LASERS

UNICAMP

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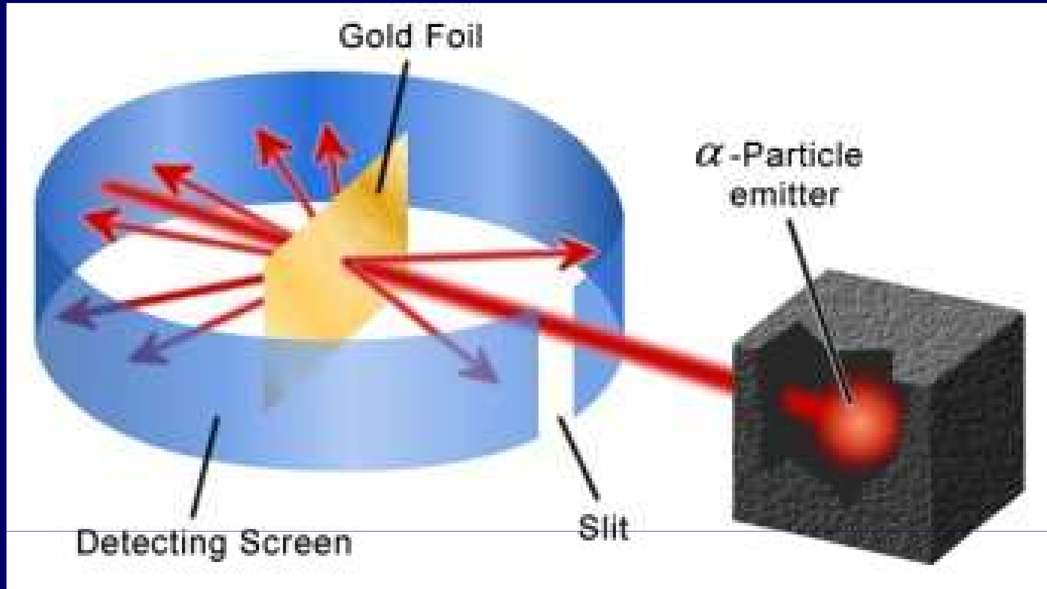
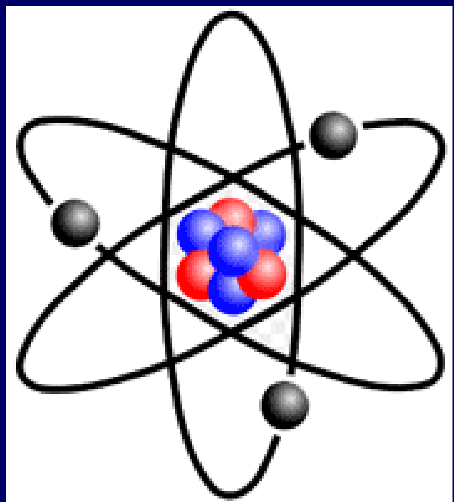
UNICAMP

Mecânica Quântica Light

Modelo atômico: Rutherford

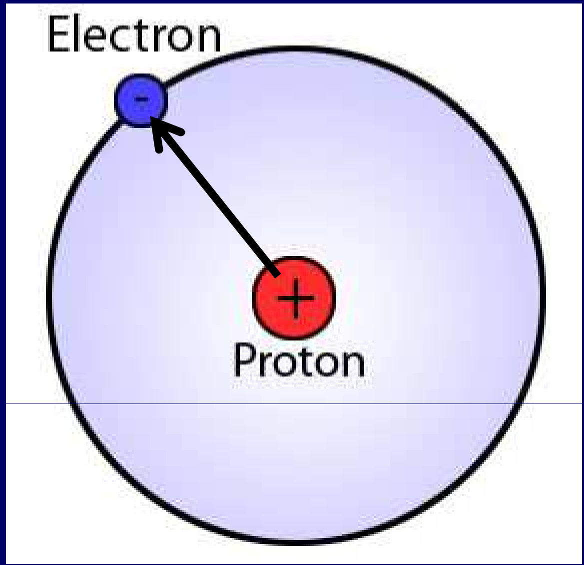


Conclusão: núcleo com carga + muito pequeno e pesado



elétrons girando em volta

Problema: átomo instável



Dipolo que oscila:
irradia – perde energia – colapsa no núcleo

Mecânica Quântica Light

Dualidade Onda-Partícula

Elementos de Mecânica Clássica

Newton: $a = \dfrac{\Delta V}{\Delta t}$ $\quad F = ma$

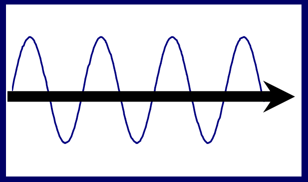
Momento: $p = mV$

$$F = \frac{\Delta p}{\Delta t}$$

Einstein e os fótons

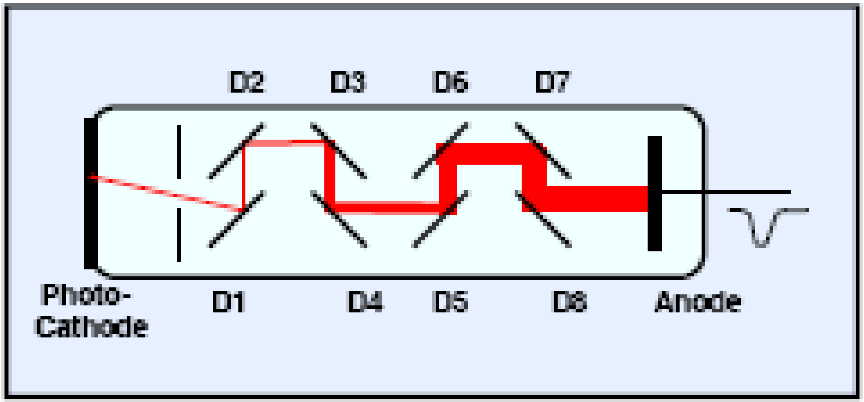
Efeito fotoelétrico: luz é partícula e onda

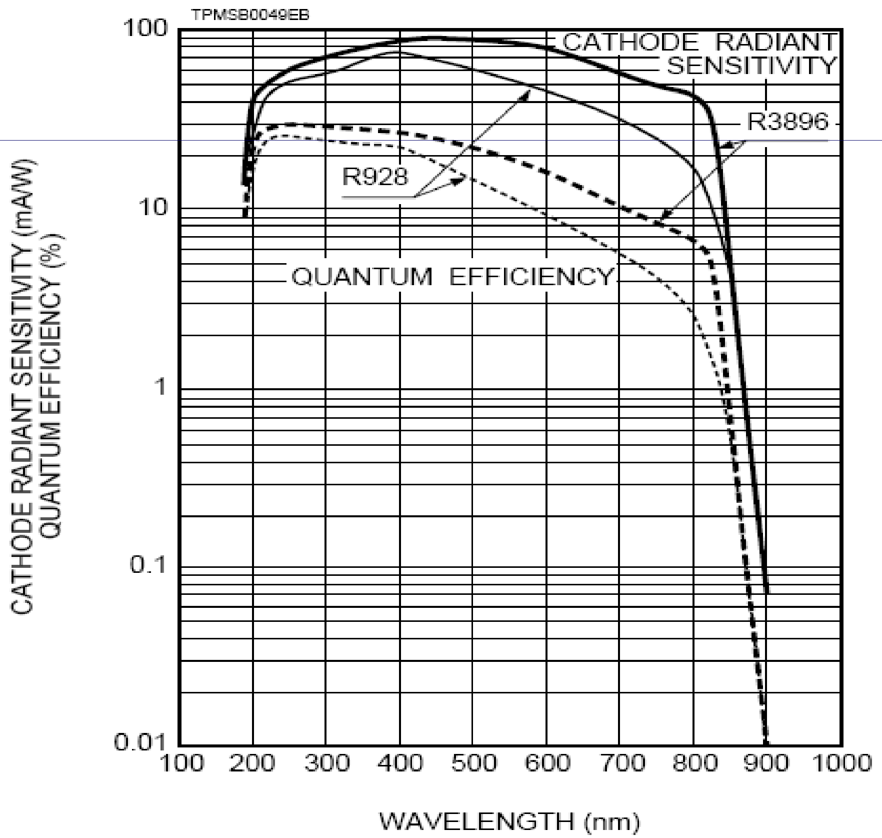
$$p_{foton} = \hbar k = \frac{h}{\lambda}$$



Gilberto Lewis [ácidos e bases]
Criou o termo fóton [foto-grafia]

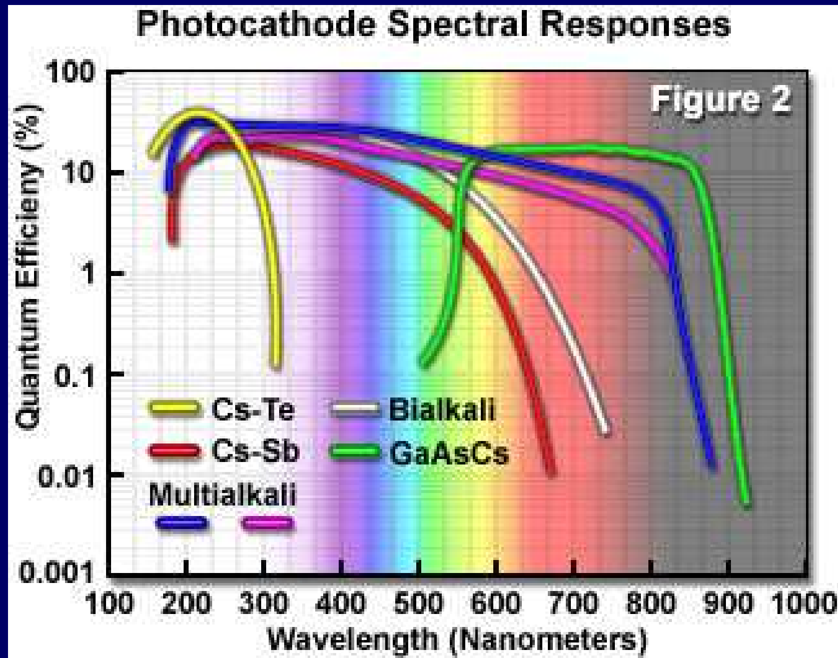
PMT: Photomultiplier Tube





Ruído:
emissão termoiônica

APD: Avalanche photodiode

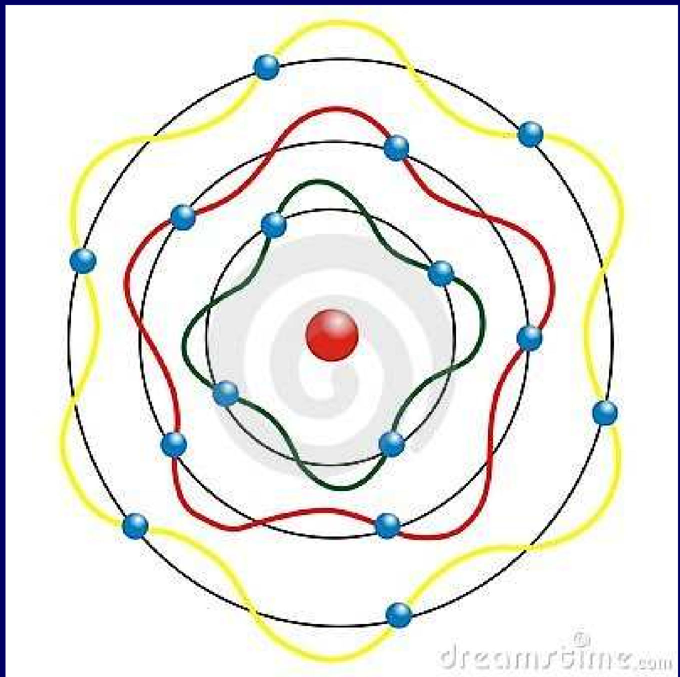


Einstein e a energia mecânica do Fóton: $E_{foton} = \hbar\omega$

Solução de Bohr para instabilidade atômica

Elétrons também são partículas e ondas: $mV = \dfrac{h}{\lambda}$

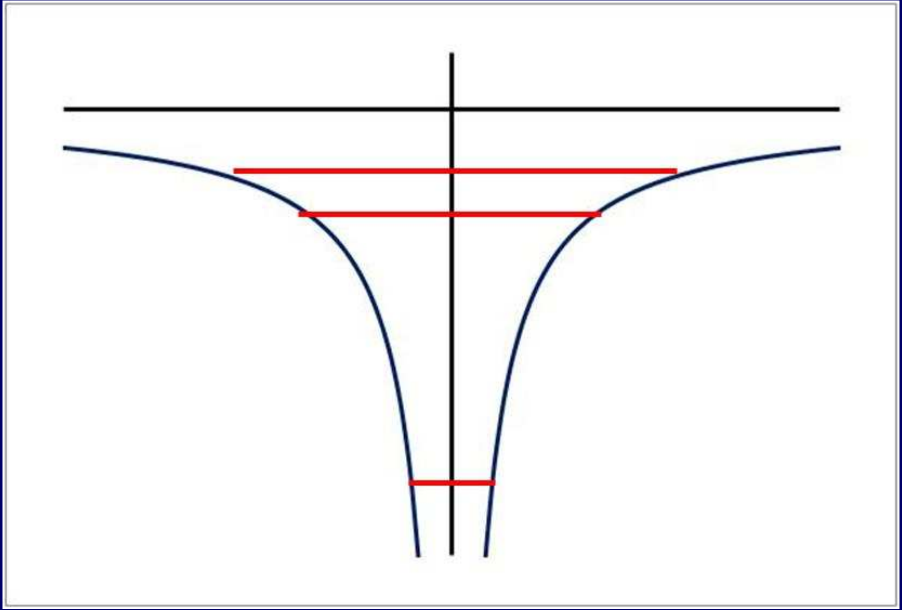
Átomo não irradia em órbitas com múltiplos de λ



