SK2411, IO2659 Exam tasks
VT10, 2010 May 26

Task 1

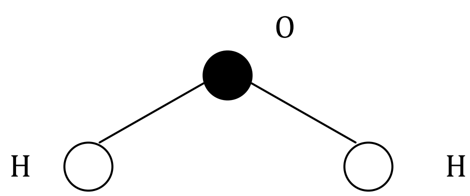
(a) What is natural linewidth ? Describe linewidth broadening mechanisms. (1 point)

(b) Explain spectral hole burning. Specifically, in which laser media can it happen? (1 point)

(c) GaAs double heterojunction optical amplifier shows gain of 4.2×10^2 cm^{-1} for the injection density of 3×10^{18} cm^{-3}. The amplifier has a form of a waveguide with the active area of 0.1 µm x 5 µm. The transparency in amplifier is reached at the charge carrier injection density of 1.3×10^{18} cm^{-3}. You need to amplify short pulses in this amplifier with good extraction efficiency but extracting pulse energy corresponding to the fluence two times below optical damage (damage occurs at 7×10^{-2} Jcm^{-2}). Calculate the required amplifier length and estimate the maximum pulse energy you can achieve. Amplifier operates at the wavelength of 800 nm and Plank constant is $h=6.62 \times 10^{-34}$ J s. (2 points)

Task 2

(a) H_2O is a nonlinear molecule (see below). How many normal vibrational modes does it have? Explain how did you reach the answer. (1 point)



(b) You need to make a laser using transitions in H_2O, operating at a wavelength of 118 µm. Which degrees of freedom (electronic, vibrational, rotational) you would employ in this laser? Which phase of H_2O (solid ice, liquid water or water vapour) this laser should use? Motivate your answer. (1 point).

(c) Low-noise amplifier designs require gain materials which have high probability for stimulated emission but low probability for spontaneous emission from the excited state. You are told to build an amplifier using Nd^{3+} ion transition at around 1 µm. Moreover you have a possibility to choose the host material from the following list: YAG (index of refraction 1.82), YVO_4 (index of refraction 2.15), phosphate glass (index of refraction 1.53). Which material would you choose and why? Give estimated improvement in the amplifier signal-to-noise ratio for the best material from the list as compared to the worst. (2 points).

Task 3

(a) It is common to use YAG crystal as a host for active laser ions. Consider YAG doped with Nd^{3+} rare earth ion and YAG doped with Cr^{4+} transitional metal ion. Both crystals can be used to make lasers but only one of them can be used to generate femtosecond pulses. Which one and why? Motivate the answer. (1 point)

(b) Explain why in vibronic transitions there is a Stokes shift of the emission peak with respect to the absorption peak. (1 point).

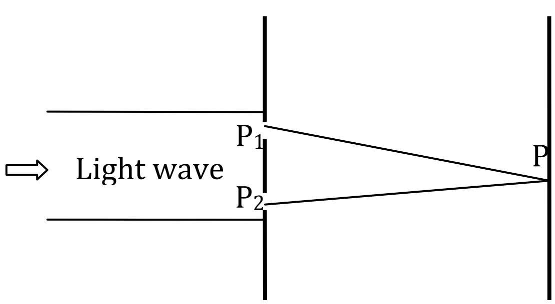
(c) GaAs and GaN are two important materials for fabrication of laser diodes operating in near-infrared and ultraviolet, respectively. Both materials are semiconductors with the same crystalline structure and consequently they both have direct bandgap. At temperature of 300K the bandgap in GaAs is 1.43eV, refractive index 3.3, while in GaN bandgap is 3.44eV and refractive index 2.67. From the measured spontaneous emission lifetime of the electrons in GaAs of 3 ns, estimate the spontaneous emission lifetime of electrons in GaN. (2 points).

Task 4.

(a) What are the most characteristic properties of laser beams? What is the relation between directionality and coherence? (1 point)

(b) One simple way of measuring the degree of spatial coherence between two points P_1 and P_2 on the wave front of a light wave is using Young interferometer. See the schematic picture below. The fringes around P can be observed, and a visibility V_p of the fringes can be defined. What is the definition of this visibility? (1 point).

(c) If measurements are made around a point P equidistant from P_1 and P_2, and the visibility of fringes obtained is V_p =0.6. The ratio $r=\langle I_1\rangle/\langle I_2\rangle$ between the average field intensities $\langle I_1\rangle$ and $\langle I_2\rangle$, measured in P when either one of the two holes in P_1 and P_2 are closed, is $r=0.2$. Calculate the magnitude of the first order spatial degree of coherence between points P_1 and P_2. (2 points)



Task 5.

(a) Consider a resonator for an Argon laser. The resonator consists of two concave spherical mirrors both with a radius of curvature of 4 m and spaced by a distance of 1 m. Calculate the spot size of the TEM_{00} mode at the resonator center and on the mirrors when laser oscillation occurs at the Ar^+ laser wavelength λ_{Ar}=514 nm. (1 point)

(b) Calculate the spot sizes on the mirrors if one of the mirrors is replaced by a plane mirror. Where the beam waist locates now? (1 point)

(c) You are asked to align an Argon laser with a confocal resonator using two mirrors of nominal radius of curvature R=2 m, Unfortunately, due to manufacturing errors, the radii of curvature of the two mirrors become $R_1=R+\Delta R$ and $R_2=R-\Delta R$, with R=2 cm. After spending unsuccessfully long nights in the lab trying to achieve laser action at the nominally confocal distance, you find out the laser works if the two mirrors are moved either slightly closer or slightly farther than the confocal position. Explain this result, and find the mirror spacing at which the laser starts working (i.e, how closer or farther should the mirrors move from the confocal position). (2 points)

Task 6.

(a) What is optical pumping for a laser? What are the main differences between coherent and in-coherent light pumping? (1 point)

(b) Consider a laser, where a 1 cm long Nd:YAG rod (refractive index 1.82) is longitudinally pumped by a diode laser array at 805-808 nm wavelength. The Nd:YAG resonant cavity is formed by a lossless plane mirror directly coated on one facet of the rod, and a 10-cm radius of curvature, 95% reflecting mirror separated by 5.5 cm from the plane mirror. The waist of the TEM_{00} laser mode is w_0=130 μm. The spot size of the pump beam provides good mode matching with this laser mode. Laser operates continuously at the wavelength 1.06 μm. $\sigma_e=2.8\times10^{-19}$ cm^2 and τ=230 μs. $\gamma=3\times10^{-2}$, and η_p=81%. Calculate the threshold pump power. (1 point)

(c) The above laser is obviously space dependent as the pump beam is spatially dependent. What will be the threshold pumping rate and population inversion under space dependent model? (1 point)

(d) Assume that the transverse efficiency is close to 1, calculate the slope efficiency η_s of the above laser. (1 point).