



50 anys del làser.

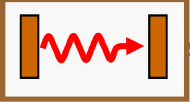
Aplicacions actuals i futures en ciència i tecnologia

Ramon Vilaseca



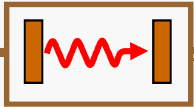
UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

Departament de Física i Enginyeria Nuclear
Campus de Terrassa (Barcelona)



Theodore Maiman, 16 May 1960



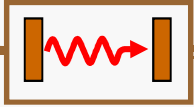


- A) Introducció, amb una mica d'història
- B) L'interior del làser *(breu)*
 - Principis de funcionament.
 - Varietat de tipus de làser segons el medi amplificador:
- C) L'exterior del làser: la radiació làser
 - Propietats de la radiació làser
- D) Aplicacions científiques i tècniques (present i futur)

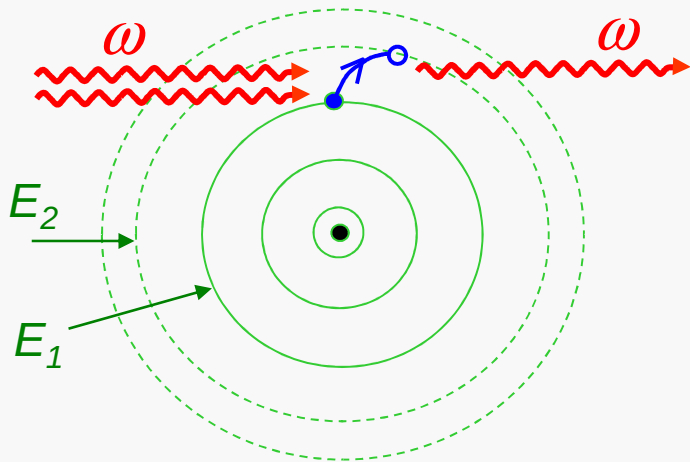


“Light Amplification by Stimulated Emission of Radiation”

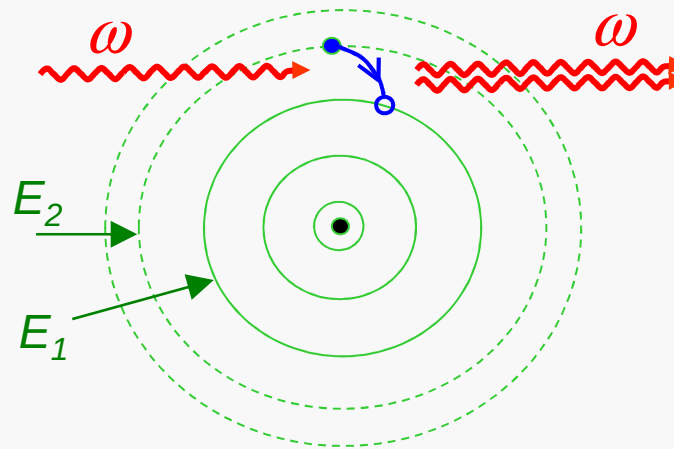
- ♦ **1917.- Einstein: concept of stimulated emission**
- ♦ **1928.- Ladenburg: confirms existence stimulated emission**
- ♦ **1939.- Fabrikant: predicts use of stim. emission to amplify “short” waves**
- ♦ **1947.- Lamb and Retherford: found apparent stimulated emission in hydrogen spectra**
- ♦ **1949-51.- Kastler: optical pumping [Nobel Prize in 1966] (+ Brossel)**
- ♦ **1954.- Townes: first MASER** (at Columbia University) [$\lambda=1$ cm, power=10 nW]
- ♦ **1956.- Bloembergen: first solid-state Maser** (at Harvard University)
- ♦ **1957.- Gould: ideas about a laser; first use of the acronym “laser”** (Columbia Univ. grad. student)
- ♦ **1958.- Schawlow, Townes: theoret. predictions about Laser** (Bell Labs) (Phys. Rev. Lett.)
Basov and Prokhorov: work on how to build a laser (URSS)
- ♦ **1959-1960.- Begining of a 30-year Laser patent dispute!, between Gould (at TRG company) and Townes-Schawlow (at Bell Labs)** [also dispute with Fabrikant –at Moscow Power Institute-: he applied for a patent in URSS in 1951, it was approved in 1959].
- ♦ **1960 (May, 16).- Maiman: first LASER (Rubi)** (at Hughes Research Laboratories, Calif.) [3-level laser]
***Nature* 187, 493-494 (1960) [no word “laser”; only 240 words; PRL rejected it]**



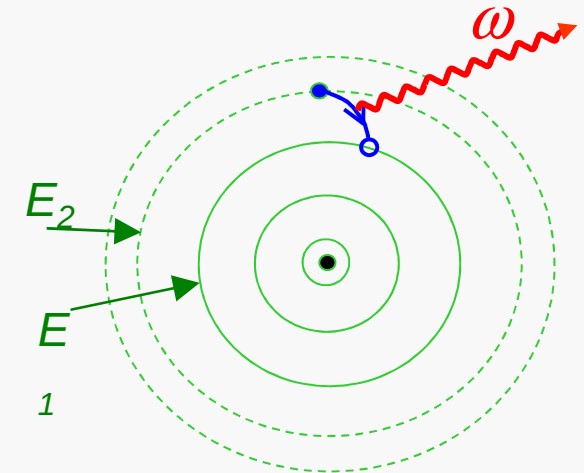
Absorption



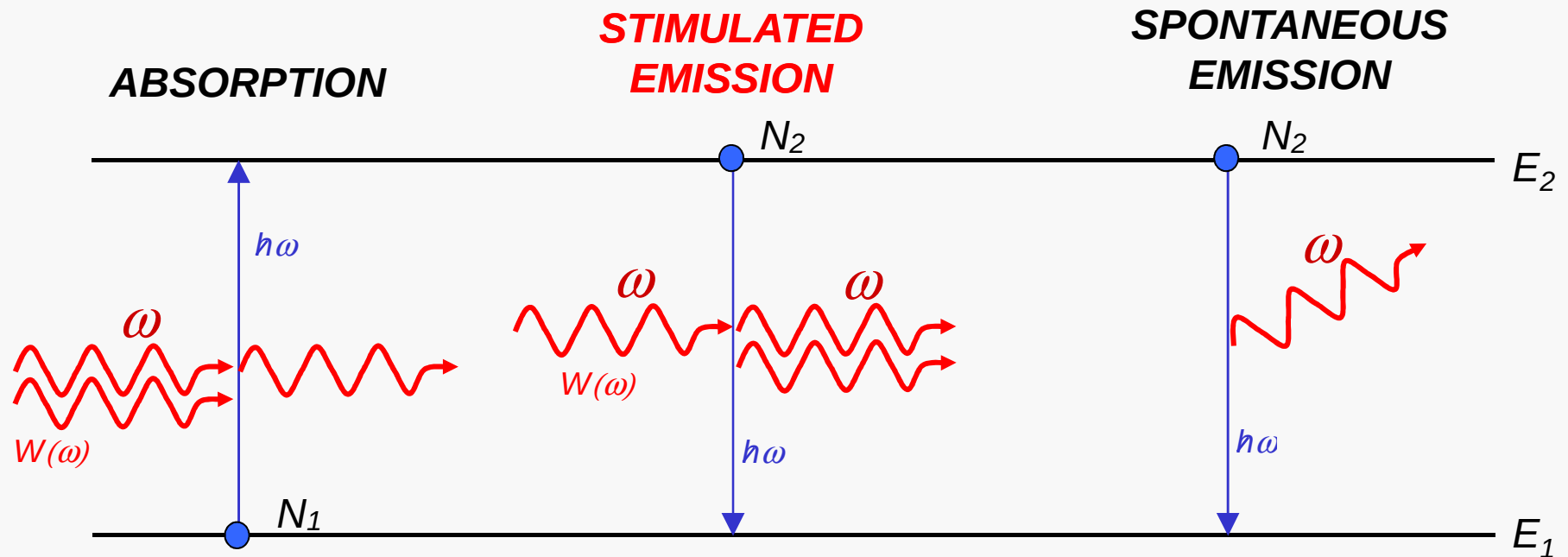
Stimulated emission



Spontaneous emission



$$E_2 - E_1 = \hbar \cdot \omega \quad \text{in all three cases}$$



In appropriate conditions:

Probabil. per u.t. =

$$B_{12} N_1 W(\omega)$$

Probabil. per u.t. =

$$B_{21} N_2 \underline{W(\omega)}$$

Probabil. per u.t. =

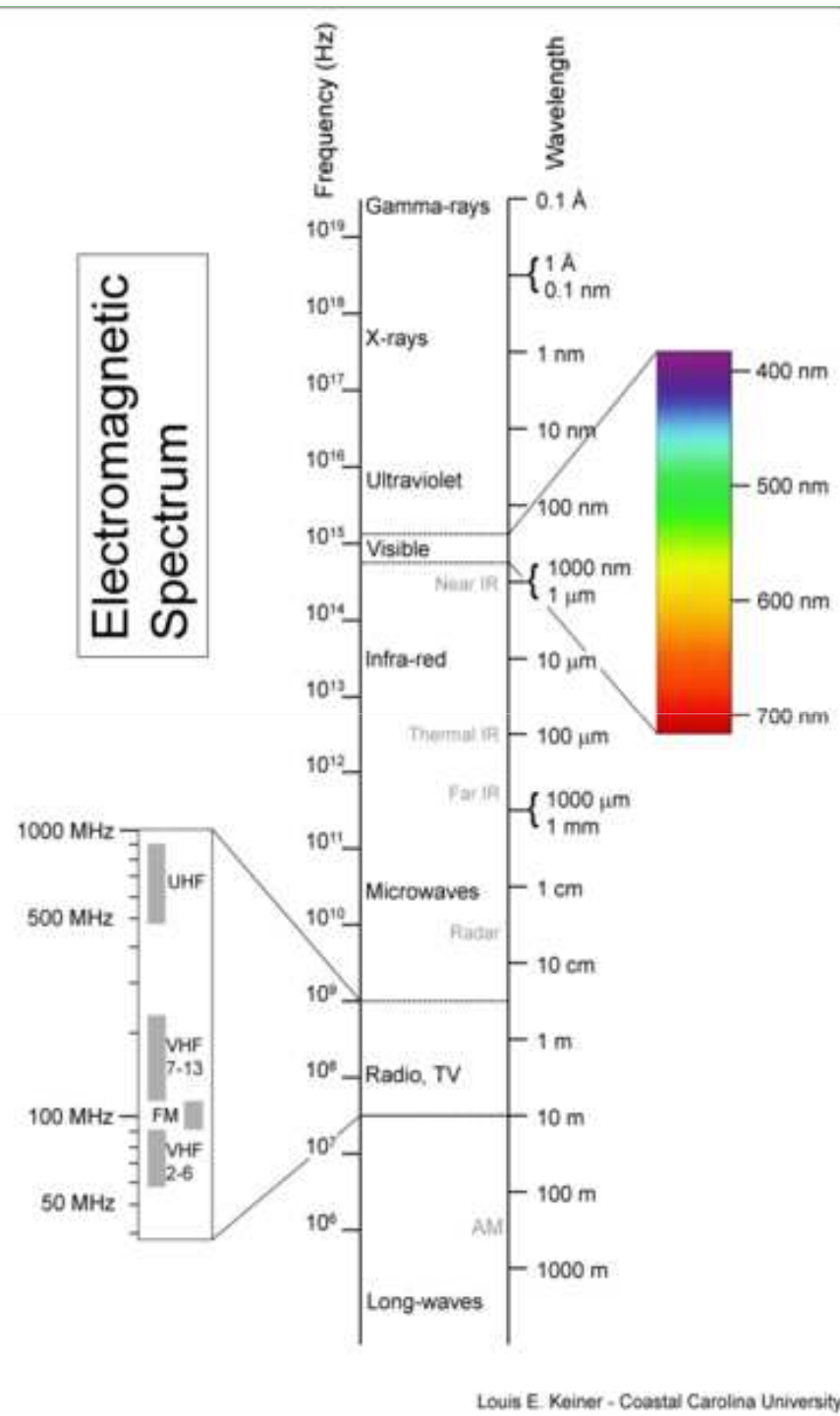
$$A_{21} N_2$$

Einstein coefficients

Einstein coeff. properties:

$$B_{12} = B_{21}$$

$$A_{21} = B_{21} \frac{8\pi h \nu_{21}^3}{c^3}$$





“Light Amplification by Stimulated Emission of Radiation”

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- ♦ **1960** (May, 16).- **Maiman: first laser (Rubi)** (at Hughes Research Laboratories, Calif.) [3-level laser]
- ♦ **1960** (Nov).- **Uranium laser :Sorokin & Stevenson** (at IBM Research Center) [solid-state, 4-level]
- ♦ **1960** (Dec).- **He-Ne Laser: Javan, Bennet, Herriot** (at Bell Labs) [first cw laser, $\lambda=1.15 \mu\text{m}$]
- ♦ **1961.- Lasers appear in commercial market** (Trion Instr., Perkin-elmer, Spectra-Physics,...)
- ♦ **1961** (Nov).- **Nd:Glass laser.- Snitzer** (American Optical Co.)
- ♦ **1961** (Dec).- **1st medical treatment** (destroying retinal tumor with a rubi laser)
- ♦ **1962.- Q-switching in rubi laser: Hellwarth, McClung** (Hughes Research Labs) [theory in 1961]
- ♦ **1962.- GaAs Semiconductor laser** (homojunction, cryogenically cooled) [GE, IBM & MIT's Lincoln Lab]
- ♦ **1962.- YAG laser** (at Bell Labs.)
- ♦ **1962.- GaAsP visible-red laser diode (basis of present LEDs)** (Holonyak at GE Co. Lab)
- ♦ **1962.- First paper on Nonlinear Optics** (Armstrong, Bloembergen, Ducuing and Pershan)
- ♦ **1963.- First mode-locked laser** (He-Ne laser with acousto-optic modulator)
- ♦ **1963.- \$1 million annual sales commercial laser market**
- ♦ **1963.- Heterostructure semiconductor laser idea** (Kroemer –Univ. California- & Alferov -Russia-).
Nobel Prize awarded later.
- ♦ **1963.- N₂ laser** (*confirm*)

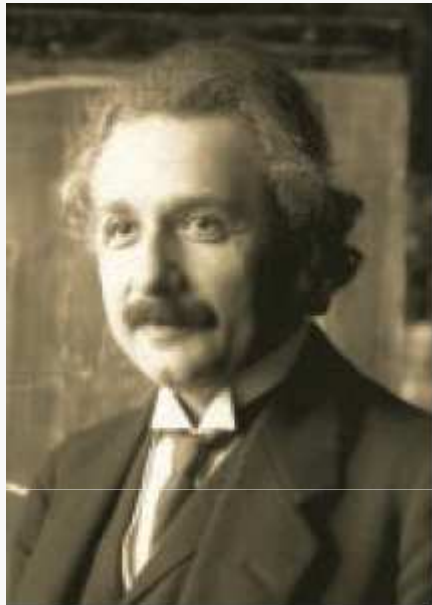
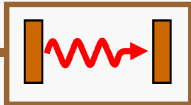


- ♦ 1964.- Ar⁺ (pulsed), Kr⁺, CO₂, Nd:YAG (Bell Labs) ,
- ♦ 1964.- Nobel Prize to Townes, Basov and Prokhorov
- ♦ 1965.- Chemical laser (HCl, $\lambda=3.7 \mu\text{m}$)
- ♦ 1966.- Dye laser (tunable)
- ♦ 1970.- Excimer laser and cw room-temperature semiconductor laser
- ♦ 1972.- Quantum-well semiconductor laser
- ♦ 1976.- Free-electron laser
- ♦ 1981.- Nobel Prize to Schawlow and Bloembergen (laser spectroscopy)
- ♦ 1982.- Ti:Sapphire laser (tunable)
- ♦ 1986.- Fibre laser (Er-doped, single-mode, cw)
- ♦ 1994.- Quantum-cascade laser (multiple λ 's) , and quantum-dot laser
- ♦ 1996.- Pulsed atom laser (matter instead of light)
- ♦ 1996.- InGaN blue laser diode (semiconductor, $\lambda = 417 \text{ nm}$)



- ♦ **2004-07.-** Towards a Si laser: Si Raman laser and electr. powered hybrid Si laser, ...
- ♦ **2009.-** NIF (National Ignition Facility, at LLNL): 192 laser beams firing onto targets.
- ♦ **2009-10.-** Intel's Light Peak fiber optic technology.
- ♦ **2009 (Dec.)-** Prediction of 11% laser market growth for 2010; total revenue \$5.9 billion.
- ♦ **2010 (Jan.)-** NIF delivers enough laser energy to achieve fusion ignition: 1MJ in a few nanoseconds [peak power 500 times larger than any previous one in USA]
- ♦ **2010 (March)-** Single-atom laser (with and without threshold) [Univ. of Innsbruck]
 -
 -
 -

THUS TECHNICAL, AND EVEN FUNDAMENTAL, DEVELOPMENT CONTINUES...



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Albert Einstein



AP Photo

Charles H. Townes, 1954



Wikimedia Commons

Nikolai G. Basov



Wikimedia Commons

Alexander M. Prokhorov

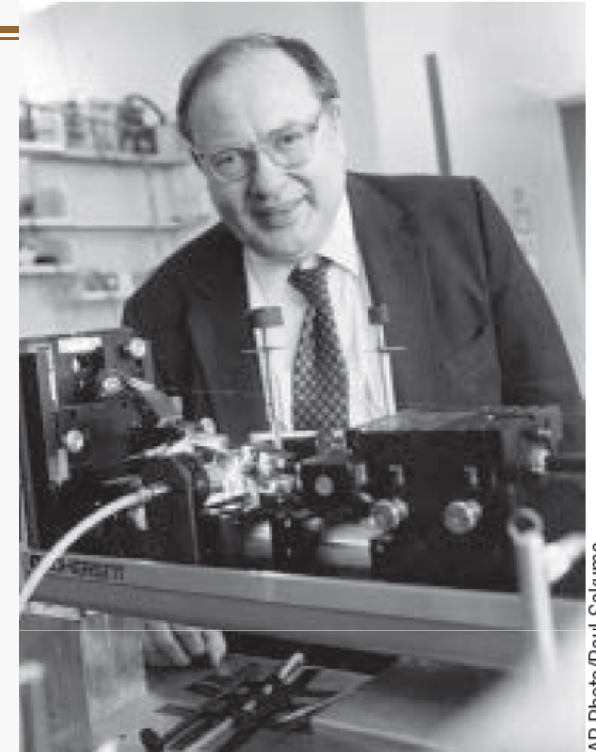
50 anys del làser...



AP Photo

**Charles H. Townes,
1954**

**Theodore Maiman,
1960**

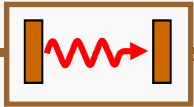


AP Photo/Paul Sakuma

Arthur Schawlow



Charles H. Townes, 2010



Nicolaas Bloembergen

Harvard University, USA



Arthur L. Schawlow

Stanford University, USA

“For their contribution to the development of laser spectroscopy”



Steven Chu

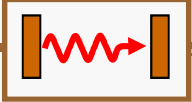


*Claude
Cohen-Tannoudji*



William D. Phillips

***“For development of methods to cool and trap atoms
with laser light”***



Eric A. Cornell

JILA and NIST
Boulder, CO, USA

Born in 1961 (Palo Alto)
PhD 1990 (MIT)



Wolfgang Ketterle

MIT
Cambridge, MA, USA

Born in 1957 (Heidelberg)
PhD 1986 (Universität München and Max-Planck-Institut für Quantenoptik, Garching)



Carl E. Wieman

JILA and Univ. of Colorado
Boulder, CO, USA

Born in 1951 (Oregon)
PhD 1977 at Stanford University

“For the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates”.

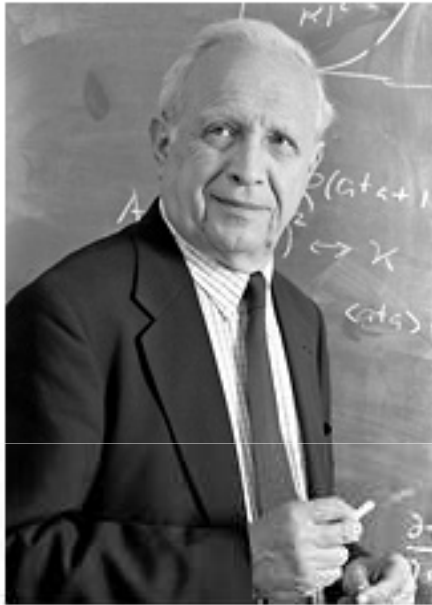
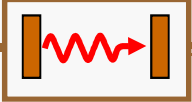


Photo: J. Reed

Roy J. Glauber



Photo: Sears P. Studio

John L. Hall



Photo: F.M. Schmidt

Theodor W. Hänsch

The Nobel Prize in Physics 2005 was divided, one half awarded to Roy J. Glauber "for his contribution to the quantum theory of optical coherence", the other half jointly to John L. Hall and Theodor W. Hänsch "for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique".



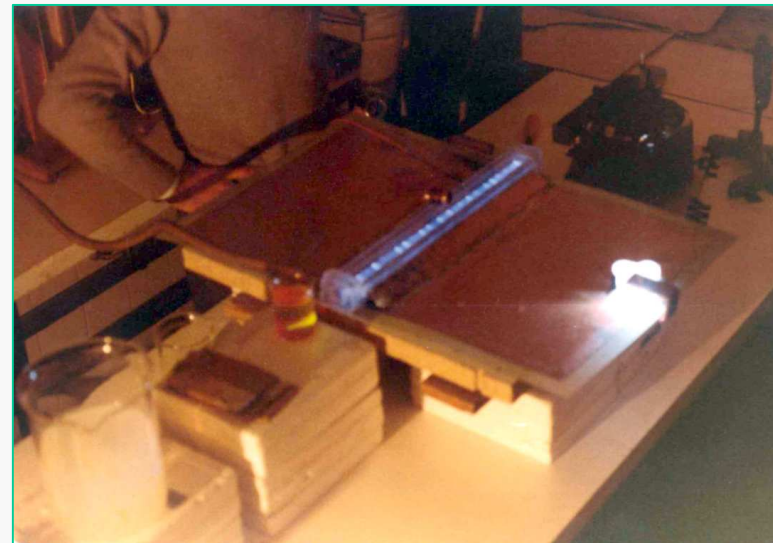
I ... a Barcelona, què ??

♦ **Primers làsers comprats:**

- **Primer làser:** probablement el làser de rubí del prof. Garrido (60's)
- **Després:** Làsers de He-Ne a la UB, a la UAB, a UPC,... (70's)
- Làsers de Ar^+ a les discoteques, a la UAB, ... (finals 70's, 80's)

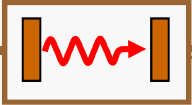
♦ **Primer làser construït:**

- **Primer làser:** Làser de N_2 , a la UAB (curs 1979-80)
- **Després:** Làsers de CO_2 , a CRILASER (principis dels 80's)



LASERS: Sumari

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A) Introducció, i una mica d'històrica

B) L'interior del làser (breu)

- Principis de funcionament.
- Varietat de tipus de làser segons el medi amplificador:
- Paper jugat pel ressonador òptic.

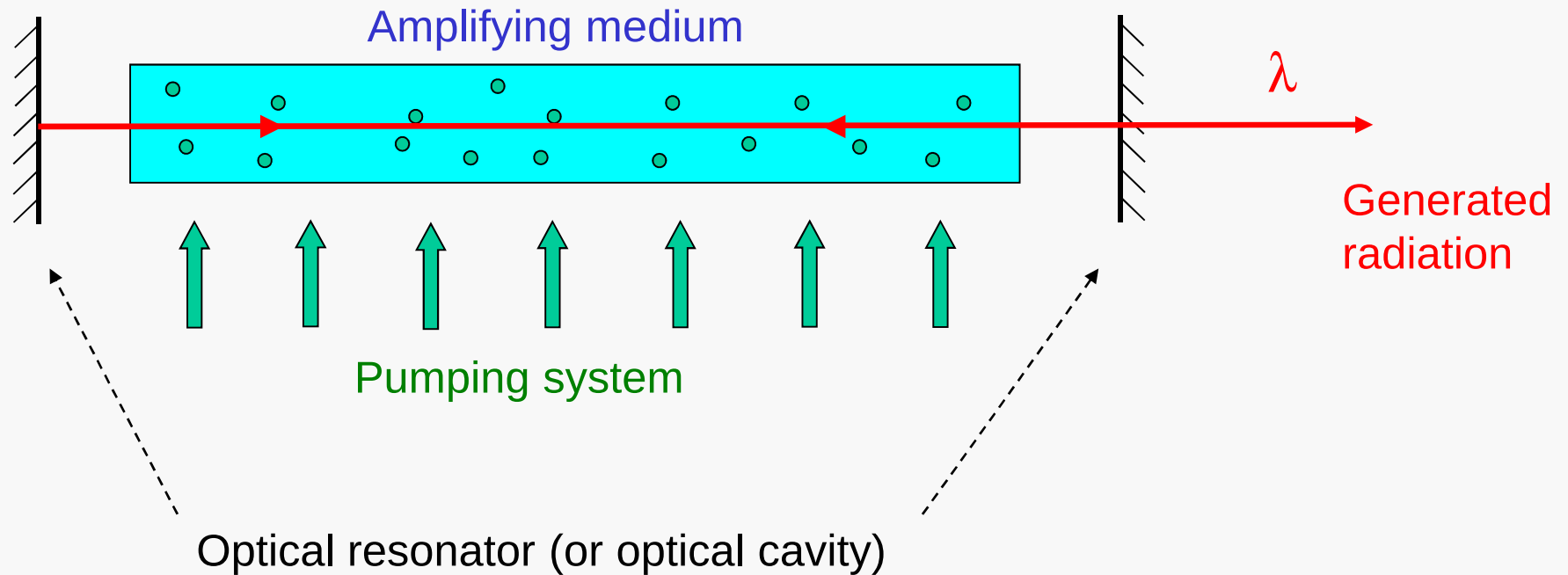
C) L'exterior del làser: la radiació làser

- Propietats de la radiació làser

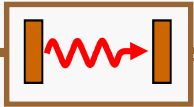
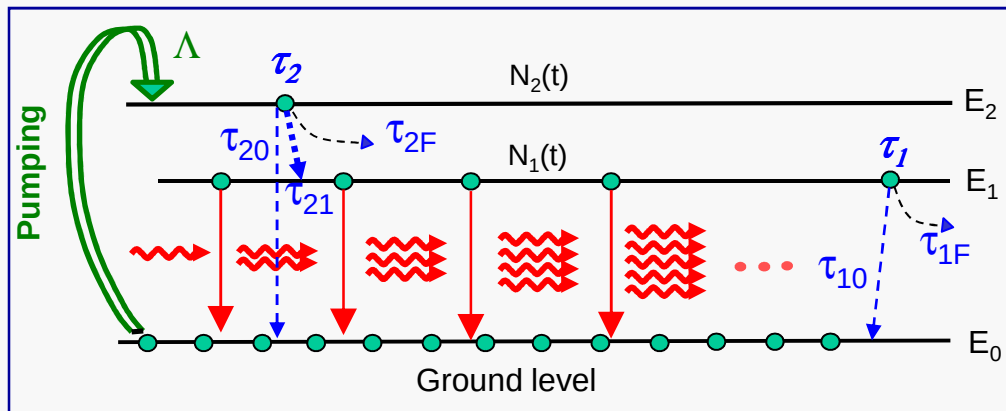
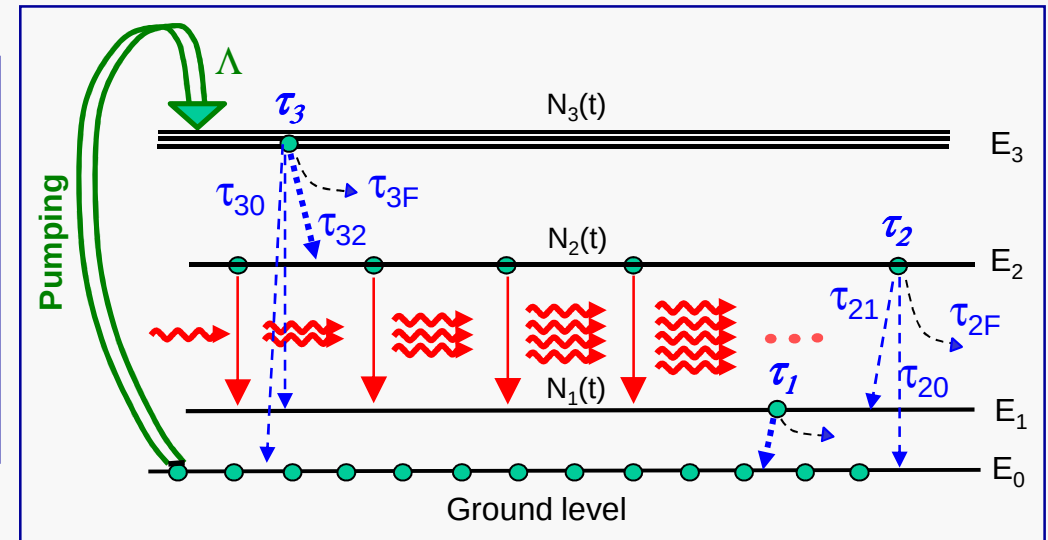
D) Aplicacions científiques i tècniques (present i futur)

Parts d'un làser, i principis de funcionament

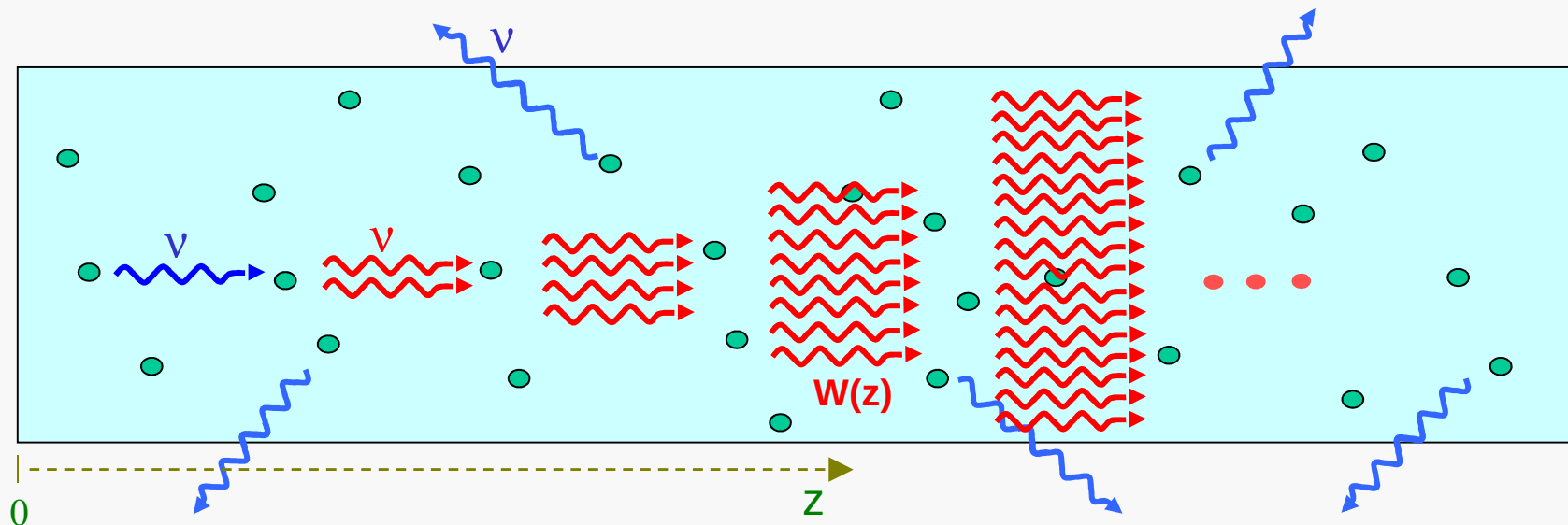
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Sistema "dissipatiu"

**“Three-level” configurations****“Four-level” configuration**

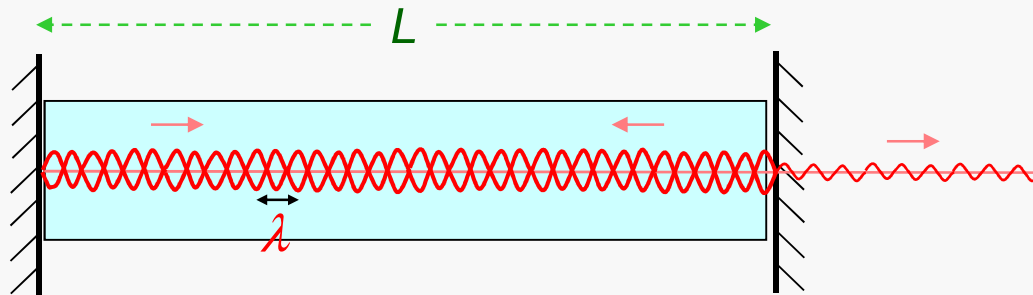
Who provides the first photon?