Transição de uma órbita à outra emitindo ou absorvendo fótons com energia

$$\hbar\omega = E_2 - E_1$$

Modelo de Bohr para o átomo de hidrogênio
Órbitas quantizadas

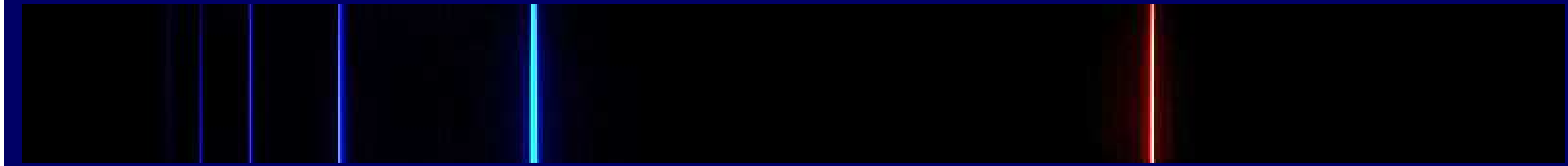


$$E_n = \frac{13.6}{n^2} eV$$

$$\lambda[nm] = \frac{1240}{E[eV]}$$

Nível final = 1	Nível inicial	Energia [eV]	λ [nm]	λ [nm] observado
Lyman-α	2	10,20	121,52	121,567
Lyman-β	3	12,09	102,517	102,518
Lyman-γ	4	12,75	97,202	97,202
ionizado		13,6	91,1265	91,1267

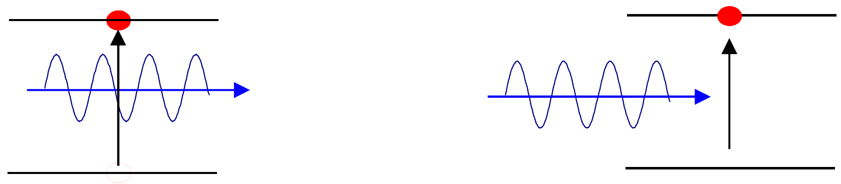
Nível final = 2	Nível inicial	Energia [eV]	λ [nm]	λ [nm] observado
H-α	3	1,889	656,11	656,3 vermelho
H-β	4	2,551	486,00	486,1 azul
H-γ	5	2,857	433,94	434,1 violeta
ionizado		3,401	364,51	364,6 ultravioleta



Linhas de emissão do hidrogênio

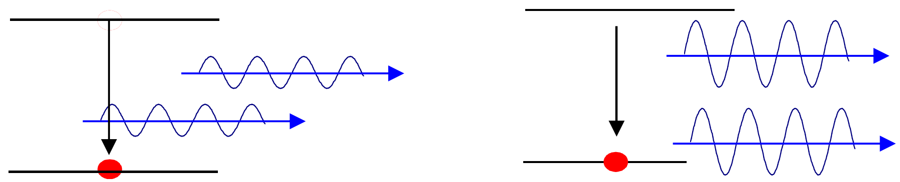
Absorção, Emissão Espontânea e Estimulada

Absorção:



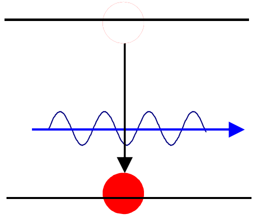
Emissão espontânea:

Emissão estimulada:



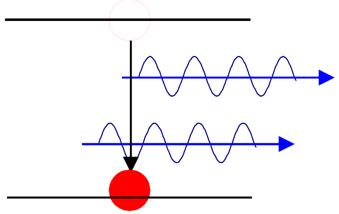
Amplificando a luz

1



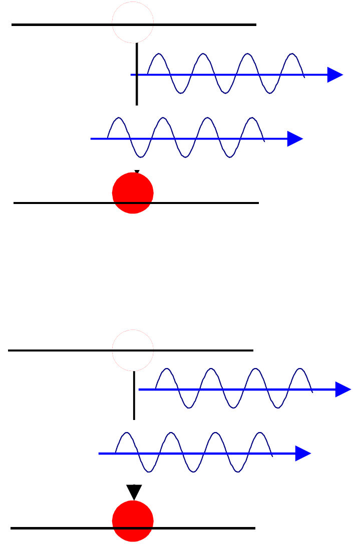
Emissão
espontânea

2

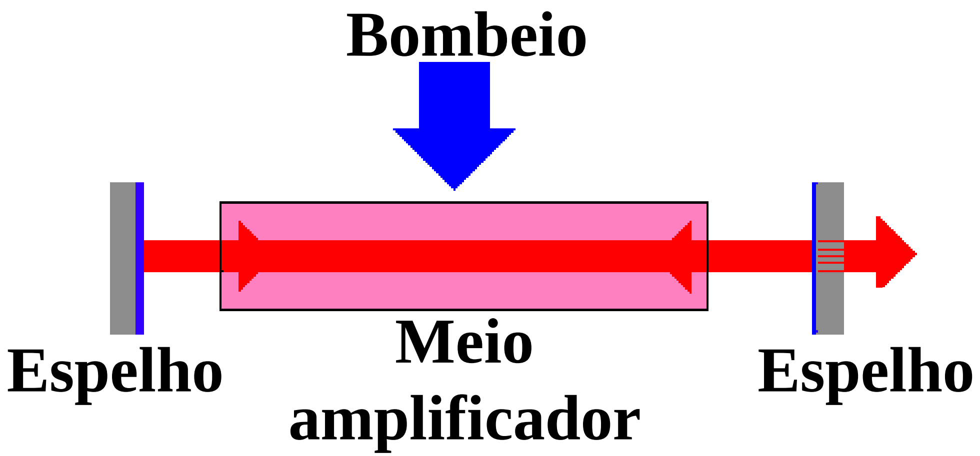


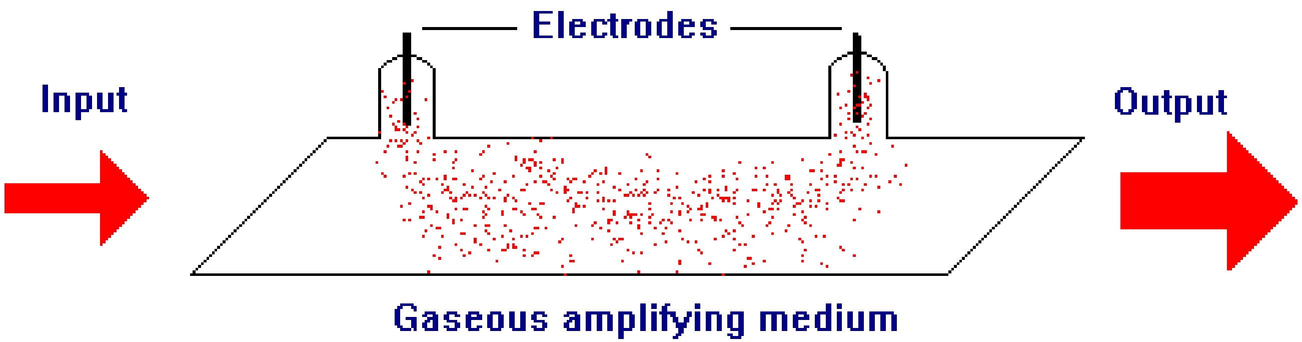
Emissão
estimulada

4



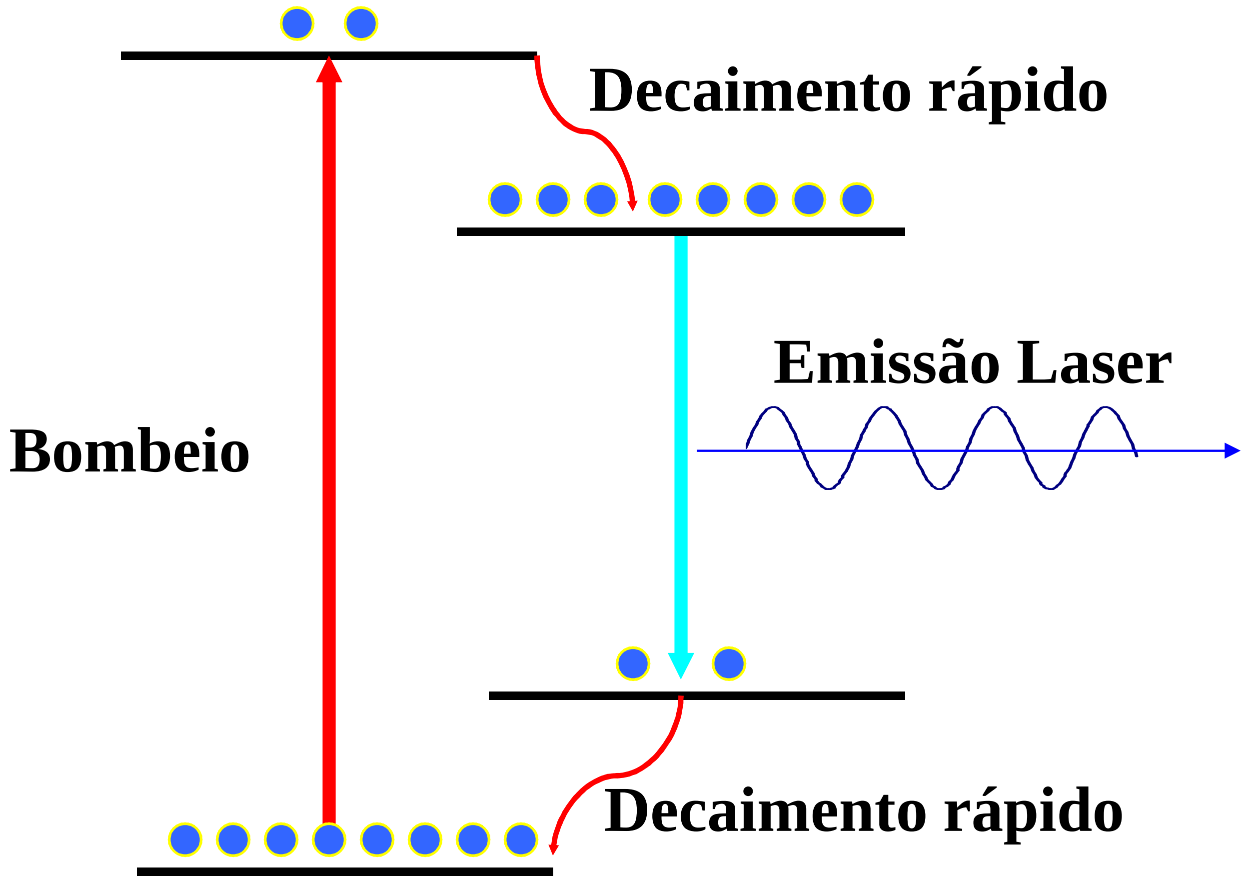
Laser: Light Amplification by Stimulated Emission Radiation



