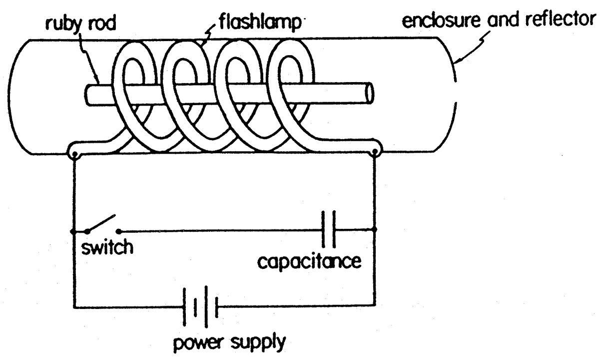
L1

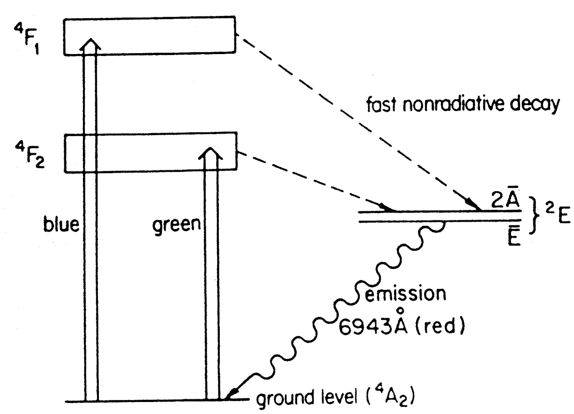
Pump Mechanisms and Types of Lasers

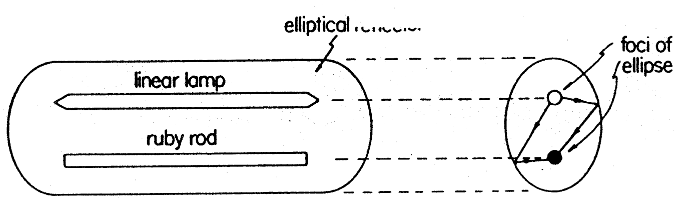
pump \ Transition	electronic bound → bound	electronic bound → free	electronic free → free	vibrational & rotational (molecular)	electronic & vibrational (vibronic)	electron & hole recombination
Electrical						
gas discharge	He-Ne; Ar^+	eximer (ArF)		CO_2		
current						semiconductor laser (GaAs)
Optical						
lamp	Nd: YAG ruby					
laser	glass fiber laser Solid State laser				dye laser Ti: sapphire	
Chemical				HF		
Nuclear	X-ray laser					
High energy particles			FEL (free electron laser)			

A. Optical Pumping

1) Ruby laser ($Cr^{3+}: Al_2O_3$)





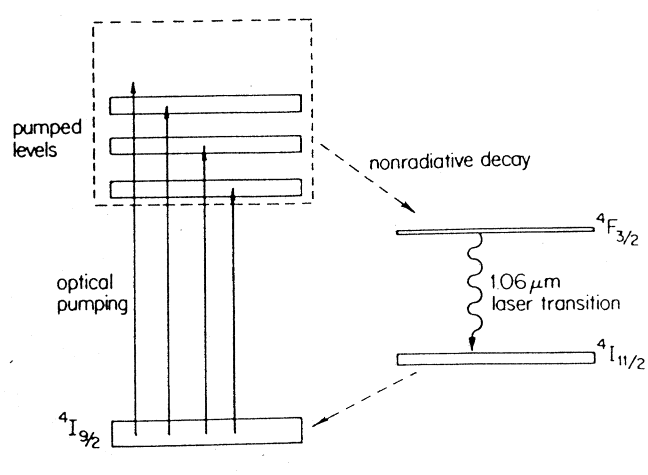


Cr^{3+} energy levels

* First demonstration of lasing (Maiman, 1960)
* Three-level system
* Pulsed operation

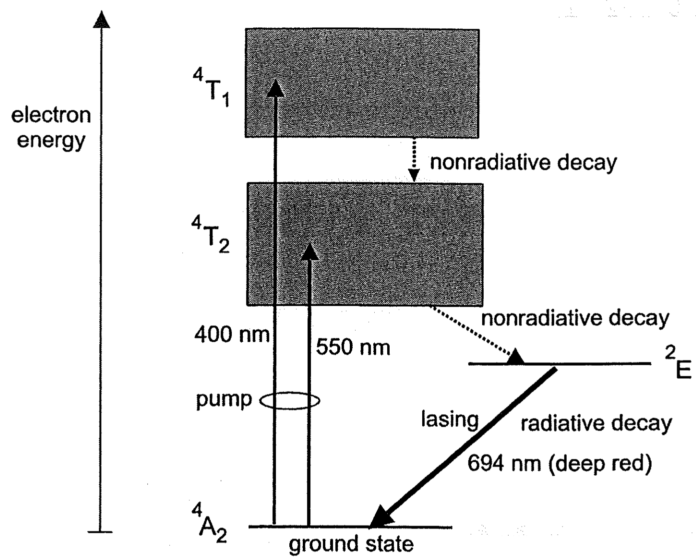
2) Nd: YAG laser

* 4 level system
* CW or pulsed
* industrial applications



Nd^{3+} energy levels

Ruby laser



Typical Parameters:

$N = 0.16 \cdot 10^{20}\ cm^{-3}$

$N_{2,th} \approx 0.08 \cdot 10^{20}\ cm^{-3}$

$\tau_2 = 3.0\ ms$

$\phi \approx 1$

$\sigma_{21} = 2.5 \cdot 10^{-20}\ cm^2$

$\Delta\nu = 0.33\ THz$

$\Delta t_p \simeq 10\ ns$ Q-switched

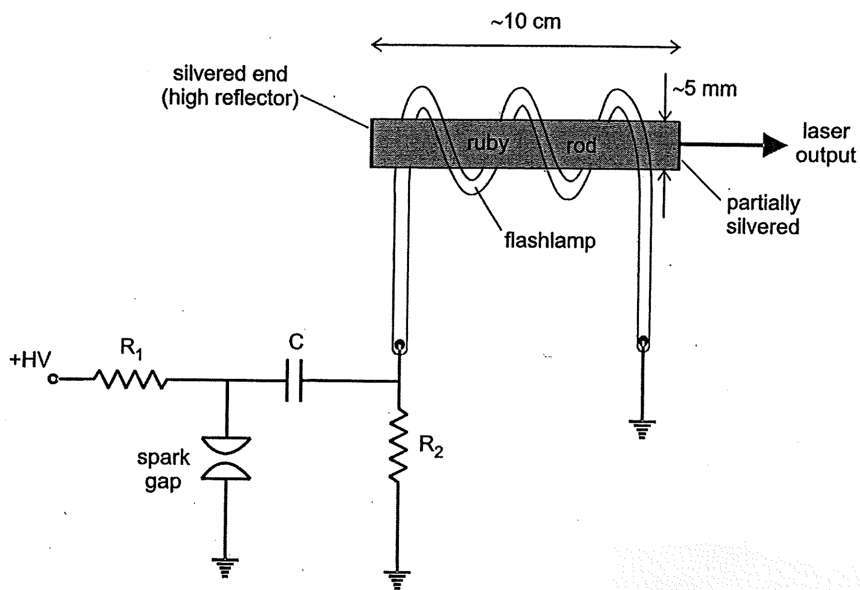
$E_{pulse} = 0.1 - 100\ J$

Flashlamp pumping:

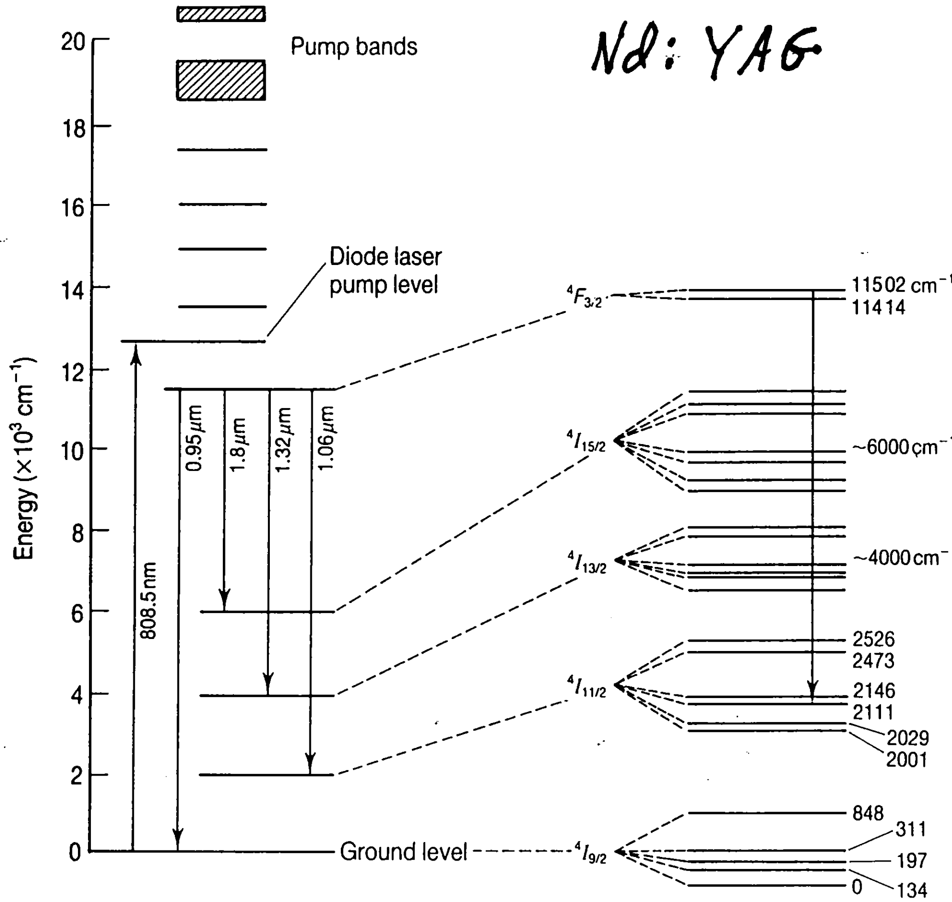
* pump pulse duration ~ 500 μs

* pumping efficiency $\eta_{pump} \sim 1\%$

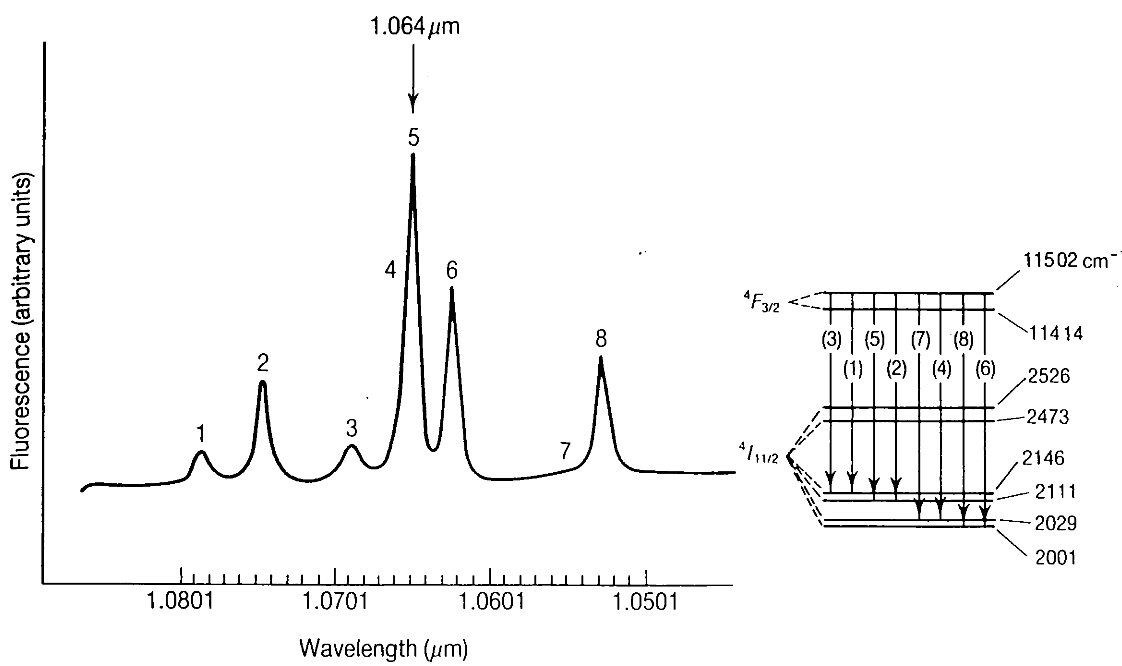
- electrical to optical
- spatial overlap of pump light with rod
- spectral overlap of lamp and Cr absorption



