03/25/05 Lecture 22. (1)

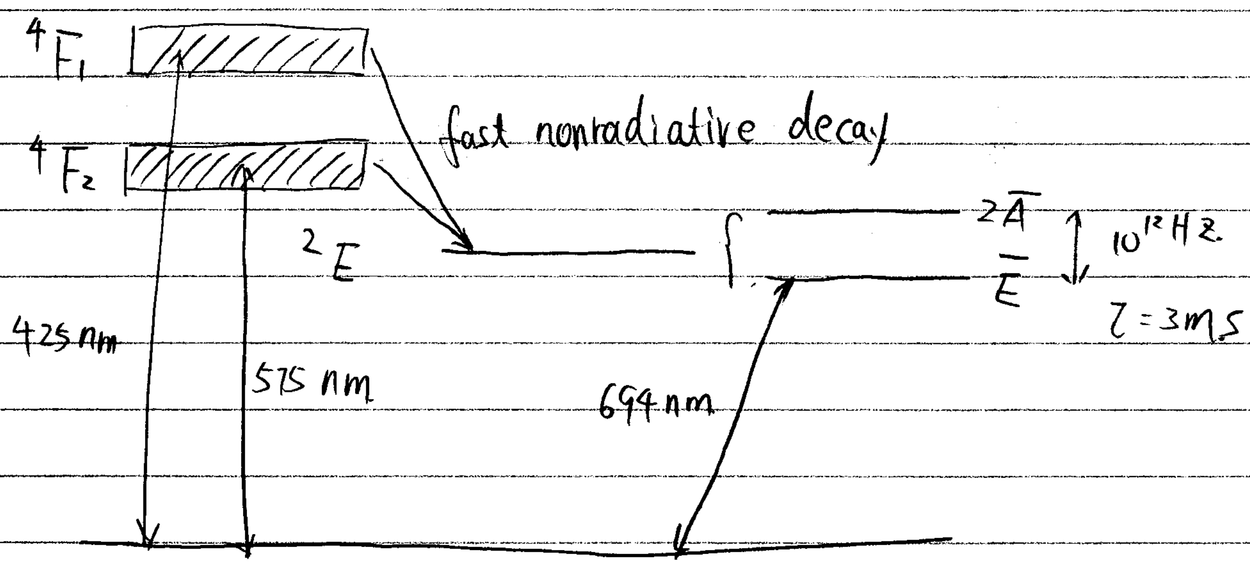
Solid state lasers:

<u>Ruby Laser</u>: first optical laser, (Maiman 1960)

Cr^{3+} ions replace Al^{3+} ions in Al_2O_3 host
Typically $2 \times 10^{19}\ cm^{-3}$

Levels:

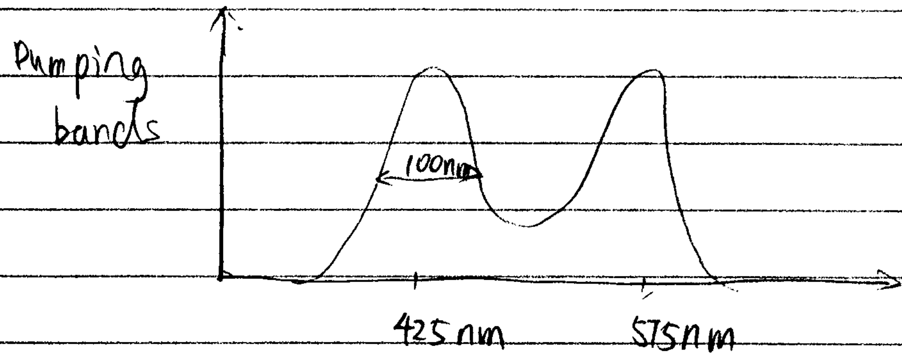
"3"



fast thermalization between $2\bar{A}$ and $\bar{E}$

3 level system

pump with flash lamp.
like big commercial flash.
discharge capacitor through light bulb



Broad bands good for flashlamp pumpings

Gives high power.

pulsed ~ 1J energy (~100 ns pulse)

~ 10 Hz repetition

P_{out} ~ 10W

Resonably efficient, few % (excellent for three-level system)

used for medical applications.