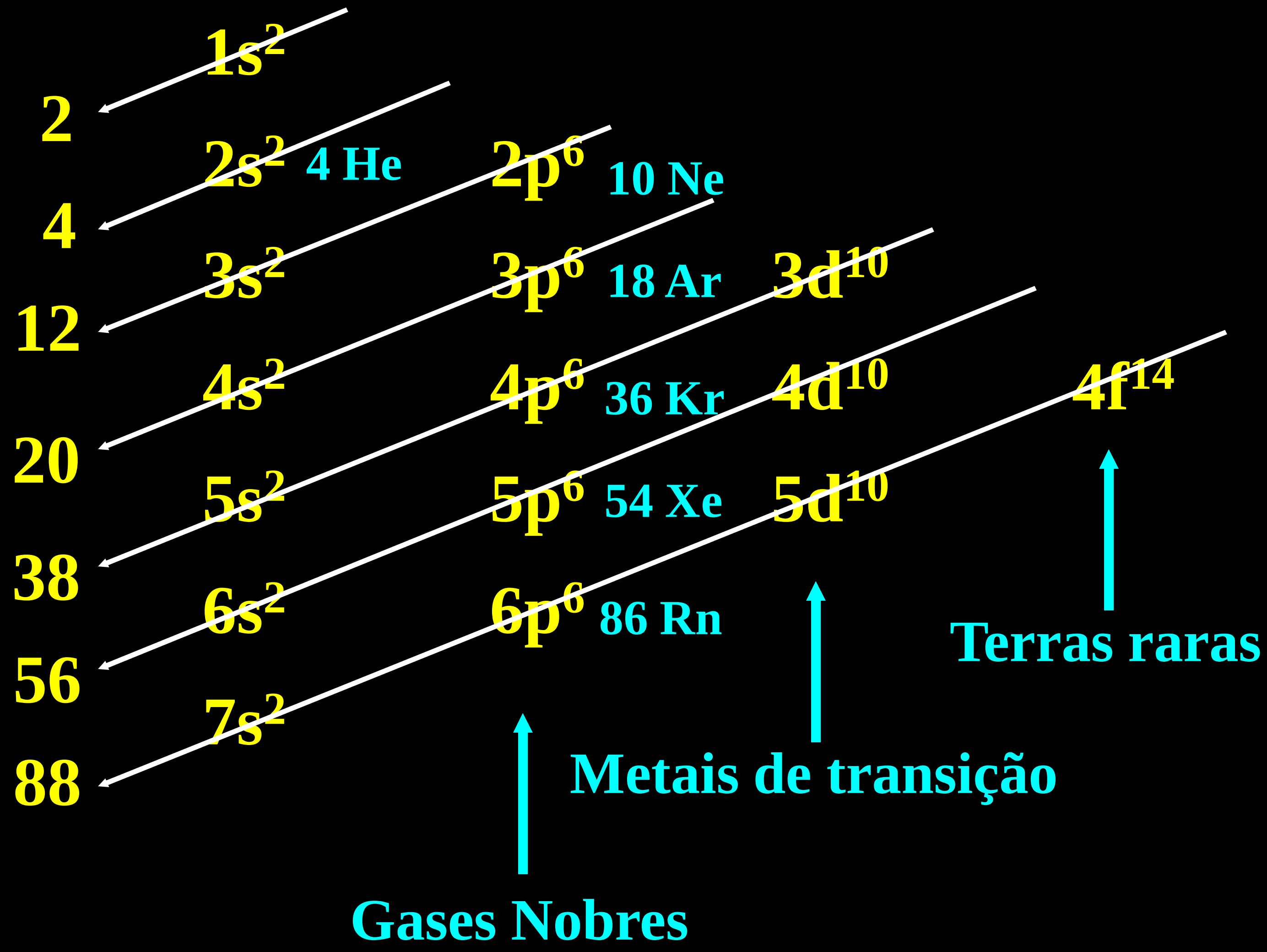


Luz coerente no tempo e no espaço

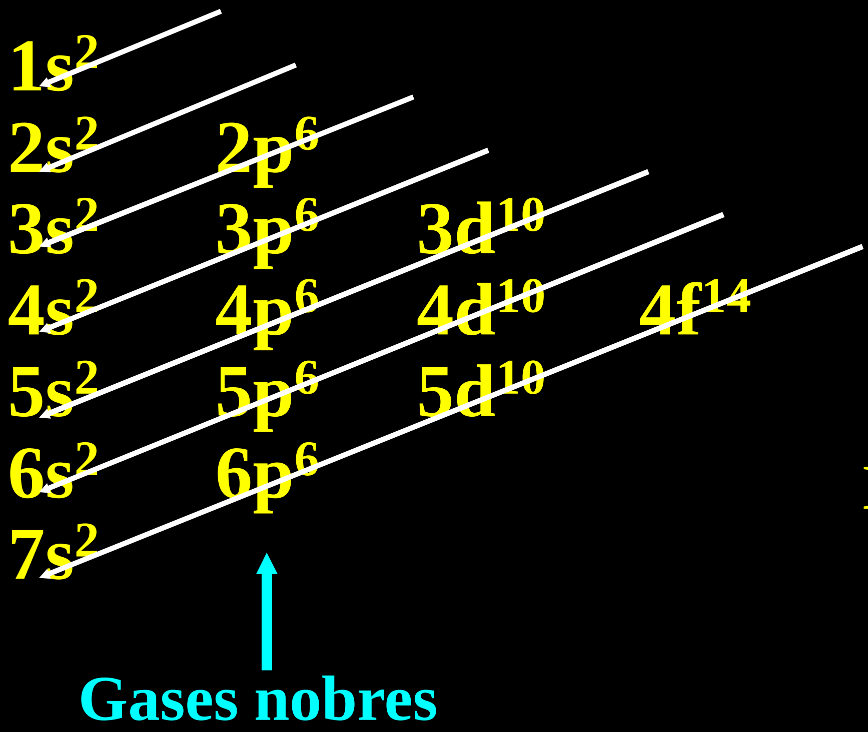
Inversão de população em Sistema de 4 níveis



Átomos e Lasers



Lasers a gás – íons gases nobres



Laser de Argônio Ar^+

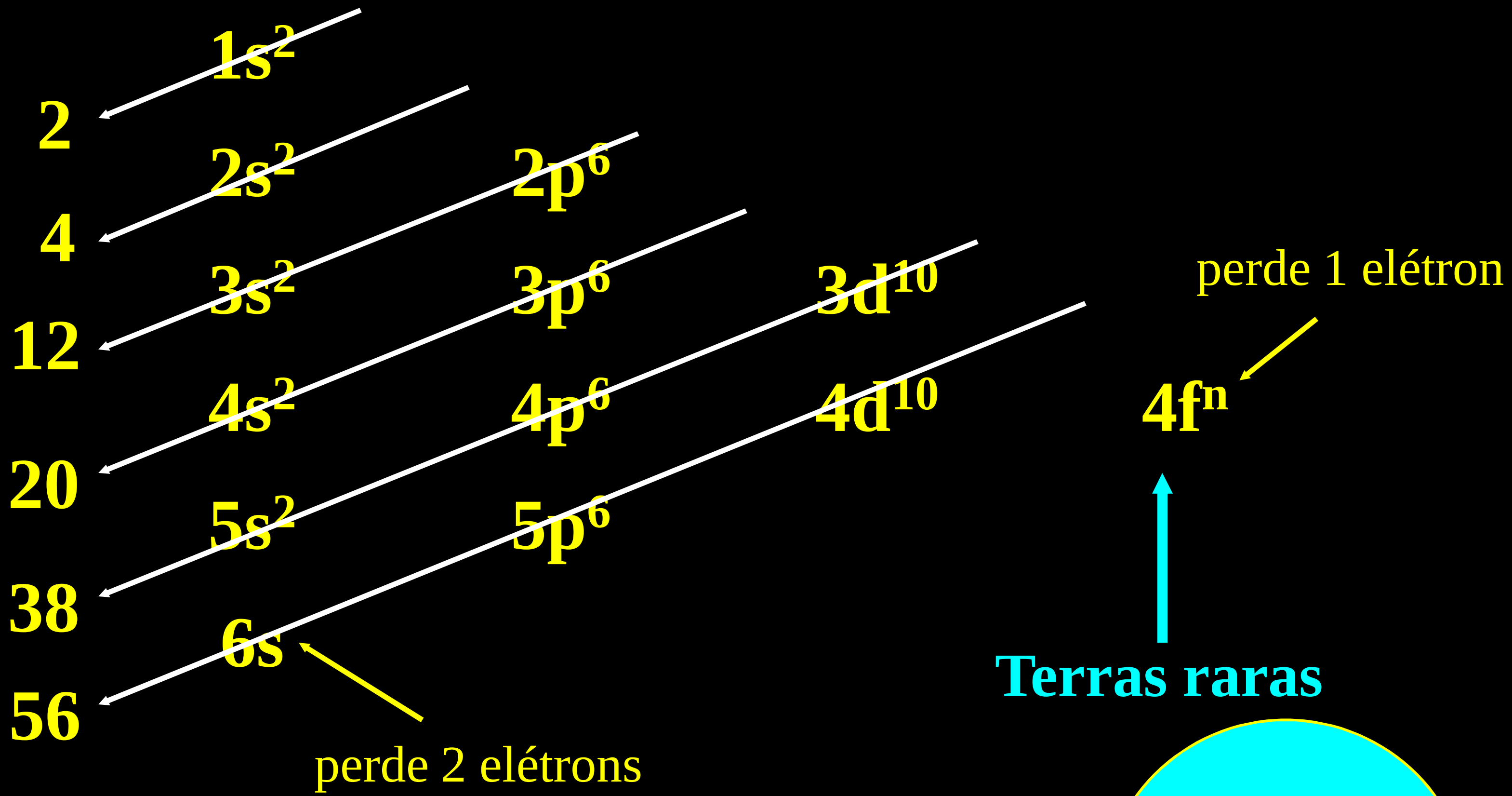
Bombeio – descarga alta tensão

Alta potência até 30 W

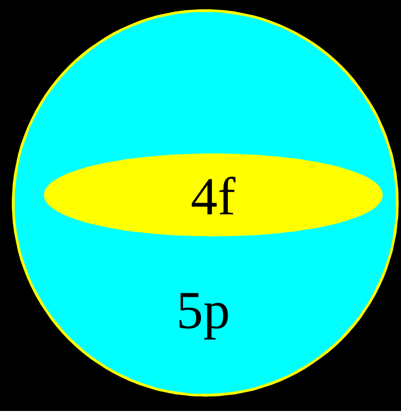
Linhas principais: 514 e 488 nm

Laser de Hélio-Neônio
Bombeio – descarga alta tensão
Baixa potência – 0,5 a 10 mW
Linha principal: 633 nm

Lasers de Terras Raras
íons trivalentes



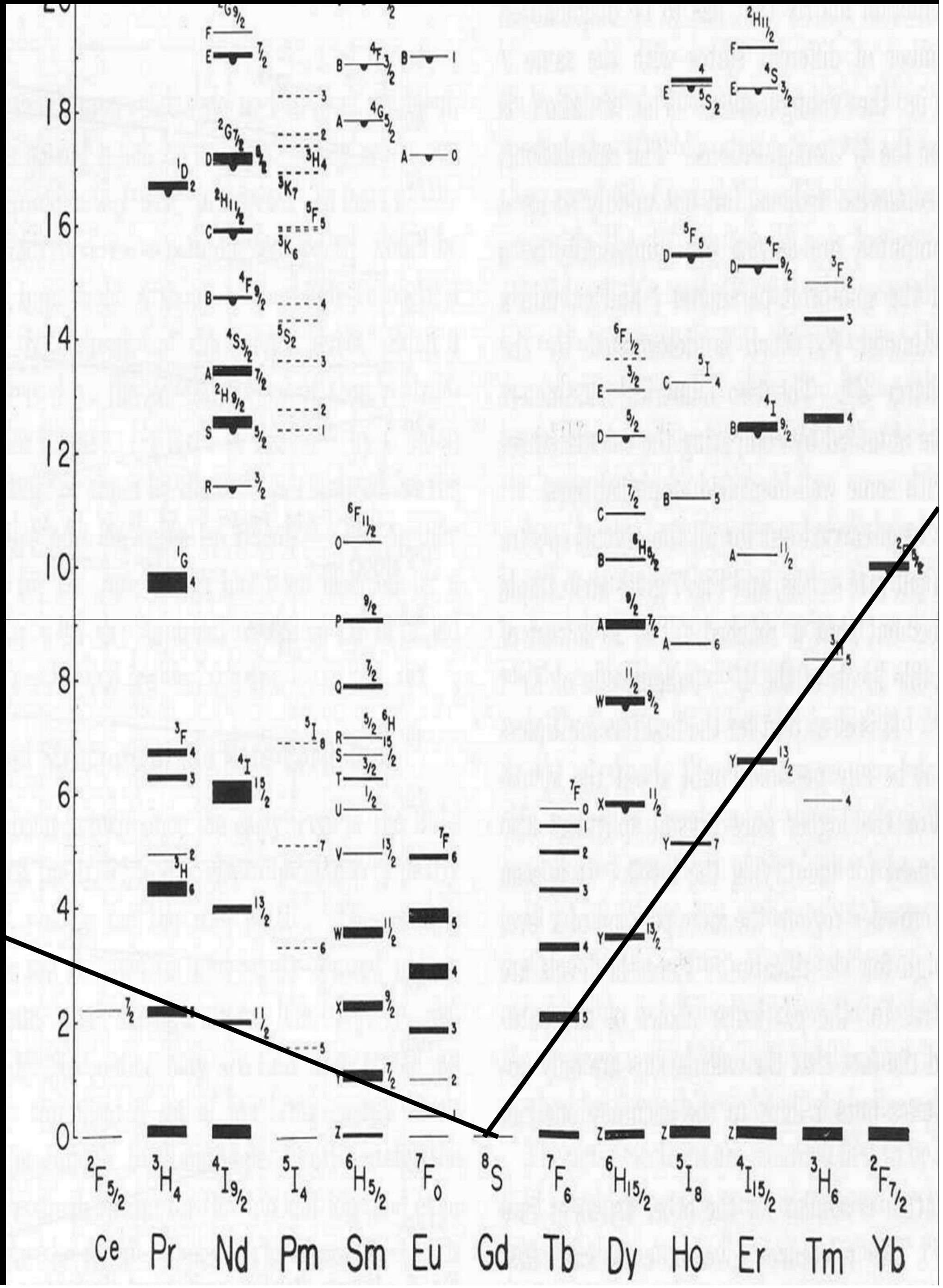
Orbitais 5p mais espalhados que os 4f
Blindagem elétrica –
níveis se mantêm em qualquer hospedeiro



Níveis de Energia dos Íons^{3+} dos Lantanídios

dopagem/codopagem cobre espectro do UV até 3000 nm

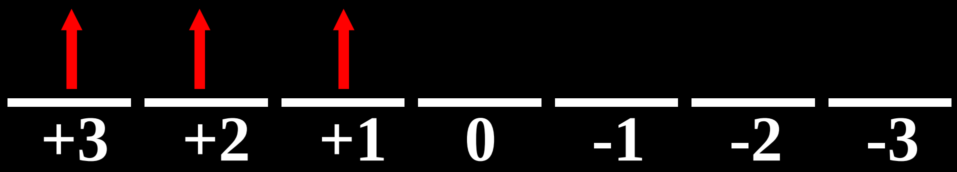
Perspectiva: lasers de fibra alta potência sintonizável pulso curto