Optical cavity: longitudinal modes

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"Fabry-Perot" cavity



Resonance condition:

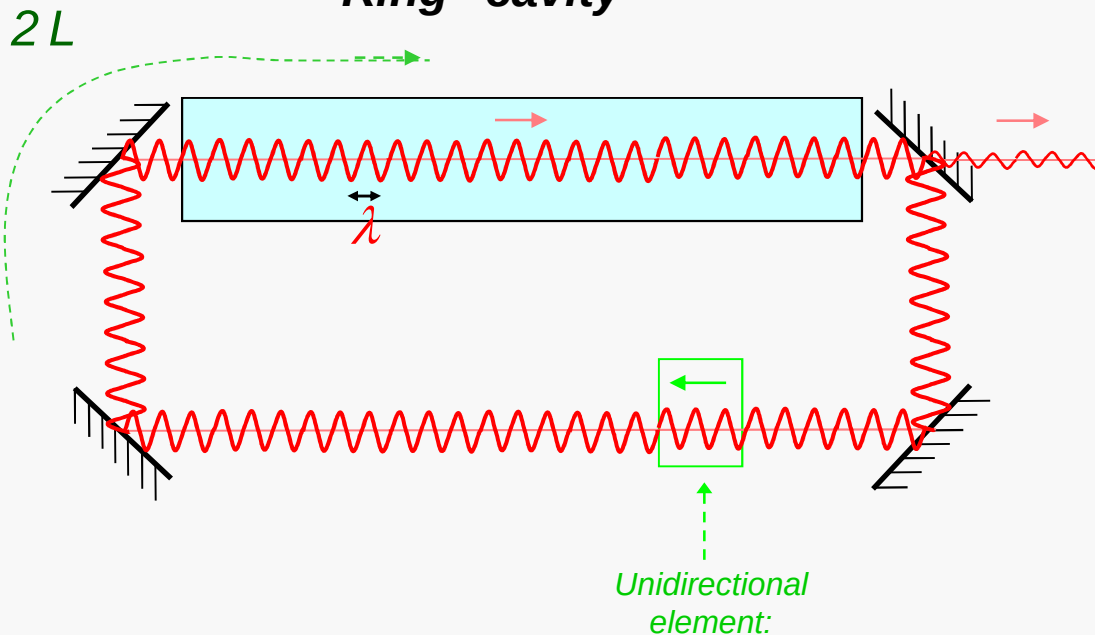
$$2L = m \lambda = m v / \nu$$

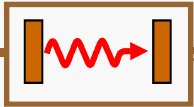


$$\nu_m = m \frac{v}{2L}$$

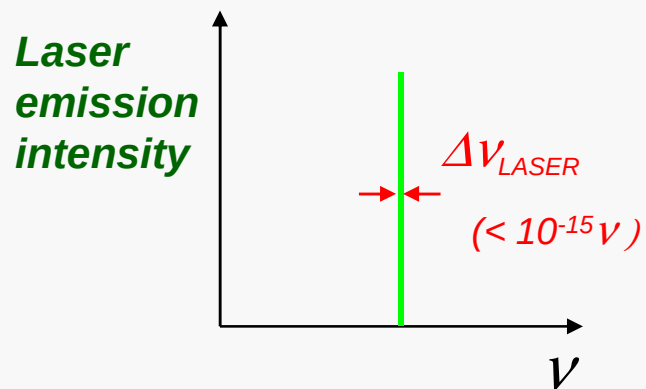
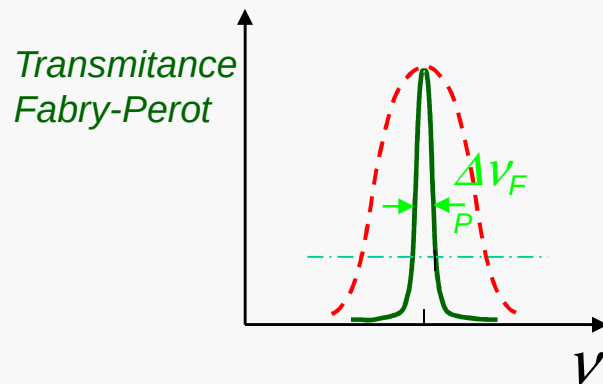
Frequency of the longitudinal mode of order m

"Ring" cavity

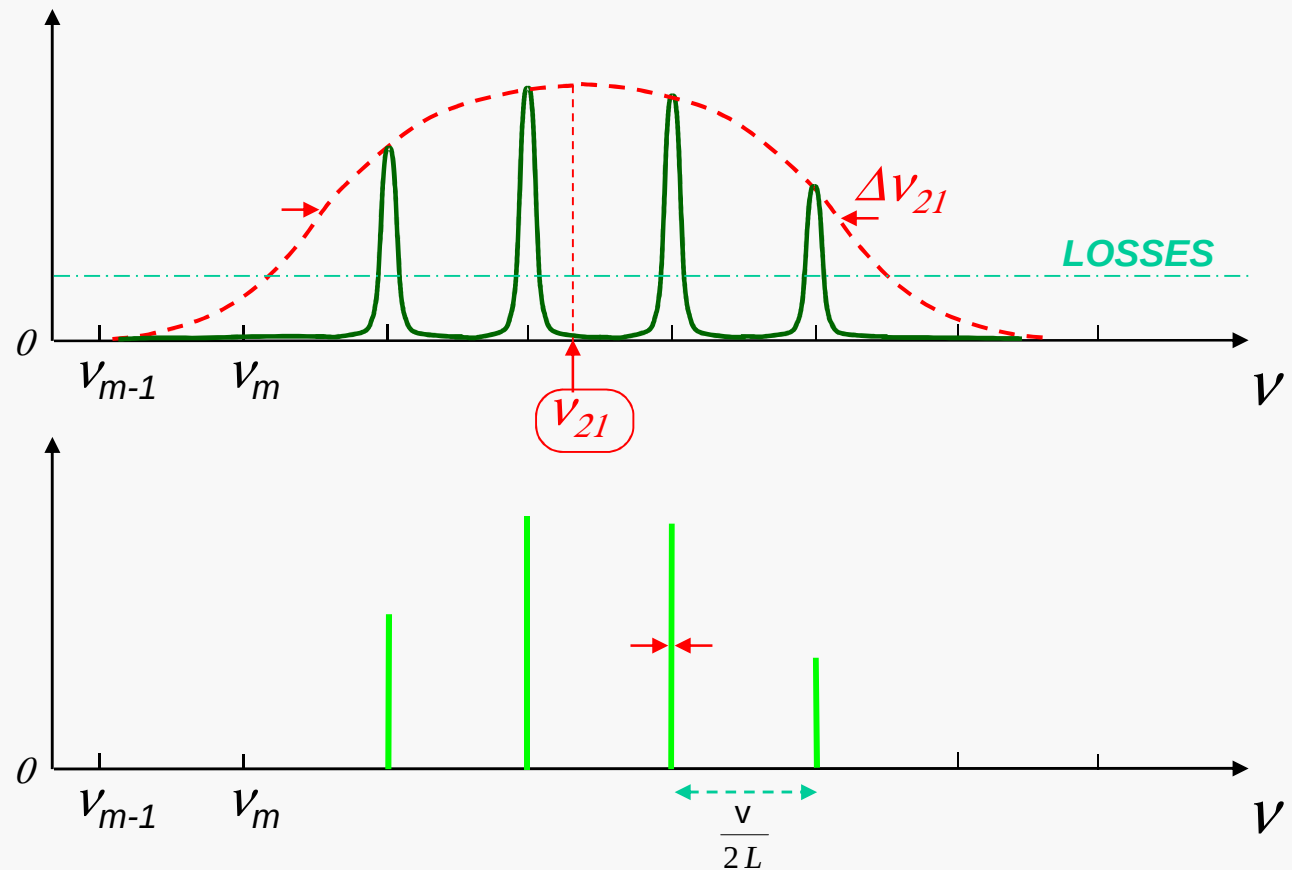




- Actually, the modes are much more monochromatic due to the competitive effect of stimulated emission !!!



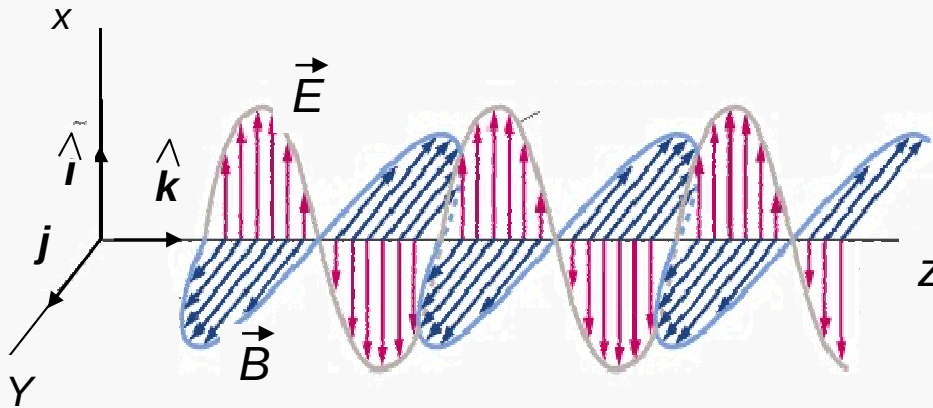
Single-mode case



Multi-mode case



Ona electromagnètica ...



$$\left\{ \begin{array}{l} \vec{E}(z,t) = \hat{i} E \cos(kz - \omega t + \varphi) \\ \vec{B}(z,t) = \hat{j} B \cos(kz - \omega t + \varphi) \end{array} \right\}$$

$$B = E / v$$

Space

- ✧ Wavelength: λ
- ✧ Wavenumber: $k = 2\pi / \lambda$

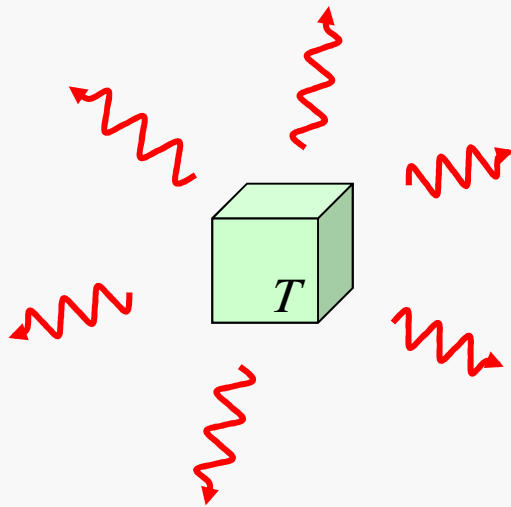
Time

- ✧ Period: T
- ✧ Frequency: $\nu = 1 / T$
- ✧ Angular frequency: $\omega = 2\pi \nu$
- ✧ Initial phase: φ

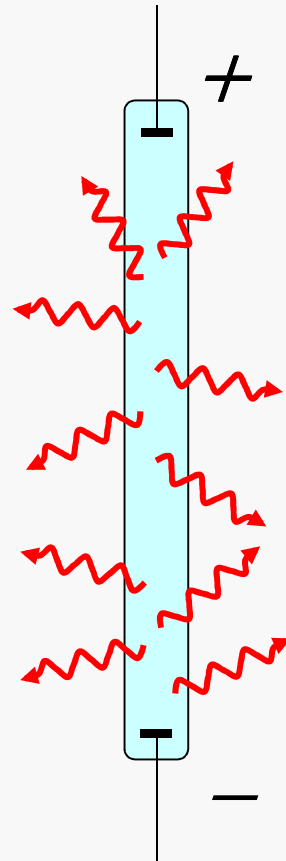
+ els aspectes corpusculars (fotons)...



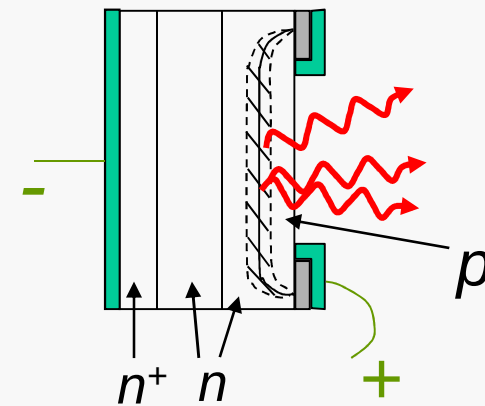
La llum làser és semblant als altres tipus de llum?



**Radiació
tèrmica**



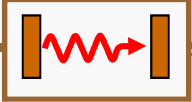
**Descàrrega
elèctrica**



L.E.D.

Varietat de tipus de medi amplificador

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a) GAS

- ♦ **Atoms:** **He-Ne**, He-Cd, Cu.
- ♦ **Ions:** **Ar⁺**, Kr⁺.
- ♦ **Molecules:** Electronic (vibronic) transitions: **Excimer**, N₂.
 Vibrational transitions: **CO₂**, CO, **chemical lasers**.
 Rotacional transitions: NH₃, CH₃OH, CH₃F.

b) LIQUID

- ♦ **Dye laser:** **Rhodamin 6G**, coumarin,

c) SOLID STATE

- ♦ **Doped crystal:** Rubi, **Nd:YAG**, Nd:Glass, **Ti:Sapphire**, Alexandrite
- ♦ **Optical fiber:** **Er³⁺:Silicon** (Er³⁺:SiO₂)
- ♦ **Others:** Color centres, Microxips,...

d) SEMICONDUCTOR (DIODE LASERS)

- ♦ **Near infrared:** **AlGaAs**, **InGaAsP**
- ♦ **Visible:** **GaInP**, **AlGaInP**, **GaP**
- ♦ **Mid infrared:** ...
- ♦ **Other types:** VCSEL's, "arrays", high power, quantum cascade, ...

e) OTHERS

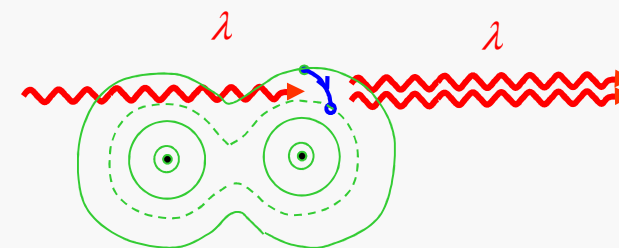
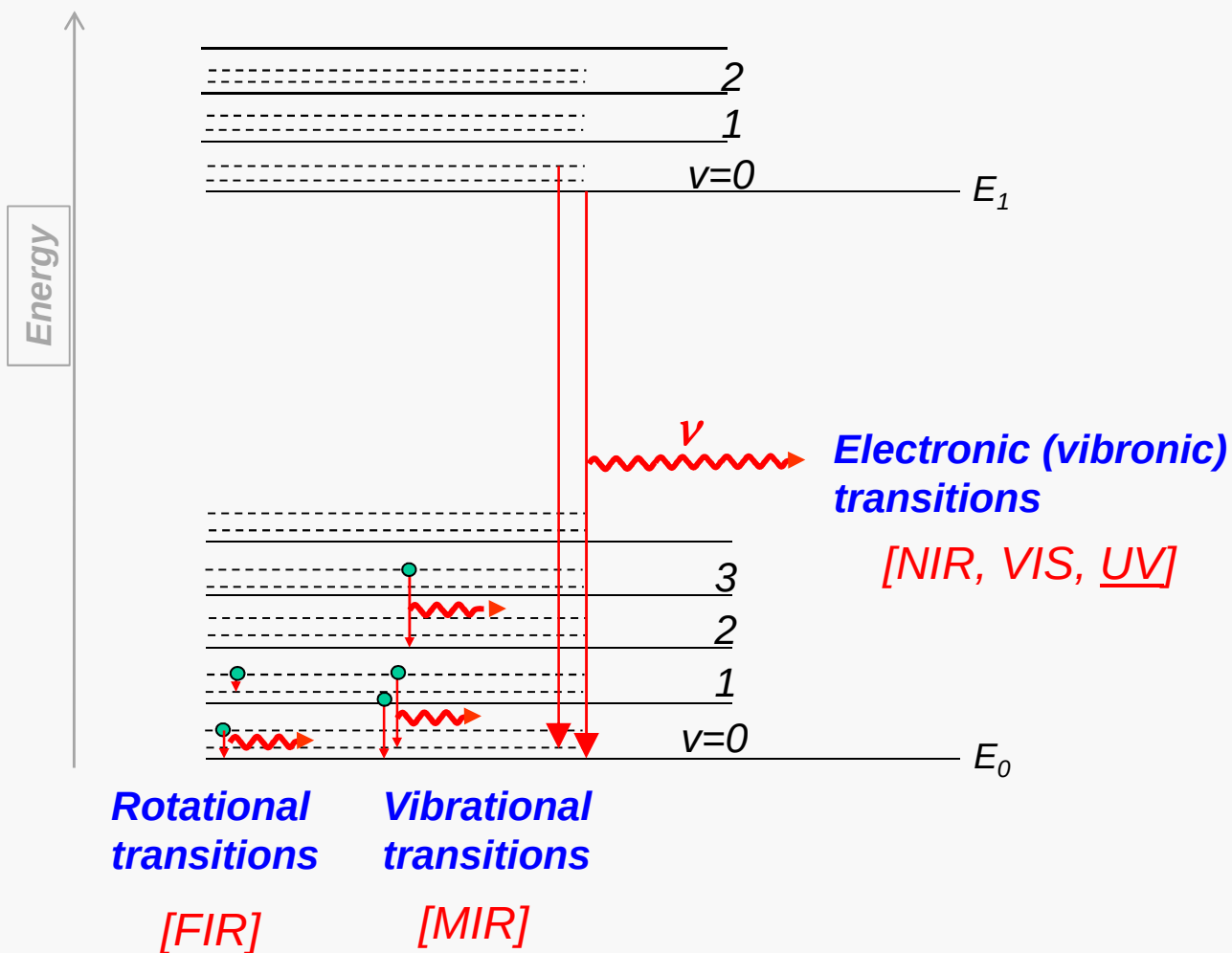
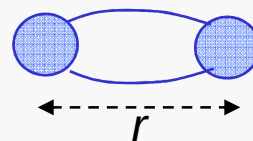
- ♦ **Free electron laser**, ♦ **X Ray**, ♦ **Random lasers**,
- ♦ **Micro- and nano-lasers** (microdisc, microsphere, quantum dot, photonic crystal, plasmon laser...), ♦ **Single-atom lasers**, ♦ **Làser d'àtoms**

B) GAS LASERS: Molecular

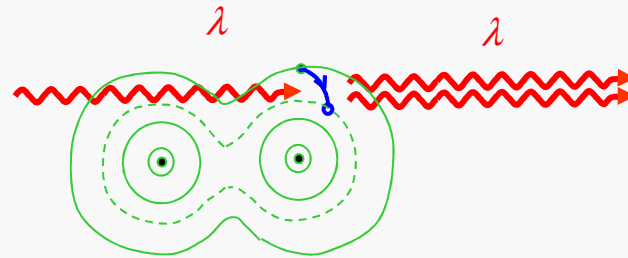
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Energy levels for a (simple) molecule :



- Pumping: electrical discharge



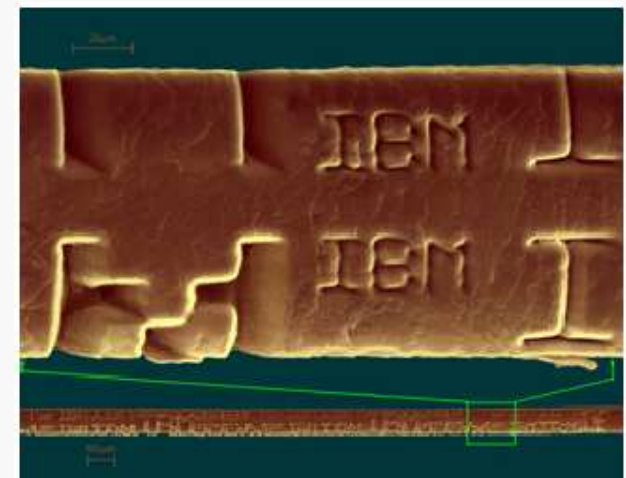
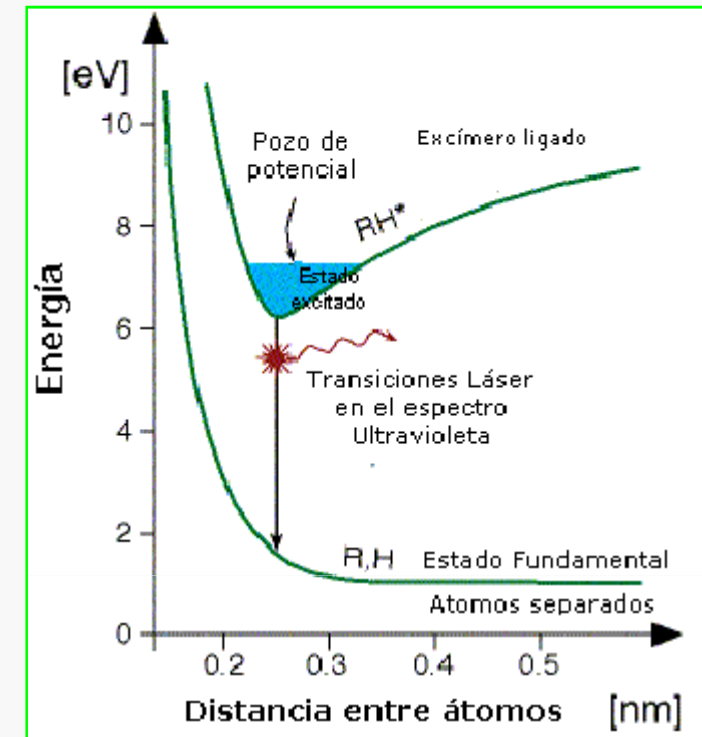
- Example: Excimer laser ($\eta \sim 1-10\%$, 3-level):

ArF $\lambda = 193 \text{ nm}$ (UV)

KrF $\lambda = 248 \text{ nm}$ (UV)

XeCl $\lambda = 309 \text{ nm}$ (UV)

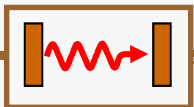
XeF $\lambda = 351 \text{ nm}$ (UV)



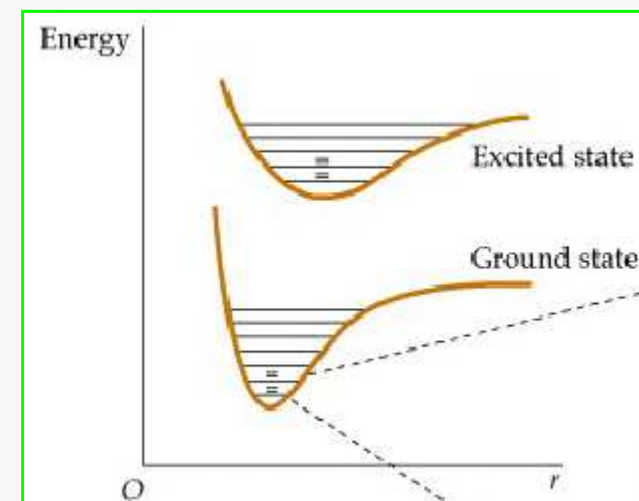
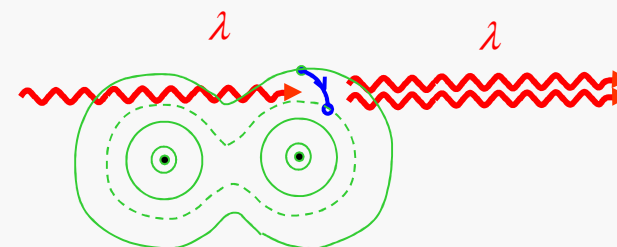
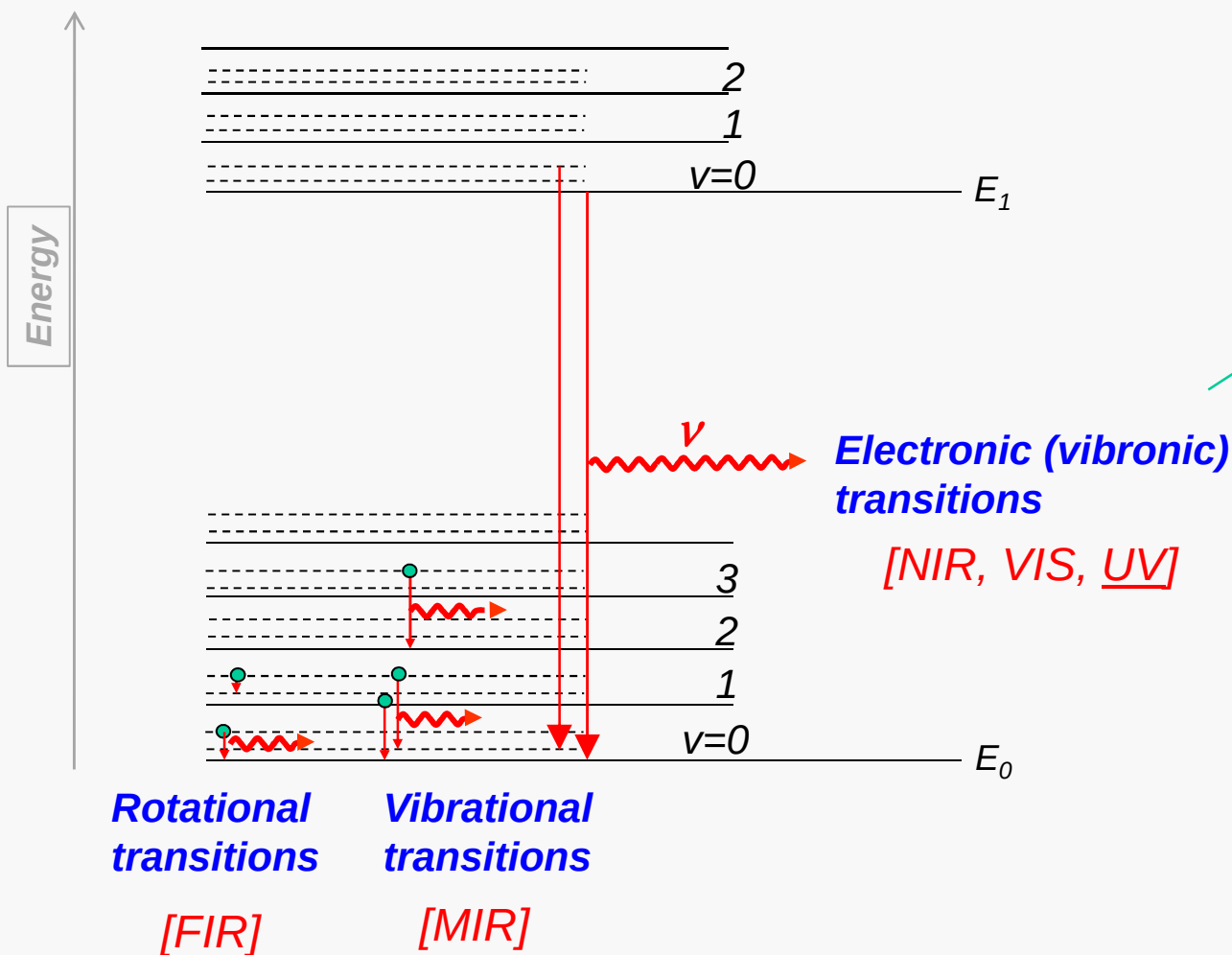
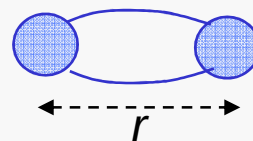
Human hair !

B) GAS LASERS: Molecular

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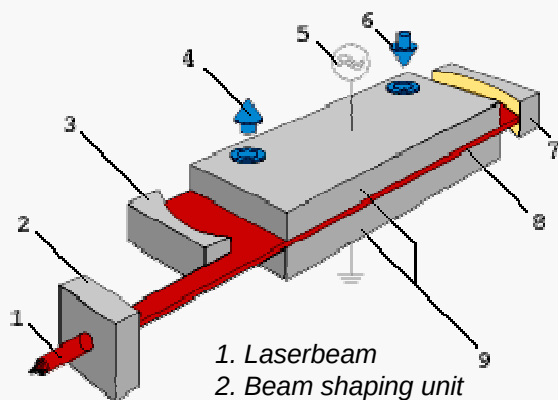


Energy levels for a (simple) molecule :




www.rofin.com

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1. Laserbeam
2. Beam shaping unit
3. Output mirror
4. Cooling water
5. RF excitation
6. Cooling water
7. Rear mirror
8. RF excited discharge
9. Waveguiding electrodes



Can it propagate
through an optical
fiber?: **No** (Why?)

	ROFIN DC 010	ROFIN DC 015	ROFIN DC 020	ROFIN DC 025
Excitation	HF	HF	HF	HF
Output power	1000 W	1500 W	2000 W	2500 W
Power range	100-1000 W	150-1500 W	200-2000 W	250-2500 W
Beam quality factor	K > 0,9	K > 0,9	K > 0,9	K > 0,9
Pulse frequency	0 or 2 up to 5000 Hz; CW	0 or 2 up to 5000 Hz; CW	0 or 2 up to 5000 Hz; CW	0 or 2 up to 5000 Hz; CW

	ROFIN DC 030	ROFIN DC 035	ROFIN DC 040	ROFIN DC 045
Excitation	HF	HF	HF	HF
Output power	3000 W	3500 W	4000 W	4500 W
Power range	300-3000 W	350-3500 W	400-4000 W	450-4500 W
Beam quality factor	K > 0,9	K > 0,9	K ≥ 0,9	K ≥ 0,9
Pulse frequency	0 or 2 up to 5000 Hz; CW	0 or 2 up to 5000 Hz; CW	0 or 2 up to 5000 Hz; CW	-

	ROFIN DC 050	ROFIN DC 060 W	ROFIN DC 080 W
Excitation	RF	RF	RF
Output power	5000 W	6000 W	8000 W
Power range	500-5000 W	1500-6000 W	800-8000 W
Beam quality factor	K ≥ 0,9	K ≥ 0,9	K ≥ 0,9
Pulse frequency	-	-	-



LASERS: TYPES OF AMPLIFYING MEDIUM

a) GAS

- ♦ Atoms: He-Ne, He-Cd, Cu.
- ♦ Ions: Ar^+ , Kr^+ .
- ♦ Molecules: Electronic (vibronic) transitions: Excimer, N_2 .
Vibrational transitions: CO_2 , CO, **chemical lasers**.
Rotacional transitions: NH_3 , CH_3OH , CH_3F .

b) LIQUID

- ♦ Dye laser: **Rhodamin 6G**, coumarin,

c) SOLID STATE

- ♦ Doped crystal: Rubi, Nd:YAG, Nd:Glass, Ti:Sapphire, Alexandrite
Microxips, microlasers
- ♦ Optical fiber: Er^{3+} :Silicon (Er^{3+} : SiO_2)
- ♦ Others: Color centres, ...

d) SEMICONDUCTOR (DIODE LASERS)

- ♦ Near infrared: AlGaAs, InGaAsP
- ♦ Visible: GaInP, AlGaInP, GaP
- ♦ Mid infrared: ...
- ♦ Other types: VCSEL's, "arrays", high power, ...