Nd : YAG

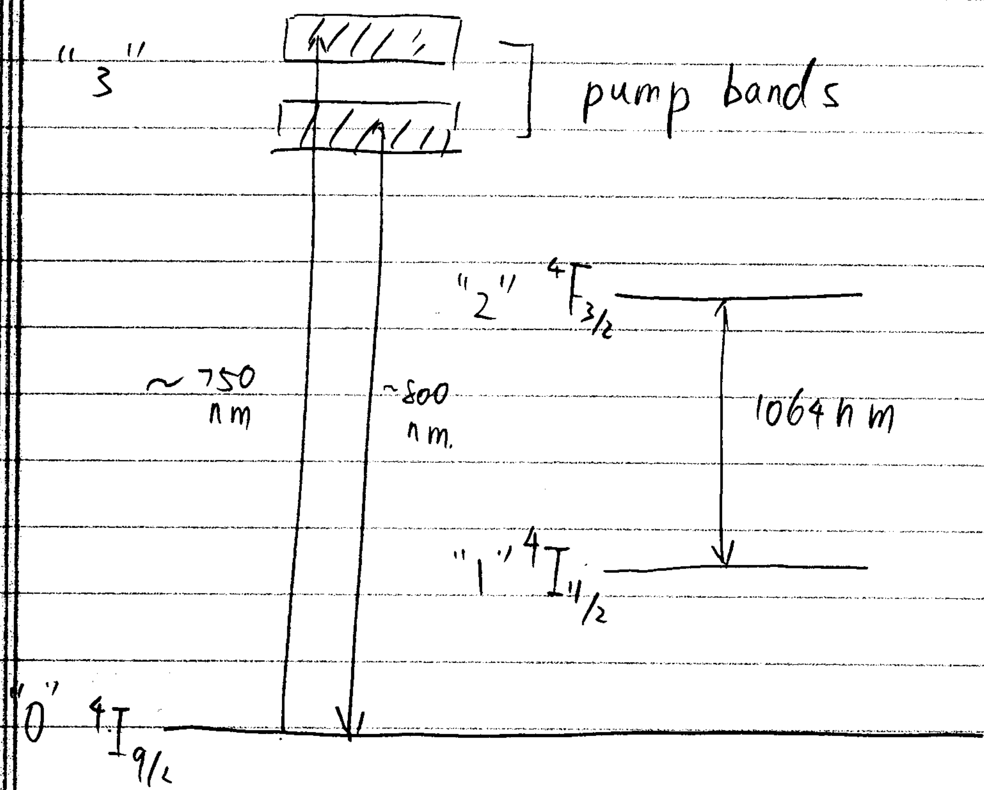
Nd^{3+} ions in $Y_3Al_5O_{12}$ (Yttrium aluminum garnet)

Similar for other host media : YVO_4
Glass
YLiF

Dopped 10^{19} cm^{-3}

All lase near λ = 1,064 μm.

Levels : 4-level system

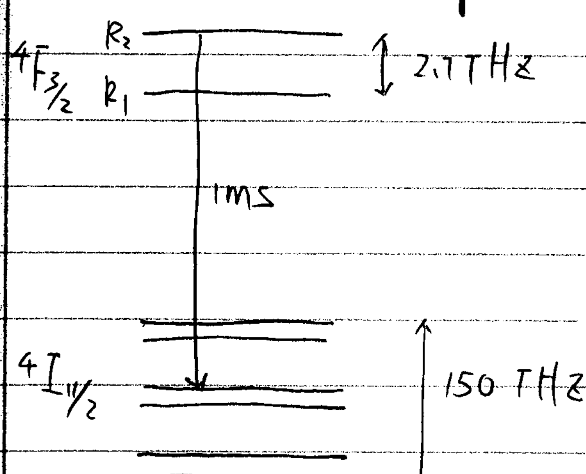


Decay rate $^4F_{3/2} \rightarrow {}^4I_{11/2}$ is $\frac{1}{\tau} = 4000\,s^{-1}$