Íons Terras Raras trivalentes: Nd^{3+}

Notação espectroscópica: $^{2s+1}L_j$

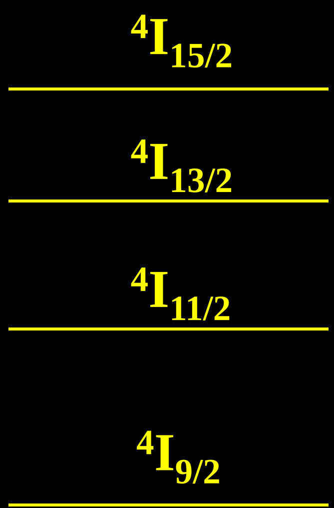
$L =$	0	1	2	3	4	5	6	7
	S	P	D	F	G	H	I	J



3 elétrons f

$L = 3+2+1= 6;\quad S=3/2$

$J_{min}= 6-3/2= 9/2\ J_{max}= 6+3/2= 15/2$



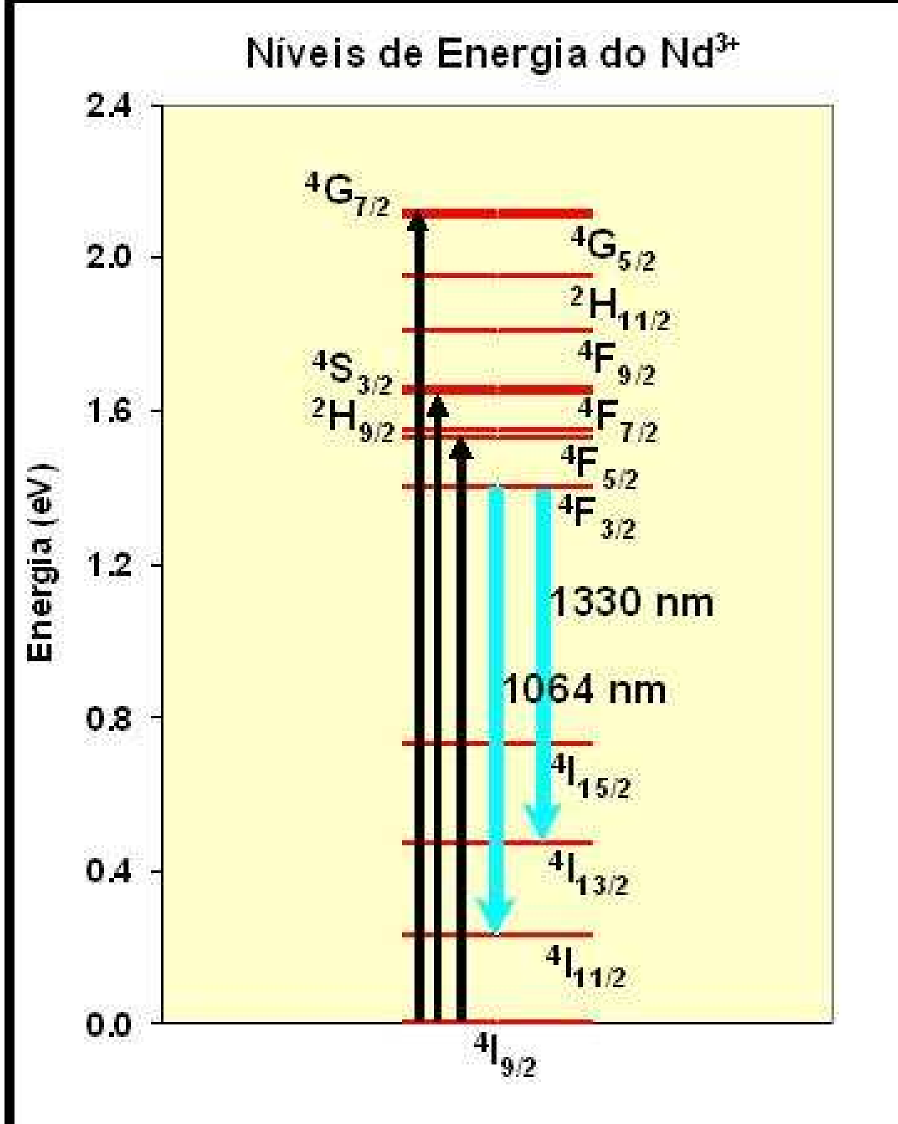
Nd:YAG (Ytrium-Aluminum-Garnet)

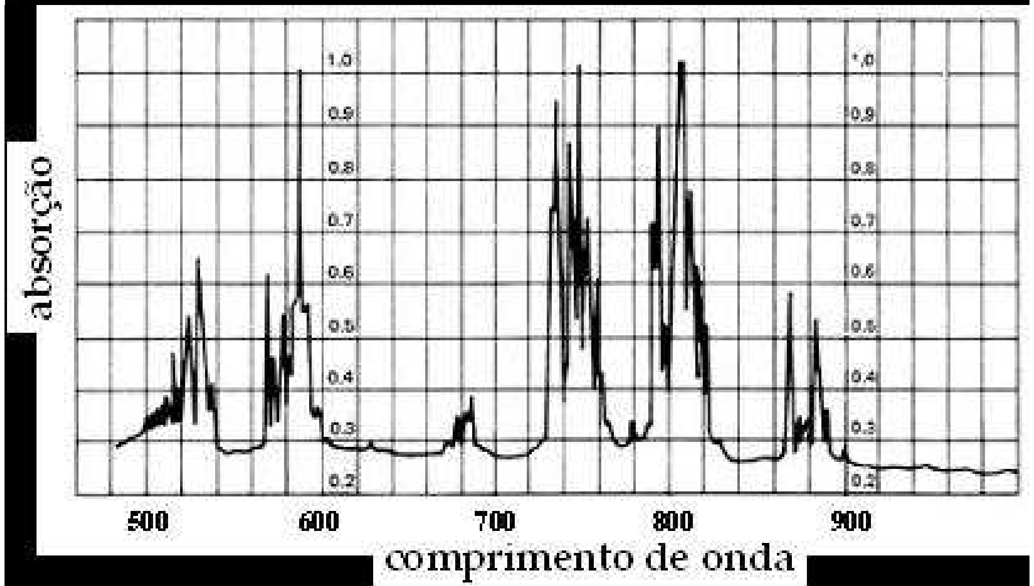
Nd:Vidro

Nd:YLF

Bombeio: lâmpada ou LEDs

Menor dano fototérmico


Níveis de Energia do Nd3+
Energia (eV)
2.4
2.0
1.6
1.2
0.8
0.4
0.0
4G7/2
4G5/2
2H11/2
4S3/2
4F9/2
2H9/2
4F7/2
4F5/2
4F3/2
1330 nm
1064 nm
4I15/2
4I13/2
4I11/2
4I9/2


