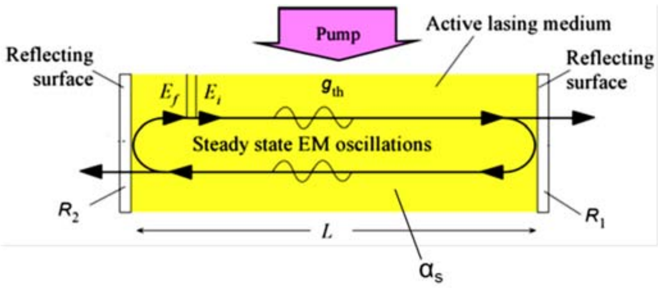
NTHU Electrical Engineering Department
EE3360 Optoelectronic Devices Spring 2019
HW #4

1. In class we've derived an expression of threshold condition for oscillation in a laser, where the "loss" of the system is only due to transmission losses through the reflectors. In fact, many other loss mechanisms exist inside the optical cavity (such as scattering). These internal cavity losses decrease the optical intensity and can be overall modeled by an internal cavity loss coefficient α_s (unit: m^{-1}), where the optical intensity decreases inside the cavity as $e^{-\alpha_s z}$.

   (a) Please derive an expression of threshold gain coefficient γ_{th}, assuming that the reflectivities of the reflectors are R_1 and R_2, the cavity length is L, internal cavity loss coefficient is α_s.



   (b) The emission wavelength of an Ar-ion gas laser is 488 nm. The tube length L=100cm, tube mirror reflectivities are approximately 92% and 98%. The linewidth $\Delta\nu$ = 3 GHz, the loss coefficient α_s is 0.15 m^{-1}, spontaneous decay time constant $1/A_{21}$=15 ns, and the refractive index of the gas is 1. Please estimate the threshold gain coefficient and threshold population inversion.

2. (a) Consider a ruby crystal with two energy levels separated by an energy difference corresponding to a free-space wavelength of 694.3nm, with a Lorentzian lineshape of width 250 GHz. The spontaneous lifetime τ_{sp} = 2.4 ms and the refractive index of ruby is 1.76. If $N_1+N_2=N=10^{25}$ cm^{-3}, please determine the population difference (N_2-N_1) and the gain coefficient at the line center under conditions of thermal equilibrium at T=300K. (b) What value should the population difference in order to achieve a gain coefficient of 1.5 cm^{-1} at the central frequency? (c) From (b), how long should the crystal be to provide an overall gain of 2.5 at the central frequency? (d) A ruby laser makes use of a 5 cm long ruby rod. Both of its end are polished and coated so that each has a reflectance of 95%. Please determine the loss of the cavity α_c. (you may assume the cavity length is the same as the rod.) (e) Please determine the threshold population inversion for laser oscillation.

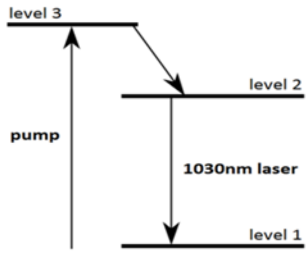
3. A Doppler-broadened gas laser has a gain coefficient with a Gaussian spectral profile given by $\gamma_0(\nu)=\gamma_0(\nu_0)\exp(-(\nu-\nu_0)^2/2\sigma_D^2)$, where $\Delta\nu_D=(8\ln 2)^{1/2}\sigma_D$ is the FWHM linewidth. (a) Please derive an expression for the allowed oscillation band B as a function of $\Delta\nu_D$ and the ratio $\gamma_0(\nu_0)/\alpha_r$, where α_r is the resonator loss coefficient. (b) A He-Ne laser has a Doppler linewidth 1.5GHz and a gain coefficient $\gamma_0(\nu_0)=2\times10^{-3}cm^{-1}$. The length of the laser resonator d=100cm, and the reflectances of the mirrors are 100% and 97%. Assuming that the refractive index n=1, please determine the number of laser modes M.

4. Yb^{3+}:YAG is a rare-earth-doped dielectric material that lases at λ_0 = 1030 nm on the level 2 → 3 transition (See figure below). This three level laser is usually optically pumped with an InGaAs laser diode. The pumped band (level 3) has a central energy of 1.31915 eV and a width of 0.02475 eV.

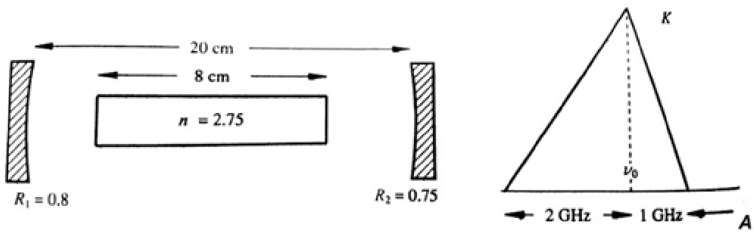
   (a) At the central frequency of the laser transition ν_0, the peak transition cross section $\sigma_0 \equiv \sigma(\nu_0) = 2 \times 10^{-20}$ cm^2. Given that the Yb3+-ion doping density is set at $N_a = 1.4 \times 10^{20} cm^{-3}$, determine the absorption and gain coefficients of the material at the center of the line, $\alpha(v_0) \equiv -\gamma(v_0)$. Assume that the material is in thermal equilibrium at T=300K (i.e., there is no pumping).

(b) Consider a laser rod constructed from this material with a length of 6 cm and a diameter of 2 mm. One of its ends is polished to a reflectance of 80% $(R_1 = 0.8)$ while the other is polished to unity reflectance $(R_1 = 1.0)$. Assuming that here is no scattering, and that there are no other extraneous losses, determine the resonator loss coefficient α_γ.

(c) As the laser is pumped, the gain coefficient $\gamma(v_0)$ increases from its initial negative value at thermal equilibrium and changes sign, thereby providing gain. Determine the threshold population difference N_t for laser oscillation.



5. Please use the results of problem 4 in HW3 where degeneracy is taken into considered for this problem. The inhomogeneous lineshape function for the laser shown below can be approximated by the triangle shown below. Use the given information to compute($A_{21} = 2.5 \times 10^6\ s^{-1}; g_2 = 3; g_1 = 1; \overline{v}_0 = 125000\ cm^{-1}; n = 2.75$)



(a) Stimulated emission cross section (b) The inversion to reach threshold for oscillation (c) The number of longitudinal modes capable of oscillation if the system were pumped to 1.25 times threshold.

6. Lasers are widely used in many applications. Please find out what kind of lasers is used in the following applications. For each laser, please specify (1) the gain medium and the energy level diagrams (2) 3 level /4 level laser/other laser system (3) the pumping method (4) the typical output power and wavelength (5) CW or pulsed laser (6) explain how laser is used in the application.

(a) in a DVD burner (b) laser surgery for correcting nearsightedness (c) red laser pointer