Not all radiative: $\tau_2 = 250\,\mu s$

$\tau_s \approx 500\,\mu s$

Also, each level is split:



All transitions possible.
strongest line $\tau_s = 1ms$

$\Delta\nu = 200\,GHz$
homogeneous

Flashlamp pumping:

$T_{flash} \simeq 10^{-4}$ s, $< \tau_2$

Simple approximation: every photon absorbed gives atom in upper level

Pump absorption:

estimate ~ 4 bands, each about 30 nm wide

peak cross section ~ 3×10^{-19} cm^2 for each

Say $N_a = 2 \times 10^{19}$ cm^{-1}

Then $\alpha_{pump} \approx 3 \times 10^{-19}$ cm^2 $\times$ 2×10^{19} cm^{-3}

$= 6$ cm^{-1}

So most pump light with right λ is absorbed

Broad pumping levels, flashlamp pumping

Gas discharge bulb: Xe or Hg

* Hg lamp: spectrum has lots of peaks, need to compare emission & absorption lines.
* Xe lamp: pretty flat from λ ~ 400 nm to 1.5 μm

Really:

$$P_{abs} = \int P_{emit}(\nu) \left[1 - e^{-\alpha(\nu) d} \right] d\nu$$

↑ Spectral density of emitted light $\left(\frac{W}{Hz}\right)$

Estimate fraction absorbed $\sim \frac{\Sigma \Delta \lambda_{abs}}{\Delta \lambda_{emit}} \sim \frac{4 \times 30\,nm}{1100\,nm}$

$\approx 10\%$

So, estimate inversion: $\Delta N \approx$ # photons absorbed $\cdot \frac{1}{\text{volumn}}$

$\approx 0.1 \times$ (# photons emitted) $\cdot \frac{1}{V}$

$= 0.1 \times \left(\frac{E_{flash}}{h\nu} \right) \cdot \frac{1}{V}$

Say $\Gamma = 5\%$ loss

$l = 20\,cm$ (crystal length) x 5mm diameter

Then

$$g_t = 2\gamma_t l = 0.05 = \frac{\lambda^2 \cdot 2l}{8\pi t_s \Delta\nu} \Delta N_t$$

$$\Delta N_t = \frac{0.05 \cdot 8\pi \cdot 1ms \cdot 200\,GHz}{(1.064\,\mu m/1.5)^2 \cdot 2 \cdot 0.2m}$$

$$= 1.2 \times 10^{15}\ cm^{-3}$$

So $E_{flash} = 10 \times V \cdot h\nu \ 10^{15}\ cm^{-3}$

$V = 20cm \times \pi \times (0.25\,cm)^2 = 4\,cm^3$

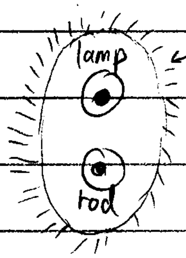
average $\lambda_{pump} \sim 700\,nm$

$h\nu_{pump} \simeq 3 \times 10^{-19}\,J$

$E_{flash} \simeq 10 \times 4cm^3 \times 3 \times 10^{-19}\,J \cdot 10^{15}\ cm^{-3} = 0.01\,J$

Well, actually don't expect all light emitted
by flashlamp to hit rod.
(Flash emits in all directions.)

Use mirrors to collect:



← elliptical cavity

still only get ~20%

So, need ~0.1J flash.

(Ruby laser, more like 100 J.)

Nd laser pretty efficient many uses