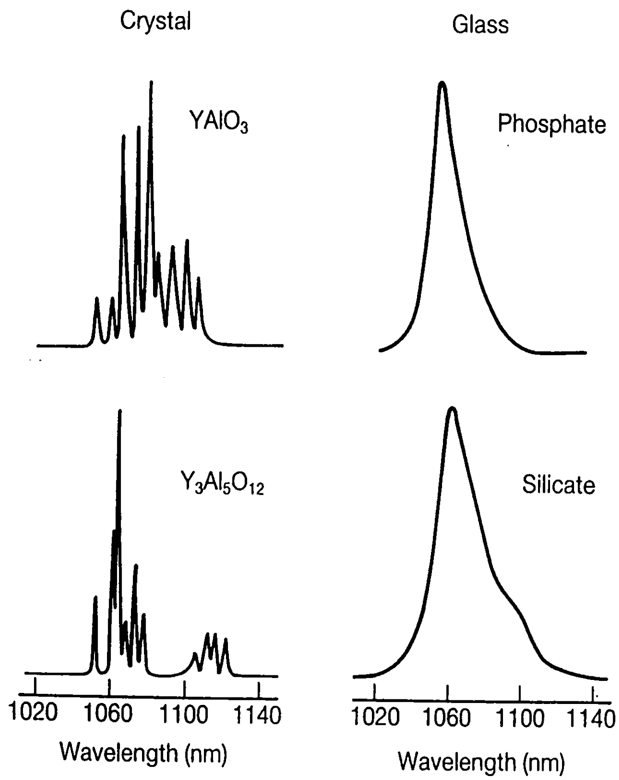
Nd: YAG



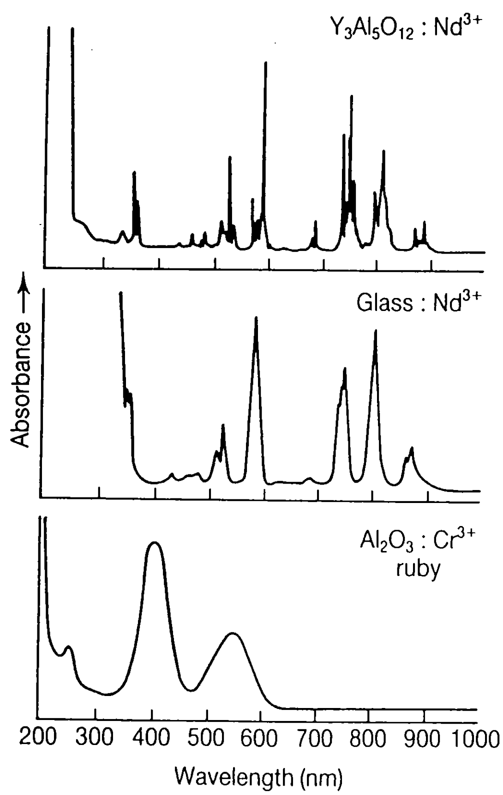
Pump bands
Diode laser pump level
Energy (×10³ cm⁻¹)
20
18
16
14
12
10
8
6
4
2
0
808.5 nm
0.95 μm
1.8 μm
1.32 μm
1.06 μm
Ground level
⁴F3/2
⁴I15/2
⁴I13/2
⁴I11/2
⁴I9/2
11502 cm⁻¹
11414
~6000 cm⁻¹
~4000 cm⁻¹
2526
2473
2146
2111
2029
2001
848
311
197
134
0

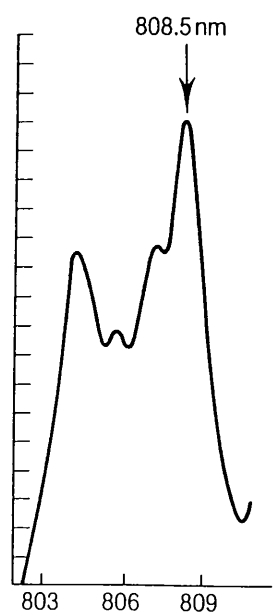


1.064 μm
1
2
3
4
5
6
7
8
Fluorescence (arbitrary units)
1.0801
1.0701
1.0601
1.0501
Wavelength (μm)
⁴F3/2
⁴I11/2
11502 cm⁻¹
11414
(3) (5) (7) (8)
(1) (2) (4) (6)
2526
2473
2146
2111
2029
2001



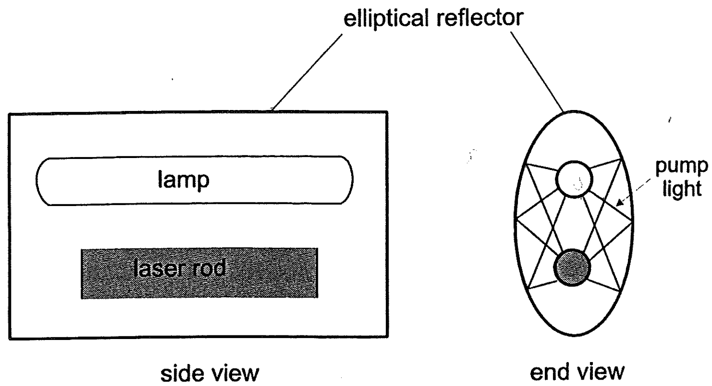
Nd^{3+} emission 300 °K





Nd^{3+} absorption 300 °K

Nd : YAG   ($Y_3 Al_5 O_{12}$)



Typical parameters:

$N \simeq 1.38 \cdot 10^{20}\ cm^{-3}$

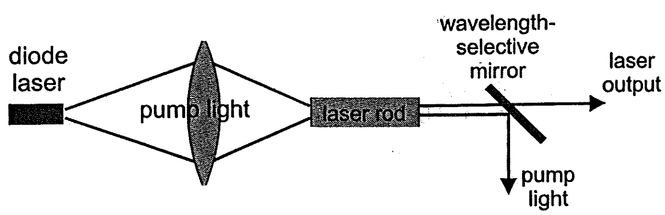
$N_{2,th} \simeq 1.5 \cdot 10^{17}\ cm^{-3}$

$\tau_2 = 230\ \mu s$

$\Delta\nu = 0.12 \cdot 10^{12}\ Hz$

$\sigma_{21} = 2.8 \cdot 10^{-19}\ cm^2$

$\tau_1 \simeq 30\ ns$ (nonradiative)