absorção
500
600
700
800
900
comprimento de onda

Ti^{3+} substitui Al^{3+} na safira Al_2O_3

$1s^2$

$2s^2$ $2p^6$

$3s^2$ $3p^6$ $3d^2$

$4s^2$

perde 1 elétron

perde 2 elétrons

Metal de transição

+2 +1 0 -1 -2

1 elétron d

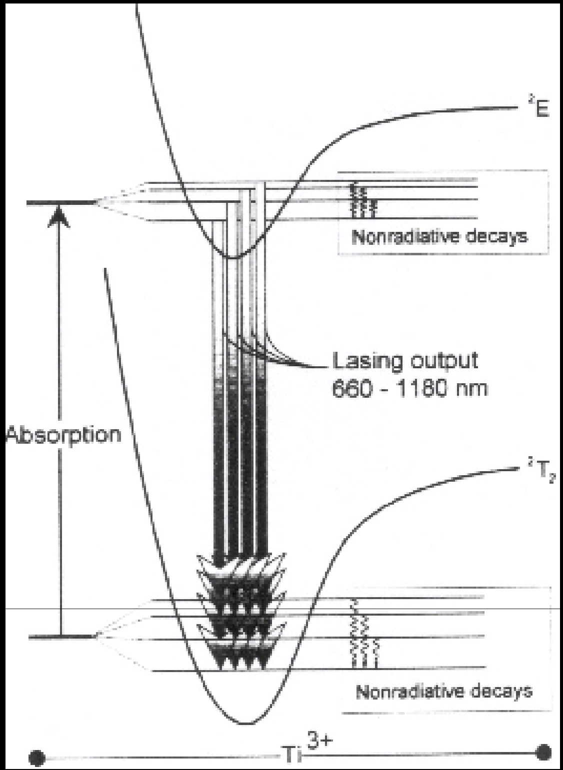
L = 2; S=1/2

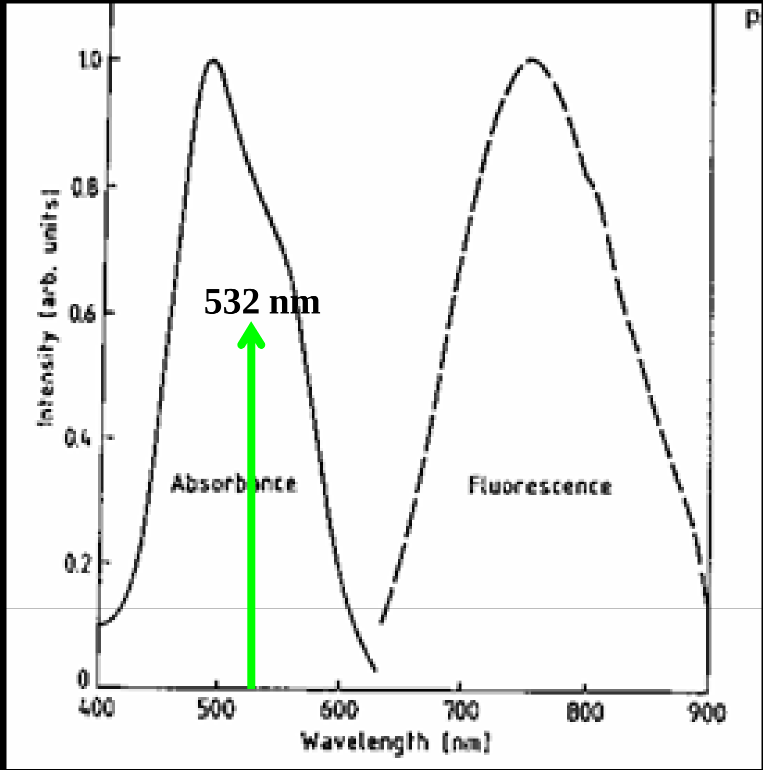
J_{min}= 2-1/2= 3/2 J_{max}= 2+1/2= 5/2

Ground state: $^2d_{3/2}$ $^2T_2$

Excited State: $^2d_{5/2}$ ^2E

Laser de Ti:safira





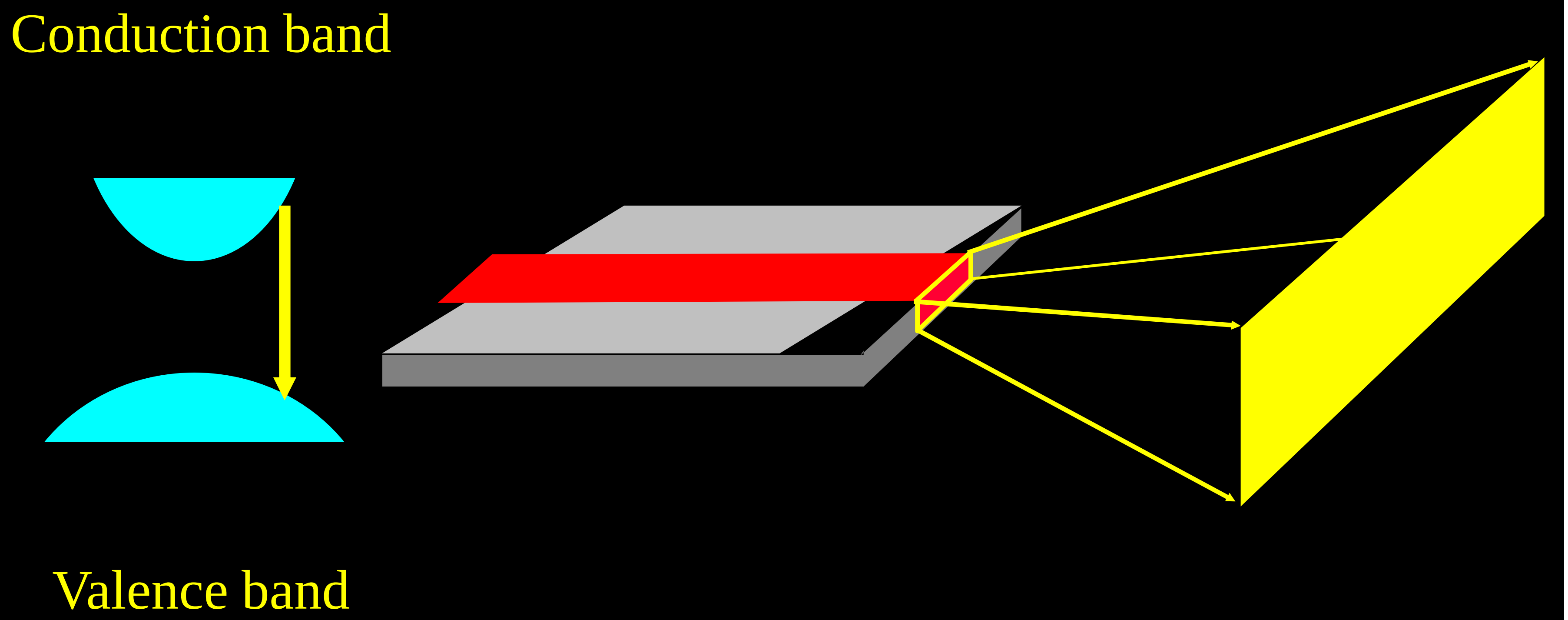
Laser bombeio DPSSL → Laser Ti:safira →

Safira é excelente condutor térmico

Laser de alta potência até 3 W sintonizável de 680 - 1100 nm

Laser Ti:Safira substituiu lasers de corante

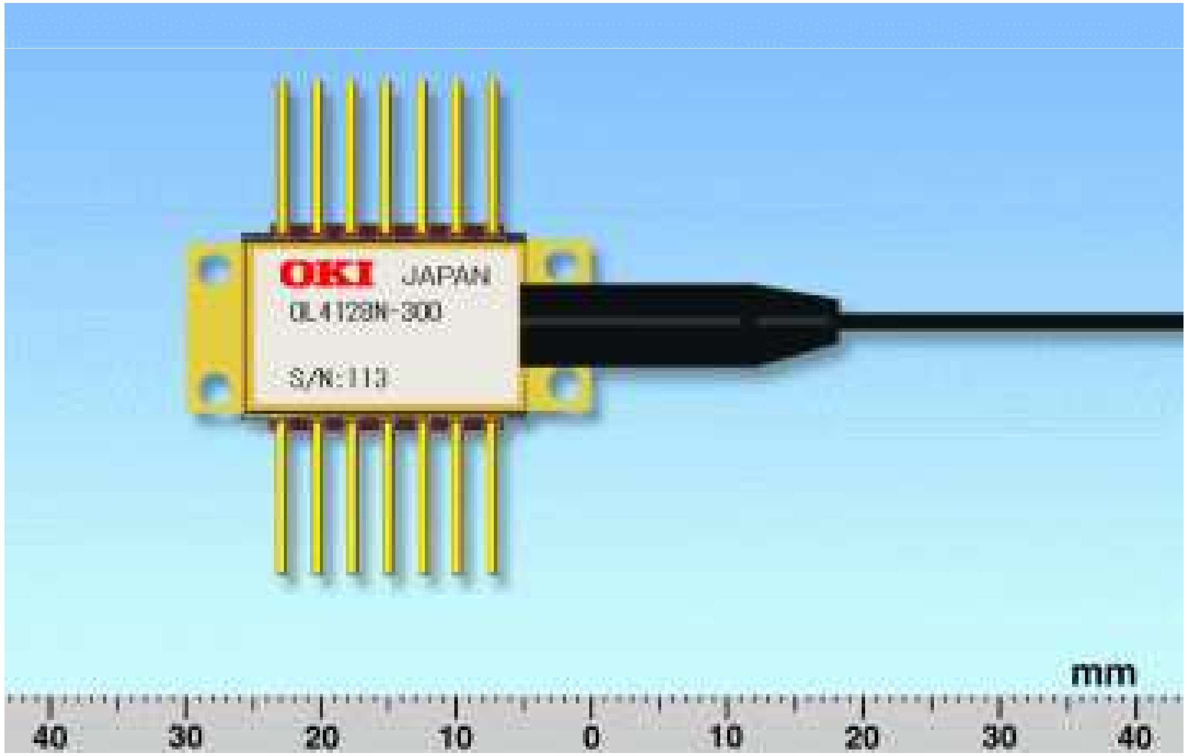
Semiconductor Diode Lasers



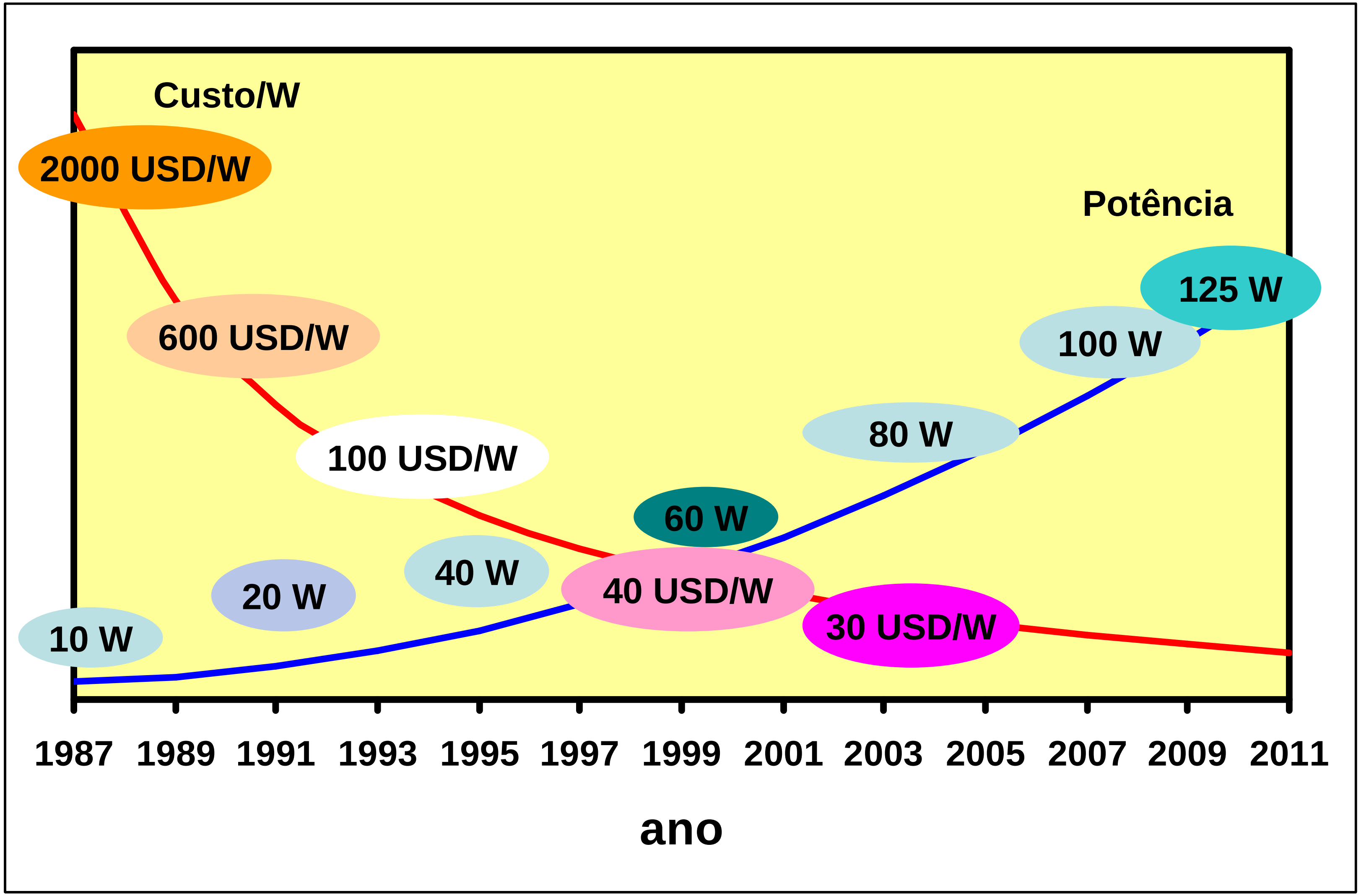
Low power mW & retangular mode
weak trapping

Revolução Lasers de diodo 1990s

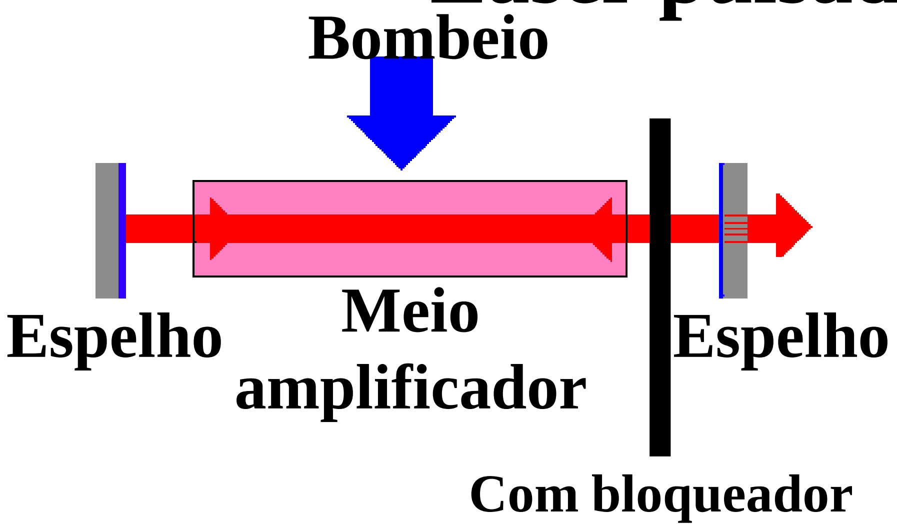
- Laser de diodo: 733 milhões unidades vendidas em 2004. Outros lasers – 131 mil unidades vendidas
- Eficiência de conversão – 71% luz direto da tomada
- Alta potência até 10 kW cw
- Tempo de vida > 100.000 horas
- Diode arrays – potência ilimitada

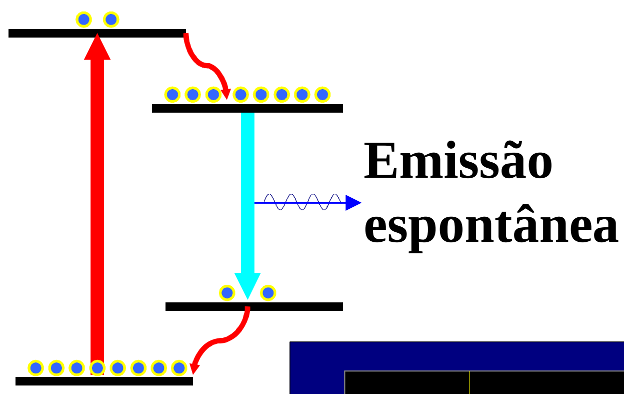


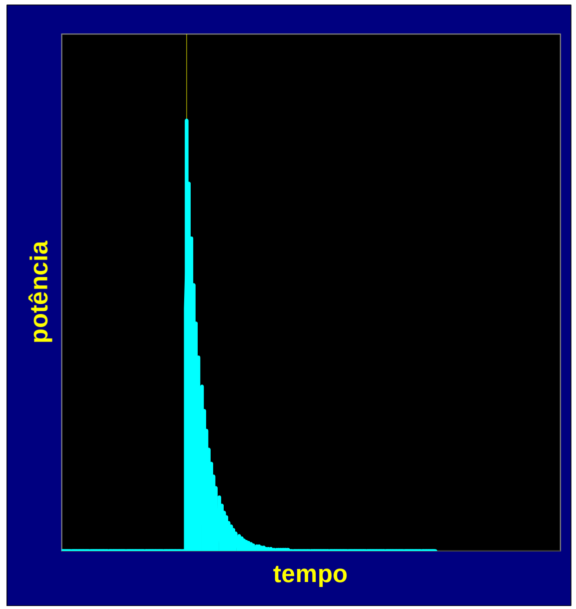
Padronização similar a microeletrônica?

