Laser Physics I — Homework 4
Due Monday, November 4, 2024

Colorful lasers

Dye lasers were very popular last Century (Gosh - a century has passed already!). The gain media were large organic dye molecules fluorescing with bright colors in the visible. Fluorescence and laser beam are visible (and illuminate the whole lab), making the alignment rather easy. Bright fluorescence implies large gain cross section. Not only was the laser bright and colorful, but the operator as well. The gain medium of a dye laser is a flowing dye jet. You would think that a flowing gain medium is the source of instability? Nevertheless, it was a dye laser that was - until very recently - the laser associated with the cesium clock; the time/length standard of NIST, built by Leo Hollberg. The dye jet is the gain medium with the largest damage threshold, since it is continuously replenished.

It can be considered as a three level system, pumped from the ground state (which is also the lower lasing level) to a group of upper levels, from which there is a very fast (near instantaneous as compared to all other time constants) relaxation to the upper lasing level. The pump is provided by green laser (up to 20 W), focused onto a 200 micron thick jet. The following parameters are given:

- gain molecule concentration: $6 \cdot 10^{17}$ cm^{-3}
- relaxation time of upper lasing level: $T_1 = 2.5$ ns
- cross section of the focused beam: 30 μm^2 (which is also the cross section of the waist of the cavity located in the jet)
- Absorption cross section of the pump beam $\sigma_p = 1. \cdot 10^{-16}$ cm^2
- Gain cross section (for the lasing beam): $\sigma = 5. \cdot 10^{-16}$ cm^2
- Pump wavelength 532 nm
- Lasing wavelength 590 nm
- Reflectivity of the output mirror: 80%

About the pumping rate R

R is the number of pump transitions/s from ground state to upper state.
I_p is the intensity of the pump beam in W/cm^2.
$\frac{I_p}{\hbar\omega}$ is the flux of pump photons in s^{-1} cm^{-2}.
The number of pump transitions per second is $\sigma \frac{I_p}{\hbar\omega} = R$

Find the pump power required to have zero gain/zero absorption

Hint: use the two-level rate equations for the population difference modified to represent a three level system. The zero gain condition defines the initial population difference. The equilibrium condition leads to R'. Backtrack the changes in variable to arrive at the pumping rate R and the pump intensity I_p.

Find the pump power required for threshold

Find the gain required to compensate the loss (due only to transmission through the output coupler). Given the gain and cross-section leads to the inversion ΔN_{eq}. From there the procedure for finding the pump power is the same as above.

What is the output power at a pump power of 6 W?

Hint: Find the pump intensity, then the pump rate R. Follow the changes in variable to find successively T_p, I'_s and R', which leads to the equilibrium inversion ΔN_e. The condition that this inversion saturated to the threshold value (previous question) leads to the intensity.