Laser Physics: PHYS 5734

Spring 2009, Homework Set - 6

Due: Friday, April 20

25. **Threshold inversion and saturation intensity in Yag**

(a) *Estimate the threshold inversion density for a four level* Nd^{3+}*:YAG laser with a 20 cm long cavity, 4% loss per round trip, refractive index* $n = 1.82$, $\lambda = 1.064\ \mu m$*, radiative decay rate* $\gamma_{21} = 1.82 \times 10^3\ s^{-1}$ *corresponding to a radiative lifetime of 550* μs*, peak transition cross-section of* $3.5 \times 10^{-19}\ \text{cm}^2$*, and linewidth (FWHM)* $\Delta\nu_H = 120$ *GHz at room temperature. How does the threshold inversion density compare to the density of* Nd^{3+} *ions given that the density of YAG* ($Y_3Al_5O_{12}$ *crystal is 4.56 g/cm*^{3} *and about 1% of Yttrium ions* (Y^{3+}) *have been substituted by Neodymium ions* (Nd^{3+})*. Assume the gain medium to fill the whole cavity. Atomic weights of Y, Al, and O are 88.91, 26.98, and 16, respectively.*

(b) Also estimate the saturation intensity for this laser. [Data from *Solid State Laser Engineering*, W. Koechner (Springer-Verlag, Berlin, 1988) 2nd edition pp 49.]

26. CO_2 **Laser: Too Hot!**

A high power CO_2 *laser has a small signal line center gain* $g_0(\nu_0) \approx .005\ \text{cm}^{-1}$*. The laser transition is homogeneously broadened with a lorentzian linewidth* $\Delta\nu_H \approx 2.0$ *GHz. The gain medium fills nearly the entire 50 cm between the cavity mirrors. Losses due to scattering and absorption are* $\approx 2\%$ *per roundtrip. One of the mirrors is perfectly reflecting.*

(a) Determine the optimum transmission of the output mirror that will produce maximum output power from the laser.

(b) The saturation intensity I_s *for this laser is estimated be 100 kW/cm*^{2}*. What is the power output if the cavity is designed to have optimal transmission? Estimate the intracavity intensity. What will be the impact of 2% internal loss in light of this?*

27. **Intracavity photon number and output photon flux**

A standing wave He:Ne laser ($\lambda = 632.8$ *nm) is 50 cm long. It has mirrors with power reflectivities* $\mathcal{R}_1 = 1.00$ *and* $\mathcal{R}_2 = 0.98$*. Losses other than output coupling are negligible. The output power of the laser is 10 mW on a single mode. Calculate the average number of photons inside the cavity. What is the photon number flux (#/s) circulating inside the cavity? What is the photon number flux leaving the cavity (#/s)?*

28. **Single-mode operation**

An Ar-ion laser oscillating at $\lambda = 514.5$ *nm is predominantly Doppler broadened with* $\Delta\nu_D = 3.5$ *GHz. It has a cavity of length* $L = 120$ *cm, a gain tube of length* $\ell_m = 100$ *cm and roundtrip cavity losses of 10%. The stimulated cross-section for the transition is* $\approx 2.5 \times 10^{-13}$ *cm*^{2} *and the upper state life time is about* 5 *ns.*

(a) *Assuming that the lifetime of the lower laser level is much shorter than that of the upper level and one cavity mode coincides with the line center, calculate threshold inversion for the central mode and threshold pump rate.*

(b) *At how high a pump rate above threshold will two adjacent modes start to oscillate?*

29. **Number of longitudinal modes** *An Ar-ion laser operating at 514 nm uses a two-mirror resonator of length 0.5 m. The gas discharge, which fills the entire cavity, is estimated to be at a temperature of 2000K, leading to a Doppler broadened gain profile. The gas density is low enough that the index of refraction can be taken to be unity. Estimate the number of longitudinal modes that will oscillate if the small signal gain is 1.5 times the total cavity loss.*