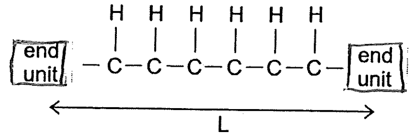


* lamp pumping
  - side coupling in elliptical reflector cavity
  - inexpensive lamps
  - low wall plug efficiency (~ 3%)
    - larger quantum defect
    - poor overlap of lamp spectrum with Nd absorption
  - noisy (due to lamp fluctuations)

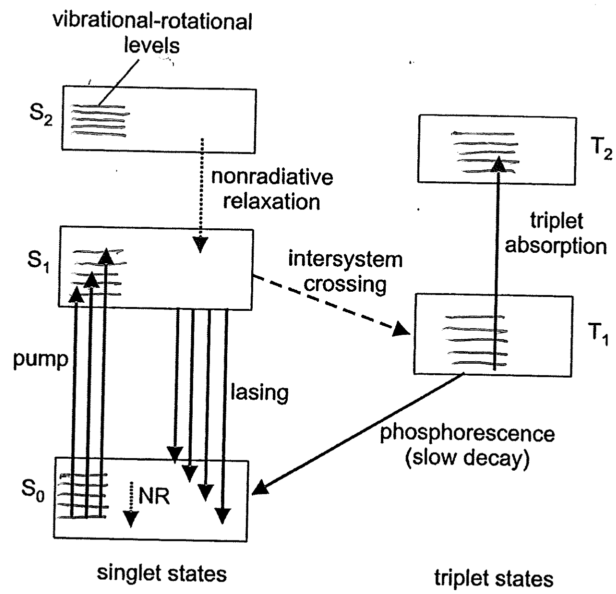
* diode laser pumping
  - end pumping: good overlap of pump light with Nd
  - laser diodes expensive but reliable
  - high wall plug efficiency (~ 30%)
    - smaller quantum defect
    - diode wavelength matches peak Nd absorption
  - stable output

* Nd: glass → $\Delta\nu \approx 5 \cdot 10^{12}\ Hz$ so shorter mode-locked pulses
  → high power pulse amplifiers

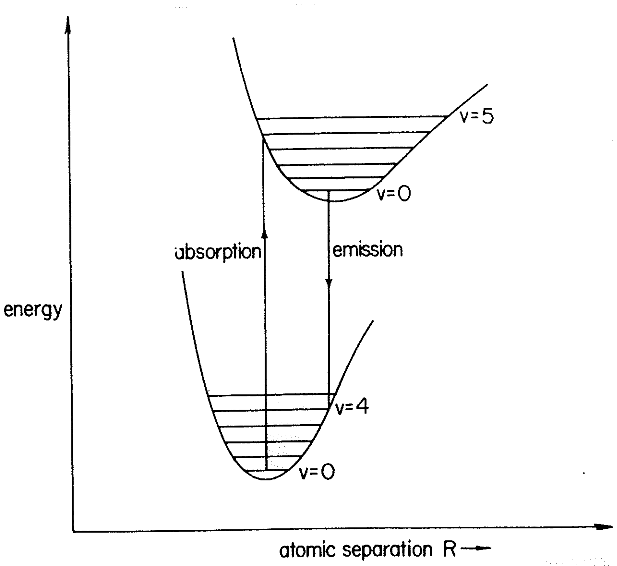
Dye Lasers

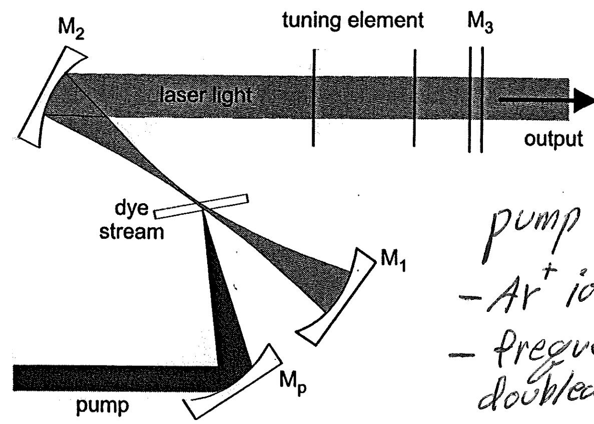


* Liquid solvent
  - fewer imperfections than in solid
  - higher gain than in gases
  - messy to work with