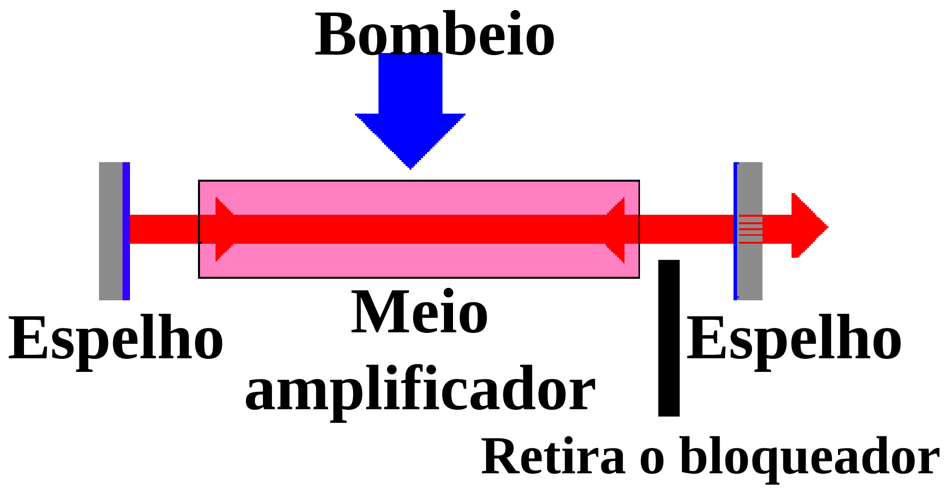


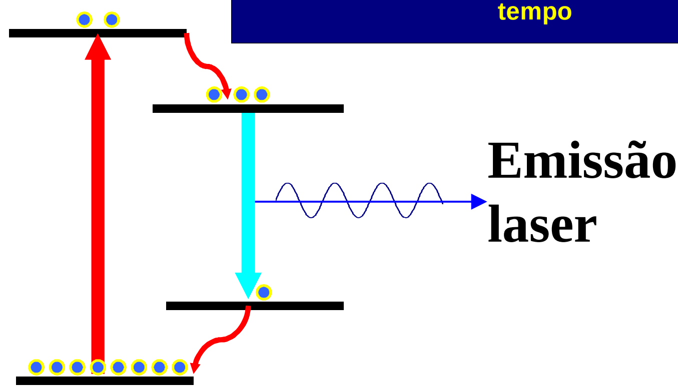
Laser pulsado: Q-switched





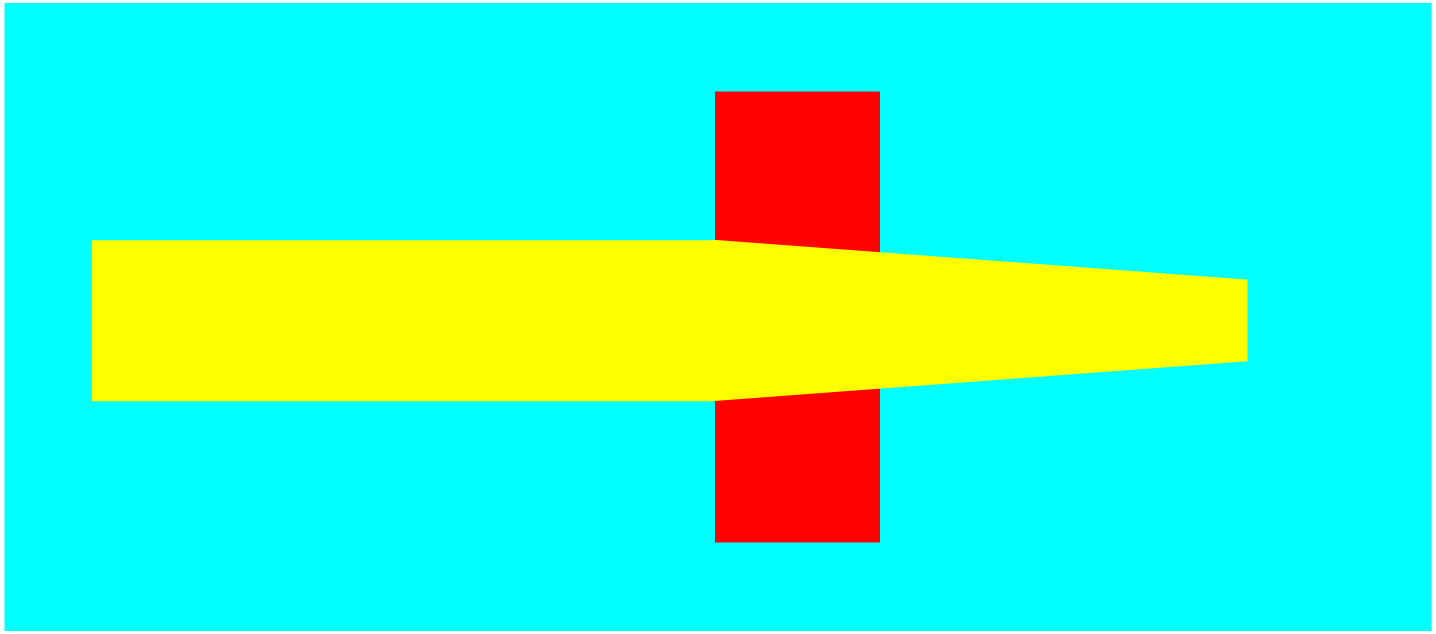






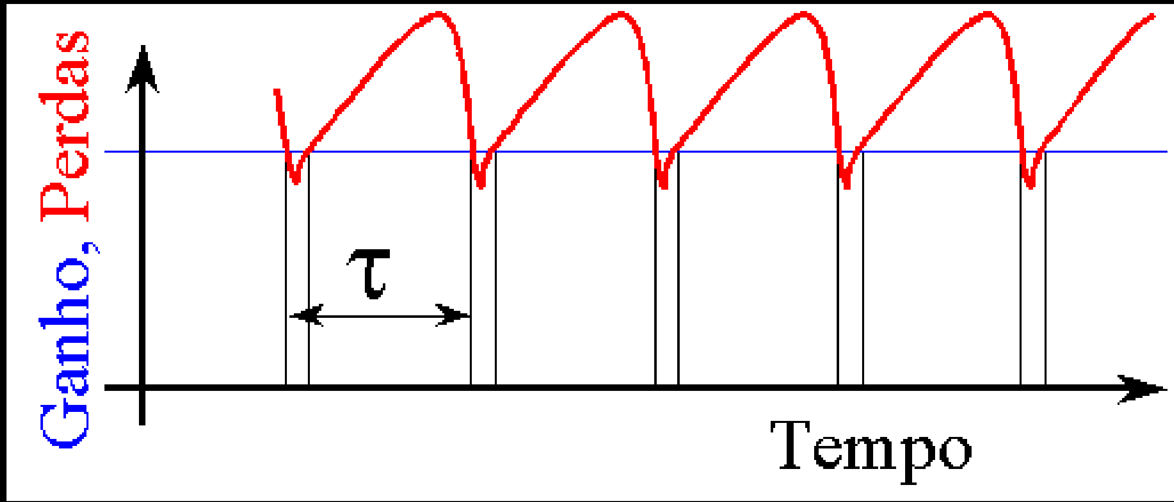
Interação com a matéria
autofocalização

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

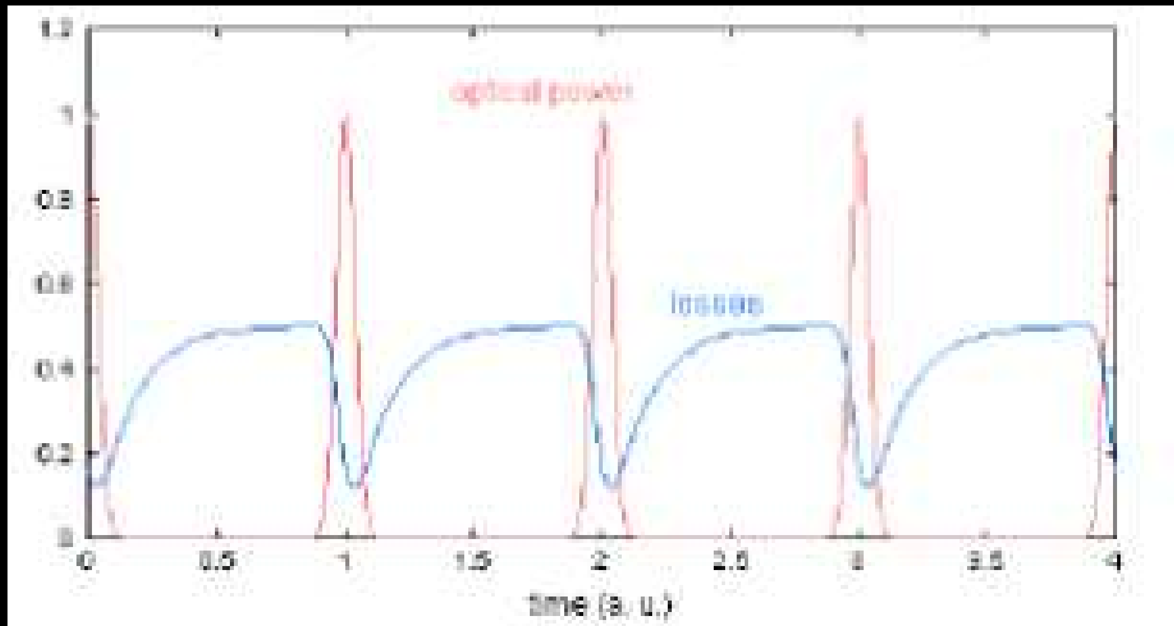


Mode-locking do Ti:safira

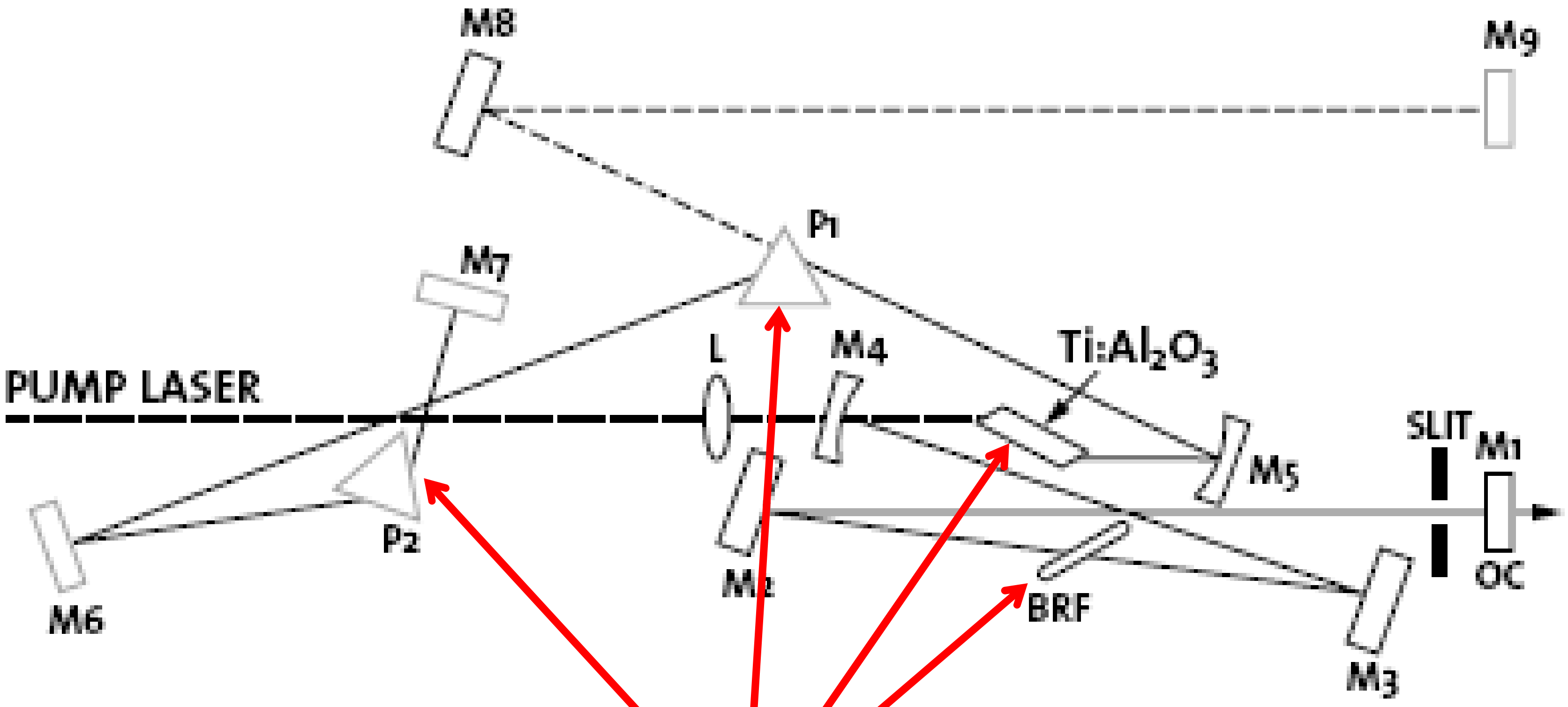
Laser pulsado: Mode-locking



Duração do pulso e round trip time: rep rate



Mira Optima 900-F / Mira 900-S



Ângulo de Brewster

Multiphoton Microscopy

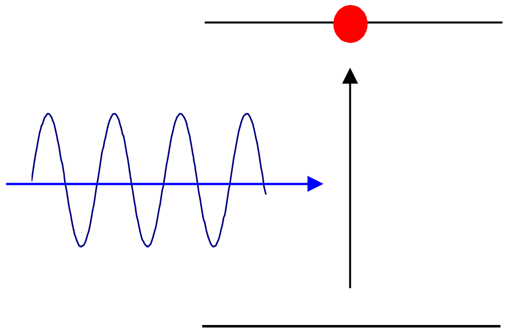
Watt W. Webb – WWW
Physicist – Cornell

http://www.drbio.cornell.edu/personnel/webb.html

More than one photon processes

Linear Optics

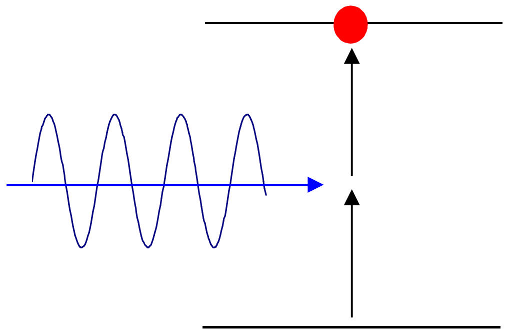
$$p \rightarrow e \qquad V \propto [p] = I$$