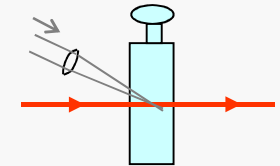
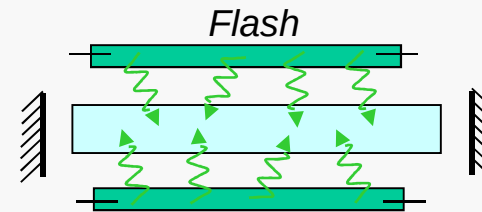
e) OTHERS

- ♦ Free electron laser, ♦ X Rays, g rays, ♦ Random lasers, (etc.)

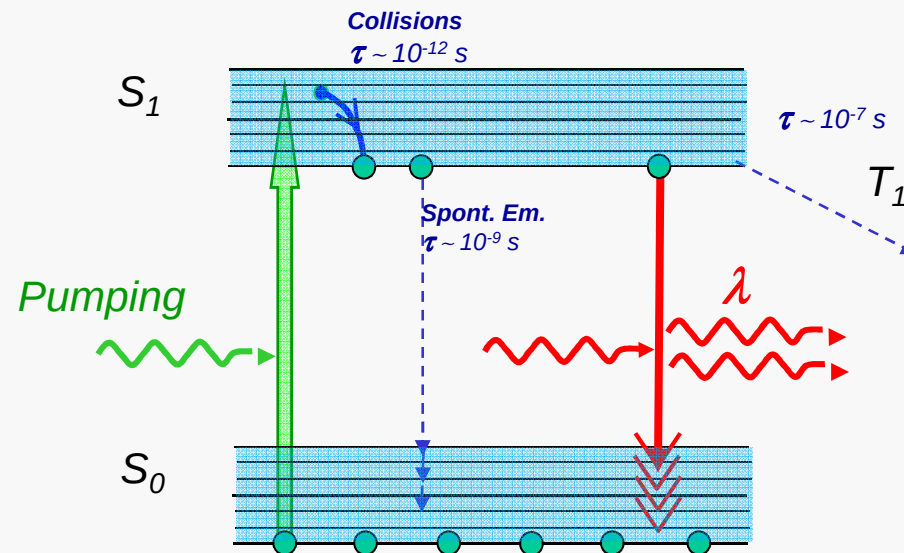
B) LIQUID LASERS: Dye laser

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- Pumping: optical: flash, or another laser



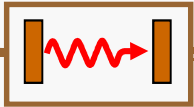
- “Vibronic” transitions
($\lambda \sim \text{VIS, NIR, near UV}$)



- $\lambda \sim 350\text{-}1000 \text{ nm}$, **TUNABLE !!**

$$\eta \sim 1\text{-}35\%$$

(how?)



LASERS: TYPES OF AMPLIFYING MEDIUM

a) GAS

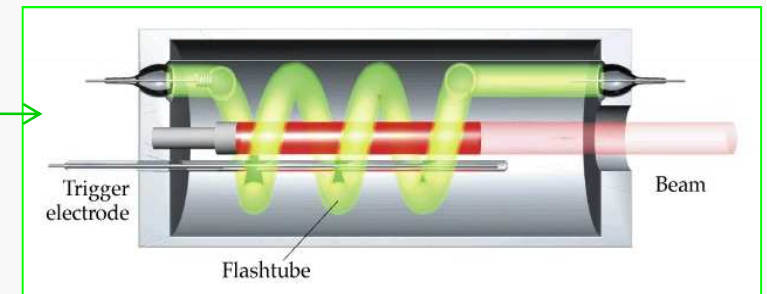
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Vibrational transitions: CO_2 , CO, **chemical lasers**.
Rotacional transitions: NH_3 , CH_3OH , CH_3F .

b) LIQUID

- ♦ Dye laser: Rhodamin 6G, coumarin,

c) SOLID STATE

- ♦ Doped crystal: Rubi, Nd:YAG, Nd:Glass, Ti:Sapphire, Alexandrite
- ♦ Optical fiber: Er^{3+} :Silica ($\text{Er}^{3+}:\text{SiO}_2$)
- ♦ Others: Color centres, microchip,...

d) SEMICONDUCTOR (DIODE LASERS)

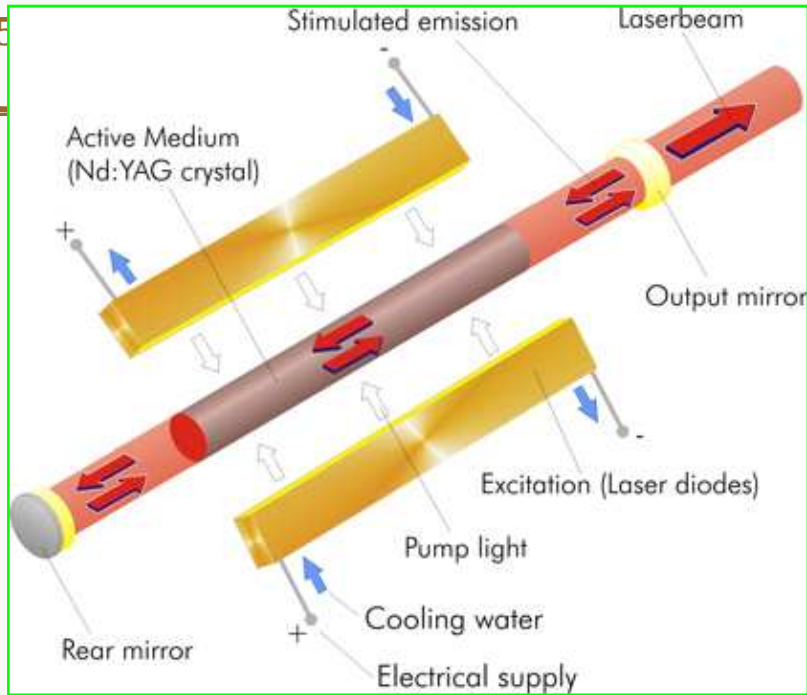
- ♦ Near infrared: AlGaAs, InGaAsP
- ♦ Visible: GaInP, AlGaInP, GaP
- ♦ Mid infrared: ...
- ♦ Other types: VCSEL's, "arrays", high power, ...

e) OTHERS

- ♦ Free electron laser, ♦ X Rays, g rays, ♦ Random lasers, (etc.)

B.c) SOLID-STATE LASERS: Nd:YAG laser

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**Excitation****Output power (@collimator)****Beam parameter product****Fiber diameter**ROFIN DP 010
HXROFIN DP 015
HX

Laser diodes

Laser diodes

100 - 1000 W

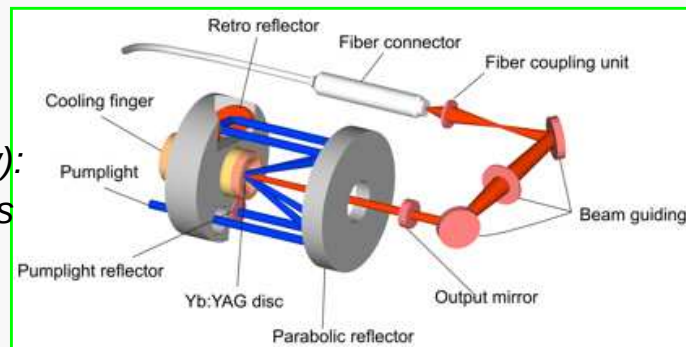
150 - 1500 W

12 mm*mrad

12 mm*mrad

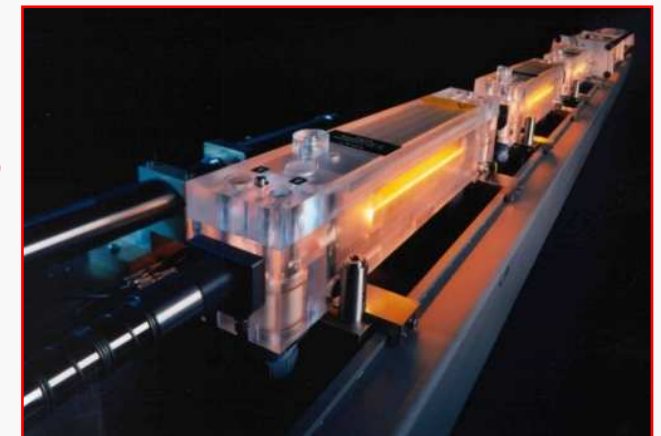
300 μ m300 μ m
www.rofin.com

Also (new):
disk series



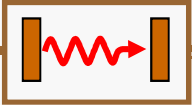
High power:
MOPA
configuration

Trumpf: up to 16 kW,
BPP ~ 2-8 mm·mrad


www.trumpf-laser.com

B) SOLID-STATE LASERS: Nd:YAG laser

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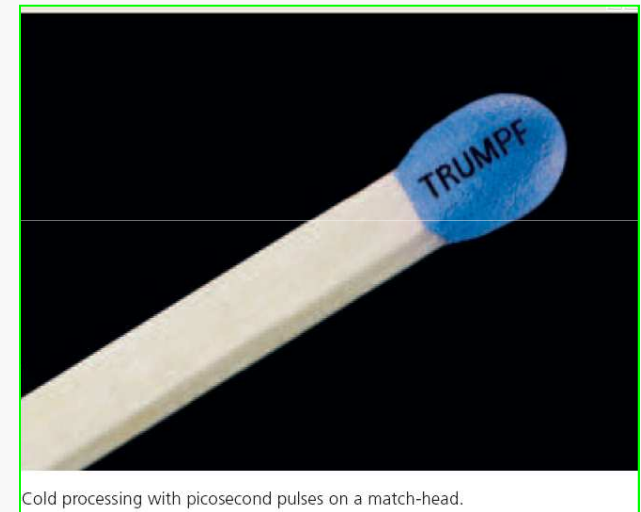
Pulsed regimes: *cw*, *ms*, *μs*, *ns*, *ps* (and *fs* for Ti:sapphire)

cw ↔ up to 10 W (and up to 4 kW in MOPA config.)

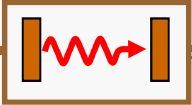
ns ↔ “Q-switching” ~ 10^8 W peak power

ps ↔ “Mode locking” ~ 10^9 W peak power

fs ↔ for Ti:Sapphire $> \sim 10^{12}$ W peak power,
if amplified



Cold processing with picosecond pulses on a match-head.



LASERS: TYPES OF AMPLIFYING MEDIUM

a) GAS

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- ♦ Ions: Ar^+ , Kr^+ .
- ♦ Molecules: Electronic (vibronic) transitions: Excimer, N_2 .
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- ♦ Dye laser: Rhodamin 6G, coumarin,

c) SOLID STATE

- ♦ Doped crystal: Rubi, Nd:YAG, Nd:Glass, Ti:Sapphire, Alexandrite
Microxips, microlasers
- ♦ Optical fiber: Er^{3+} :Silicon (Er^{3+} : SiO_2)
- ♦ Others: Color centres, ...

d) SEMICONDUCTOR (DIODE LASERS)

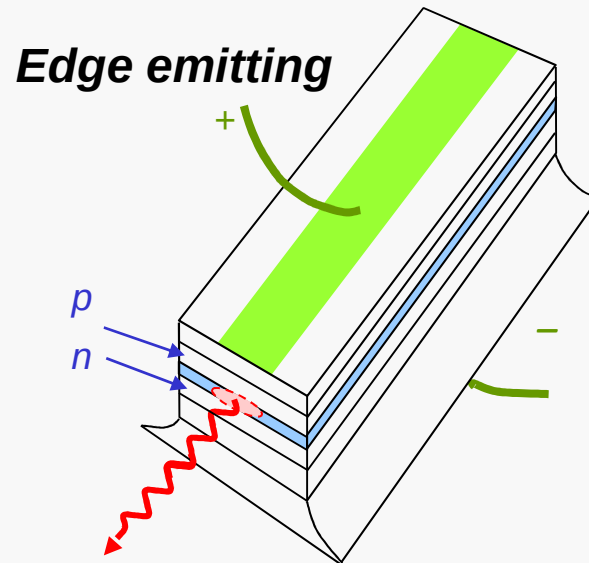
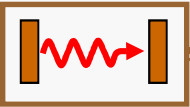
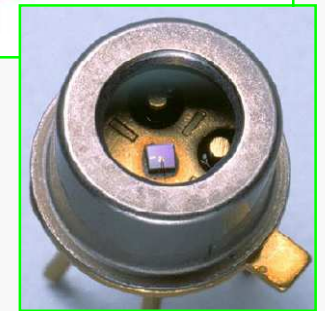
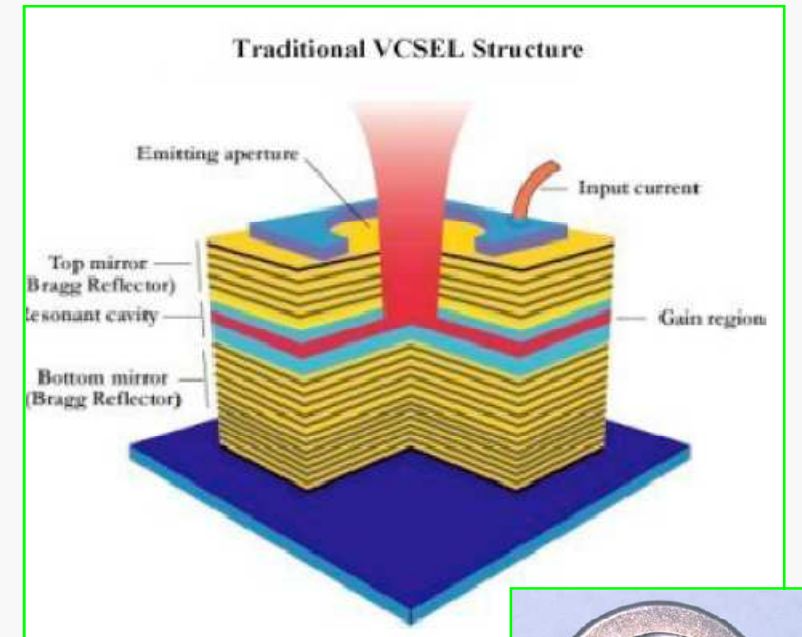
- ♦ Near infrared: AlGaAs, InGaAsP
- ♦ Visible: GaInP, AlGaInP, GaP
- ♦ Mid infrared: ...
- ♦ Other types: VCSEL's, "arrays", high power, quantum cascade, ...

e) OTHERS

- ♦ Free electron laser, ♦ X Rays, g rays, ♦ Random lasers, (etc.)

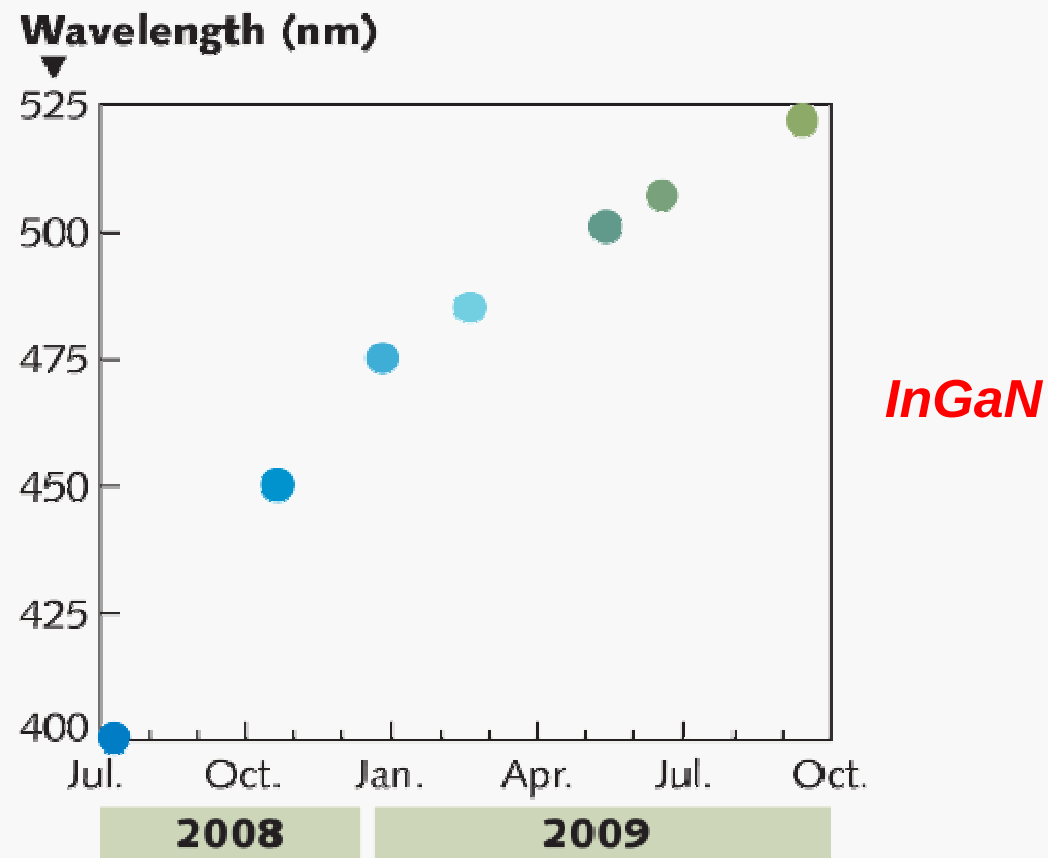
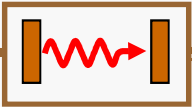
SEMICONDUCTOR LASERS

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"Double heterojunction"Examples:

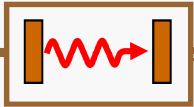
- (Al)GaAs laser: $\lambda \sim 850 \text{ nm}$, IR $\eta \sim 20-60\%$,
- InGaAsP laser: $\lambda \sim 1300-1600 \text{ nm}$, IR
- GaInP laser: $\lambda \sim 620-750 \text{ nm}$ [RED]
- GaN, InGaN laser: $\lambda \sim 450 \text{ nm}$ [BLUE laser]
- Recently: InGaN: $\lambda \sim 520 \text{ nm}$ [GREEN laser]
- Future Si laser ???

Also:
2 kW high power !



*Indium gallium nitride (InGaN)-based laser diodes were first demonstrated in 1995.
Since then their output has steadily progressed toward the green*

*Diode GREEN laser a ~530 nm: molt esperat per a aplicacions: imatges,
projectors, sensors, accions sobre l'ull....*



L'interior del làser: Tipus de medi amplificador

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LASERS: TYPES OF AMPLIFYING MEDIUM

a) **GAS**

- ♦ **Atoms:** He-Ne, He-Cd, Cu.
- ♦ **Ions:** Ar⁺, Kr⁺.
- ♦ **Molecules:** Electronic (vibronic) transitions: Excimer, N₂.
Vibrational transitions: CO₂, CO, **chemical lasers**.
Rotacional transitions: NH₃, CH₃OH, CH₃F.

b) **LIQUID**

- ♦ **Dye laser:** Rhodamin 6G, coumarin,

c) **SOLID STATE**

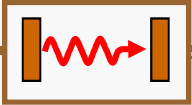
- ♦ **Doped crystal:** Rubi, Nd:YAG, Nd:Glass, Ti:Sapphire, Alexandrite
Microxips, microlasers
- ♦ **Optical fiber:** Er³⁺:Silicon (Er³⁺:SiO₂)
- ♦ **Others:** Color centres, ...

d) **SEMICONDUCTOR (DIODE LASERS)**

- ♦ **Near infrared:** AlGaAs, InGaAsP
- ♦ **Visible:** GaInP, AlGaInP, GaP
- ♦ **Mid infrared:** ...
- ♦ **Other types:** VCSEL's, "arrays", high power, ...

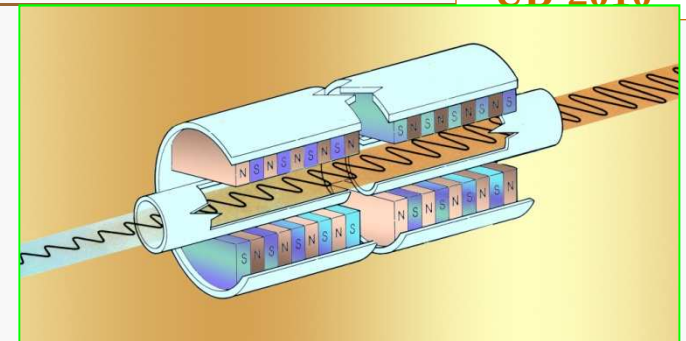
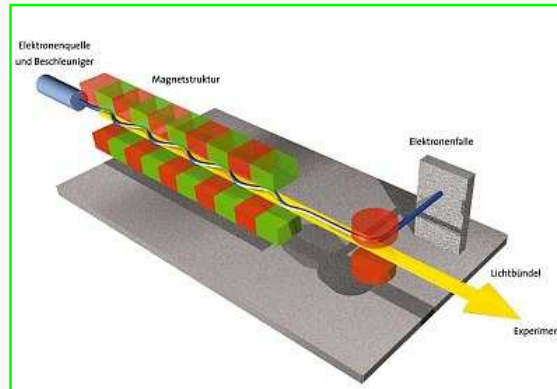
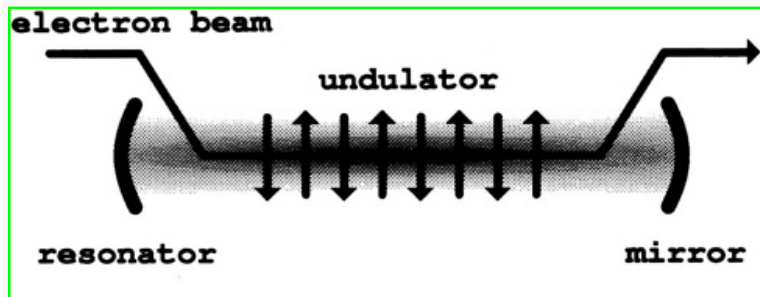
e) **OTHERS**

- ♦ **Free electron laser**, ♦ **X Ray**, ♦ **Random lasers**, ♦ **Micro- and nano-lasers** (microdisc, microsphere, quantum dot, guided-wave photonic crystal,...), ♦ **Single-atom lasers**, ♦ **Atom laser**

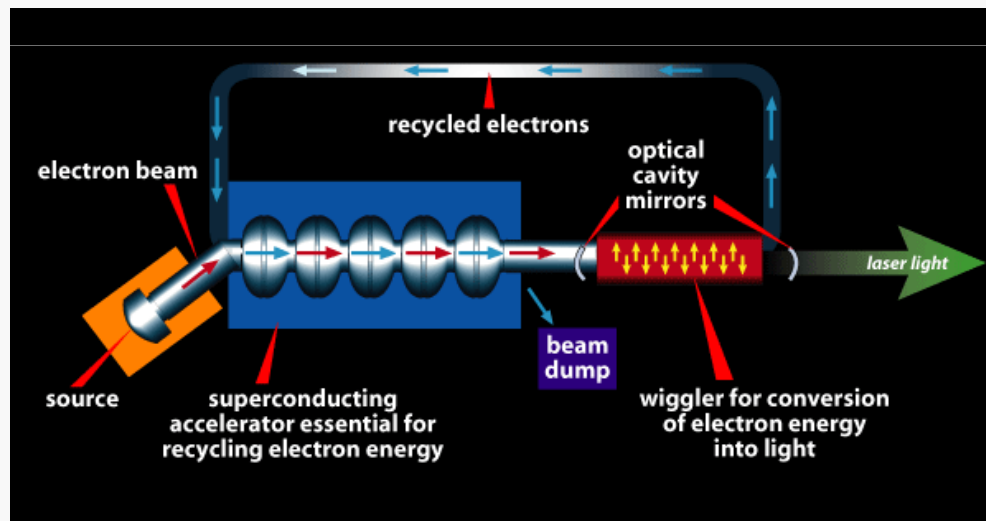


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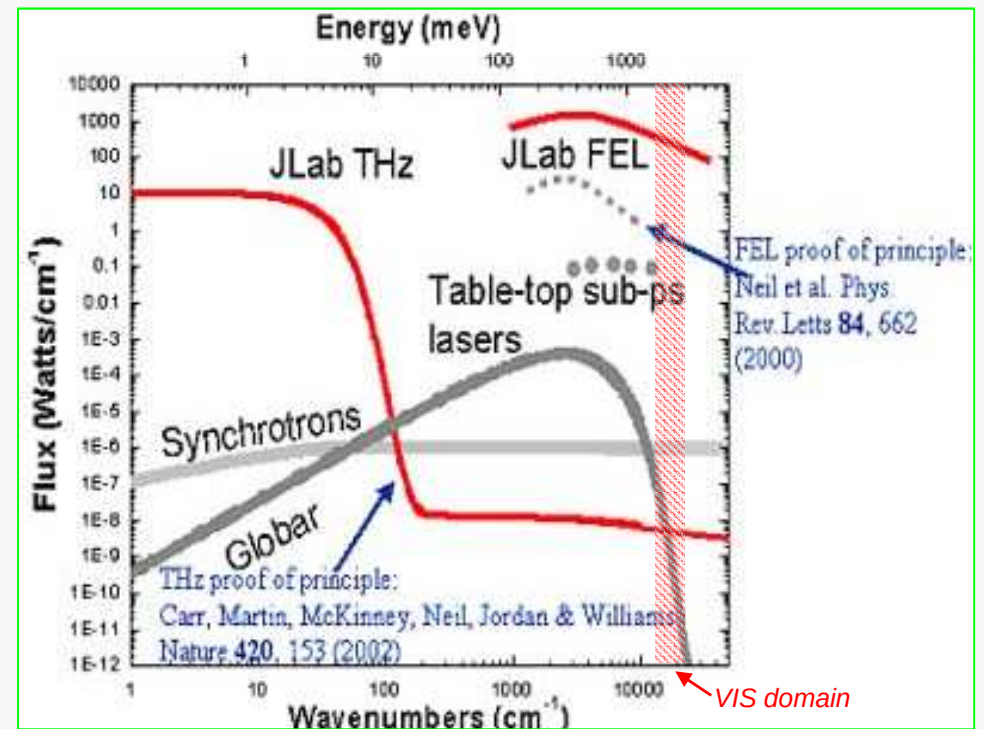
- Free-electron laser (FEL)



<http://newscenter.lbl.gov/feature-stories/2007/11/14/into-the-future-at-the-s-of-light/>



<http://www.jlab.org/FEL/images/FELdiagram.gif>



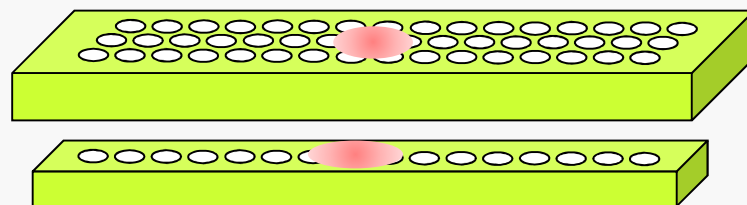
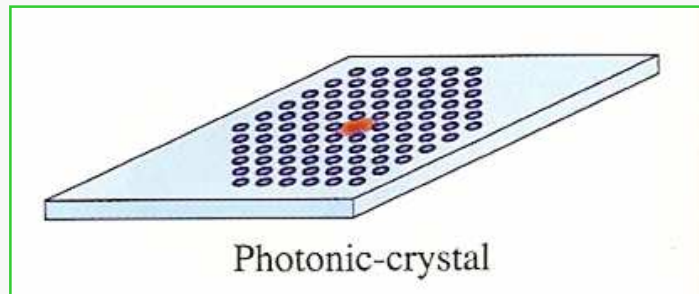
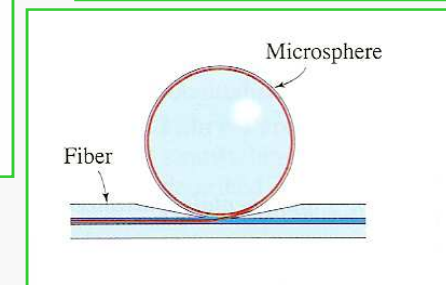
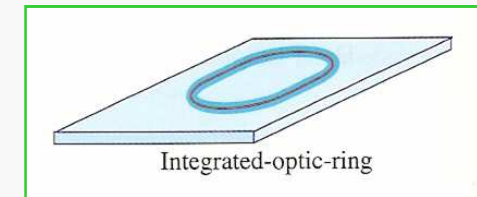
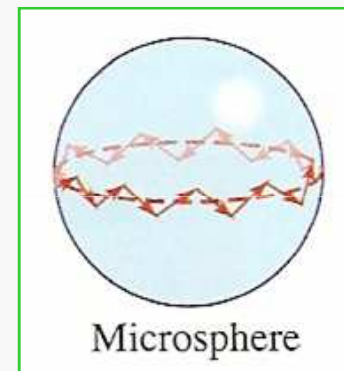
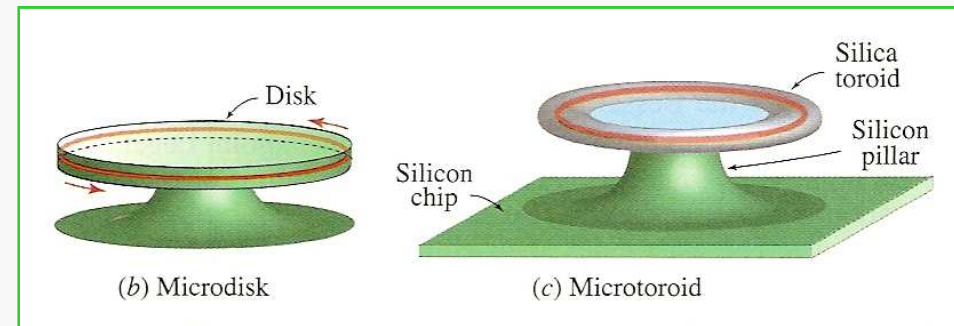
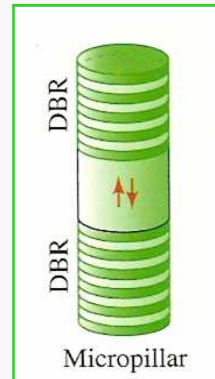
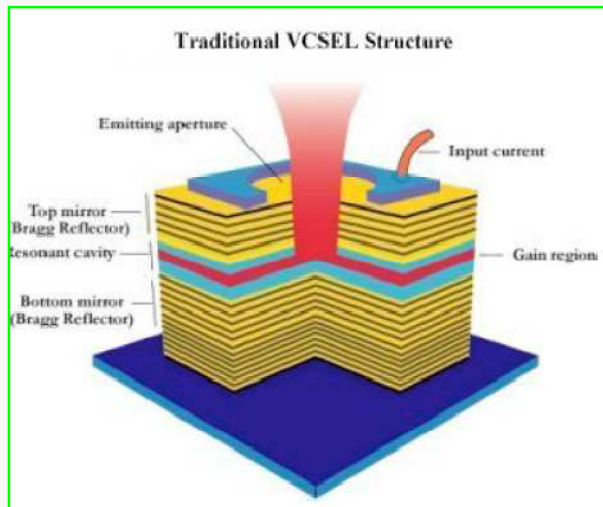
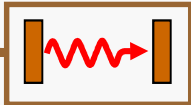
<http://www.jlab.org/FEL/images/FELoutput.jpg>



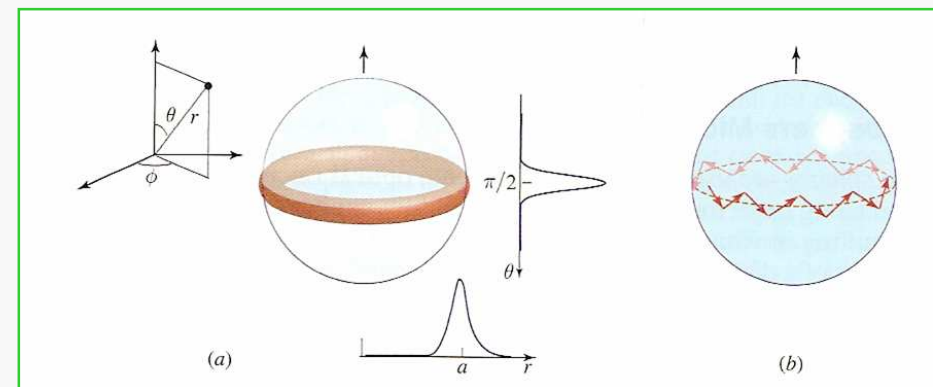
Two-beam Novatia laser at ESRF generates second-harmonic pulses of green light for the first laboratory X-ray laser.