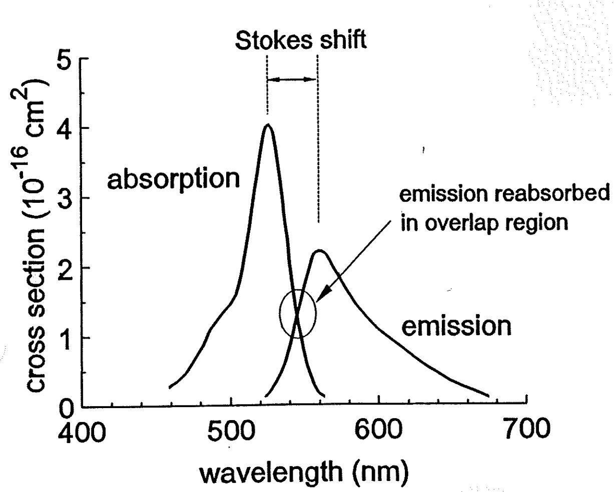


* Dye molecules
  - vibronic transition
  - broad spectral width
  - Stokes shift





pump with
- Ar^+ ion laser
- frequency doubled Nd:YAG
- Excimer laser



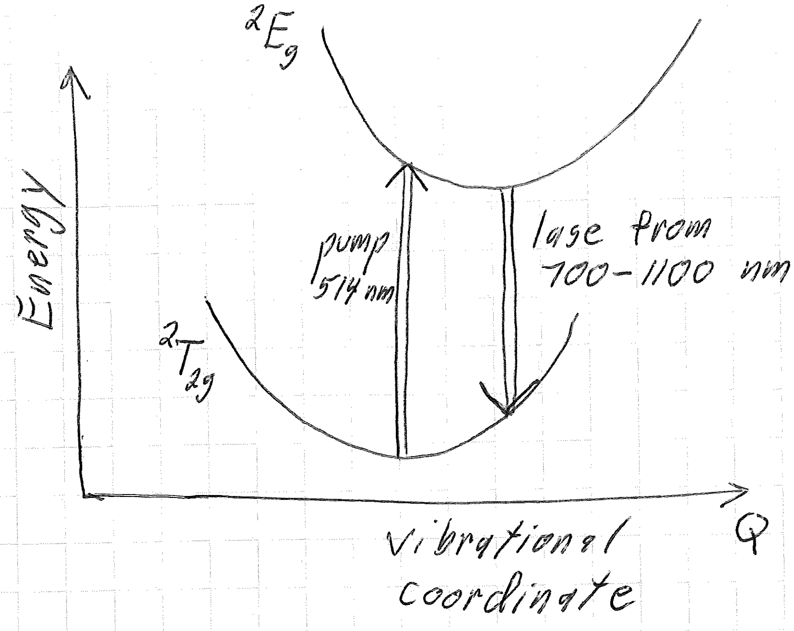
* flowing dye stream removes heat and avoids triplet accumulation
* $\tau_{21} \sim 5$ ns (allowed transition)
* high efficiency ($\phi \approx 0.2 - 1.0$)
* broad tuning $\Delta\lambda \approx 50$ nm

  $\Delta\nu \approx 45$ THz

  $\Delta t_p \sim \frac{1}{\Delta\nu} \cong 20$ fs

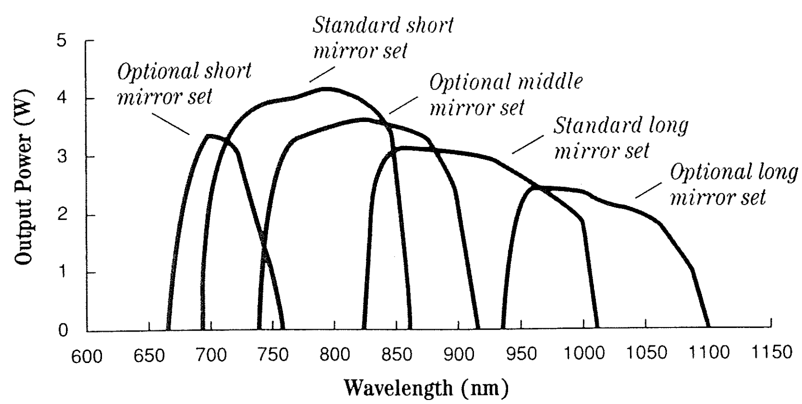
Ti : sapphire laser

Similar to dye laser, except replace dye stream with $Ti^{3+}:Al_2O_3$ crystal



Ti^{3+} energy level scheme

quasi-4 level



Pump power 12 W

$\lambda_p = 514.5$ nm

Typical parameters:

$\tau_2 = 3.8\ \mu s$

$\phi \approx 1$

$\sigma_{21} = 34 \cdot 10^{-20}\ cm^2$

$\Delta\nu \approx 40$ THz

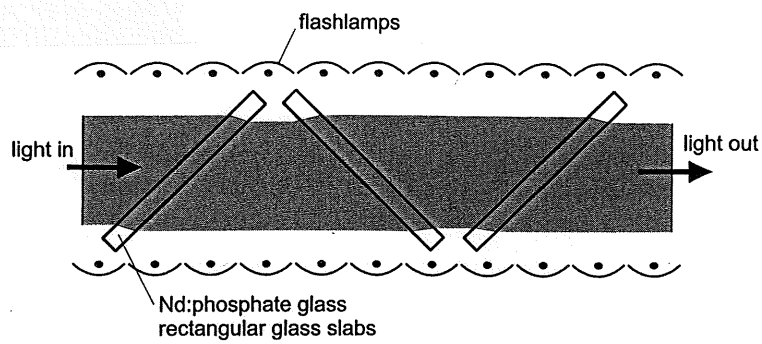
$N = 3 \cdot 10^{19}\ cm^{-3}$

$N_{2,th} \approx 6 \cdot 10^{17}\ cm^{-3}$

Advantages:

* little maintenance
* widely tunable
* high power

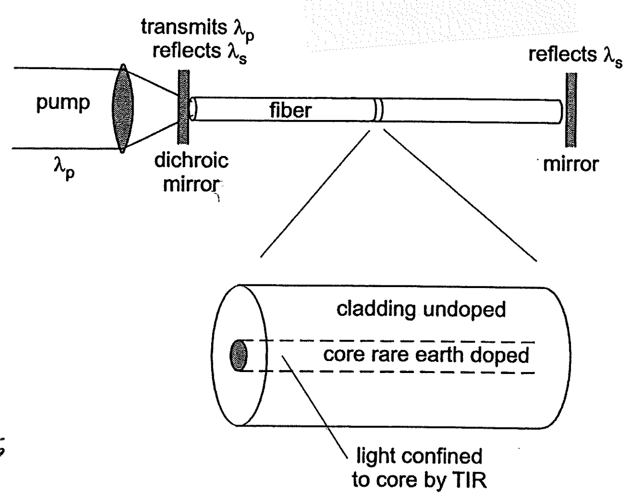
High power slab lasers and amplifiers



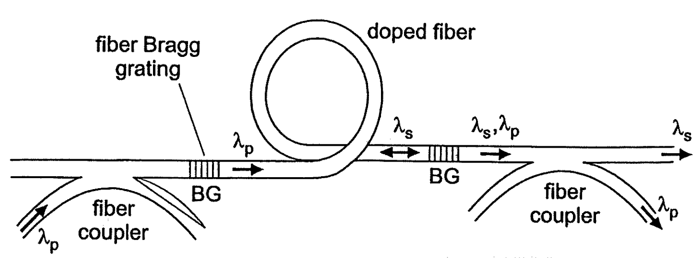
* good heat dissipation
* tilted at Brewster's angle
* Nd: glass slabs used in NIF to generate pulses for laser-induced fusion

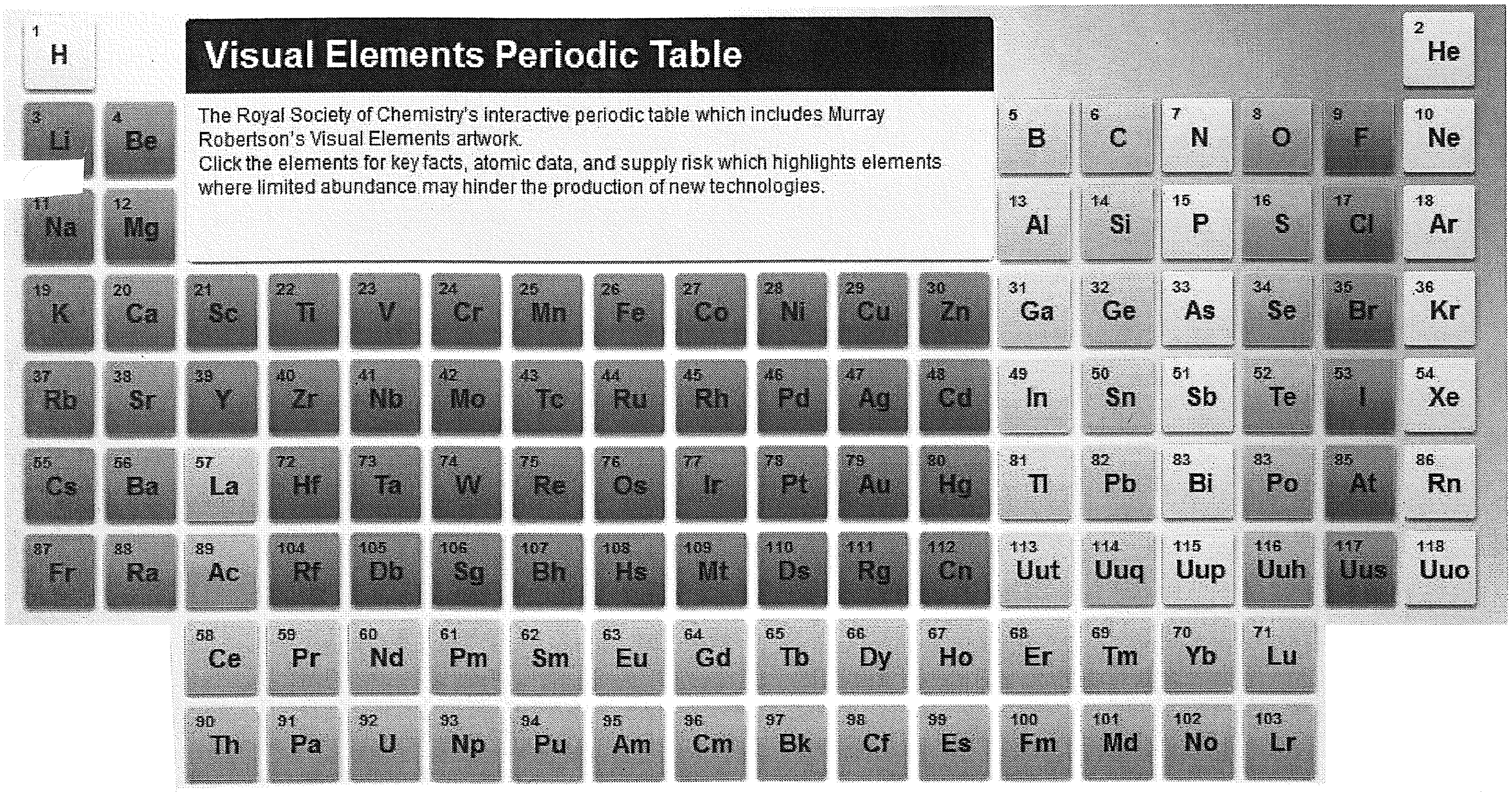
$$\left.\begin{array}{l} E_p \approx 3\ MJ \\ \Delta t_p \simeq 3.5\ ns \end{array}\right\} P \approx 8 \cdot 10^{14}\ W$$

