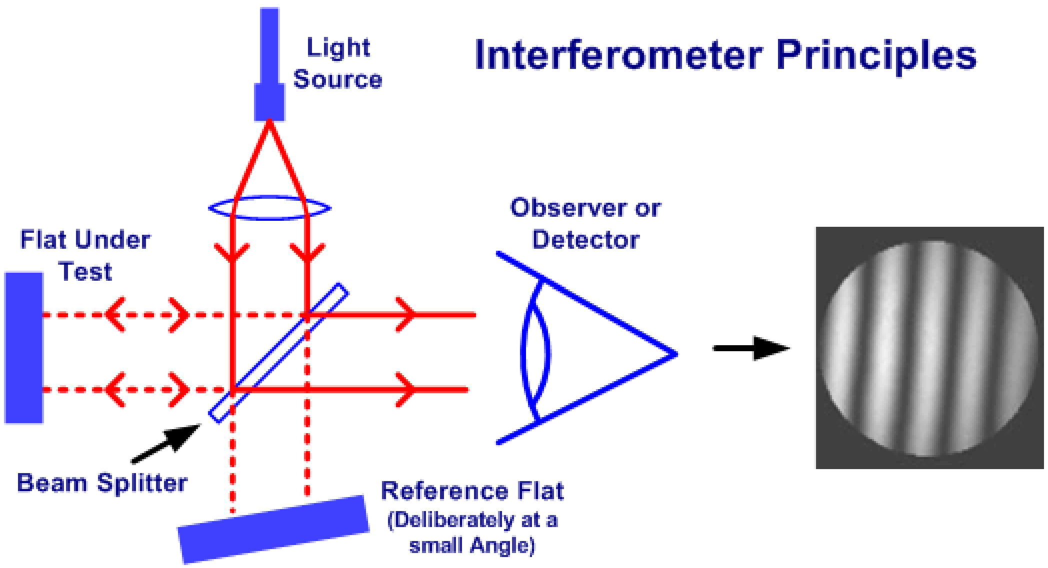
Holography

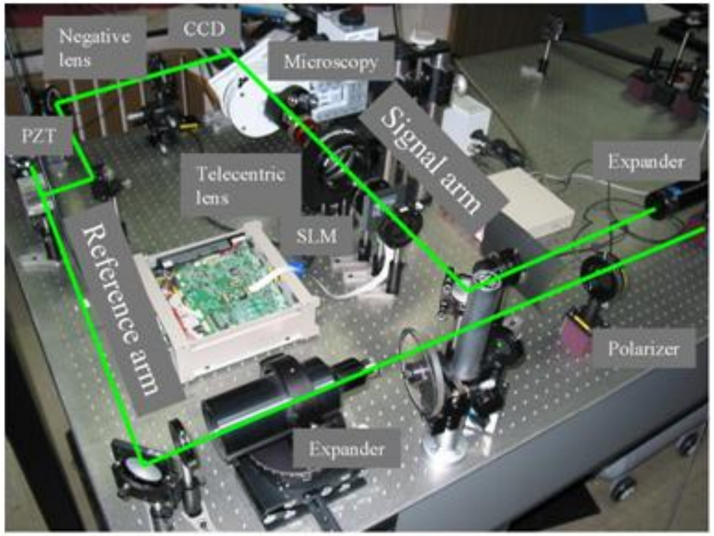


Holographic portrait of Prof. Yuri Denisyuk.
Courtesy of State Optical Institute
(St.Petersburg, Russia).

Laser applications: science

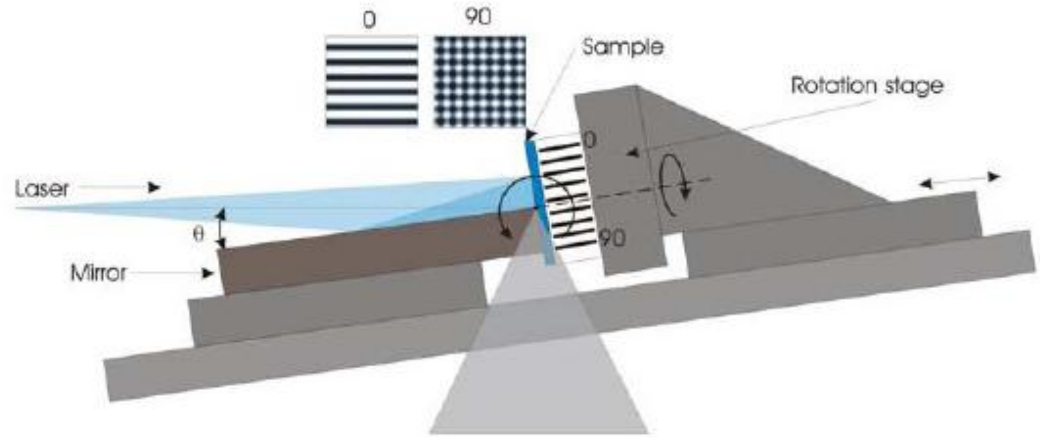
Interferemeter

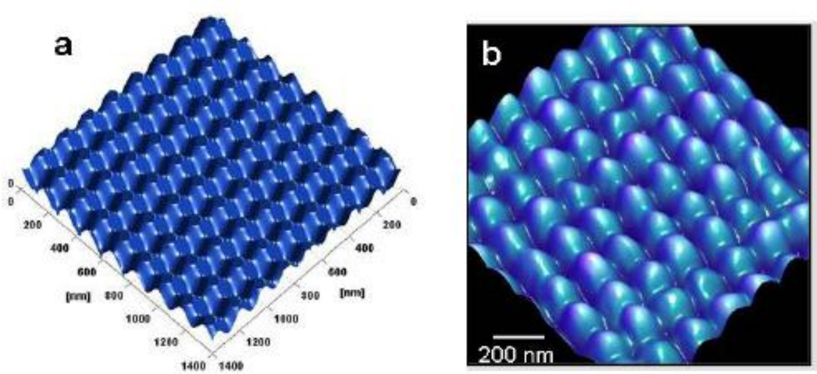


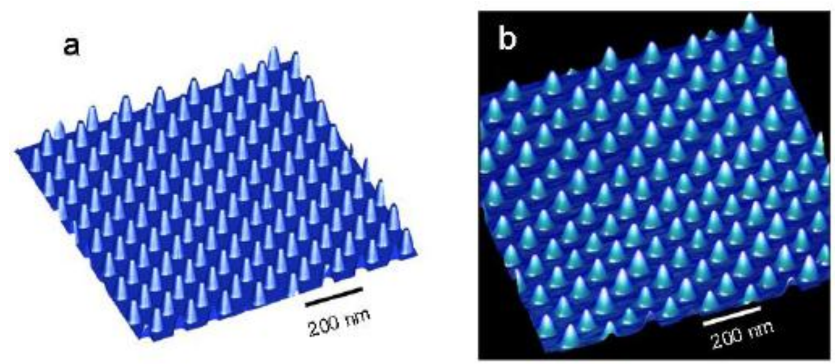


Laser applications: science

Lithography







P. W. Wachulak, et. al, Opt. Express **15** 3465-3469 (2007)

Laser applications: science

Surface plasmons