Antics intents de construir un laser de raigs X

*(actualment s'hi està arribant
per la via del làser d'electrons
lliures i de la generació
d'harmonics elevats)*

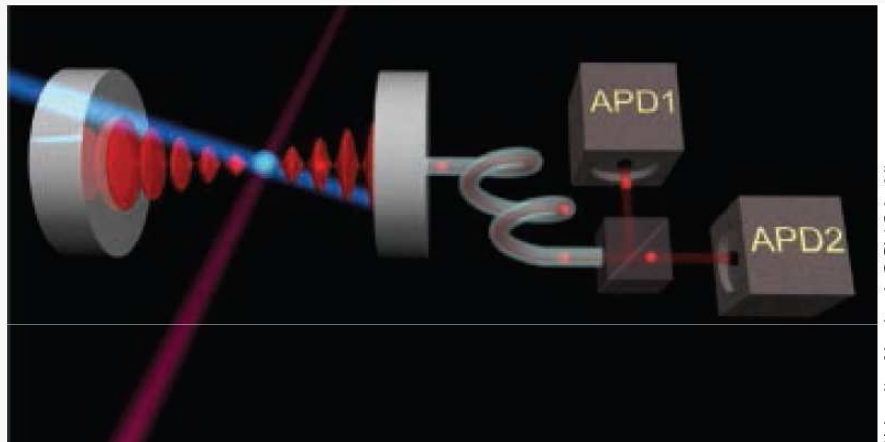


Wave-guide photonic-crystal cavity
(the smallest laser?)



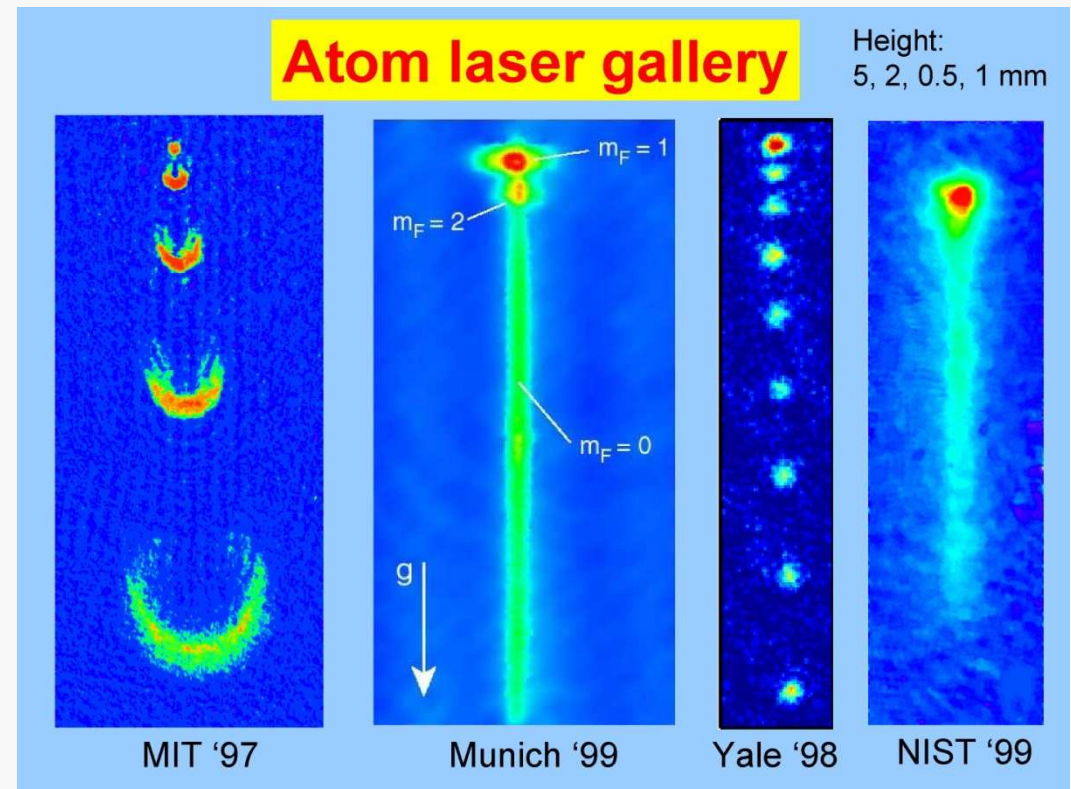


Single-atom laser



A high-finesse optical cavity consisting of two mirrors traps and accumulates the photons emitted by the ion into a mode. The ion is excited cyclically by an external laser and at each cycle a photon is added to the cavity mode, which amplifies the light.

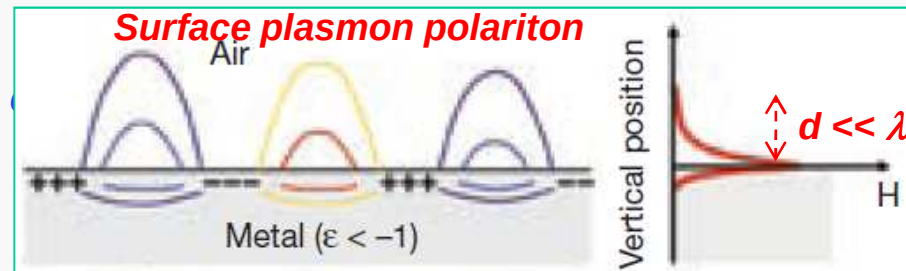
"Atom laser"



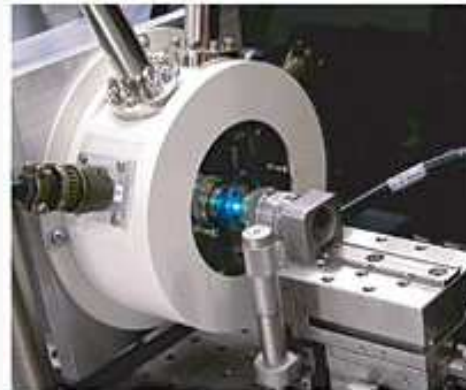
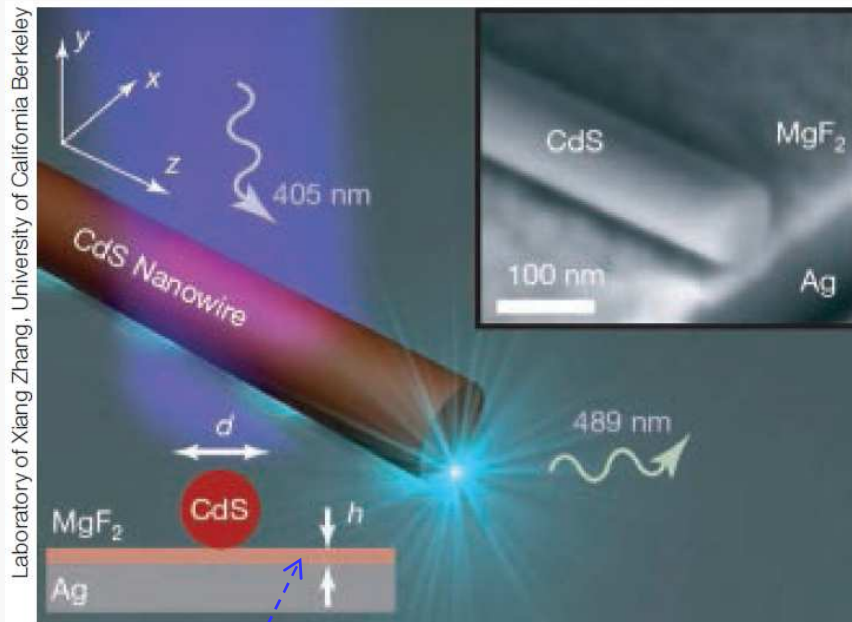


"Plasmon laser" (or "spaser"?): The smallest semiconductor laser:

- Norfolk + Purdue + Cornell Univs. :
A 44-nm-diameter "Cornell dot" with a gold shell
Noginov et al., *Nature* 460, 1110 (2009)



- UC at Berkeley:
A cadmium sulfide nanowire with a silver surface separated by an insulating gap of only 5 nm
(a laser with a 5×30 nm lasing region)
Oulton, ..., Zhang, *Nature* 461, 629 (2009)

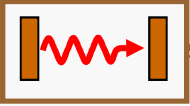


Berkeley researchers eventually hope to shrink the lasing cavity to **1 nm** (the wavelength of an electron), opening up new applications in **molecular probing (biomedical,...)**, **faster communications**, and **quantum computing**.

The gap region stores light within an area 20 times smaller than its wavelength

LASERS: Sumari

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A) Introducció, i una mica d'històrica

B) L'interior del làser *(breu)*

- Principis de funcionament.
- Varietat de tipus de làser segons el medi amplificador:
- Paper jugat pel ressonador òptic.

C) L'exterior del làser: la radiació làser emesa

- Propietats de la radiació làser

D) Aplicacions científiques i tècniques (present i futur)

Summary of properties of laser light

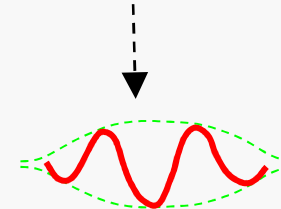
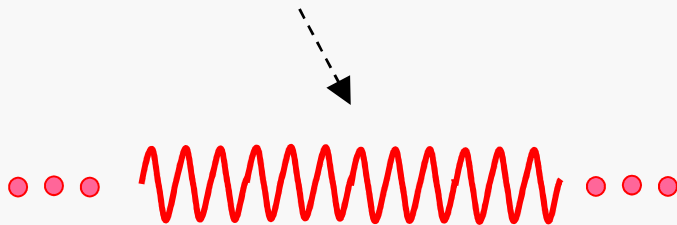
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1) FREQUENCY (ν)

LASERs + nonlinear crystals (SHG, OPO): ~ cover most of the spectral optical domain

2) DURATION (Δt)

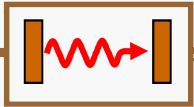
cw - **ms** - **μ s** - **ns** - **ps** - **fs** - **(as)**



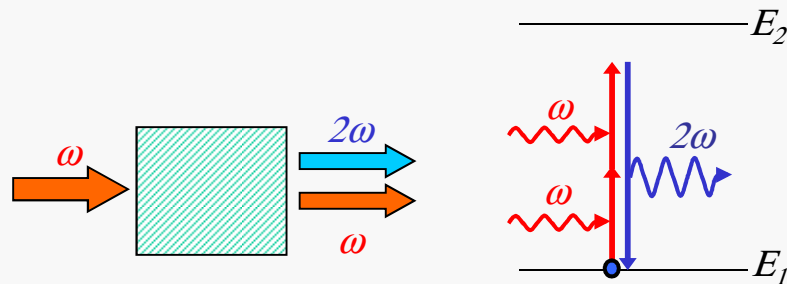
To go below ~100 fs special pulse compression techniques are needed.

Record value (2010): 123 as (Milano)

PERMETRÀ FER FOTOS INSTANTÀNIES DEL MOVIMENT DE L'ELECTRÓ EN UN ÀTOM!

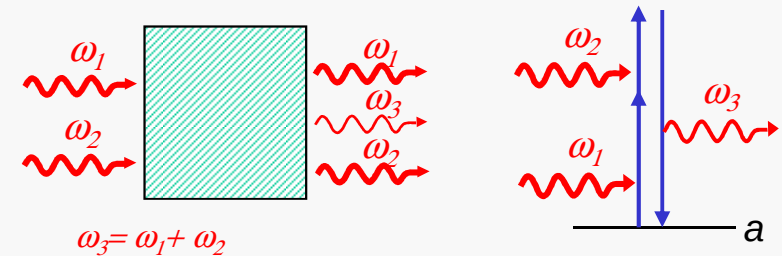


▪ Second harmonic generation (SHG)

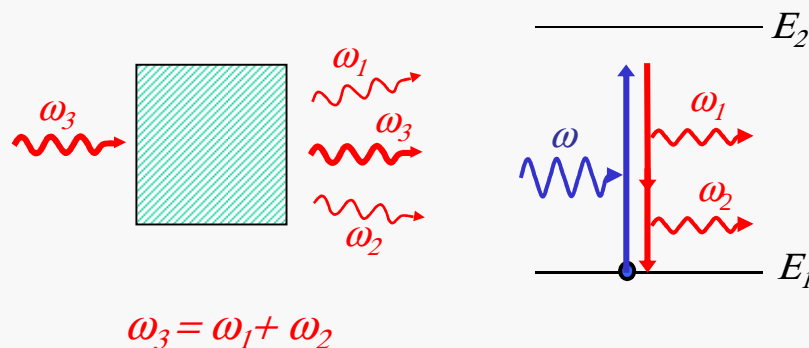


Exemple punter làser verd...

▪ Sum frequency generation (SFG)

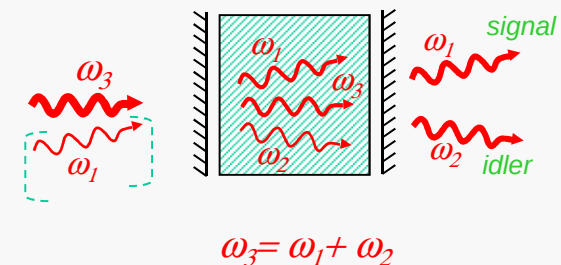


▪ Down conversion (parametric fluorescence)



Molt utilitzat en Òptica Quàntica !

▪ Optical parametric oscillation (OPO)



Summary of properties of laser light

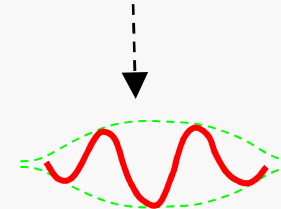
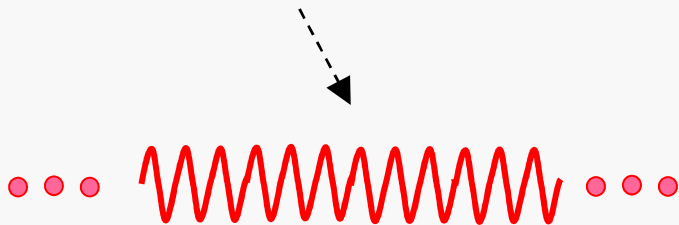
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1) FREQUENCY (ν)

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cw - **ms** - **μ s** - **ns** - **ps** - **fs** - **(as)**



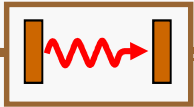
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Record value (2010): 123 as (Milano)

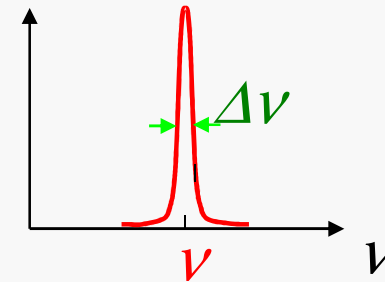
PERMETRÀ FER FOTOS INSTANTÀNIES DEL MOVIMENT DE L'ELECTRÓ EN UN ÀTOM!

D) Summary of properties of laser light

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3) MONOCHROMATICITY ($\Delta\nu$)

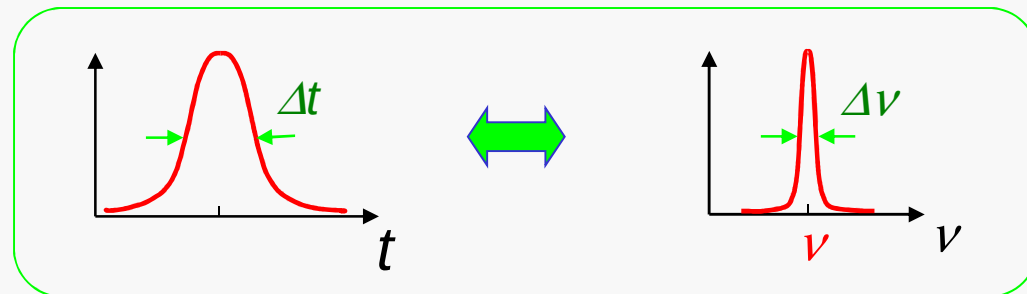


➤ **cw regime:**

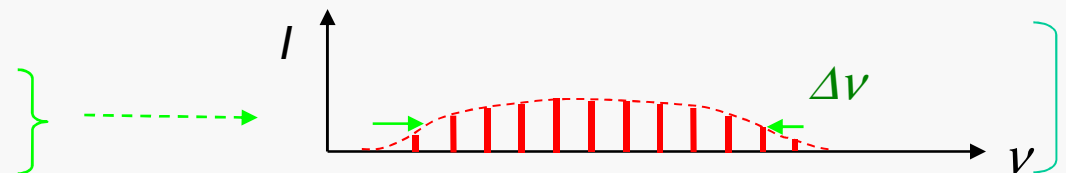
- Typical values (commercial lasers): $\Delta\nu/\nu \sim 10^{-3} - 10^{-5}$
- Record values: $\Delta\nu/\nu \sim 10^{-12} - 10^{-14} !!$

➤ **Pulsed regime:**

$$\Delta t \cdot \Delta\nu \geq 2\pi$$

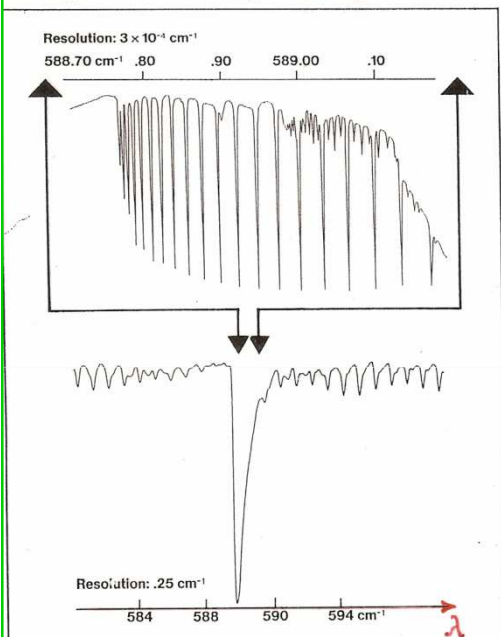
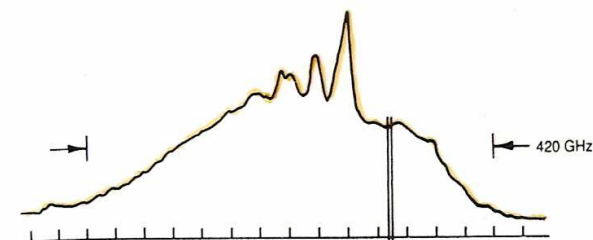
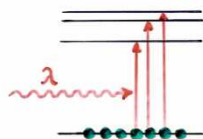
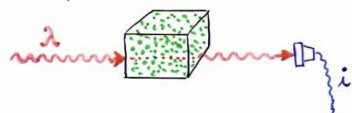


- Pump modulation: ms, μ s
- Q-switching: ns
- Mode-locking: ps
- Additional manipulations: fs, as.

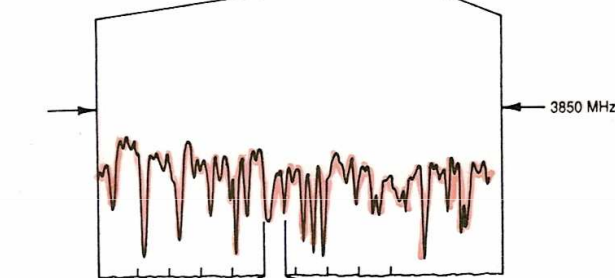


Laser Source Spectrometer

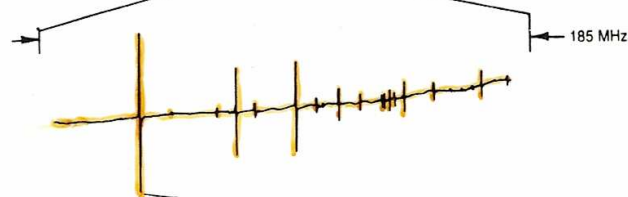
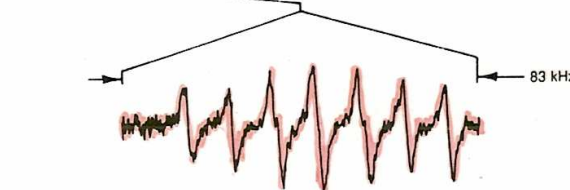
Ultra High Resolution – Seeing is Believing

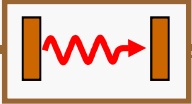
DIODE
LÀSERESPECTROFOTÒMETRE
CONVENCIONAL

CONVENCIONAL

 $\times 100$ 

DIODE LÀSER

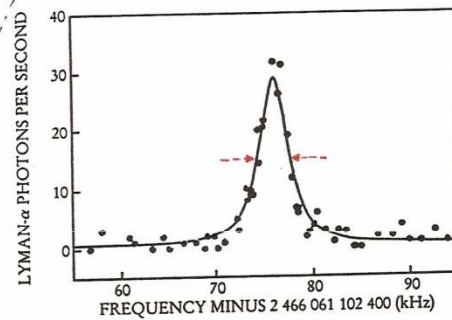
 $\times 20$ LÀSER
[SUB-DOPPLER] $\times 2000$ (IDEM)
[LÀSER SUPER-ESTA-
BILITZAT].



Udem, ..., Hänsch : Phys. Rev. Lett. 79, 2646 (1997)

(H)

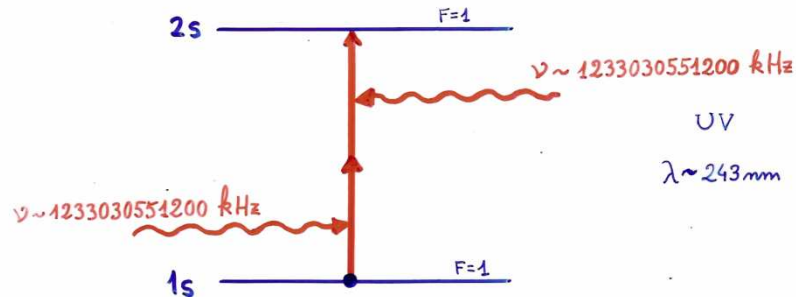
1s - 2s



$$\frac{\nu}{\Delta\nu} = 3 \times 10^{13}$$

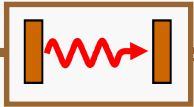
!!

Applications even in
Cosmology...

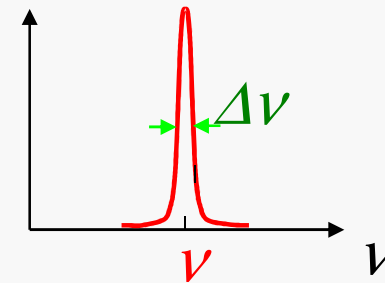


Transició F=0 : $\nu = 2.46606141318734(84) \times 10^{15} \text{ Hz}$

RÈCORD DE PRECISIÓ EN EL VIS I UV



3) MONOCHROMATICITY ($\Delta\nu$)

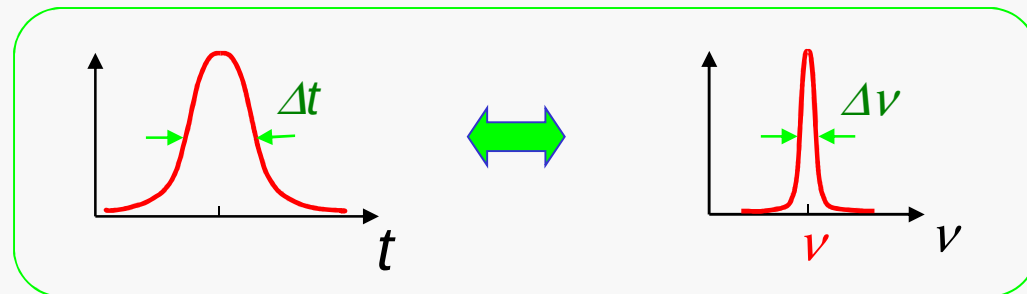


➤ **cw regime:**

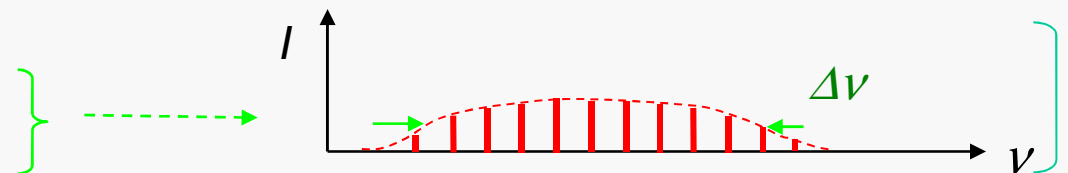
- Typical values (commercial lasers): $\Delta\nu/\nu \sim 10^{-3} - 10^{-5}$
- Record values: $\Delta\nu/\nu \sim 10^{-12} - 10^{-14} !!$

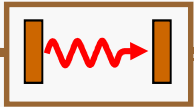
➤ **Pulsed regime:**

$$\Delta t \cdot \Delta\nu \geq 2\pi$$

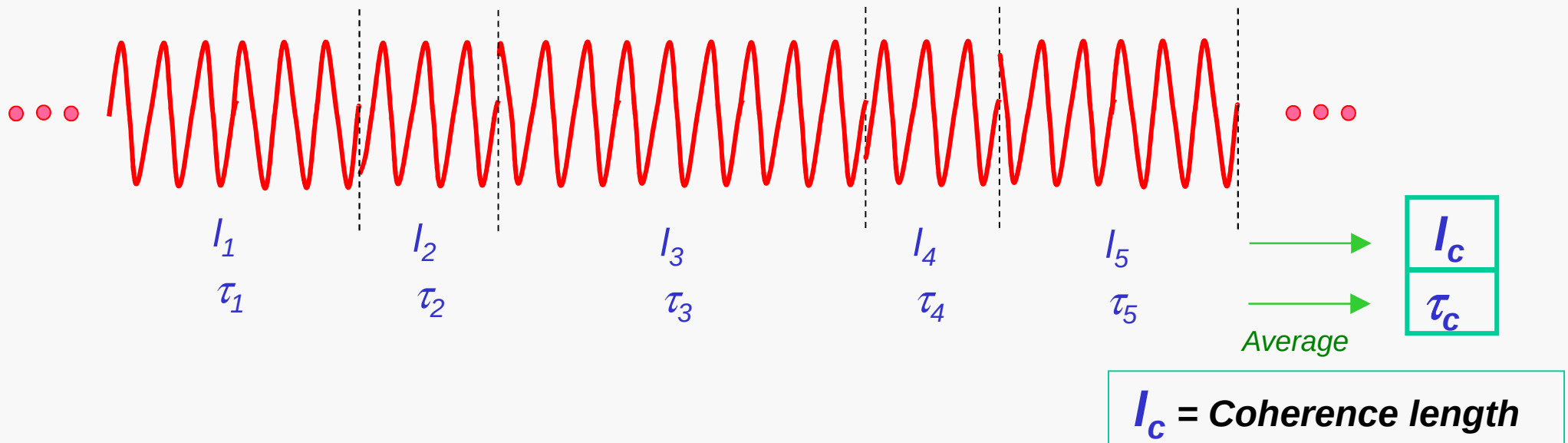


- Pump modulation: ms, μ s
- Q-switching: ns
- Mode-locking: ps
- Additional manipulations: fs, as.

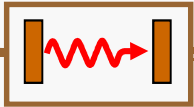




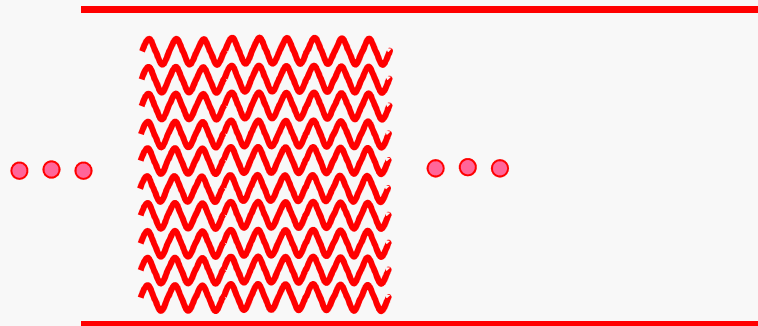
4) TEMPORAL COHERENCE (or LONGITUDINAL COHERENCE)



- Typical values (commercial lasers): $l_c \sim 1-10-100 \text{ cm}$
- Record values: $l_c \sim 10^3 \text{ km} \quad !!$
- Values for other light sources: $l_c \gtrsim 10 \mu\text{m}$ (record: 30 cm)



5) SPATIAL COHERENCE (or TRANSVERSAL)



For a laser:
Maximum possible
value (for single-mode
transverse emission)

6) DIRECCIONALITY:

LASER

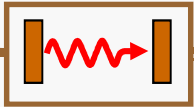


$$\theta \approx \frac{\lambda M^2}{\pi W_0}$$

Only limit:
diffraction

Example: impact over the Moon < 1 km of diameter (if initial diameter enlarged with the objective lens of a telescope)

($\Rightarrow$ measurement of distance moon-earth with precision: ~ 20 cm !!)