$$I = \frac{power}{area}$$

Non Linear Optics

$$p + p + \cdots + p \rightarrow e$$

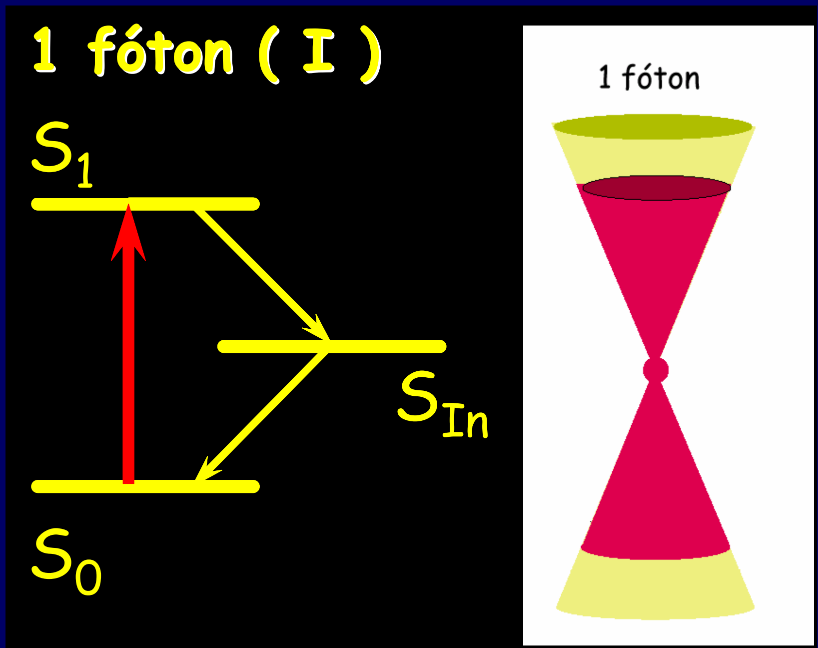


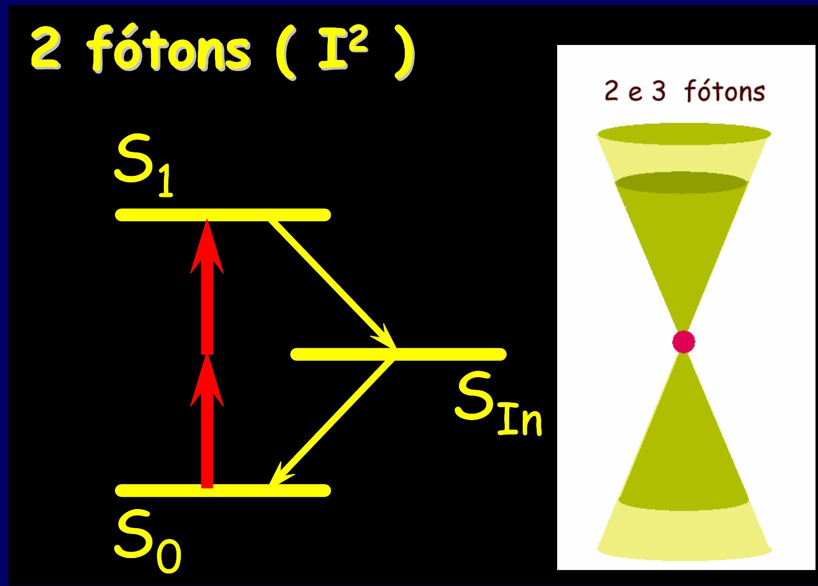
$$V \propto [p]^n = I^n$$

Confocality of NLO Non linear Optics

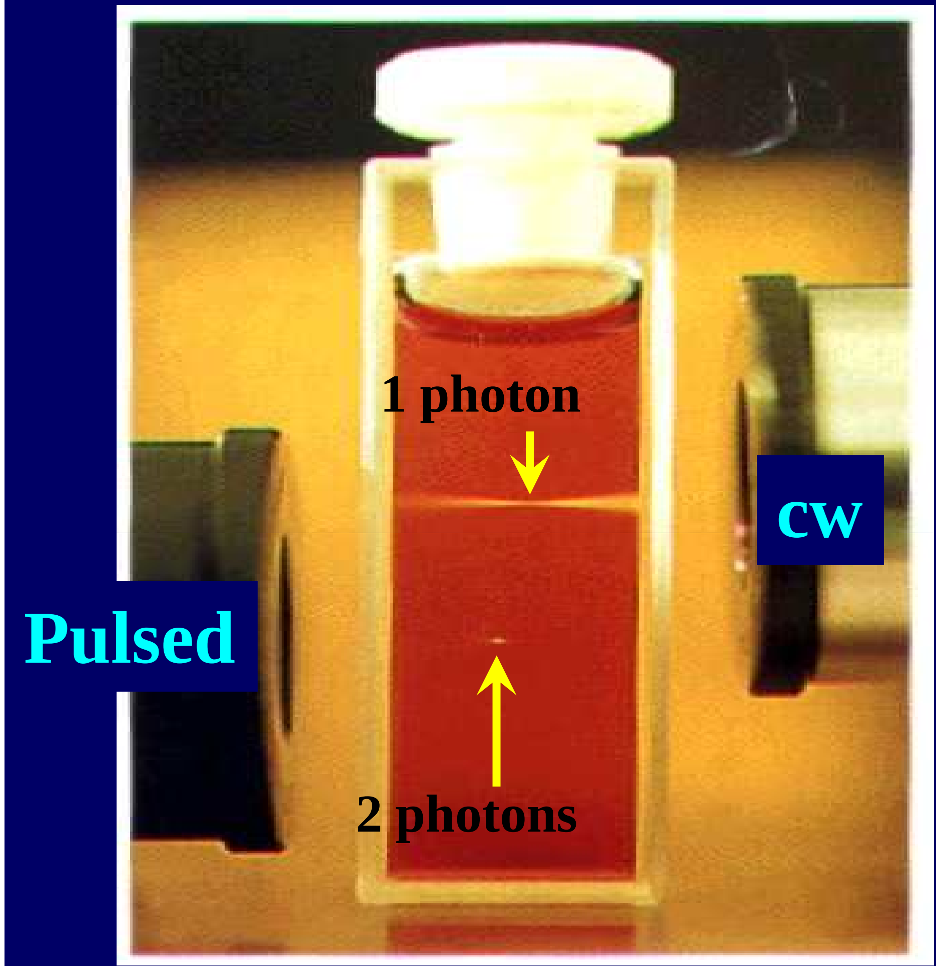
$$N_{events} \propto I \times area = \frac{power}{area} \times area$$

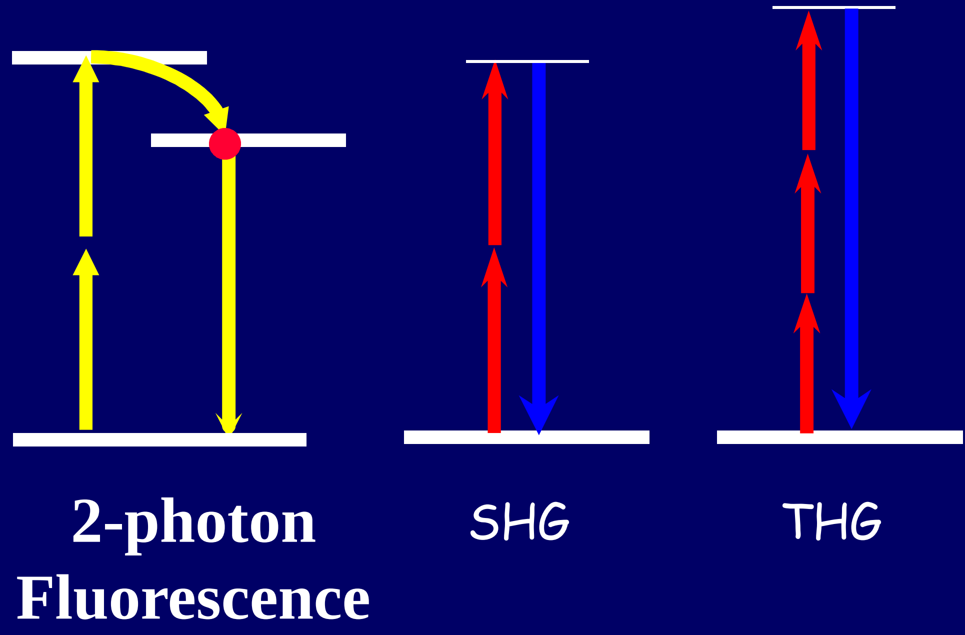
$$N_{eventos} \propto I^{2} \times area = \frac{power^{2}}{area}$$

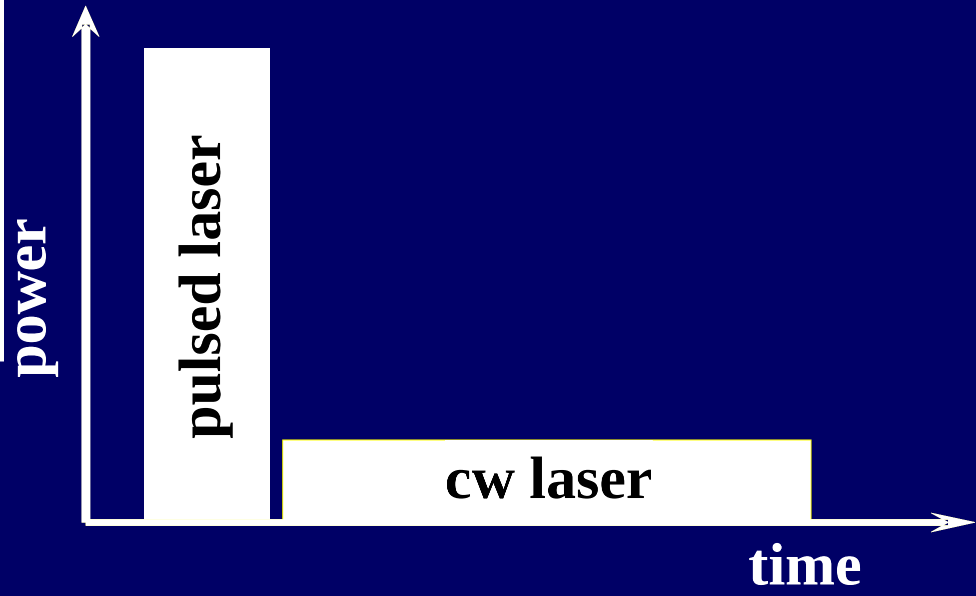




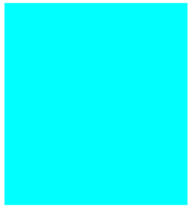
Multiphoton – spatial localization

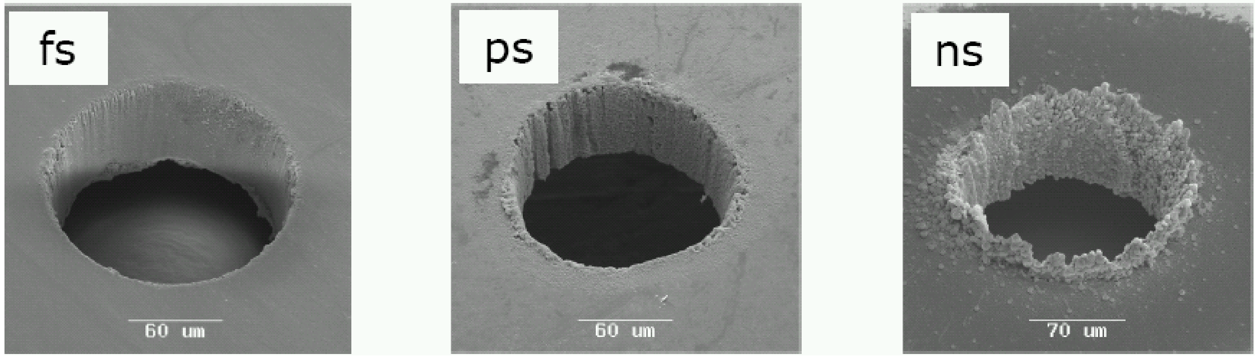


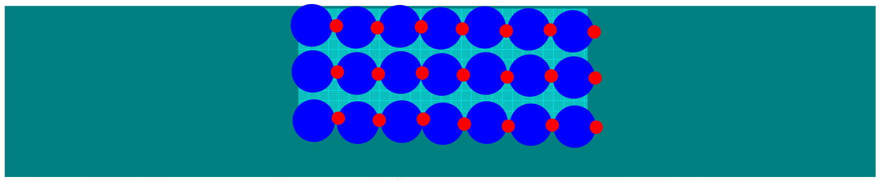


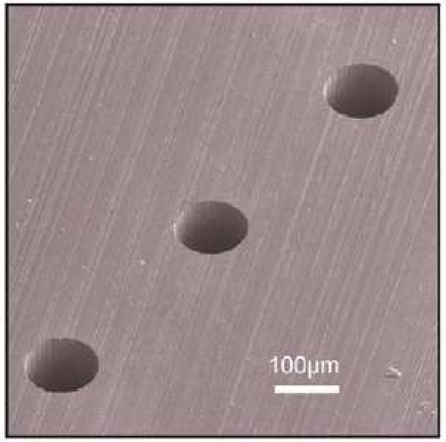


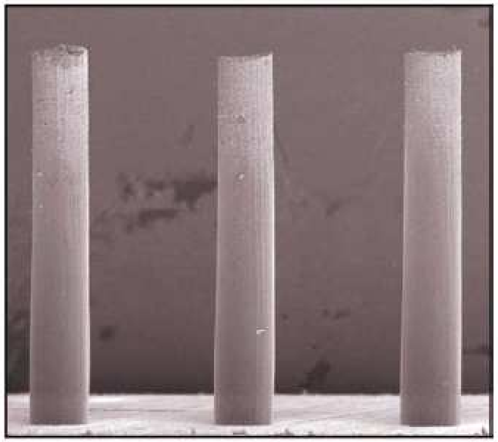
Revolução Lasers de femtossegundos 2000s:











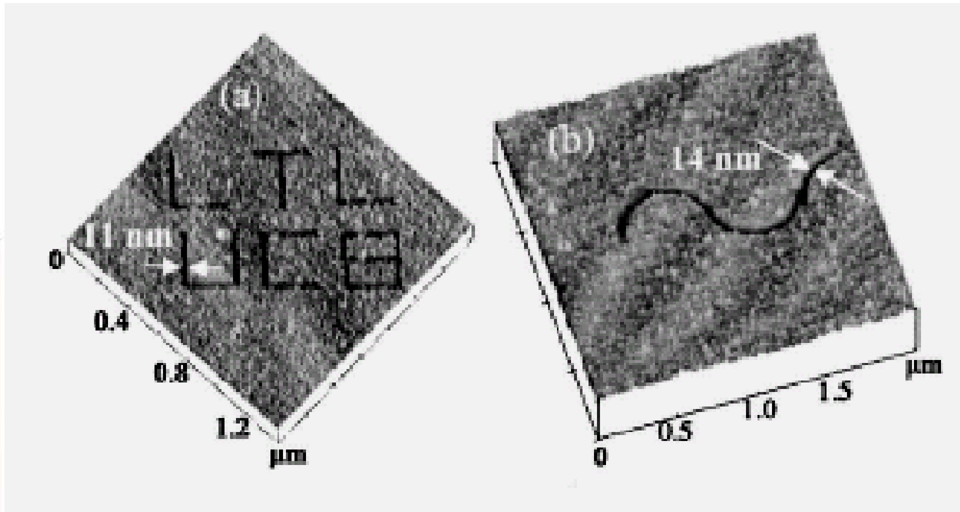
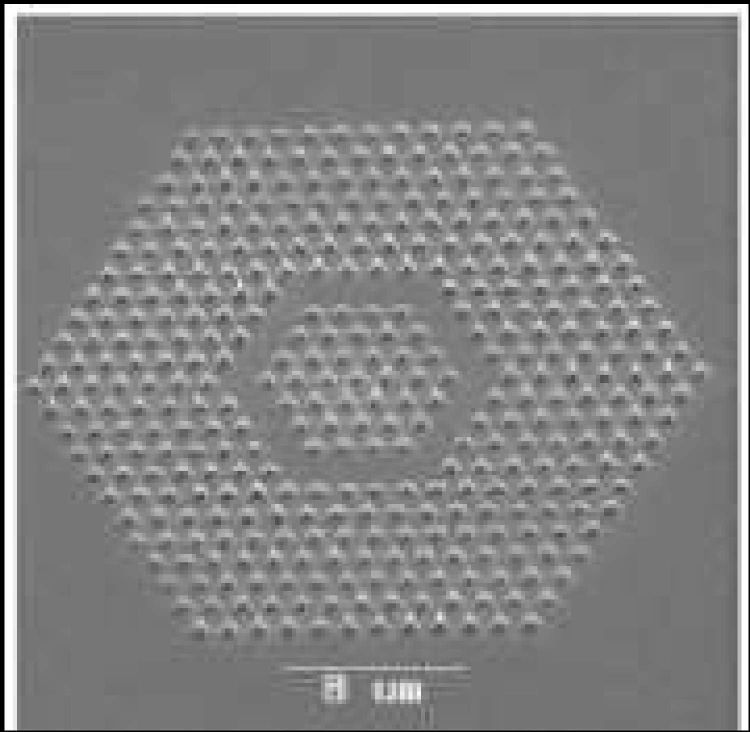
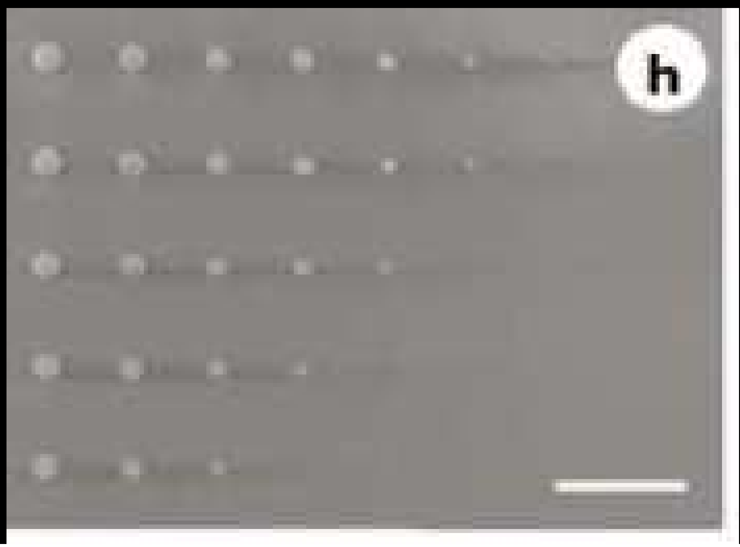


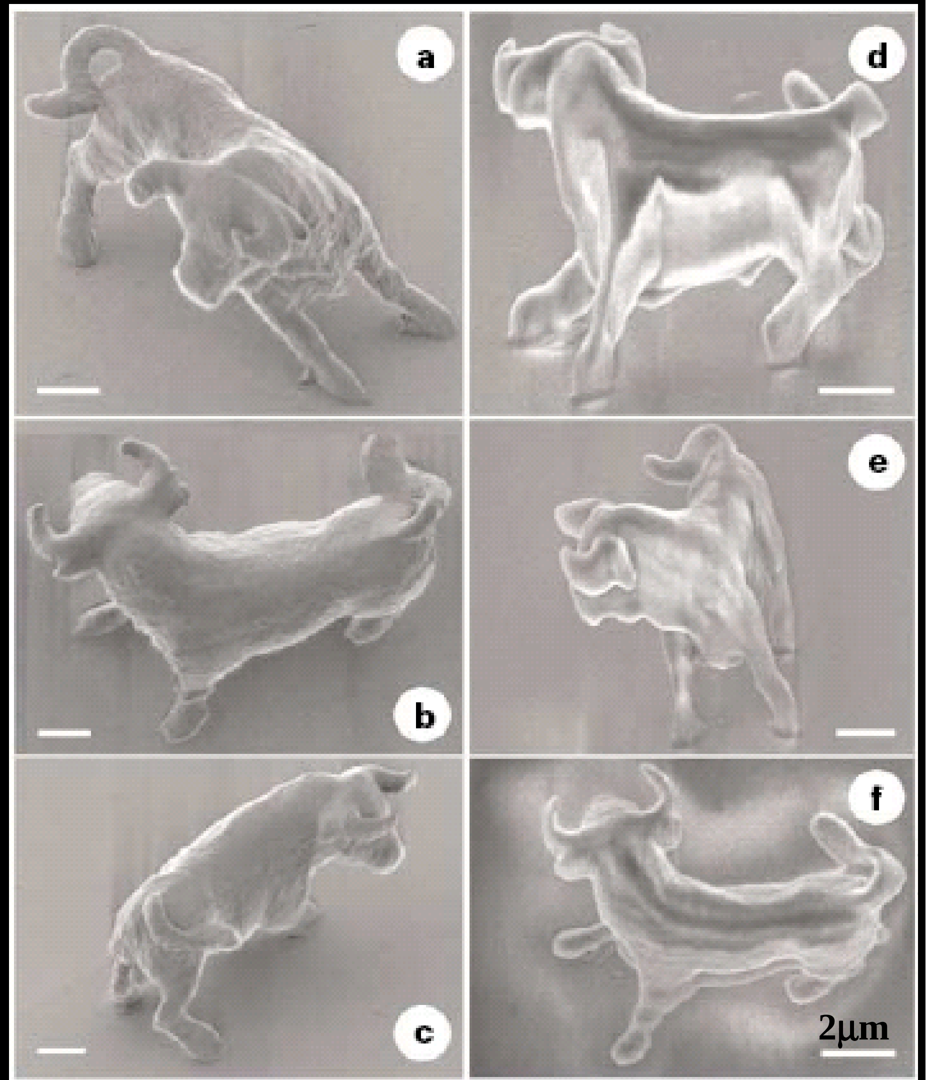
FIGURE 1 Scanning electron microscope image of holes drilled in a 1 mm thick stainless steel plate by femtosecond laser pulses and their replicas

Femtosecond sculpturing

S. Kawata et al: NATURE 412, 697 (2001)





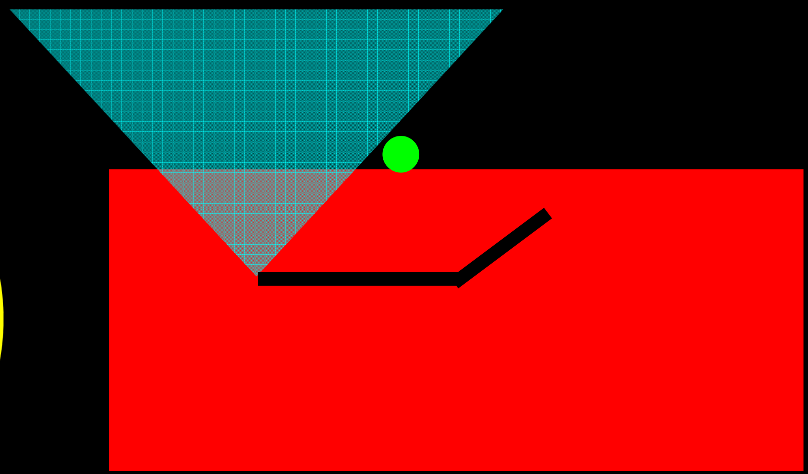


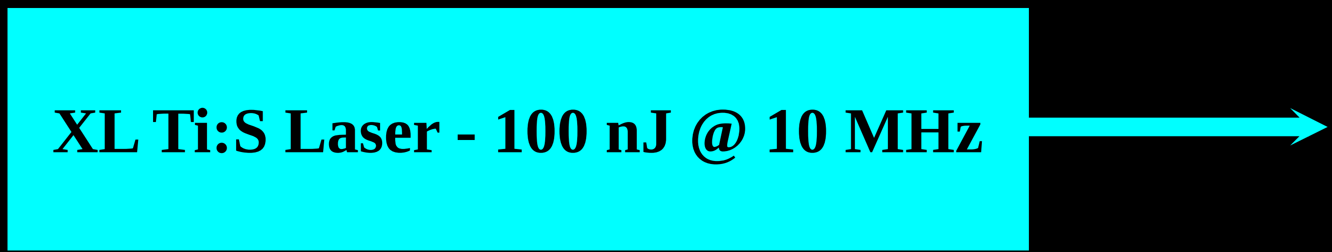
Ti:S 76 MHz, 780 nm, 150 fs. Objective NA 1.4.
a–c: Bull sculpture by raster scanning - 180 min.
d–f: Surface defined by TPA - 13 min.

Femtosecond Cornea Surgery: Girard Mourou

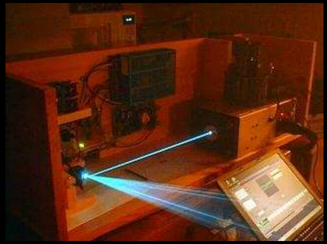
incluir tratamento de tatuagem
mostrar cirurgia nos neuronios do Eric Mansur

Waveguide Scribing

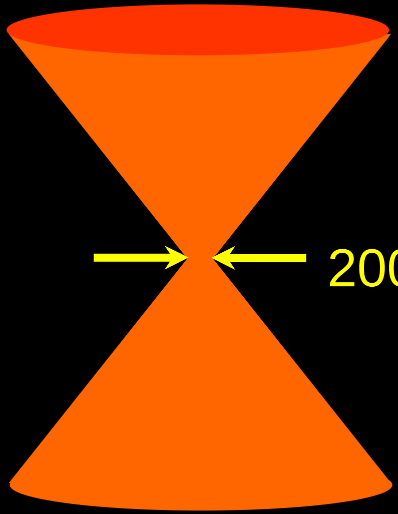




Exclusividade dos LASERS:
Controle da Energia no ESPAÇO e no TEMPO



- **No ESPAÇO: Intensidade = Potência/área**



$$P = 100\,KW \quad e \quad D = 200\,nm$$

$$I \cong 300 \times 10^{12}\,W / cm^2$$

Potência de Itaipu ~ 14 GW
21.000 Itaipus em 1 cm^2

Ablação de todo e qualquer sólido!
Metálico ou transparente

- **No TEMPO:**
  - **lasers contínuos (cw) e pulsados com: mili (ms), micro (μs), nano (ns), femto (fs) (10^{-15}) e ato (as) (10^{-18}) segundos.**
  - **Em 100 fs luz percorre 30 μm ~ 1/3 fio de cabelo.**

Processando materiais com Lasers

Lasers de fibra óptica

The End!!

Thanks for the attention