SK2411, IO2659 VT2009 Exam tasks

Task 1.

(a) Prove formally that the maximum four-level laser efficiency (ratio of the laser output power to the pump power), when the laser is operating far above the threshold ($\frac{P_{pump}}{P_{th}} \gg 1$) depends only on the laser and pump photon energies and the pumping efficiency. For simplicity consider longitudinal pumping with perfect beam matching between the pump and laser mode ($w_0 = w_p$). The maximum efficiency also implies that there are no other losses except for those due to output coupling. (3 points)

(b) There are two lasers generating 100 W output power each and operating under maximum efficiency conditions and with maximum pumping efficiency:

(i) Nd:YAG pumped at 808 nm and generating radiation at 1064 nm,

(ii)Yb:YAG pumped at 940 nm and generating radiation at 1040 nm

Calculate the heat power produced by these lasers. (1 point)

Task 2.

(a)Which laser diode structure, homojunction or heterojunction has lower threshold current density and why? (1 point)

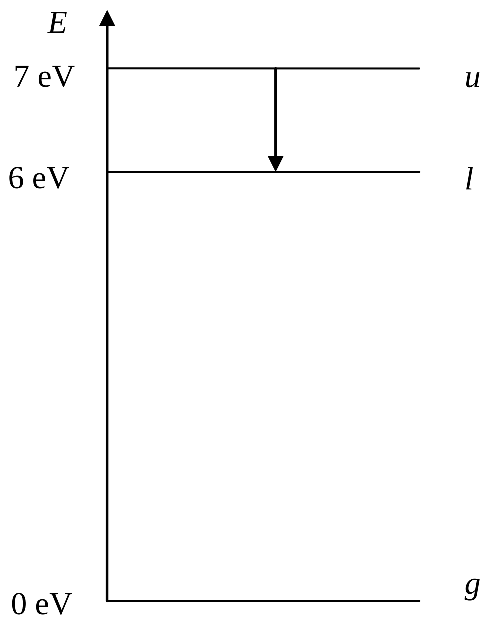
(b) What is natural linewidth? What determines it? (1 point)

(c) You have a choice of two laser gain materials, Nd:YAG and Nd:glass, and need to make a laser at the peak of four-level transition spectral line. Homogeneously broadened linewidth in Nd:YAG is 13.5 GHz and upper laser level lifetime is 230 μs. The same transition in Nd:glass is inhomogeneously broadened to 5.4 THz and the upper laser level lifetime is 300 μs. Which material would provide smaller laser threshold and how many times considering that cavity losses are the same in both cases? (2 points)

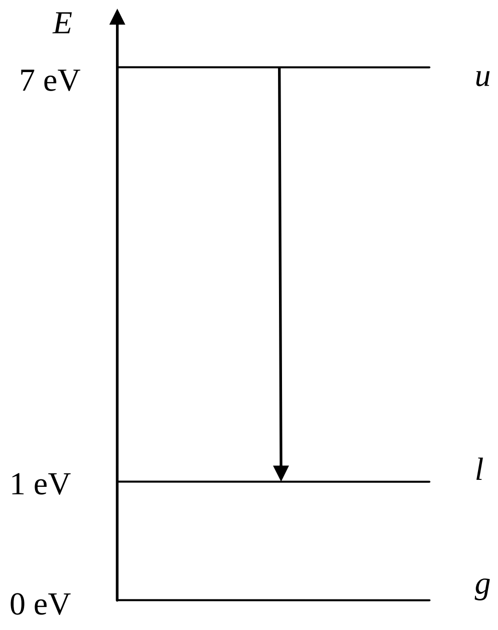
Task 3.