7) POWER

➤ Limited by: **Capacity of heat extraction !**

➤ Pulsed lasers: *shorter duration* $\Rightarrow$ *higher peak power*

➤ **Typical powers:**

He-Ne

0.5 a 50 mW

Diode láser

0.5 mW to 2 kW

CO₂

1 W to 20000 W

Nd:YAG

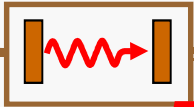
0.1 a 4000 W (cw or long pulses)

$< \sim 10^8$ W (peak power) ("Q-switched")

$< \sim 10^9$ W (" ") ("mode-locked")

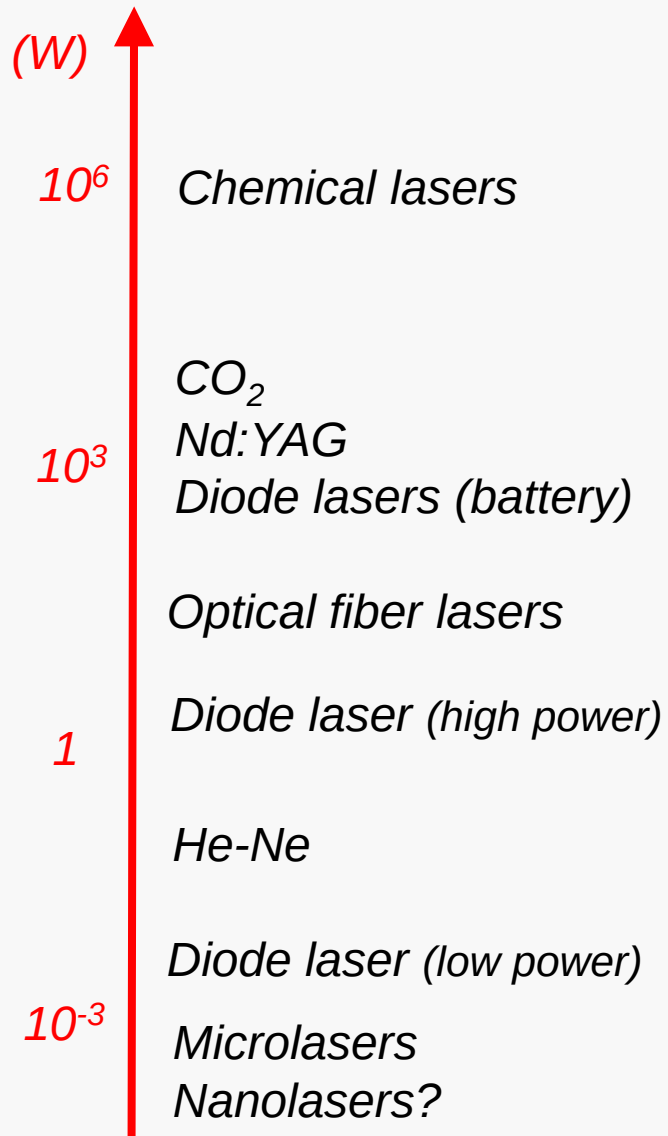
➤ **Record powers:**

{	cw	→	2 MW !! (chemical laser)	}
	Pulses 10^{-9} s	→	10 TW !! (nuclear fusion)	
	Pulses fs, as		> PW !! (with amplification out of the cavity)	

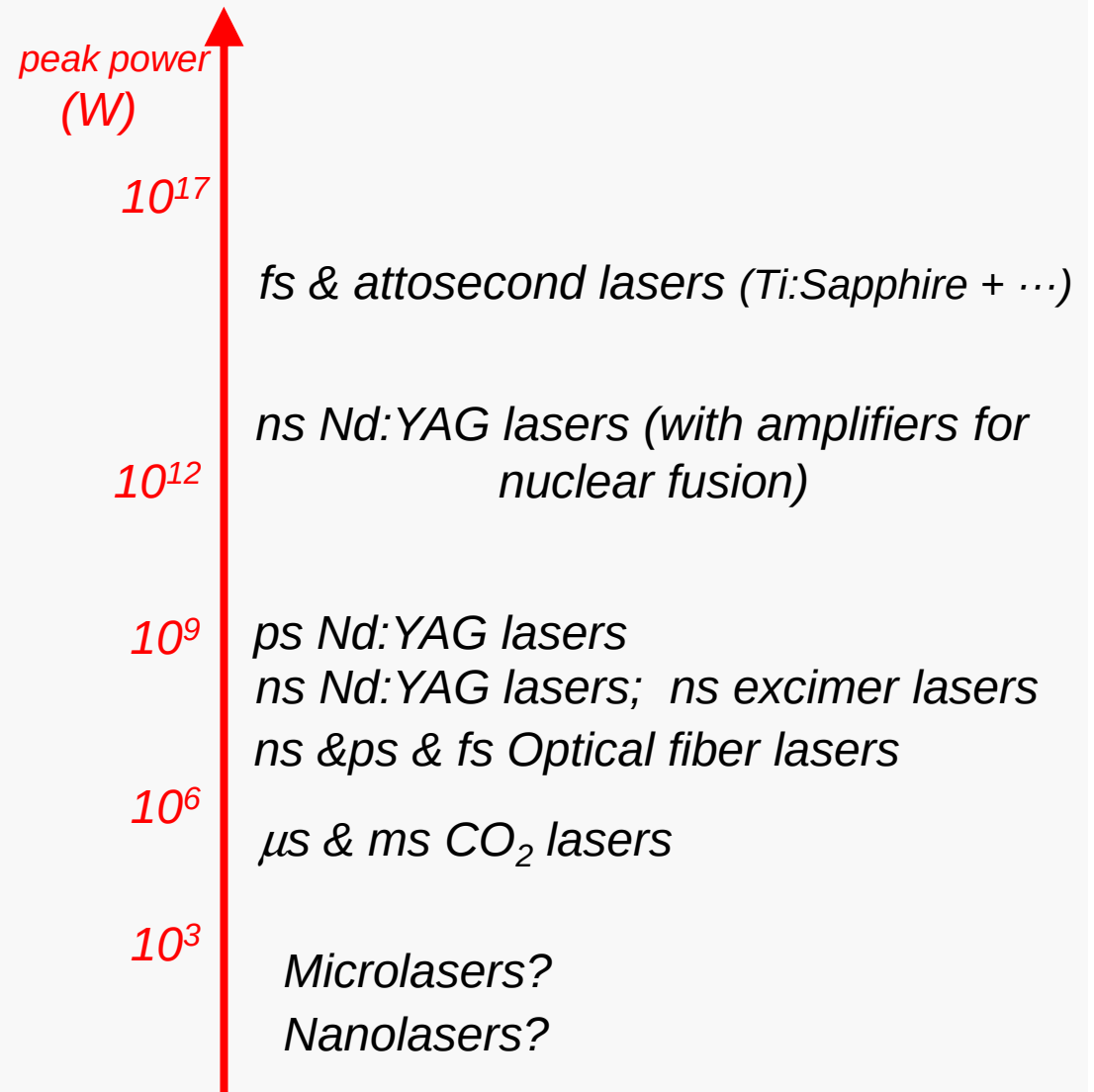


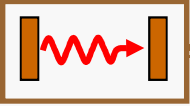
7) POWER

Power (cw regime)

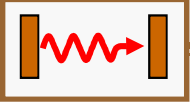


Power (pulsed regime)





D) Aplicacions científiques i tècniques dels làsers



Mercado del sector, 2005
total: 228 billones Euros

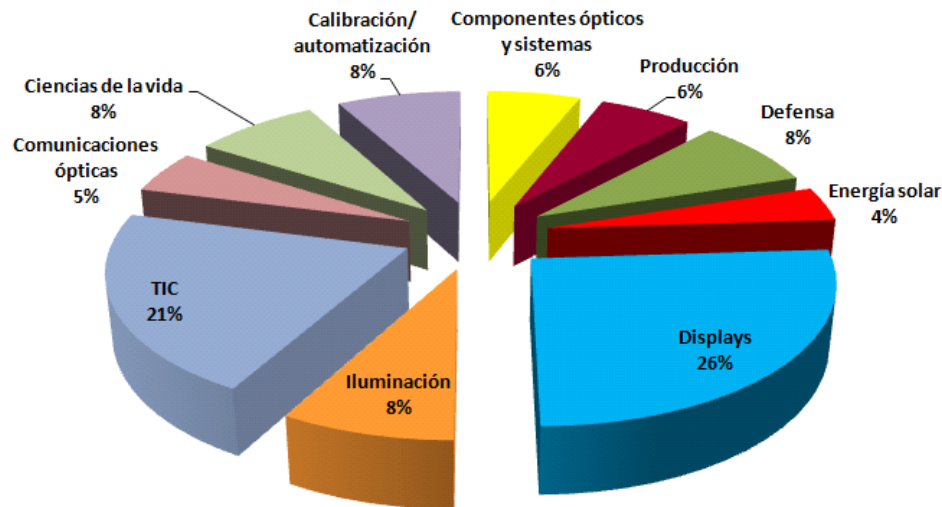


Figura 4: Mercado del sector (Fuente: Optech Consulting, Octubre 2007). Reproducido de FOTONICA 21

Producción europea, 2005
total: 43.5 billones Euros

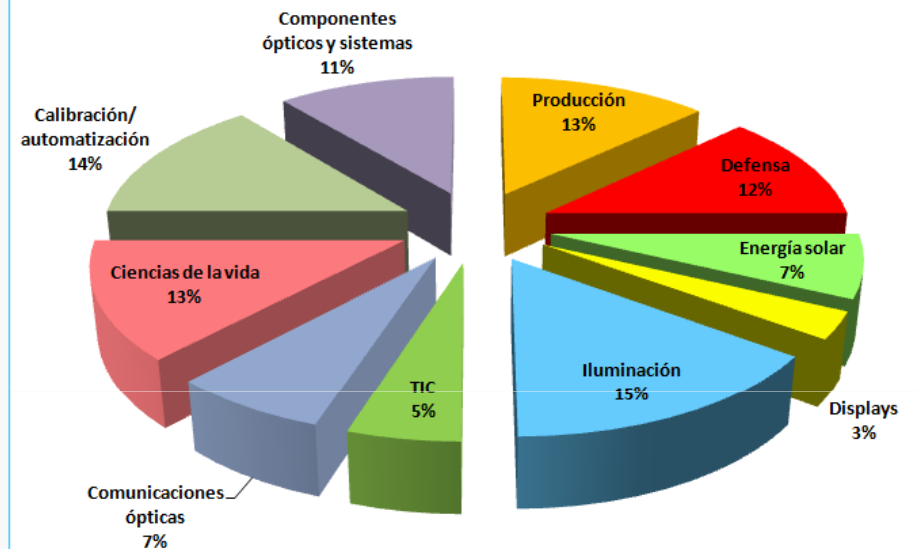
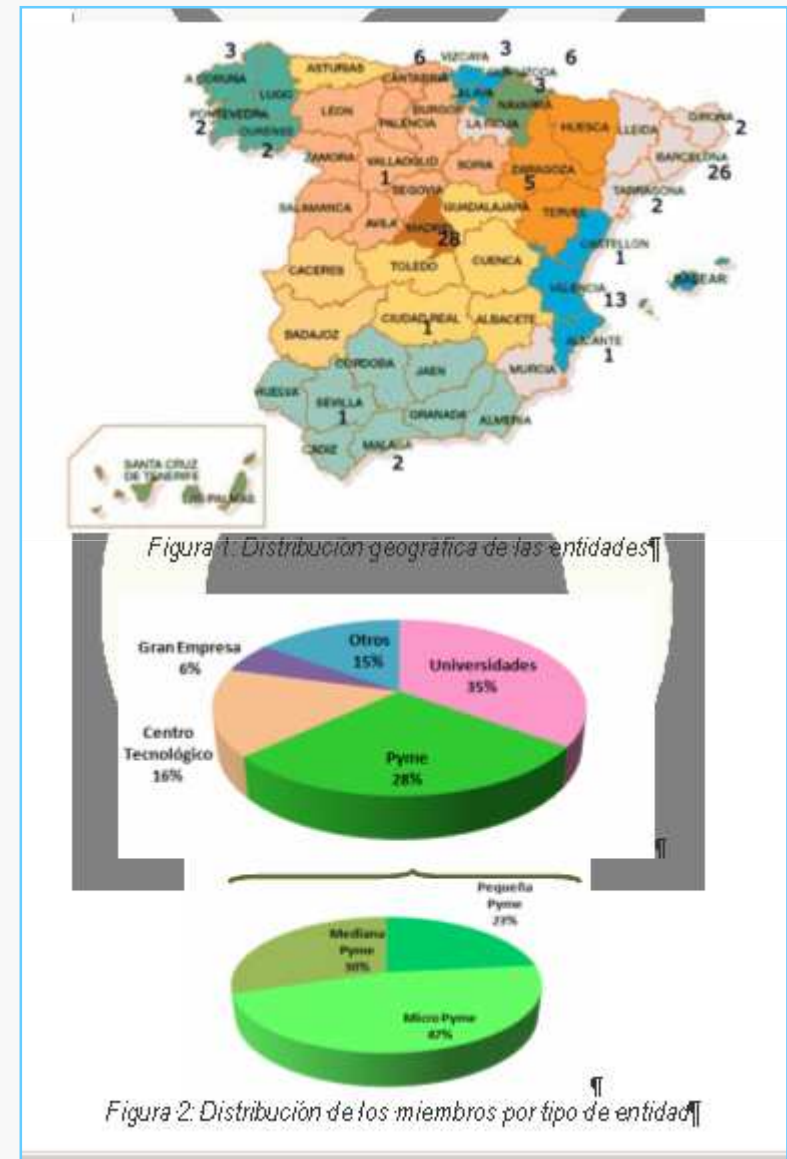


Figura 5: Producción europea del sector (Fuente: Optech Consulting, Octubre 2007). Reproducido de FOTONICA 21

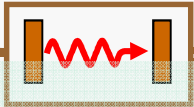
Present forecast (2010):

- ♦ **LASER:** \$ 300 billion
- ♦ **MICROELECTRONICS:** \$ 270 billion

Laser overtakes Micro-Electronics for the first time!



Recent: SECPhO Cluster



Làsers: Aplicacions científiques i tècniques

UB-2010

Gran

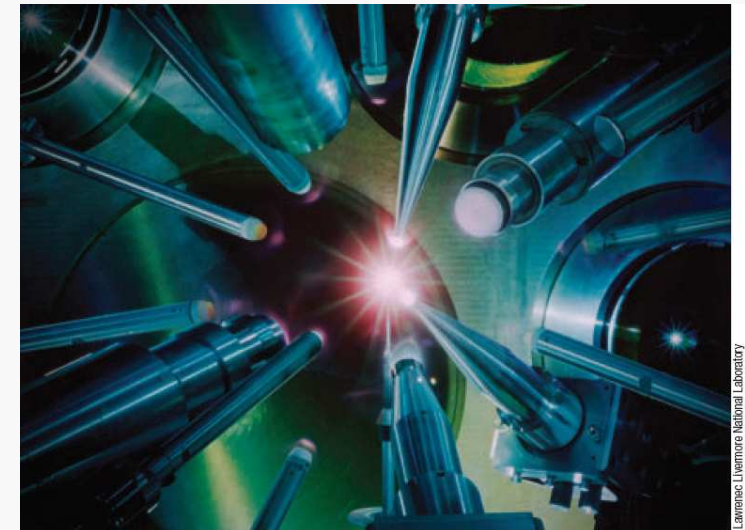
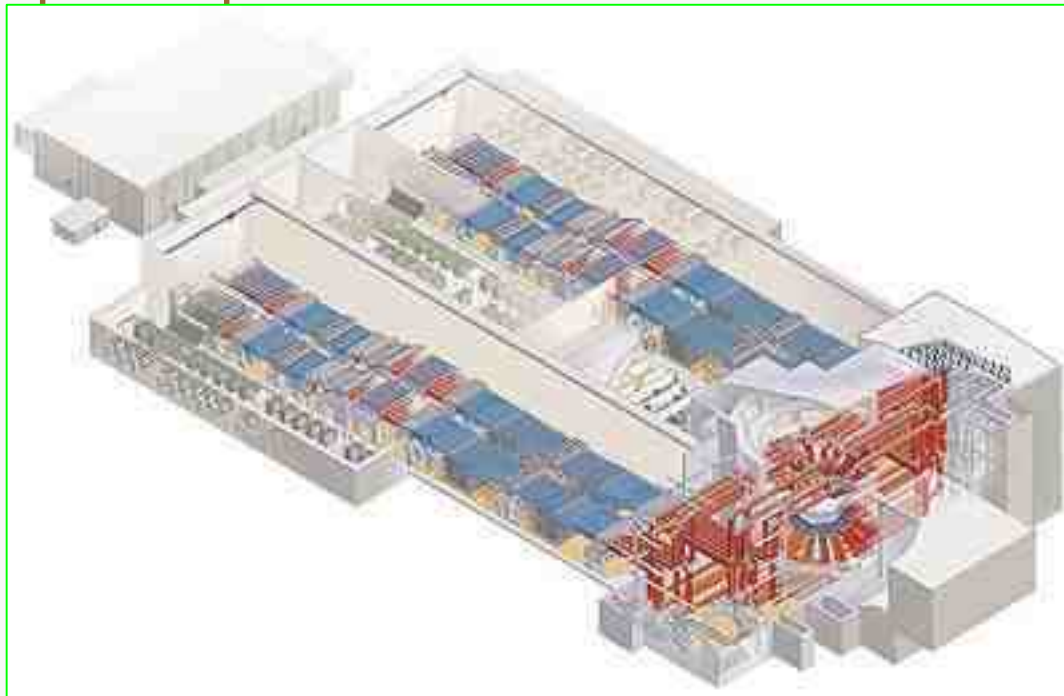
Mitjana

Petita

POTÈNCIA

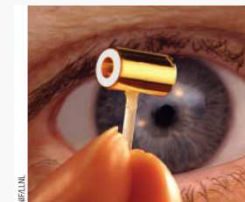
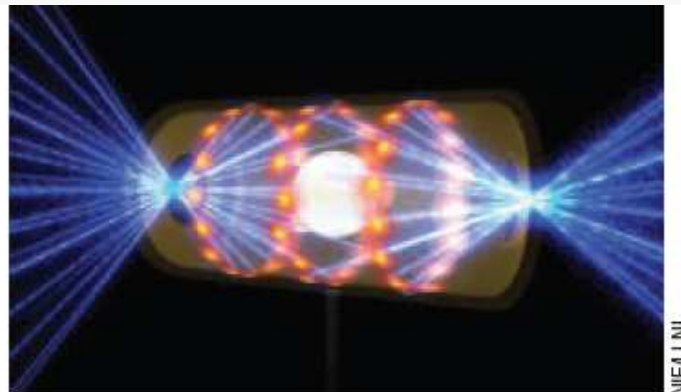
↑

- *Fusió nuclear*
- *Làser d'electrons lliures, làser de raigs X*
- *Làsers de Terawatt: generació d'altres freqüències i de polsos ultra-curts (atto-segons), aplicacions a Física Atòmica i Nuclear, acceleració de partícules.*
- *Transport d'energia a distància (futur)*
- *Aplics. militars*
- *Processat de materials: tall, soldadura, perforació, marcatge, tractaments de superfície, prototipat 3D (100 nm resol amb femtosecond 2-photon), ...*
- *Espectacles lluminosos*
- *Òptica no lineal, per a diverses aplicacions (incloent la generació de extrem UV -13.5 nm- per a dissenyar petites estructures electròniques i estendre Moore's law, informació quàntica,...)*
- *Fotoquímica: estimulació i control de reaccions químiques (fins i tot unir àtoms freds) , foto-dissociació, foto-ionització, ...*
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- *Control remot: LIDAR, control de l'atmosfera*
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- *Òptica integrada, integració amb micro-electrònica (computació, etc.). Micro- i nano-làsers.*
- *Nanolàsers i single-atom lasers per a informació quàntica, ...*

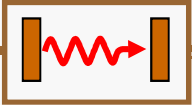


The international inertial confinement fusion community, including LLNL researchers, uses the OMEGA laser at the University of Rochester's Laboratory for Laser Energetics to conduct experiments and test target designs and diagnostics. The 60-beam OMEGA laser at the University of Rochester has been operational since 1995.

This artist's rendering shows an NIF target pellet inside a hohlraum capsule with laser beams entering through openings on either end. The beams compress and heat the target to the necessary conditions for nuclear fusion to occur. Ignition experiments on NIF will be the culmination of more than 30 years of inertial confinement fusion research and development, opening the door to exploration of previously inaccessible physical regimes. Credit is given to Lawrence Livermore National Security LLC, Lawrence Livermore National Laboratory and the US Department of Energy, under whose auspices this work was performed.



A National Ignition Facility (NIF) hohlraum. The hohlraum cylinder, which contains the fusion fuel capsule, is just a few millimeters wide, about the size of a pencil eraser, with beam entrance holes at either end. The fuel capsule is the size of a small pea. Credit is given to Lawrence Livermore National Security LLC, Lawrence Livermore National Laboratory and the US Department of Energy, under whose auspices this work was performed.



ELI: “Extreme Light Infrastructure”

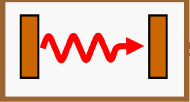
Megalasers to pulse in several new EU countries

As the world celebrates 50 years since the invention of the laser, a European facility approaching exawatt power is expected to stimulate new research areas and communities.

Lasers planned for the Extreme Light Infrastructure*

Country	Facility focus	Power (PW)	Pulse energy (J)	Pulse width (fs)	Rep rate (Hz)
Romania	Nuclear physics	10 (×2)	200	20	0.1
Hungary	Attosecond physics	1	5	5	1000
		20	400	20	0.1
Czech Republic	Secondary beam radiation, high-energy particles	1	10	10	10
		5	50	10	10
		10 (×2)	200	20	0.1
To be determined	High intensity	10 beams of 10–20 PW each, phased and combined to create total power of 100–200 PW			

*Laser parameters still subject to change.



Terawatt short-pulse lasers

"Table Top Terawatt" laser (T³)

Quan la llum és més densa que la matèria

50è aniversari del làser

Luis Roso
Director

CLPU CENTRO DE LASERES PULSADOS ULTRACORTOS METAMENSOS

UPC Terrassa
7 maig 2010

LASERFEST
CELEBRATING 50 YEARS OF LASER INNOVATION

<http://www.clpu.es/>

Light bullets

CLPU

100 femtosegundos = 30 micras

Pulso láser

Same density at
10e24 W/cm²

Cabello humano

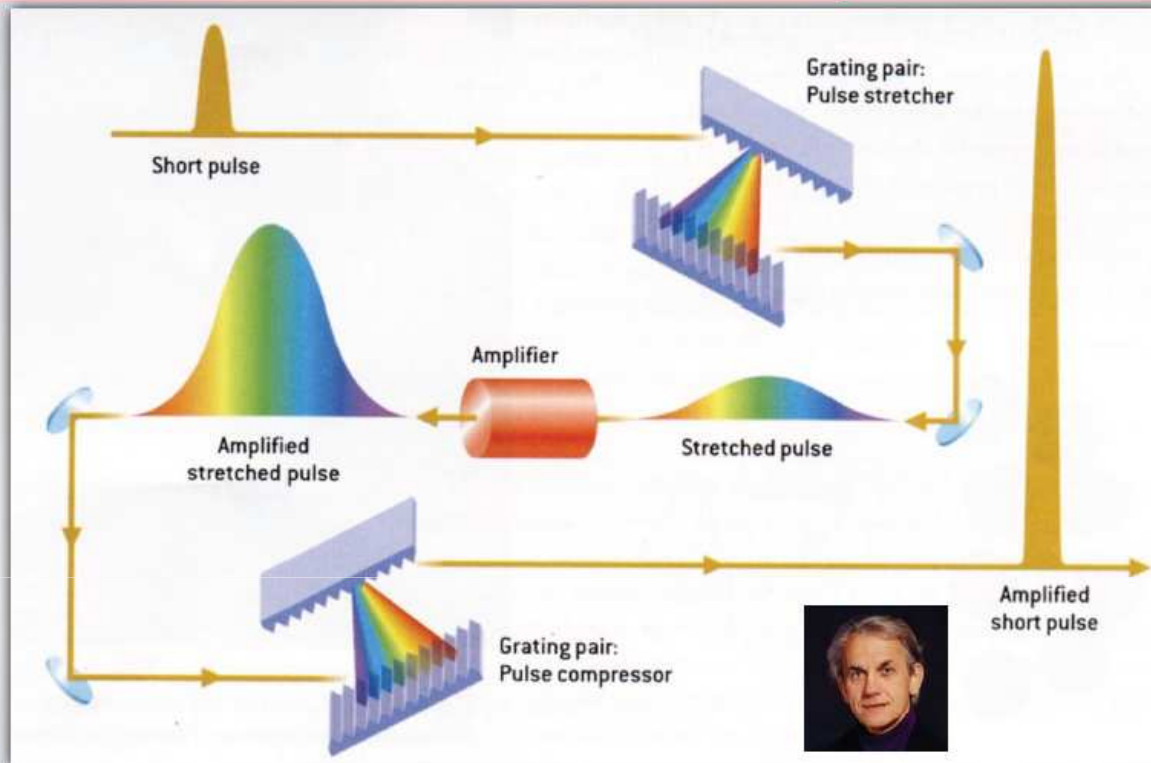
x800 0075 15kV 50µm

Copy of transparencies from Prof. Luis Roso, Salamanca)

Modern CPA system

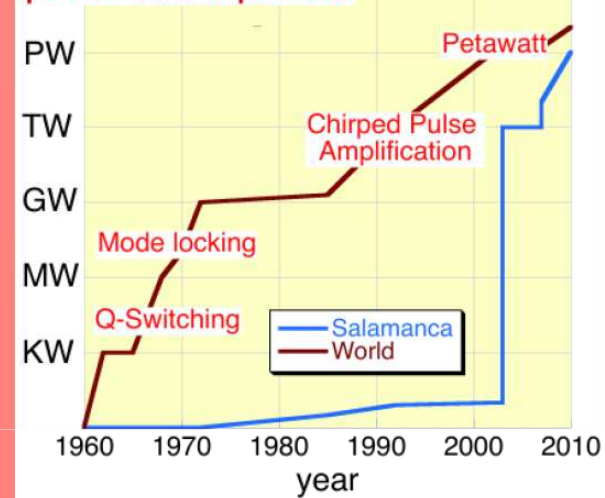


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Evolution in time

peak laser power



Salamanca
big
Lasers

First laser
0,5 TW
March 2003

Second Laser
20 TW
Sept 2007

"Table Top Terawatt" laser (T^3)

Copy of
transparencies from
Prof. Luis Roso,
Salamanca)

Multi-Terawatt laser at Salamanca



Atomic unit of intensity $3,4 \times 10^{16} \text{ W/cm}^2$

UNIVERSITAT DE SALAMANCA

10e21 W/cm²

10e20

10e19

10e18

10e17

10e16

10e15

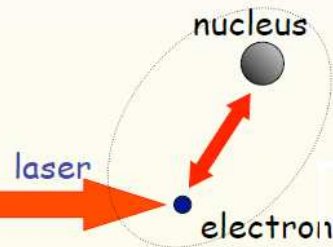
10e14

10e13

10e12

10e11

10e10

W/cm²

Intensity

 $3,4 \times 10^{16} \text{ W/cm}^2$

Electric field

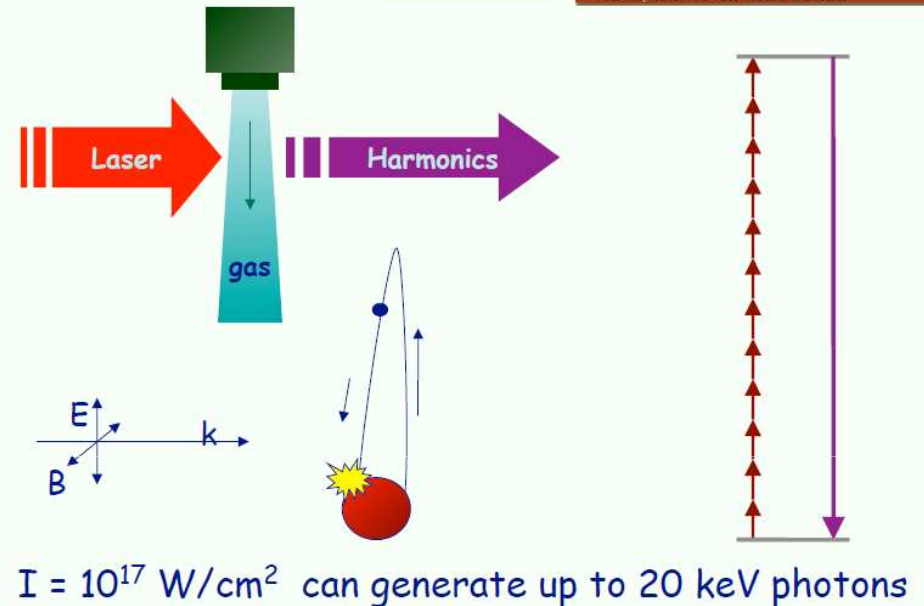
 $5,1 \times 10^9 \text{ V/cm}$

Interaction:
electron-nucleus
electron-laser
of same strength

Atom loses its meaning
beyond atomic unit of intensity ... plasma

High order harmonics

UNIVERSITAT DE SALAMANCA



10^{17} W/cm^2 : Nuclear effects

10^{18} W/cm^2 : Relativistic effects: particle acceleration!! (beyond 100 TW)

10^{26} W/cm^2 : unstable vacuum: virtual pair (electron-positron) creation !!

Copy of transparencies from Prof. Luis Roso, Salamanca)

beaming. The concept behind this is that laser beams transport energy to places that are not easily reached via conventional methods. Examples include supplying energy to remote military camps or to a zeppelin (airship) stationed above a specific area for observation tasks.

The space elevator is another project on

reaching enough, it might be possible not only to have laser pointers in a Swiss army knife, as we do today, but also even to replace the stainless steel blade with a laser blade. Just imagine the possibilities for a moment: You could cut down that tree in your backyard with a laser.

Now that we've speculated about the

tion, I'd have to say that it's a pretty safe bet that lasers will be around long after I'm gone.

Meet the author

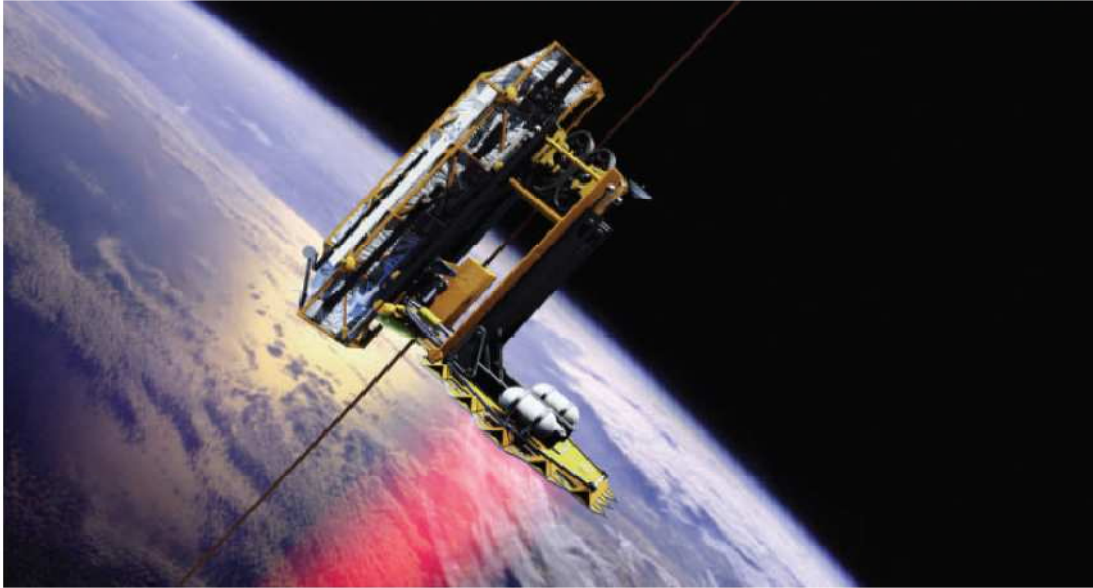
Jochen Deile is the manager of new laser products for Trumpf Inc. in Farmington, Conn.; e-mail: jochen.deile@us.trumpf.com.

Power beaming

66

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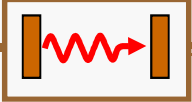
Traslladat energia a llocs llunyans o inaccessibles.



Photonics Spectra July 2010

PHOTONICS MEDIA 57

- *Un petitet avió ha sigut propulsat des de terra!*
- *Elevador espacial*
- *Comunicacions inter-planetàries*
- *Captar energia dalt i enviar-la cap a la terra (o a l'inrevés)*

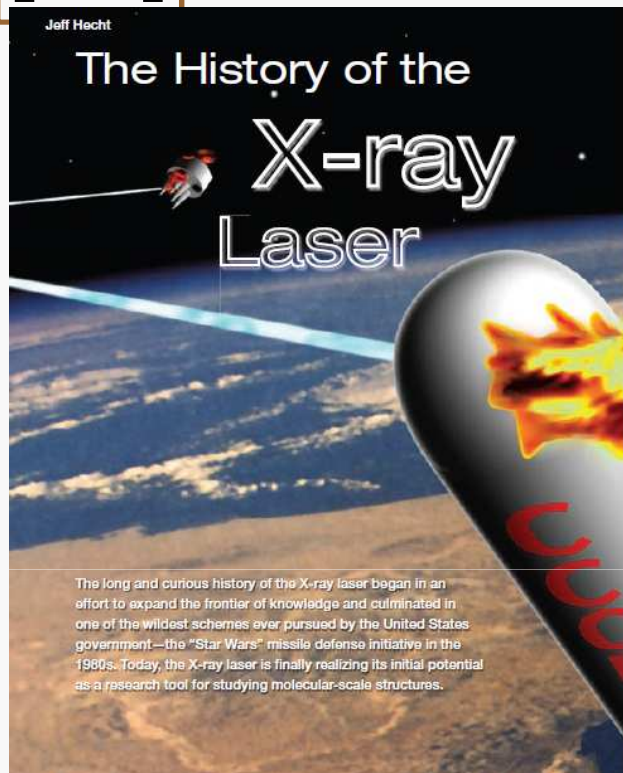


Aplics. militars?

James Bond ...

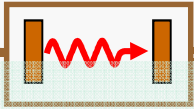


Is Mazinger possible?



Cold-war fever in the 1980s...