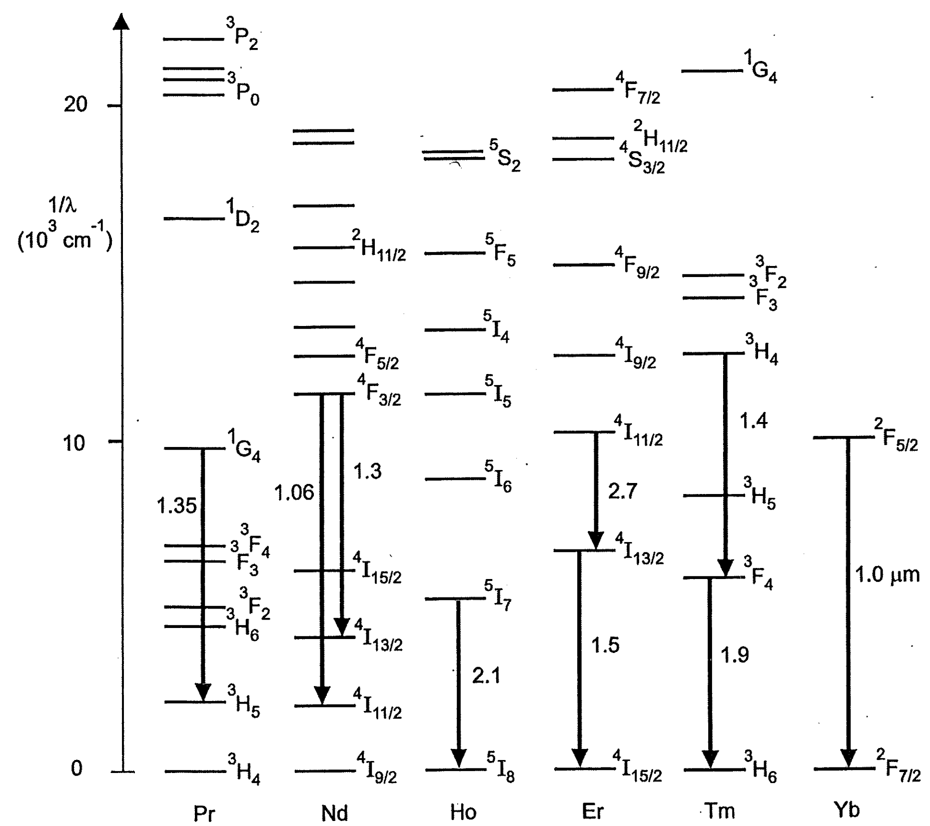
Fiber lasers



* Can use flat mirrors (mode confinement by fiber)
* $I = \frac{P}{A}$ is large (small A)
  - large ΔN; low P_{th}
  - cw lasing on 3-level systems
* can obtain single transverse mode (Gaussian beam out)
* compact and lightweight
* high efficiency, no cooling
* efficient coupling to fiber
* tunable (30–50 nm)
* many RE transitions can be used.







$$E \approx h\nu = \frac{hc}{\lambda}$$

$$\frac{1}{\lambda} = \frac{E}{hc}$$ is measure of energy

$1\ eV \Longleftrightarrow 8064\ cm^{-1}$