(a) Consider two three-level schemes:

(i)



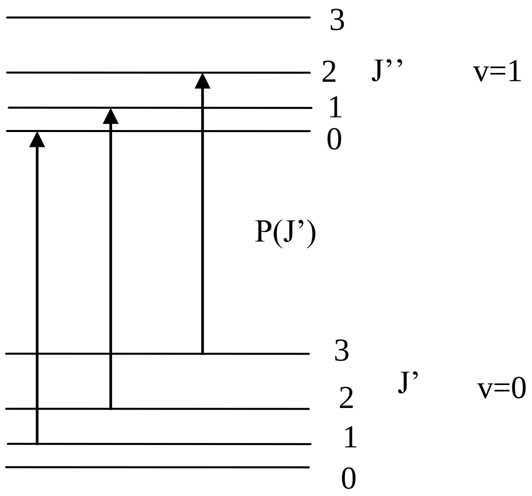
(ii)



Which scheme would be suitable for making a continuous wave laser for transitions between u and l levels, assuming that the transitions u-l, l-g are dipole-allowed and have equal transition dipole matrix elements, while the transition u-g is dipole-forbidden? Motivate your answer. (1 point).

(b) Semiconductor chip manufacturer has given you a task to find a suitable laser technology for lithography used in manufacturing next generation chips with the smallest feature size of 100 nm. Which laser type would you choose and why? (1 point).

(c) Rotational-vibrational absorption and emission spectrum consists of series of lines attributed to P, and R branches. Take for instance a P branch of the absorption which corresponds to transitions J''=J'-1 (see Figure below) and prove that the separation of absorption and emission lines in frequency is equidistant, i.e. the frequency separation between adjacent spectral lines in the rotational-vibrational spectrum remain the same, regardless of the initial rotational quantum number J'. (2 points)



Task 4.

(a) What is the Rayleigh range of a Gaussian beam? (1 point)

(b) For a ray entering a spherical dielectric interface from a medium of refractive index n_1 to a medium of refractive index n_2, with radius of curvature R (assume R>0 if the center of curvature is to the left of the surface), the ABCD matrix is $\begin{bmatrix} 1 & 0 \\ \frac{n_2-n_1}{n_2R} & \frac{n_1}{n_2} \end{bmatrix}$. The ABCD matrix for a thin lens is $\begin{bmatrix} 1 & 0 \\ \frac{-1}{f} & 1 \end{bmatrix}$. Calculate the ABCD matrix of a spherical lens, made up of two closely spaced dielectric interfaces, of radii R_1 and R_2, enclosing a material of refractive index n_2. The lens is immersed in a medium of refractive index n_1. Derive the expression of f using R_1 and R_2. (1 point)

(c) A given He-Ne laser oscillating in a pure Gaussian TEM_{00} mode at λ=632.8 nm with an output power of P=5 mW has a far-field divergence-angle of 1 mrad. Calculate spot size and peak intensity at the waist position. (2 points).

Task 5.

Consider the optical pumping system.

(a) What is longitudinal pumping? What is transverse pumping? (1 point)

(b) Describe the pumping efficiency, and four main terms contributing to the pumping efficiency. Explain why diode laser pumping is more efficient than lamp pumping. (1 point)

(c) Consider a rod-shaped active medium pumped by a laser beam, and let z be the longitudinal coordinate along the rod axis. r is the radial distance from the rod axis. Prove that, for longitudinal pumping, the pump rate is $R_p(r,z)=\alpha I_p(r,z)/h\nu_p$, where $I_p(r,z)$ is the pump intensity in the active medium and α is the absorption coefficient at the frequency ν_p of the pump. (2 points)

Task 6.

(a) Write down the space independent rate equations for a quasi-three level system, and explain the physical meaning of each parameter and the equation itself. (1 point)

(b) Derive the critical pumping rate from the above rate equations. (1 point)

(c) Calculate the population inversion necessary to achieve CW laser oscillation in a ruby laser (quasi-three level system) at the wavelength λ=694.3 nm. Assume a Fabry-Perot resonator with mirror reflectivity 100% and 96%, a scattering loss of 3% per round trip, and a 6 cm long ruby rod. Assume also equal values for absorption and stimulated emission peak cross sections $\sigma_a = \sigma_e = 2.7\text{x}10^{-20}$ cm^2. (1 point)

(d) Assume the above laser is operating at the transient mode through mode locking. If the bandwidth of the laser transition for the above laser is 11 cm^{-1} (in the unit of wave-number) and the mode amplitude spectrum has a Gaussian shape, calculate the pulse width. (1 point)