Lockheed aerospace engineer Maxwell Hunter put forth the boldest plans—a fleet of 18 orbiting chemical laser battle stations, which he claimed could block a surprise attack by thousands of Soviet nuclear missiles. [Around year 1980]



Làsers: Aplicacions científiques i tècniques

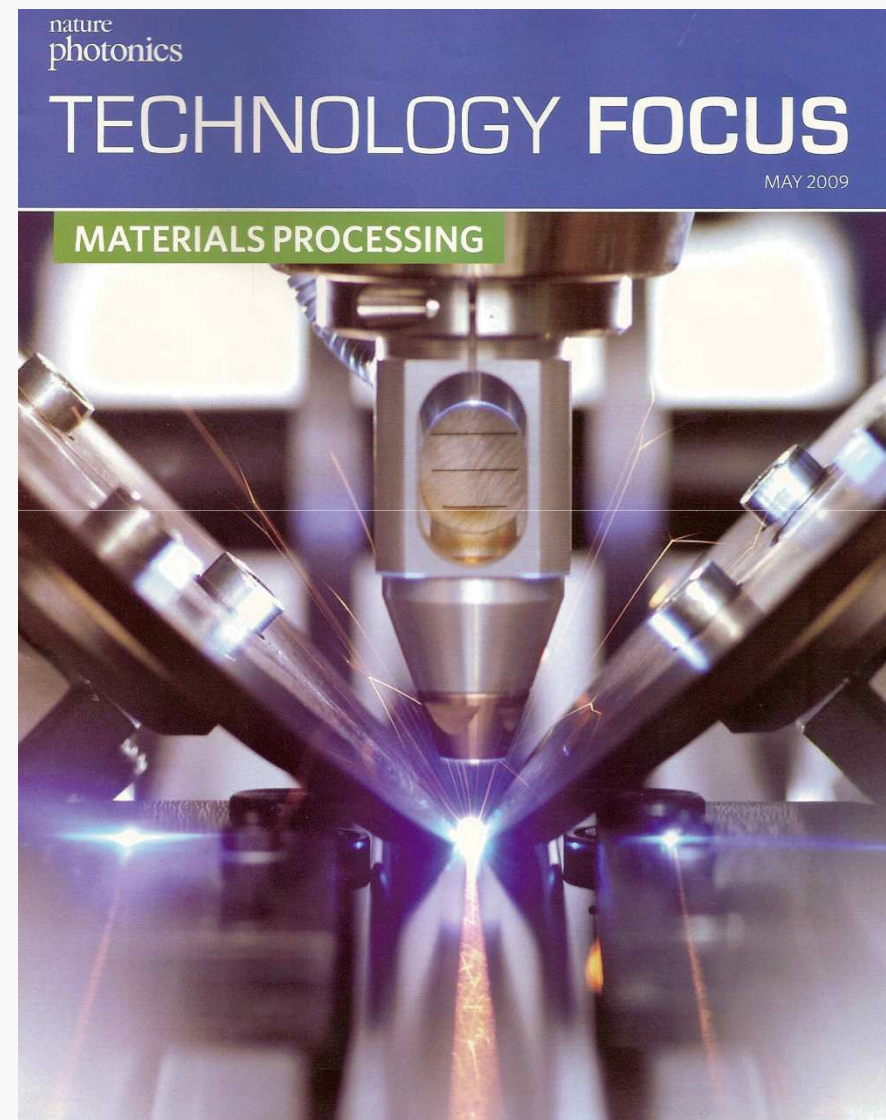
POTÈNCIA

Gran

Mitjana

Petita

- *Fusió nuclear*
- *Làser d'electrons lliures, làser de raigs X*
- *Làsers de Terawatt: generació d'altres freqüències i de polsos ultra-curts (atto-segons), aplicacions a Física Atòmica i Nuclear, acceleració de partícules.*
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- **Processat de materials: tall, soldadura, perforació, marcatge, tractaments de superfície, prototipat 3D (100 nm resol amb femtosecond 2-photon), ...**
- **Espectacles lluminosos**
- **Fotoquímica: estimulació i control de reaccions químiques (fins i tot unir àtoms freds), foto-dissociació, foto-ionització, ...**
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- **Biofotònica, aplicacions mèdiques**
- **Control remot: LIDAR, control de l'atmosfera**
- **Arts gràfiques, impressores, memòries (CD, DVD),... [Futur: projectors, imatges color]**
- **Holografia, interferometria, Òptica en general (futurs displays, projectors?)**
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- **Atrapament i refredament d'àtoms, condensació de Bose-Einstein (BEC)**
- **Sensors: de presència, posició, vibració i moviment. Lectors de codis, etc.**
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- **Nanolàsers i single-atom lasers per a informació quàntica, ...**



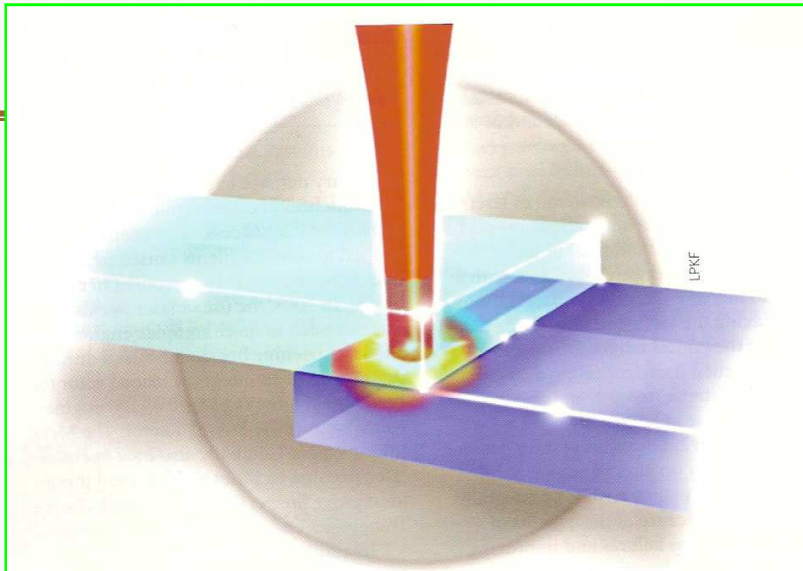


Figure 1 | Principle of laser transmission welding of two plastic components. The laser beam passes through the upper plastic layer but is absorbed by the lower one, generating heat that fuses the two components together, which then cool and harden.

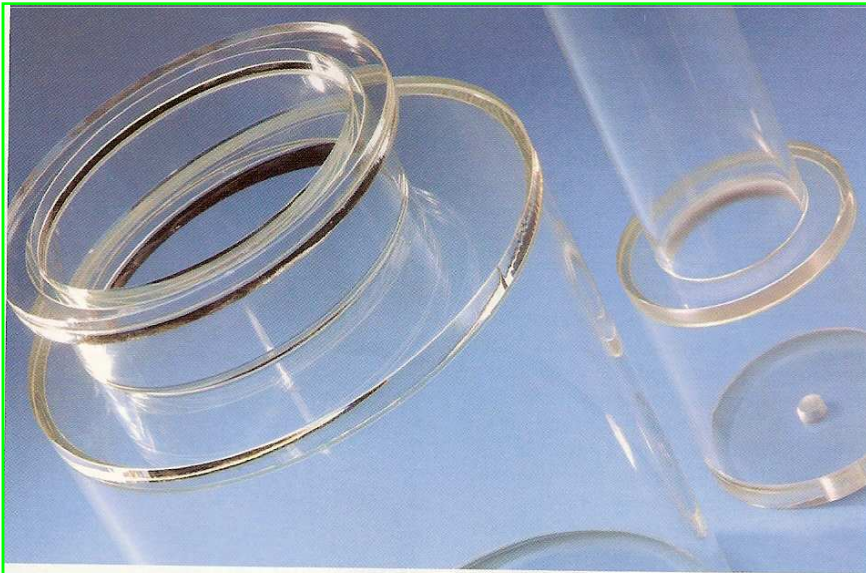


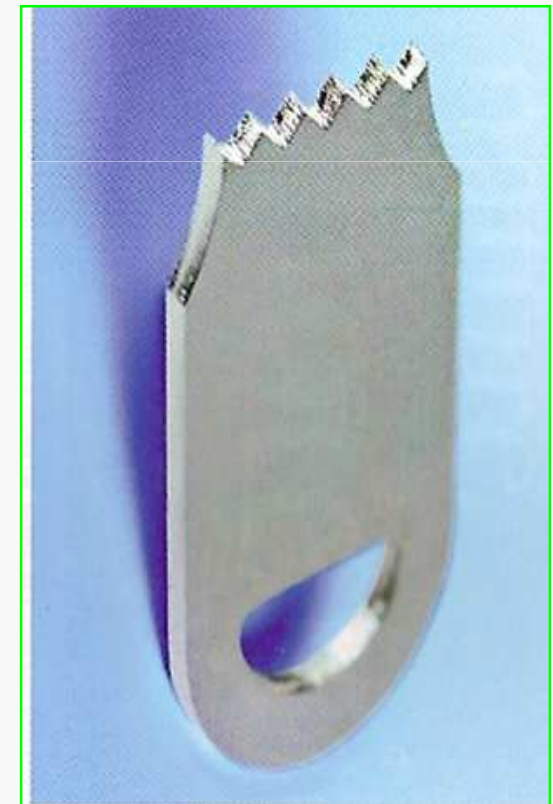
Figure 2 | Example of high-quality laser welding of transparent plastic parts using the Clearweld technology. A light-absorbing dye is sandwiched between the components to be joined. On illumination with a laser it heats up, melting the interface between the parts. Advantageously, the dye becomes colourless in the process leaving a weld seam that is invisible to the naked eye.



Figure 4 | A hybrid system with an example application of an automotive tail light.

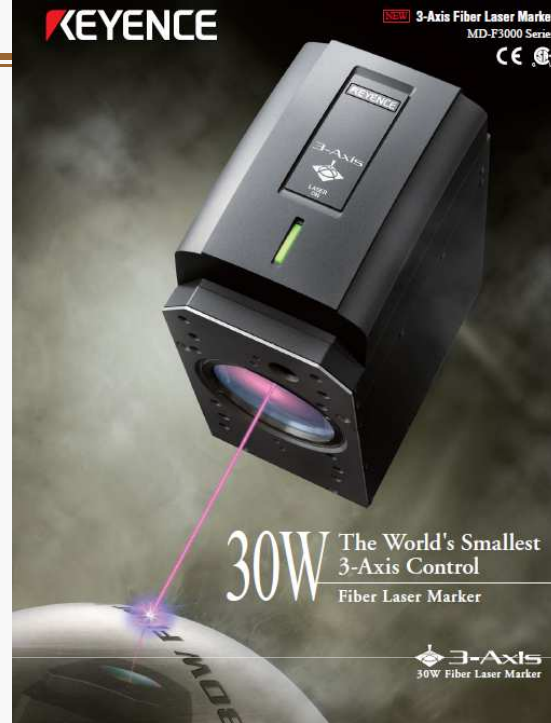


Figure 5 | Electric shaver welded by laser.

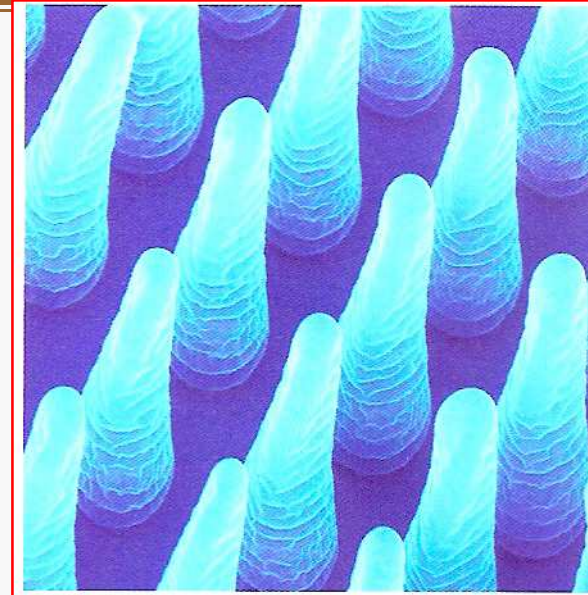




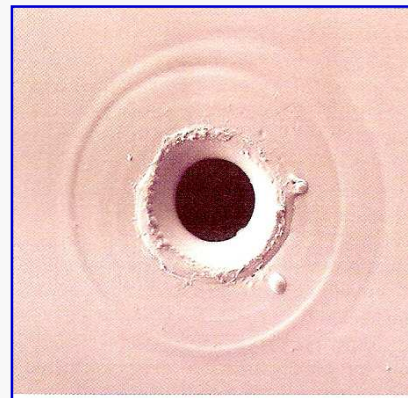
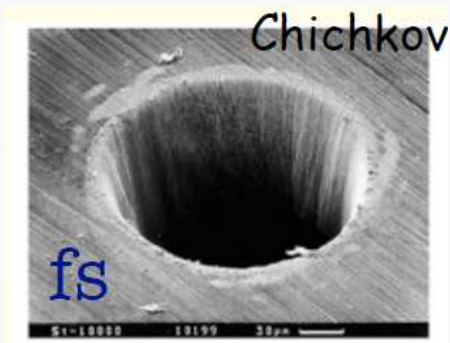
A solid-state laser cutting a series of fine patterns in a medical instrument.



CESSING



UB-2010



Optical tweezers boost direct-write nanolithography
Opt. Express **17**, 3640-3650 (2009)

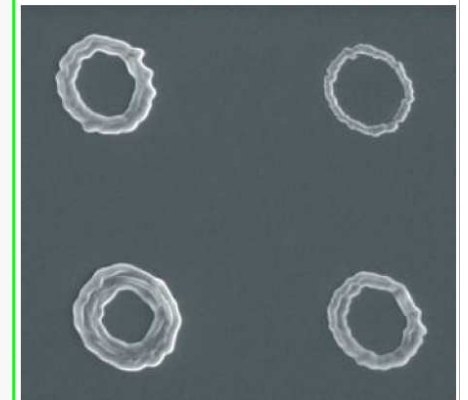




Figure 1 | Laser sintering in action. A laser beam melts a layer of metal powder which then solidifies. By repeating the process a three-dimensional part can be made.

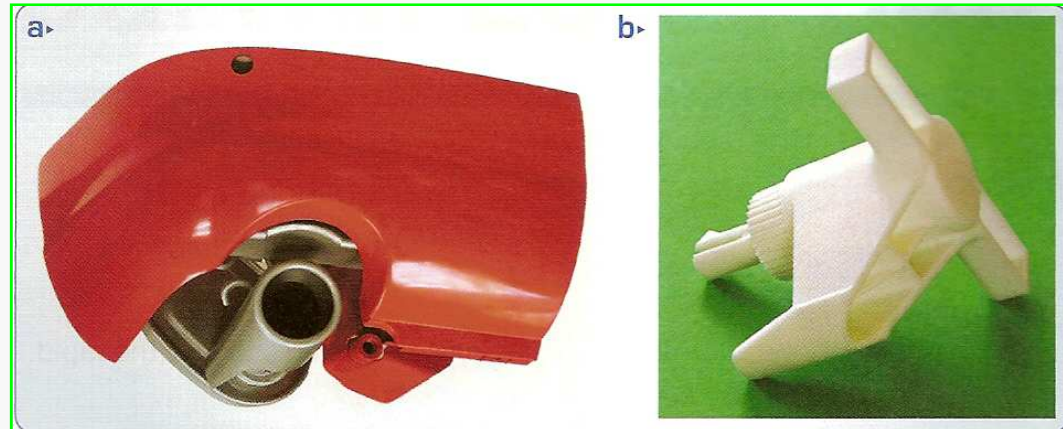


Figure 2 | Laser sintering and cars. **a**, Close-up of the laser-sintered prototype bumper section for the Jaguar XJ. The painted model was used to visualize the fit and finish of key components before production. **b**, The laser-sintered plastic tool that assists operators working on the new Jaguar XK production line to position window lift mechanisms during assembly.

Nature Photonics, May 2009



Figure 3 | Prototype plate bender, used to contour plates for spinal surgery, built by DePuy using a laser-sintering system.



Digital light processing (DLP) technology used in concert with a laser-assisted manufacturing, rapid-prototyping process can speed dental and hearing aid implant manufacture by varying the illumination intensity (and corresponding cure depth) pixel-by-pixel in the fabrication process. (Courtesy of EnvisionTEC)



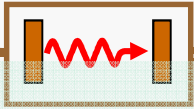
A 30W CO₂ laser allows for sharp well defined marking even on high-speed production lines.

From Keyence - 2010

Laser Engraving on Implant Products



Precision engraving on crown bridges and various shaped implants. The MD-F Series is capable of marking ultra small 2D codes as well.



Làsers: Aplicacions científiques i tècniques

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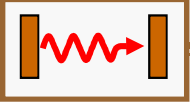
POTÈNCIA ↑

Gran

Mitjana

Petita

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- *Làser d'electrons lliures, làser de raigs X*
- *Làsers de Terawatt: generació d'altres freqüències i de polsos ultra-curts (atto-segons), aplicacions a Física Atòmica i Nuclear, acceleració de partícules.*
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See the light

Artist Hiro Yamagata linked science with art at his “Photon 999” exhibition, where multiple laser systems immersed the viewers in a moving-light show.

LIDAR (measuring distances, controlling atmosphere pollution, etc.

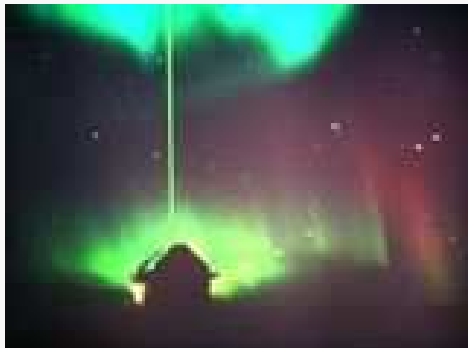
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A FASOR used at the Starfire Optical Range for LIDAR and laser guide star experiments is tuned to the sodium D2a line and used to excite sodium atoms in the upper atmosphere

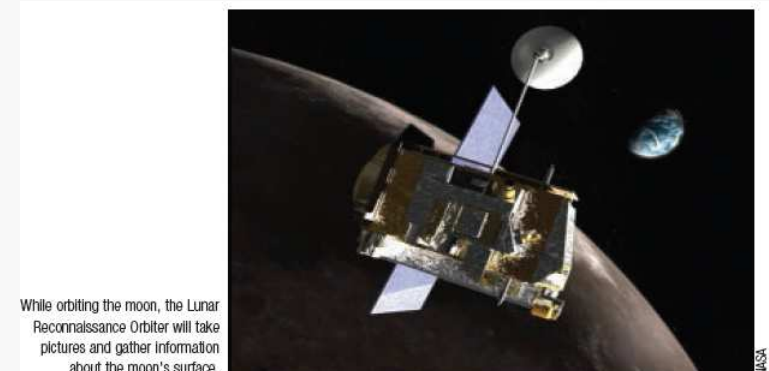


Chet Gardner, Univ. of Illinois

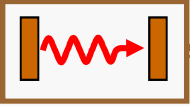
Also on earth, mobile (with a van), to measure air pollution near a factory, etc.)



The lidar operating at Davis with an aurora in the background.
Photo: David Correll

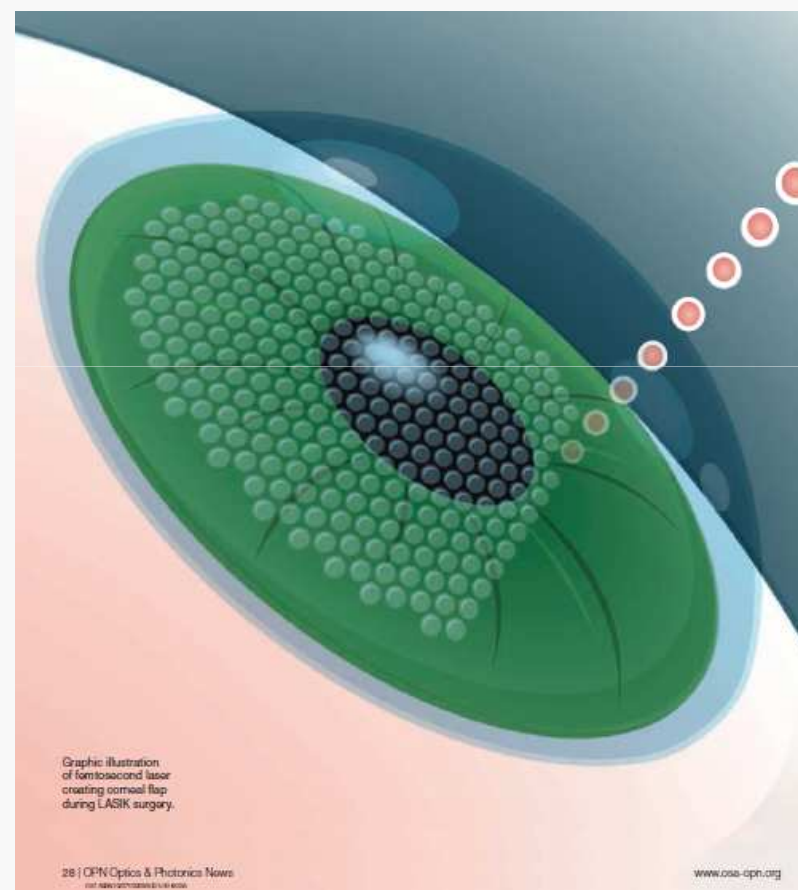
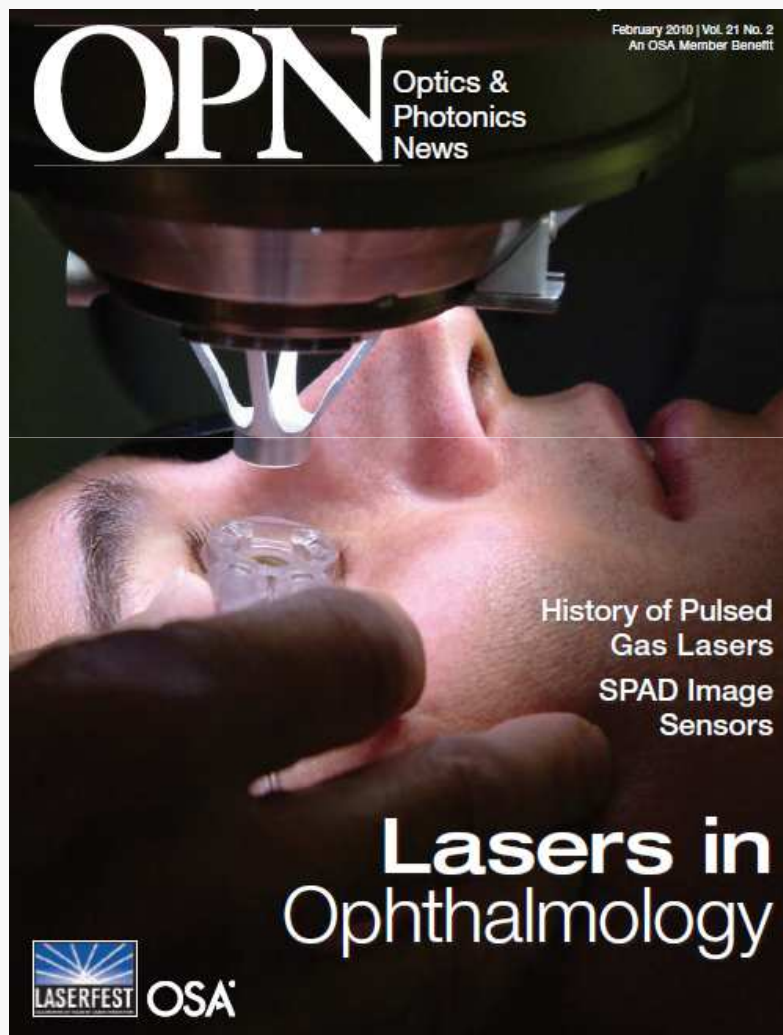


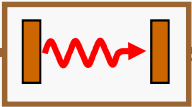
While orbiting the moon, the Lunar Reconnaissance Orbiter will take pictures and gather information about the moon's surface.



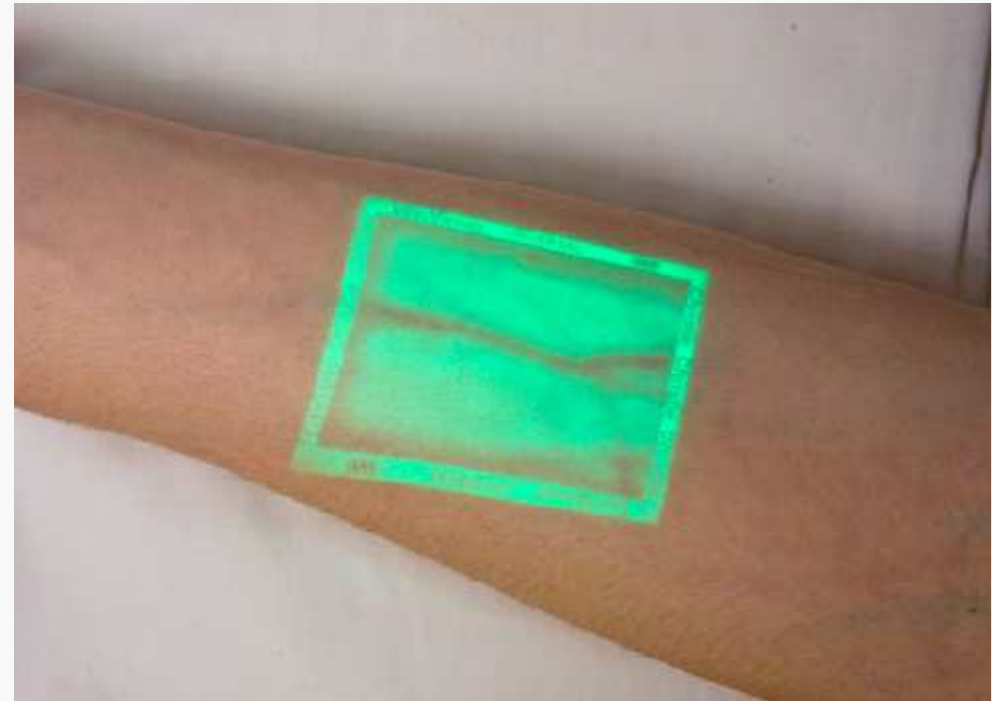
Applications in biology (biophotonics) and medicine:

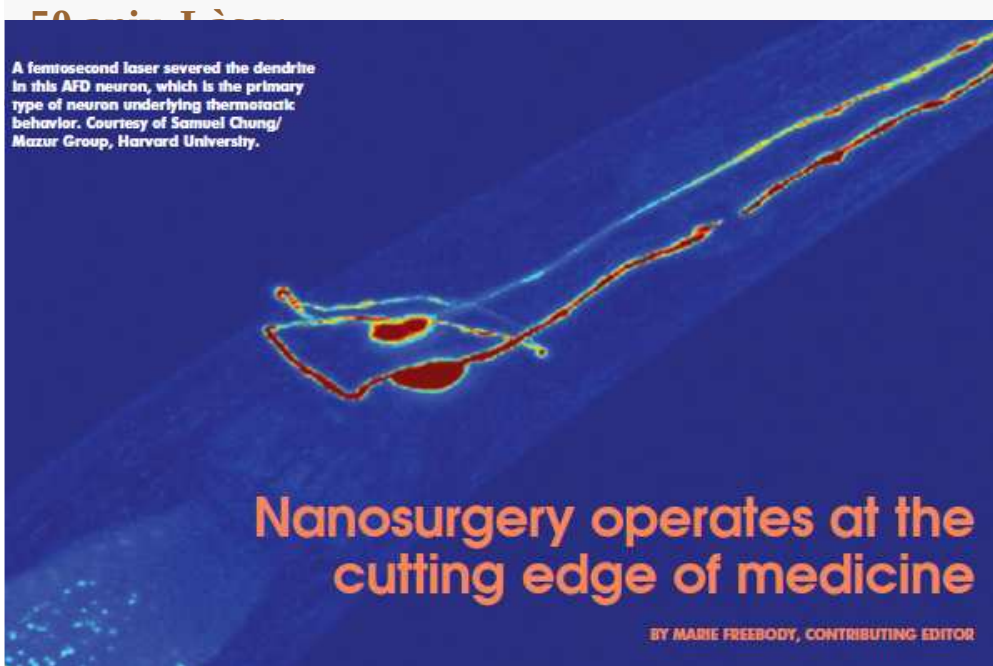
- **Vision:** *LASIK, diabetic retinopathy, ...*
- **Skin**
- **Rheumatism**
- **Laser thermotherapy –by heat-, photodynamic therapy –by light activated drugs-:**
Remove obstructions in arteries and veins, ulcers, tumors (cancer),...
(use of drugs, fluophores, plasmon particles,...)
- **Surgery:** *laser scalpel, nanosurgery*
- **Analysis of blood, cells and tissues by:**
spectroscopy (helped with fluophores,...)
light scattering + spectroscopy (even in the brain!)
two-photon spectroscopy,
Optical coherence tomography (OCT),
Light scattering
- **Measurement of blood concentration of particles, velocities, tissue coagulation**
(by light scattering, Doppler shift,...)
-





*It works with **OCT**
(not X-ray Computer
Tomography, CT)*



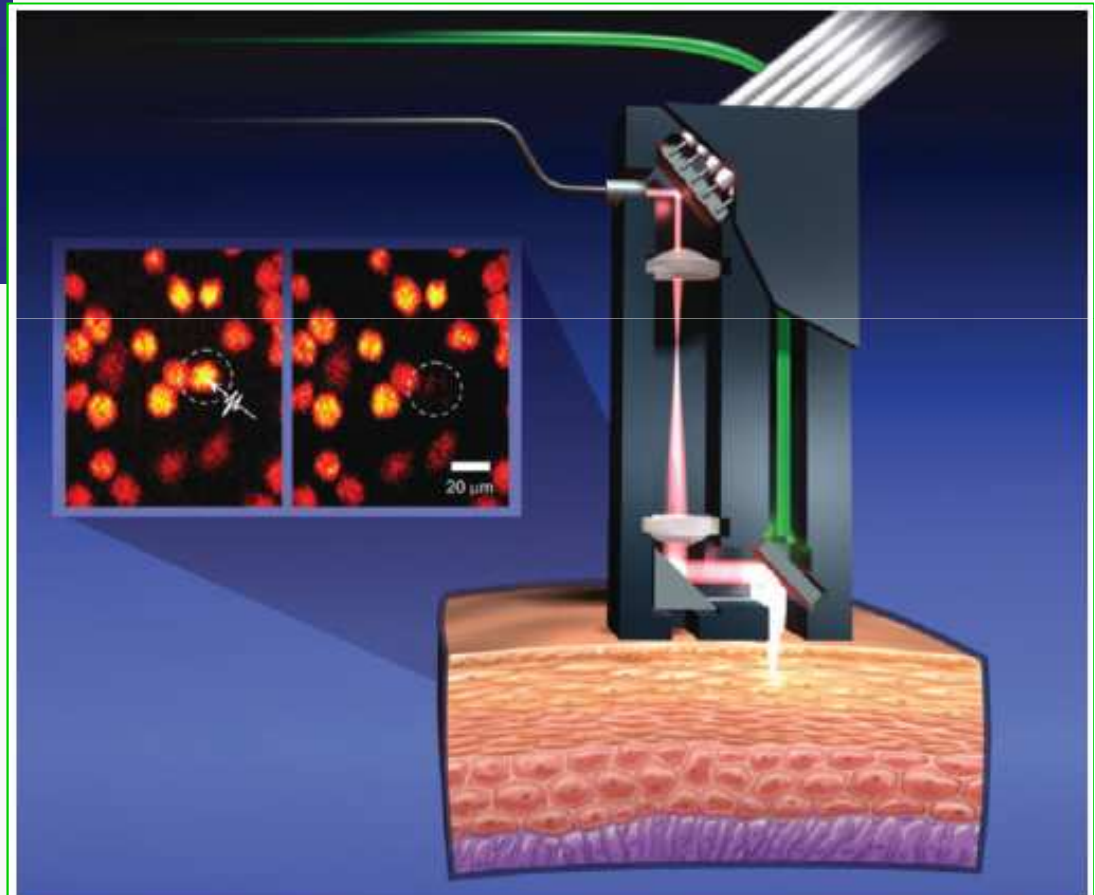


Biophotonics, July-August 2010

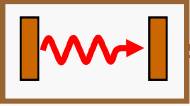


Shown is a model of femtosecond laser nanosurgery-on-a-chip for nerve regeneration studies in vivo using a whole organism, *C. elegans*. The chip allows chemical-free immobilization of the worm for precise laser nanosurgery of its axons. The full automation of this chip now provides the possibility for high-throughput screening of genes affecting nerve regeneration. Courtesy of Ben-Yakar Group.

Nanosurgery



A clinical endoscope is used to perform image-guided femtosecond laser microsurgery of cancer cells. The inset shows two-photon fluorescence images of cancer cells taken with the prototype (left image) and the same region after the targeted ablation of a single cell. The targeted cell was instantly destroyed, while neighboring cells were left intact. Courtesy of Ben-Yakar Group, University of Texas, Austin.



Laser interferometry for gravitational wave observation: LISA and LISA Pathfinder

FELIPE GUZMÁN CERVANTES

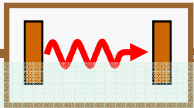
NASA Goddard Space Flight Center

Greenbelt, Maryland, UNITED STATES

The Laser Interferometer Space Antenna (LISA) is a planned NASA-ESA gravitational wave observatory in the frequency range of 0.1mHz-100mHz. This observation band is inaccessible to ground-based detectors due to the large ground motions of the Earth.

Gravitational wave sources for LISA include galactic binaries, mergers of supermassive black-hole binaries, extreme-mass-ratio inspirals, and possibly from as yet unimagined sources.

*LISA is a constellation of three spacecraft separated by 5 million km in an equilateral triangle, whose center follows the Earth in a heliocentric orbit with an orbital phase offset of 20 degrees. Challenging technology is required to ensure pure geodetic trajectories of the six onboard test masses, ***whose distance fluctuations will be measured by interspacecraft laser interferometers with picometer accuracy.****



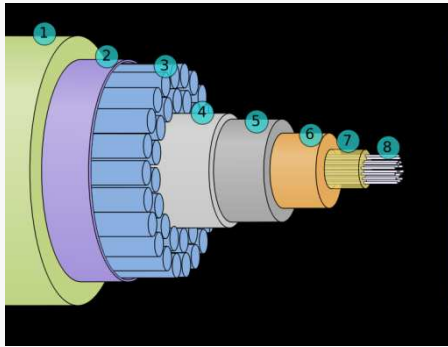
POTÈNCIA ↑

Gran

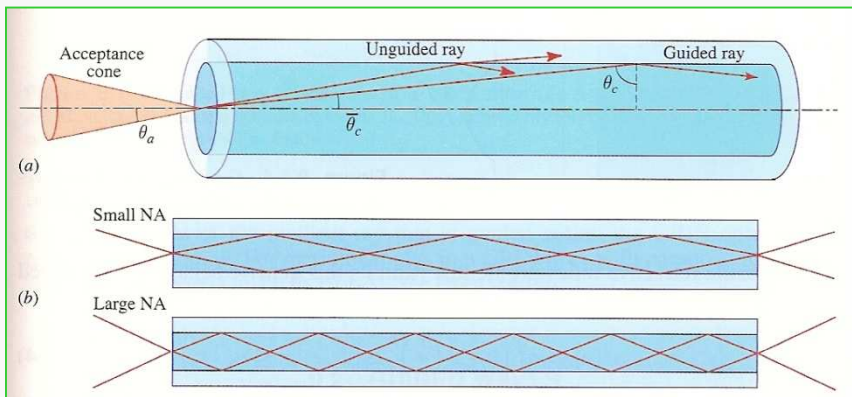
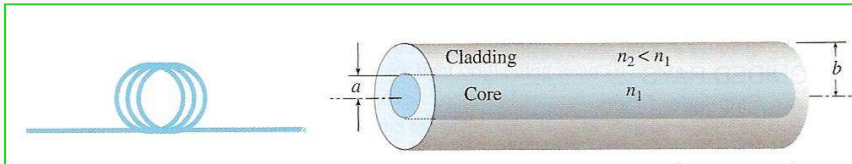
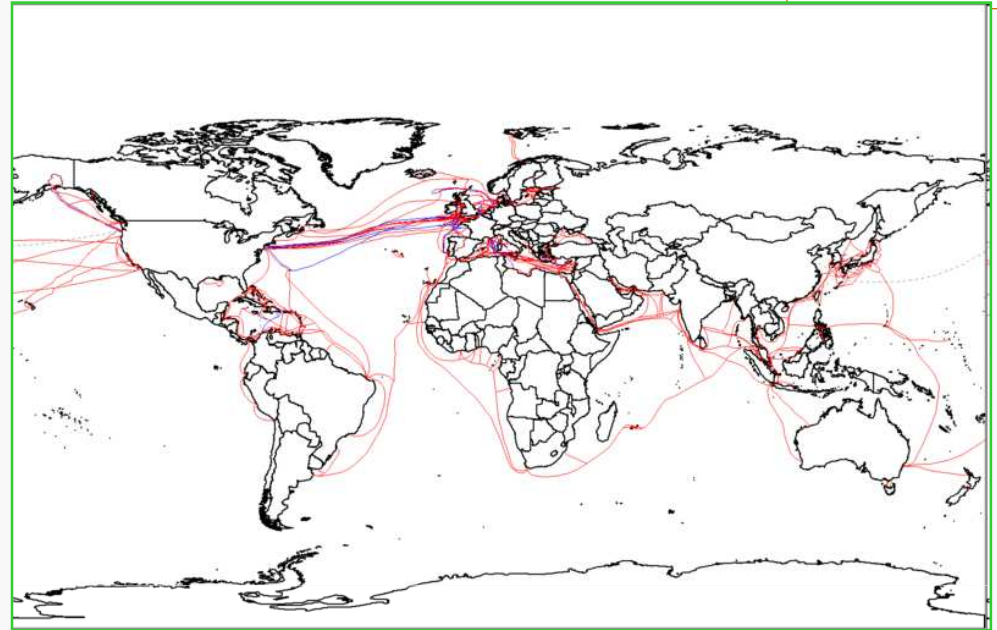
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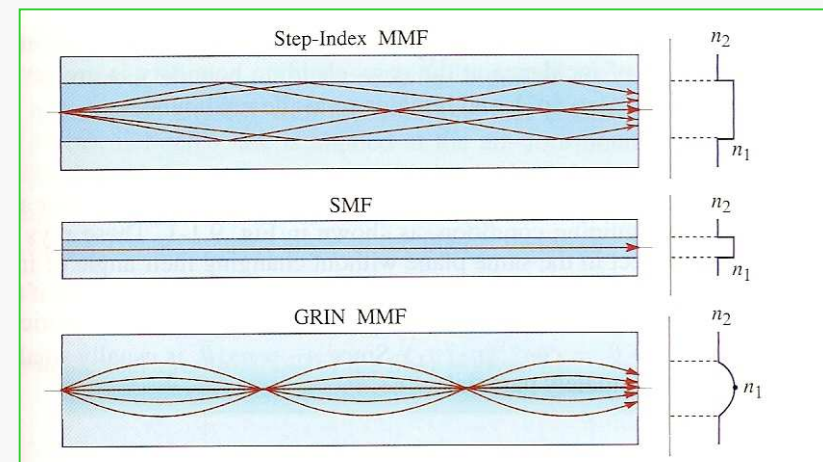
OPTICAL
FIBERS



$$NA = \sin \theta_a$$

$$V = (2\pi a / \lambda_0) \cdot NA$$

“Fiber parameter”





Jeffrey Tseng/Intel

Light Peak module close-up with laser light added for illustration (actual Infrared light is invisible to the eye).



MANIFESTATIONS OF THE SUPERPOSITION PRINCIPLE (and Quantum measurement) (III): QUANTUM CRYPTOGRAPHY

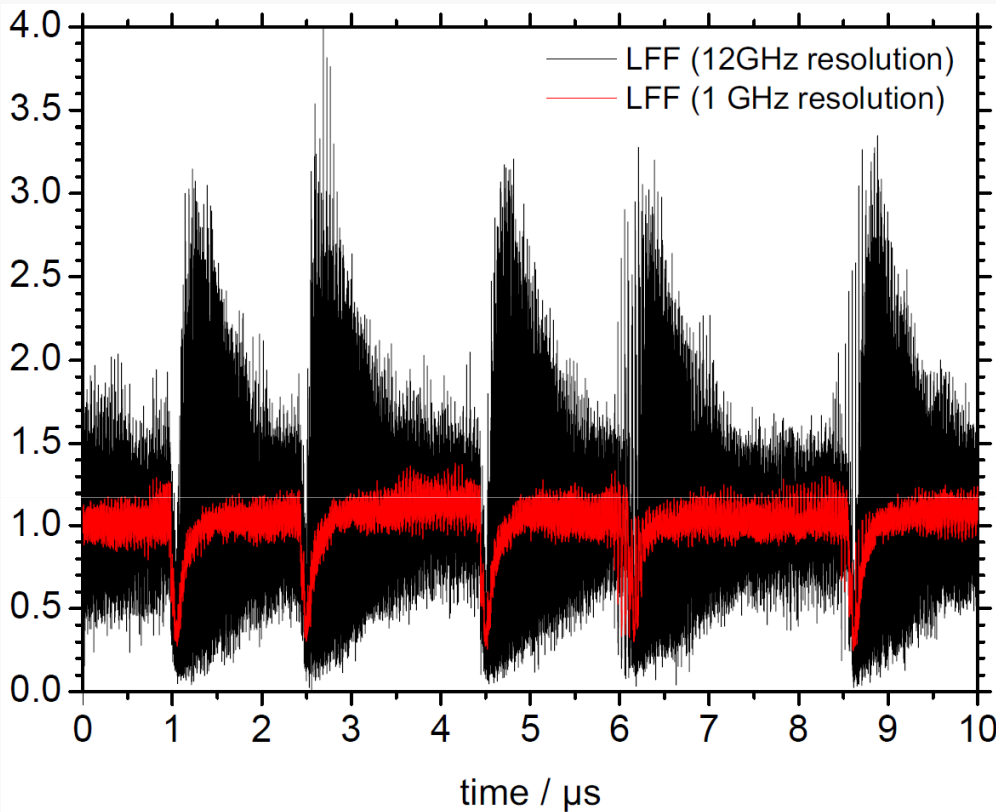
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<http://www.idquantique.com/>



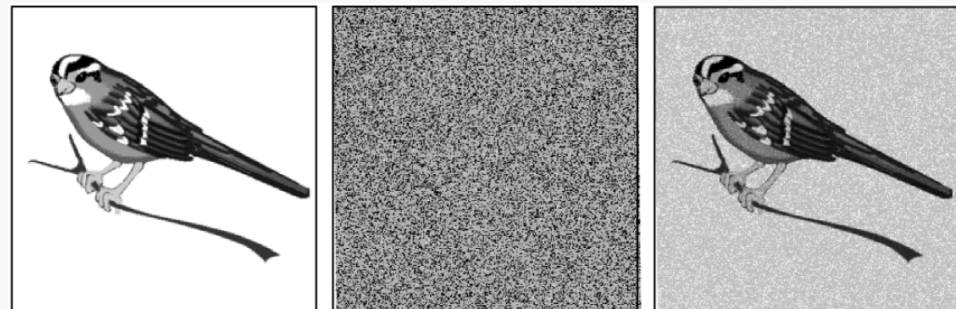
Cryptography based on chaos...

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High-dimensionality chaos generated by a semiconductor laser with feedback

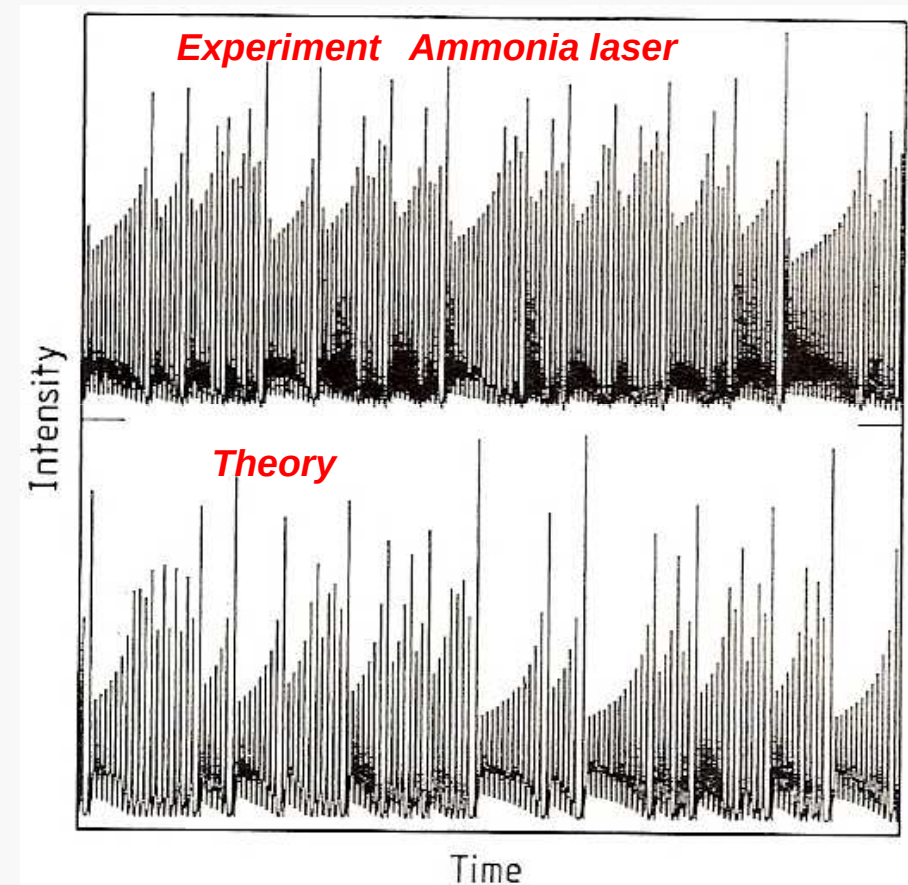
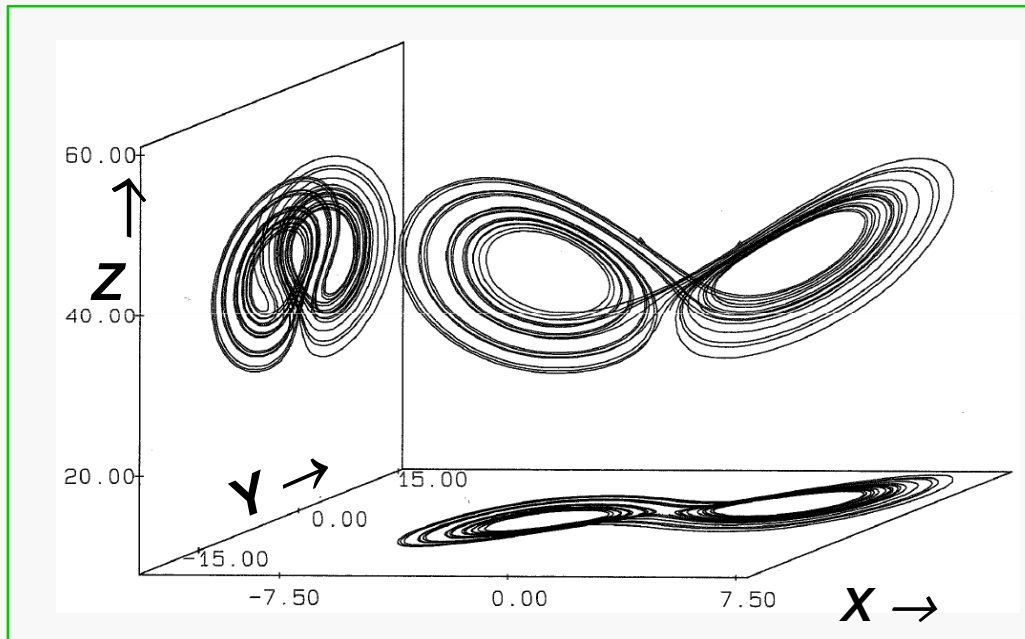
Ingo Fisher et al, IFISC, 2010



J. García-Ojalvo and R. Roy, Phys. Rev. Lett. 86, 5204 (2001).

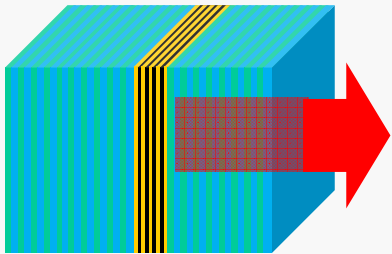


Verificació experimental del paradigmatic Model de Lorenz, en un làser

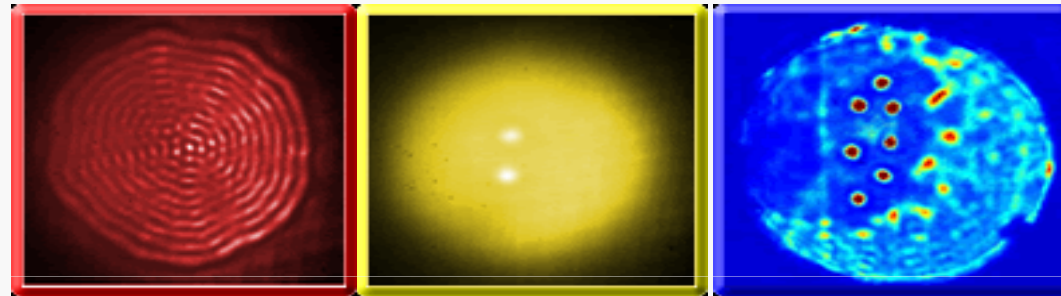


C.O. Weiss and J. Brock, *Phys. Rev. Lett.* 57, 2804 (1986).

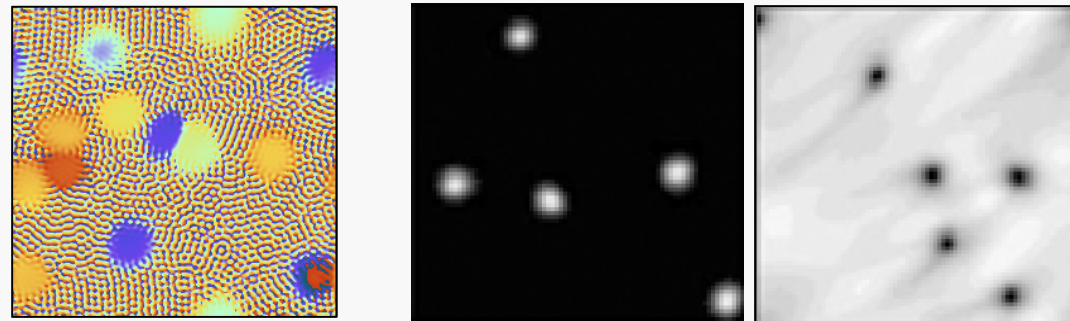
C.O. Weiss and R. Vilaseca, *Dynamics of Lasers* (VCH, Weinheim, 1991).



**Wide-aperture
laser**



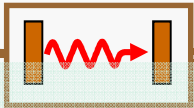
Barland, Tredicce et al, *Nature* 419, 699 (2002)



Cavity solitons

**Optical
vortices**

Vilaseca, García-Ojalvo, Torrent, M.B., San Miguel,
Phys. Rev. Lett. 87, 083902 (2001)



POTÈNCIA ↑

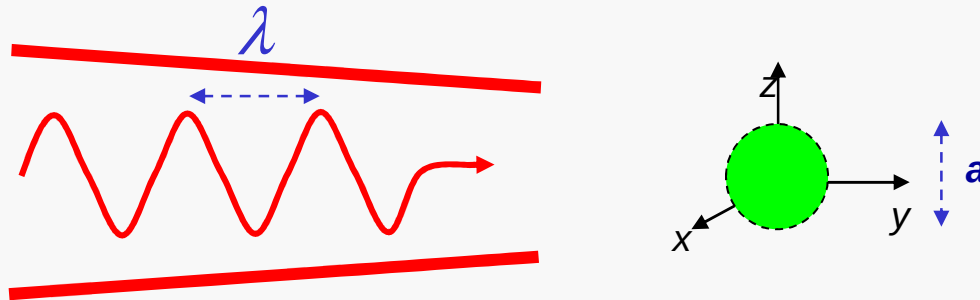
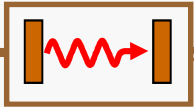
Gran

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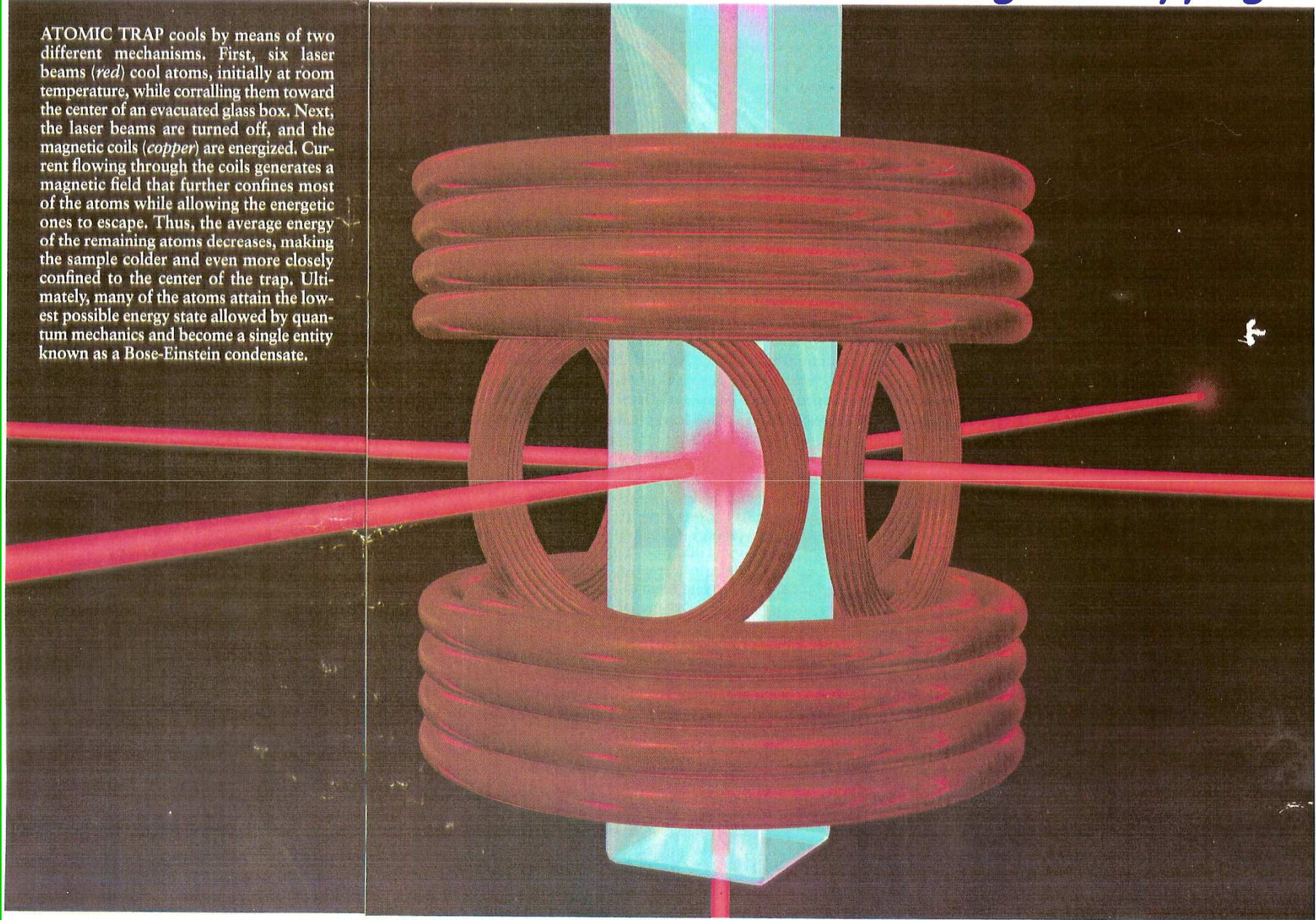
Action over the atom's center of mass: cooling and trapping of atoms



Forces over an object
(atom,...), from an
electromagnetic wave :

- **Radiation pressure:** $\Rightarrow$ “OPTICAL MOLASSES”
- **Dipolar (if $\lambda \gg a$) or momentum-exchange (if $\lambda \ll a$)**
 $\Rightarrow$ “OPTICAL TWEEZERS”

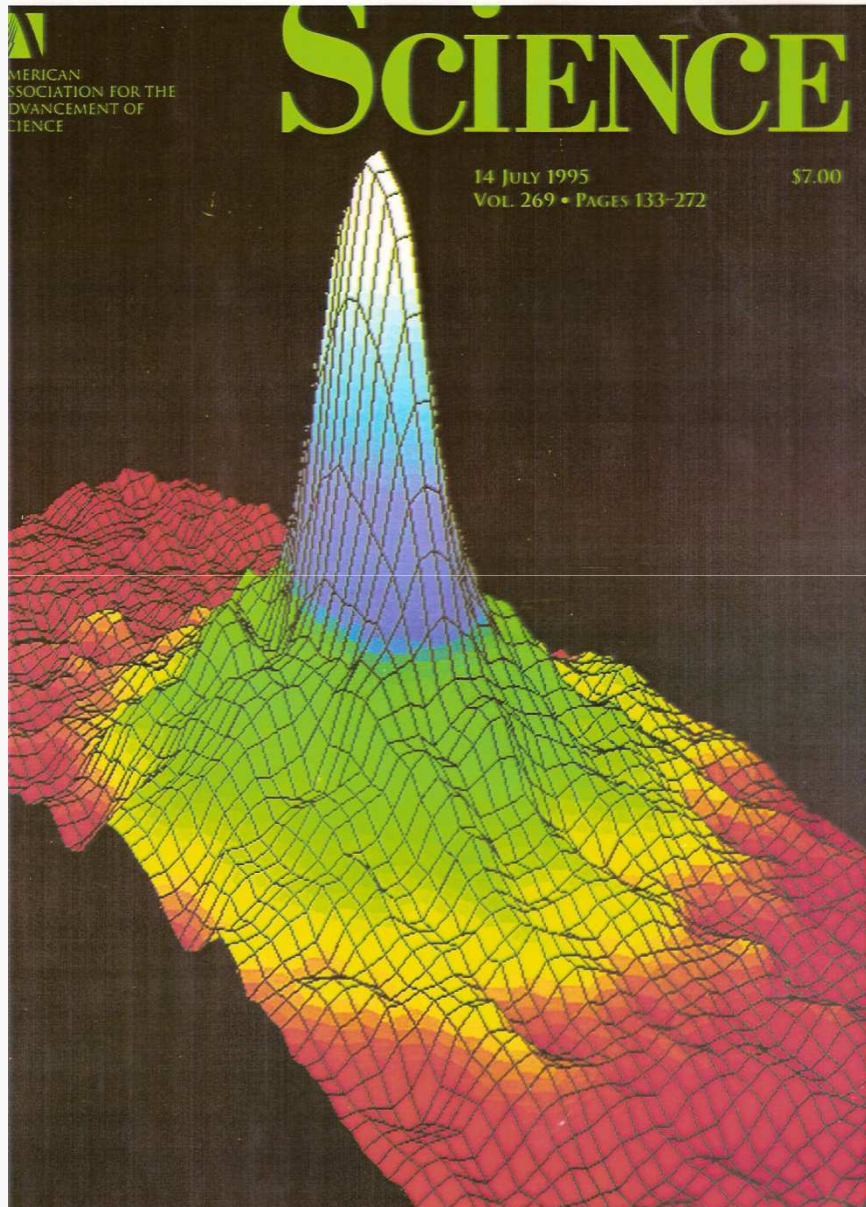
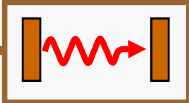
ATOMIC TRAP cools by means of two different mechanisms. First, six laser beams (*red*) cool atoms, initially at room temperature, while corralling them toward the center of an evacuated glass box. Next, the laser beams are turned off, and the magnetic coils (*copper*) are energized. Current flowing through the coils generates a magnetic field that further confines most of the atoms while allowing the energetic ones to escape. Thus, the average energy of the remaining atoms decreases, making the sample colder and even more closely confined to the center of the trap. Ultimately, many of the atoms attain the lowest possible energy state allowed by quantum mechanics and become a single entity known as a Bose-Einstein condensate.



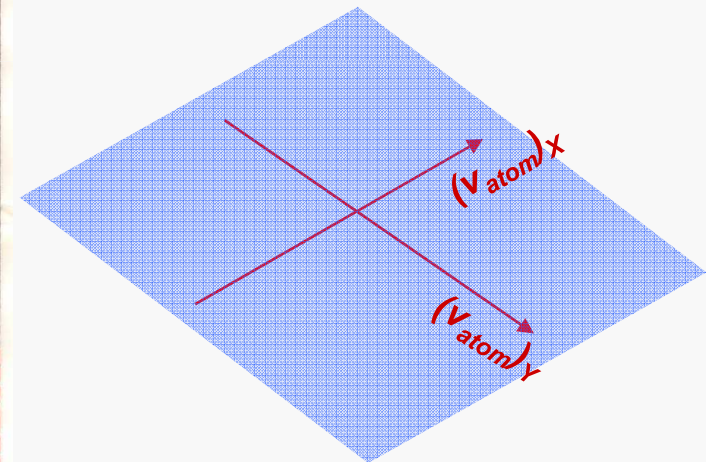
E. A. Cornell, C. E. Wieman : Sci. Am. (March 1998), p. 26

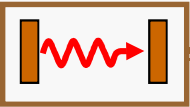
First achievement of BEC (Bose-Einstein condensation)

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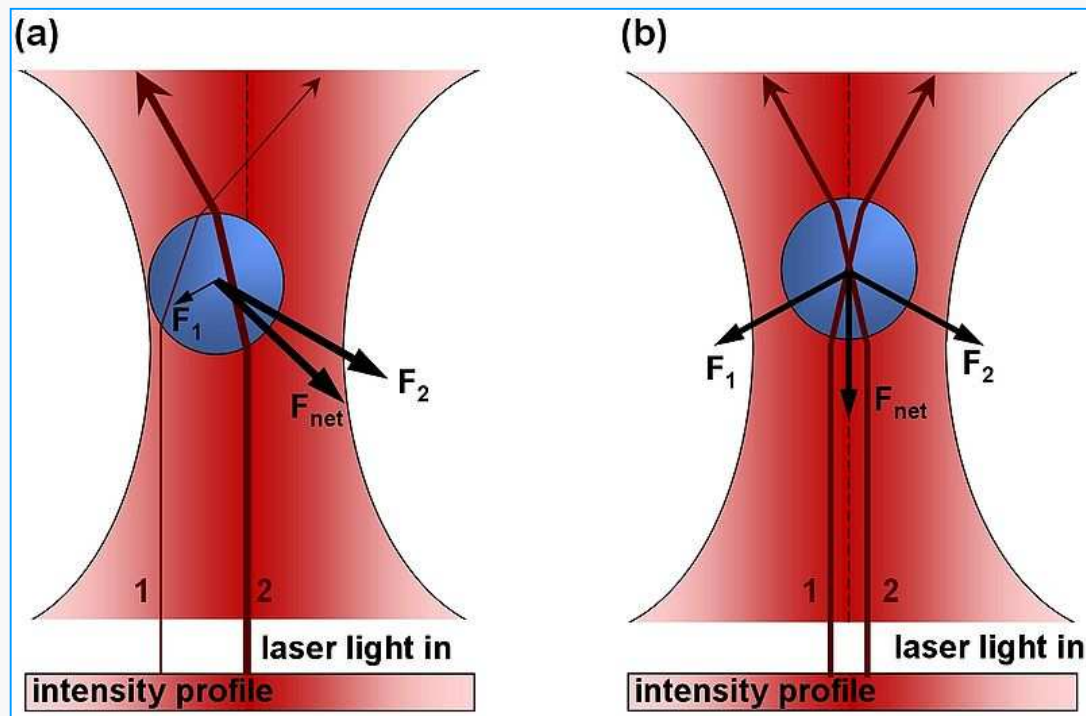
* Anderson, Ensher, Matthews, Wieman, Grnelli: *Science* 269, 198-201 (1995)





Optical tweezers

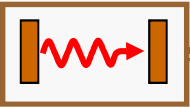
- b) (General Mie regime): $\lambda \ll a$. The gradient forces is dominated by the momentum reaction to the light deviation by refraction inside the sphere (if it is transparent), on the walls: “Momentum–exchange” force. (Many applications in biology)



Ray-optics and linear-momentum explanation:

When the bead is displaced from the beam center, as in (a), the larger momentum change of the more intense rays cause a net force to be applied back toward the center of the trap. When the bead is laterally centered on the beam, as in (b), the net force points toward the beam waist.

(www.wikipedia.org)



There have been different modifications of the optical tweezers configurations. For instance:

Optical tweezers based on SPP evanescent fields

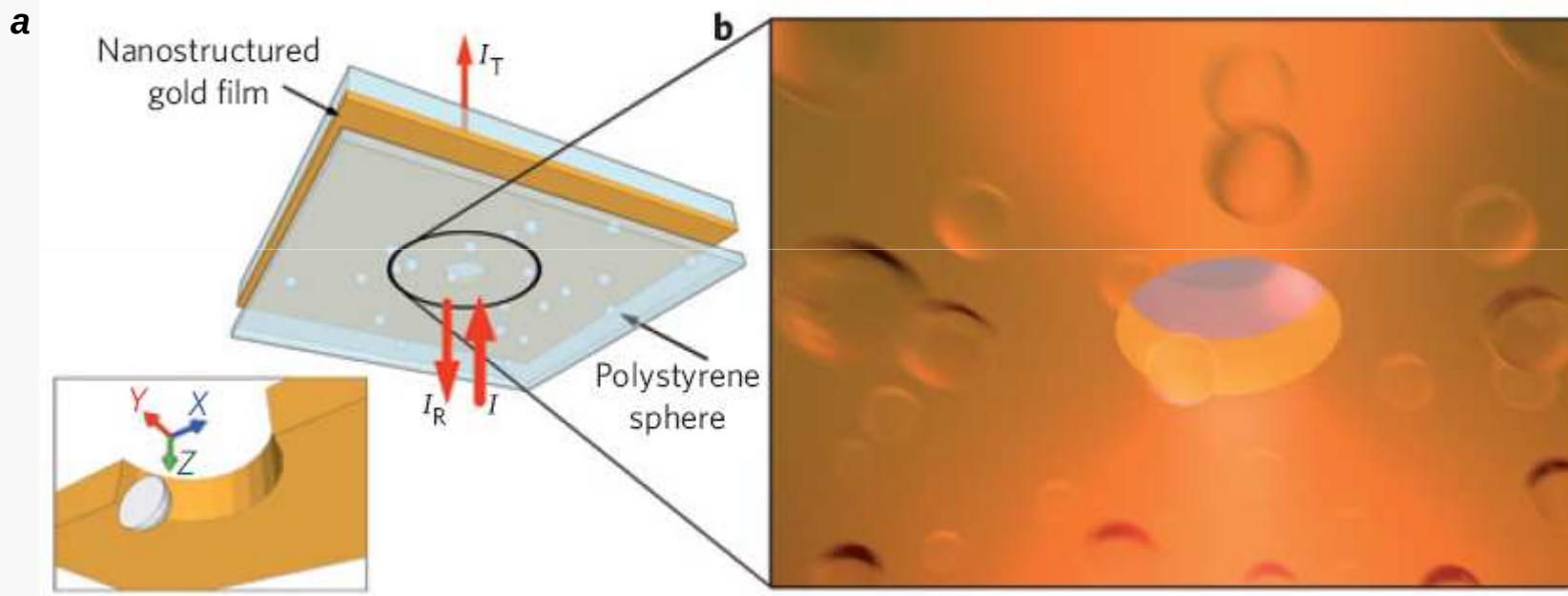
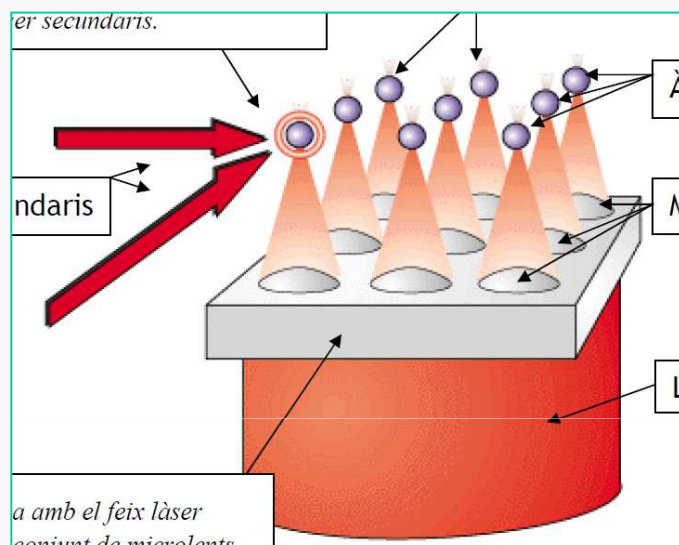


Figure 1 j SIBA optical trapping using a nanoaperture in a metallic film. *a*, Schematic representation of the trapping set-up for a 310nm aperture in a 100-nm-thick gold film and 100-nm polystyrene spheres in water. The diagram in the left-bottom corner shows the coordinate system used, with the origin at the centre of the aperture. *b*, Schematic of the trapping of a single polystyrene sphere, while others experience thermal diffusion.

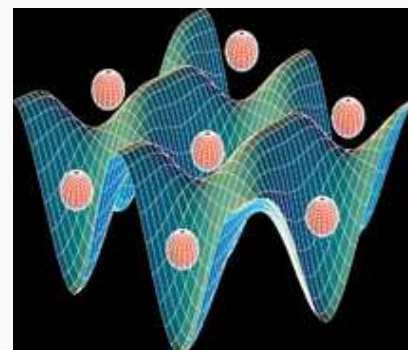
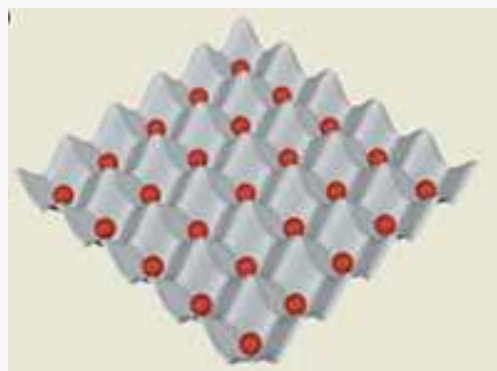
M.L. Juan, ..., Romain Quidant: *Nature Physics* (2009)

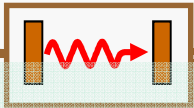


Optical lattices created with optical tweezers



Optical lattices allow us to study entanglement between atoms





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- **Sensors: de presència, posició, vibració i moviment. Lectors de codis, etc.**
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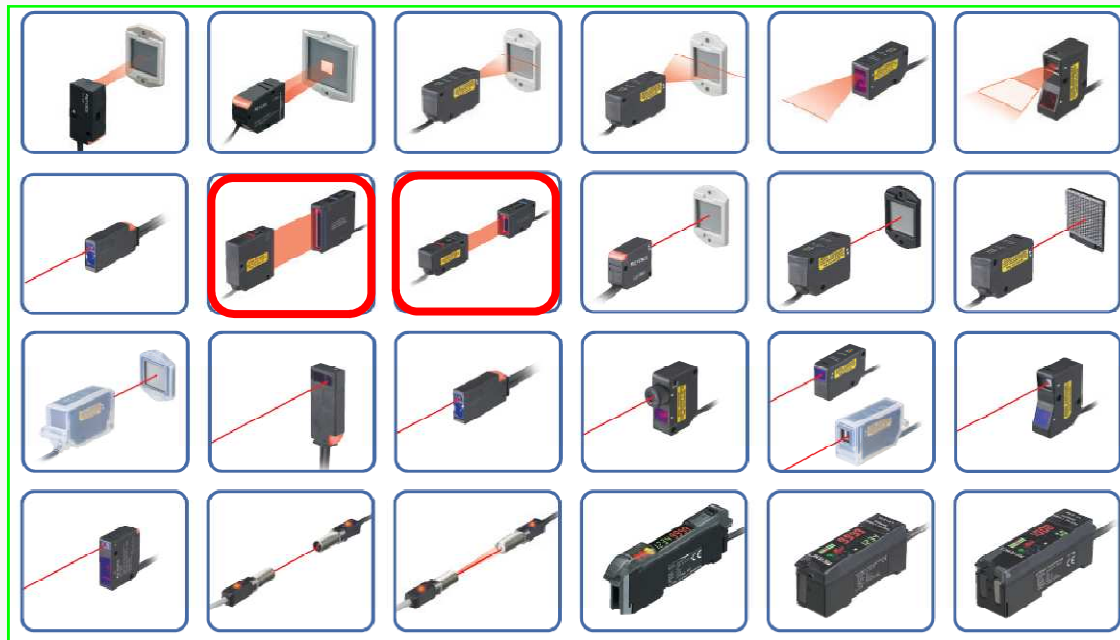
one photoemitter + one photodetector

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Distance meter in the transverse direction:

- diameter or gap measurements by “light curtain” (gaging, laser micrometer)*

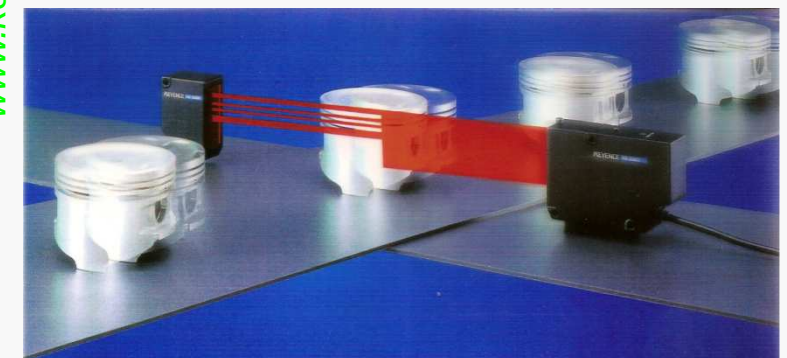
Need a scanning system, and/or a CCD detector.



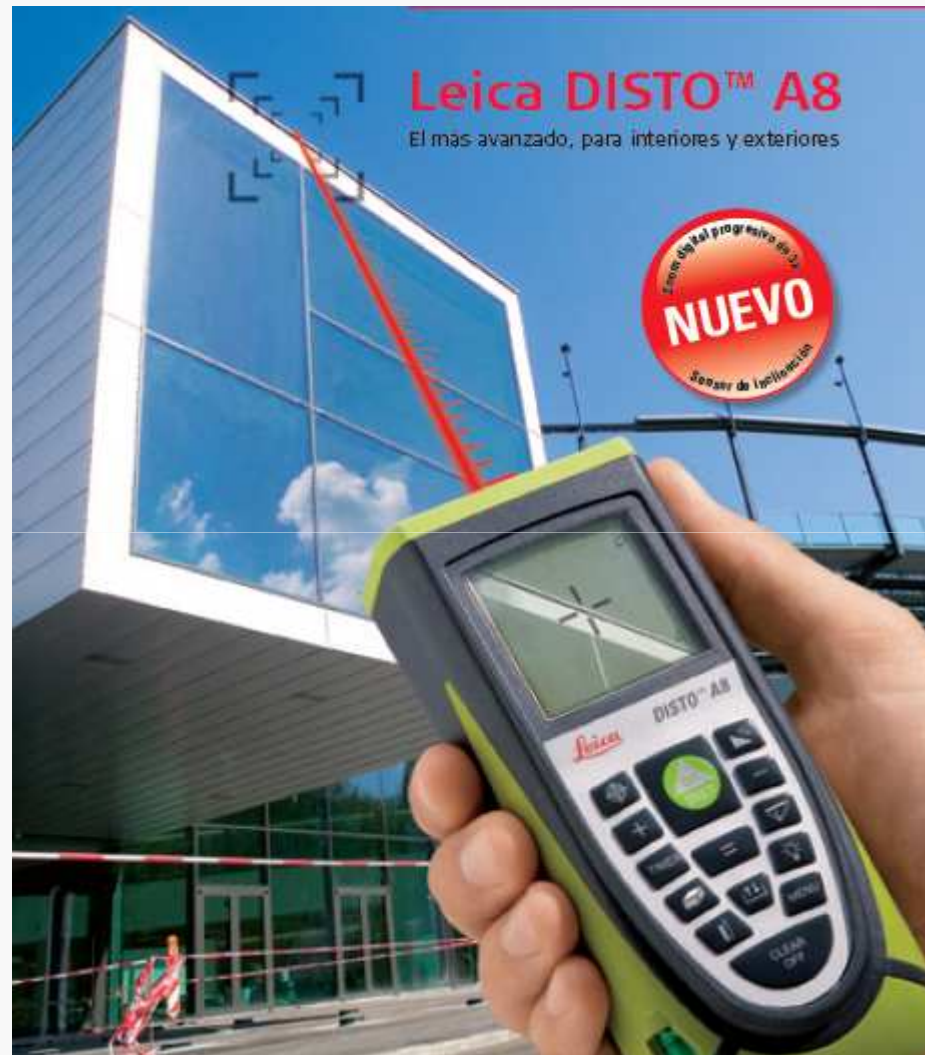
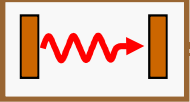
Several types of small devices, for different purposes

www.keyence.com

www.keyence.com



Laser micrometer (for gaging)



one photoemitter + one photodetector

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Distance meter in the transverse direction:**• LASER DOPPLER VELOCIMETRY (OR ANEMOMETRY)**

For measuring velocities of particles in suspension in a fluid,
moving in transverse direction

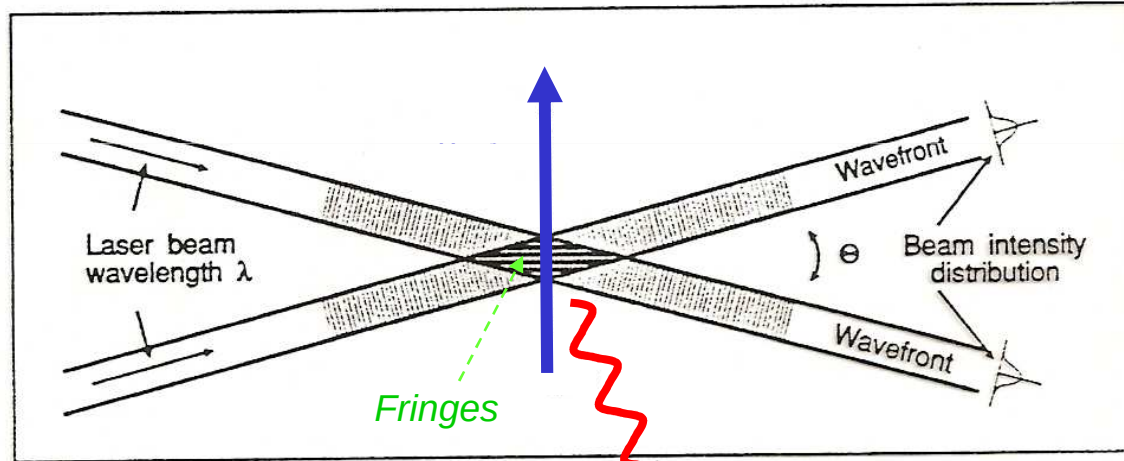


Figure 10. Two laser beams crossing.

Detecting
Scattered light

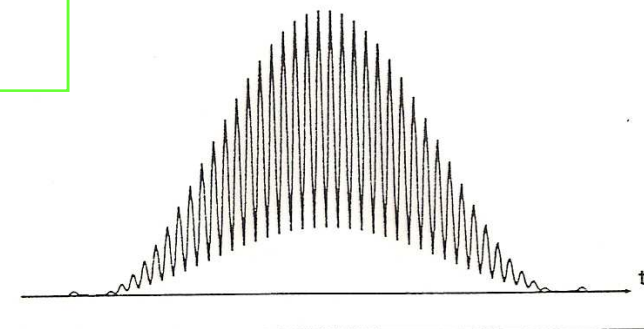
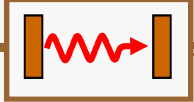


Figure 11. Doppler burst (Doppler signal).



Some EXAMPLES of combinations of one photoemitter + one photodetector

Measuring distances in Z (longitudinal) direction, by TRIANGULATION (1D)

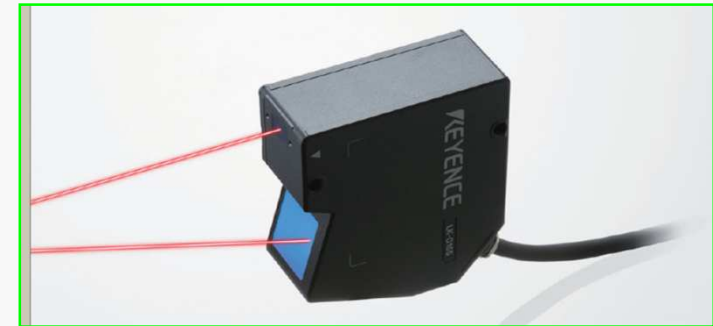
KEYENCE

NEW Ultra High-Speed/High-Accuracy
CMOS Laser Displacement Sensor
LK-G5000 Series
CE

KEYENCE LK-H02B

BEST SPECIFICATIONS IN THE WORLD

Fastest in the world	Highest accuracy in its class	Highest repeatability in its class
392 kHz	±0.02%	0.0004 Mil (0.01 μm)



Triangulation (1D)



Triangulation (2D)

TRIANGULATION (1D)

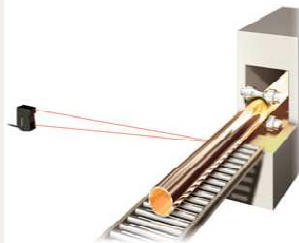
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Measuring height of an air suspension vehicle



Checking vehicle height



Detecting the position of hot steel shafts



Measuring the profile of a chip



Measuring amplitude of a speaker cone



Detecting the runout of a HDD



Measuring the surface runout of a flywheel



Measuring a valve stroke



Detecting double-fed steel plates



Measuring coplanarity of a pins on a connector



Measuring the vibration of a motor shaft



Measuring runout of a polygon mirror

TRIANGULATION (2D)

www.keyence.com

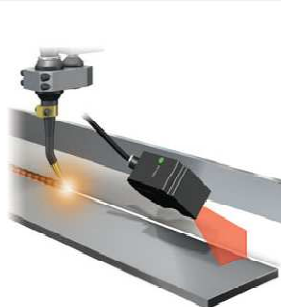
Checking the assembly accuracy of an auto body



Sealant bead height, width and area measurement



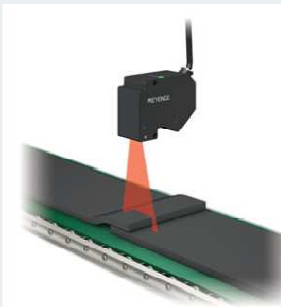
Position feedback in an automated welding operation



Measuring the step height/profile of a key



Measuring the height/width of overlapping rubber



Step height measurement of a roll and a blade



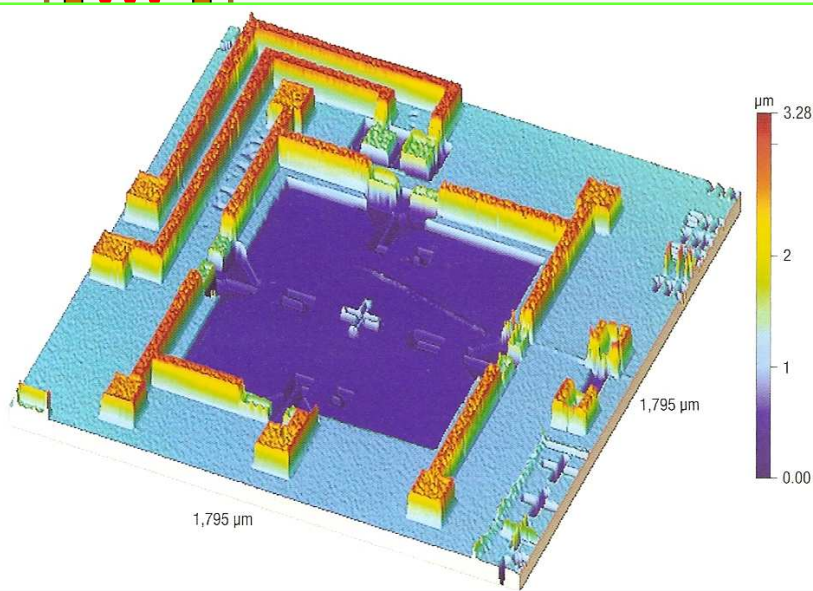
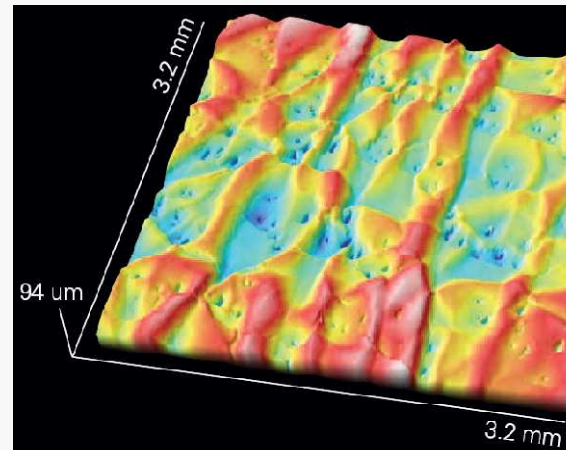


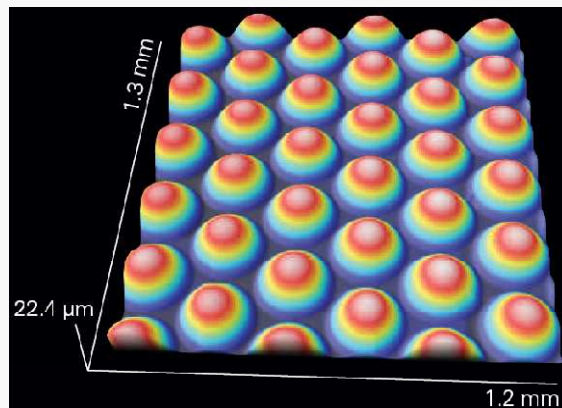
Figure 1 An interferometry measurement of a MEMS piezoelectric pressure sensor. Typically both the step height and roughness are of interest to ensure that the device works correctly.



Biotechnology (leader)

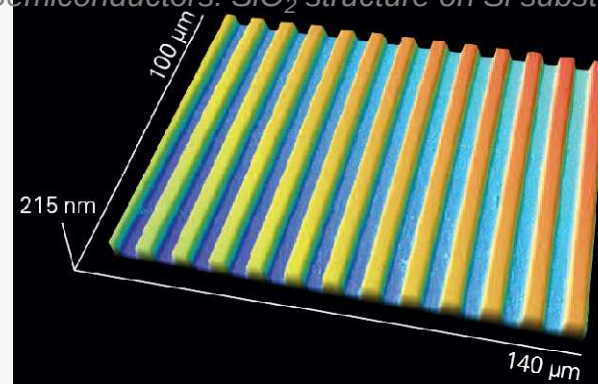
**OPTICAL IMAGING PROFILER
(3D):**

**Confocal
+
interferometer (PSI+VSI)**



Micro-optics: array of glass microlenses

Semiconductors: SiO₂ structure on Si substrate



Semiconductors: SiO₂ structure on Si substrate



Confocal + Interferometer (3D)



No sols a curtes distàncies:

- Arquitectes:

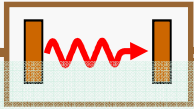
*mesura ràpida de distàncies,
escanejat 3-D d'edificis...*

Estudi sobre la Sagrada Família

J. Regot et al., 2006

(Escola d'Arquitectura, Univ. de Barcelona)





Làsers: Aplicacions científiques i tècniques

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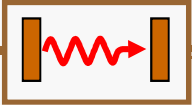
POTÈNCIA ↑

Gran

Mitjana

Petita

- *Fusió nuclear*
- *Làser d'electrons lliures, làser de raigs X*
- *Làsers de Terawatt: generació d'altres freqüències i de polsos ultra-curts (atto-segons), aplicacions a Física Atòmica i Nuclear, acceleració de partícules.*
- *Transport d'energia a distància (futur)*
- *Aplics. militars*
- *Processat de materials: tall, soldadura, perforació, marcatge, tractaments de superfície, prototipat 3D (100 nm resol amb femtosecond 2-photon), ...*
- *Espectacles lluminosos*
- *Fotoquímica: estimulació i control de reaccions químiques (fins i tot unir àtoms freds), foto-dissociació, foto-ionització, ...*
- *Òptica no lineal, per a diverses aplicacions (incloent la generació de extrem UV -13.5 nm- per a dissenyar petites estruct. electròniques i estendre Moore's law, informació quàntica,...)*
- *Biofotònica, aplicacions mèdiques*
- *Control remot: LIDAR, control de l'atmosfera*
- *Arts gràfiques, impressores, memòries (CD, DVD),... [Futur: imatges color i projectors, il·lum.]*
- *Holografia, interferometria, Òptica en general (futurs displays, projectors?)*
- *Espectroscòpia: anàlisi de materials, de contaminants, etc.*
- *Comunicacions òptiques; comunicacions quàntiques (criptografia quàntica, etc.)*
- *Atrapament i refredament d'àtoms, condensació de Bose-Einstein (BEC)*
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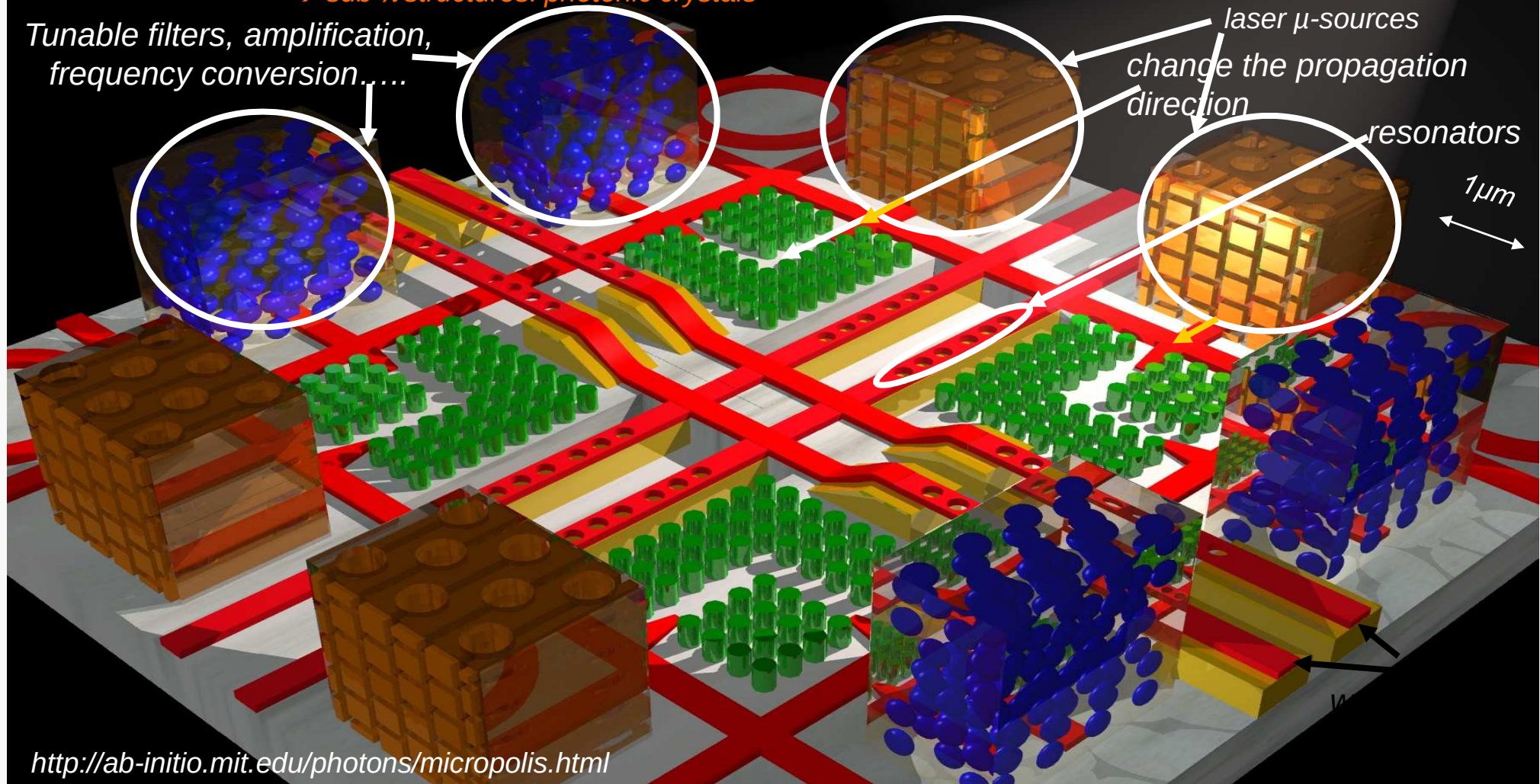


Photonic circuits: the dream.....

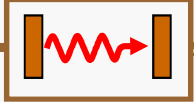
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- These optical circuits should provide active functions for all-optical information processing.
- These optical circuits should be able to perfectly control the propagation of the light
 - use of nonlinear optics
 - sub- λ structures: photonic crystals

Tunable filters, amplification,
frequency conversion.....



<http://ab-initio.mit.edu/photons/micropolis.html>



*The European Union (EU) has defined, in 2010, several
“Key Enabling Technologies” (KET)
 for sustainable European industry:*



European Commission
Enterprise and Industry

European Commission > Enterprise and Industry > Sectors > ... > Information and communication technologies > Key enabling technologies

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Enterprise and Industry

Information and communication technologies

- ICT Competitiveness
- Key Enabling Technologies**
- e-Skills for the 21st Century
- ICT Standardisation
- e-Invoicing
- Assessing ICT and e-business impact
- Boosting e-Business for SMEs

Advanced search  Share  

Information and communication technologies

Key Enabling Technologies

A significant part of future goods and services are as yet unknown, but the main driving force behind their development will be Key Enabling Technologies (KETs), such as nanotechnology, micro- and nanoelectronics including semiconductors, advanced materials, biotechnology and photonics. Mastering these technologies means being at the forefront of managing the shift to a low carbon, knowledge-based economy. They play an important role in the R&D, innovation and cluster strategies of many industries and are regarded as crucial to ensure the competitiveness of European industries in the knowledge economy.

These technologies enable the development of new goods and services and the restructuring of industrial processes needed to modernise EU industry and make the transition to a knowledge-based and low carbon resource-efficient economy. Whilst the EU has very good research and development capacities in some key enabling technology areas, it has not been as





Futur ...?

- *Millora eficiències, en tots tipus de làsers i aplicacions*
- *Micro- i nano-lasers: sensors, integració electrònica-fotònica, computació, comunicacions*
- *Més progrés en biofotònica (aplics. en biologia i medicina)*
- *Imatge, projecció*
- *Comunicacions a l'espai, a molt llarga distància*
- *"Power beaming"*
- *Fusió nuclear controlada?*
- *Informació quàntica? (criptografia, simulació, computació, teleportació,...)*

En parlarem, si és possible, en el 100 aniversari del làser...