SK2411 Tenta 1 VT-2013

2013 May 20

Grading ABCDEFx/F Maximum points 24. Minimum points for grade above F: 12.

Task 1

a. (1 point). Liquid water has a prominent absorption peak at photon energies between 534 eV and 545 eV. Which wavelengths those energies correspond to? You are interested in generating amplification of stimulated emission in this spectral range. Which medium would you propose to use: solid state dielectric, semiconductor, gas? Explain your choice. (electron charge=1.602×10^{-19}C, Planck's constant= 6.626×10^{-34} J/s, speed of light=3×10^{8} m/s).

b. (1 point). One the other hand liquid water has very low absorption in the spectral range 300 nm - 500 nm which one can exploit for undersea communications and different underwater sensors. One possibility to reach these wavelengths is by using semiconductor laser diodes based on GaN. Propose other laser technologies for the same purpose.

c. (2 points). The maximum extractable energy in a laser amplifier can be estimated as $E_m = \Gamma_d l_m^2$ where Γ_d is the dielectric damage energy fluence and l_m is the minimum amplifier length at which amplified spontaneous emission saturates the amplifier. Prove that the maximum extractable energy is proportional to the small signal gain squared. (Hints: consider small signal amplification case and a single photon input at the beginning of the amplifier).

Task 2

a. (1 point). (i) Explain homogeneous and inhomogeneous broadening.

b. (1 point). (i) Explain briefly vibronic transitions. (ii) Give two examples of vibronic lasers. (iii) Can one call Nd^{3+}:YAG a vibronic laser material? Motivate your answer.

c. (2 points). We know that radiative lifetime in GaAs at T=300 K and electron-hole concentration of 10^{18} cm^{-3} is equal to 1.38 ns. GaAs index of refraction is 3.66 and bandgap energy 1.42 eV. Estimate the radiative lifetime in GaN at the same excitation conditions. GaN index of refraction is 2.3 and the bandgap energy 3.5 eV. Assume that the transition dipole moments are equal in GaAs and GaN.

Task 3

a. (1 point). The absorption spectrum of CO_2 molecule looks as shown in the Fig. 1. Explain which degrees of freedom are responsible for the transitions and explain briefly the structure of the spectrum. Make a sketch of the energy levels which would give such spectral shape.

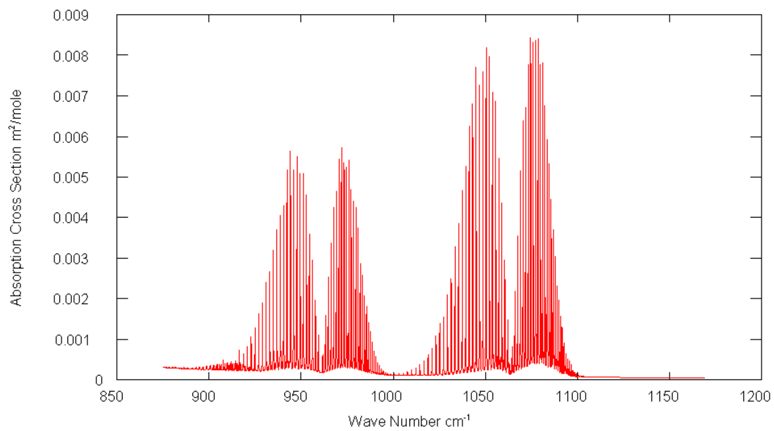

Fig. 1 Absorption spectrum of CO_2 gas

b. (1 point). Resonant energy transfer is widely exploited process in lasers. Give two examples.

c. (2 points). We have proved rigorously in the lectures that the laser reaches oscillation threshold when the critical population inversion is achieved giving the roundtrip gain exactly equal to the resonator losses. Further we learn that the gain in fact depends on the intensity circulating inside resonator, i.e. it decreases with increasing intensity due to gain saturation. Now consider a resonator with the single source of losses – an output coupler mirror with reflectivity R. The intensity circulating inside the laser then would be $I_{out}/(1-R)$, where I_{out} is the laser output intensity. The laser will reach threshold when gain equal to losses, i.e., $g = -\ln R$. Right at the threshold the intensity will be very low and gain is nonsaturated. However, as the intensity is increased by increasing pumping power, the gain has nowhere to go but drop due to saturation. That should lead to the situation where losses exceed the gain and laser stops working. Obviously this does not happen in reality and the output intensity as well as intracavity intensity continuously increase with increasing pumping. What is wrong in this naïve picture?

Task 4:

a. (1 pt) The active medium Nd:YAG has refractive index of n = 1.82 and gain linewidth of $\Delta\nu_0$ = 120GHz. A Nd:YAG laser (λ = 1.064μm) has a cavity length L=50cm, within which a Nd:YAG crystal of length l=10 cm is placed. Determine the number of longitudinal modes supported within the FWHM gain spectral range.

b. (1 pt) Explain, preferably with drawing, how a Fabry-Pérot interferometer or etalon is used in laser design for reducing the number of longitudinal modes.
c. (2 pts) You bought a Fabry-Pérot interferometer which is made of two identical air-spaced mirrors. First, assume that the mirrors are highly reflective, with no absorption or diffraction losses. Since the interferometer's specification sheet was unfortunately lost, you would like to determine more exactly its parameters. In order to do that, the normal-incident transmittance spectrum is measured. You find that the free spectral range of the interferometer is 3GHz and its resolution is 60MHz. Calculate its finesse, the separation of the mirrors, and mirror reflectivity. If the peak transmittance is 50%, what is the mirror loss?

Task 5:

a. (1 pt) A two-mirror cavity is formed by a convex mirror of radius R_1 = -1m and a concave mirror of radius R_2 = 1.5m. What is the maximum possible mirror separation if this is to remain a stable resonator?
b. (1 pt) Describe and explain the advantage of using unstable cavities in laser design.
c. (1 pt) A Nd:YLF rod 5mm in diameter, 6.5cm long, with 1.3×10^{20} Nd atoms/cm^3 is CW-pumped by two lamps in a close-coupled configuration. Energy separation between the upper laser level and the ground level corresponds to a photon wavelength of 940nm. The electrical pump power consumed by each lamp at the threshold, when the rod is inserted in the laser cavity, is P_{lamp} = 1kW. Assume that the rod is uniformly pumped with an overall pump efficiency η_p = 4%. Calculate the critical pump rate.
d. (1 pt) What is the consequence of spatial hole burning to the operation of a CW laser based on homogeneously-broadened gain medium?

Task 6:

a. (2 pt) Assume Nd:YAG has an effective stimulated cross-section $\sigma_e = 2.8\times10^{-19} cm^2$, an upper-level lifetime of τ = 230μs, a refractive index of n = 1.82. A Nd:YAG CW laser (λ = 1.064μm) has the following parameters: cavity length L=9cm; Nd:YAG crystal thickness l = 5mm; two mirrors with power reflectivities R_1 = 100% and R_2 = 94%; internal logarithmic loss per transit γ_i = 0.03. Calculate the critical pump rate and the critical population inversion. The laser operates with a pump rate twice as much as the critical pump rate. Assume that the beam has a circular cross-section with a uniform intensity distribution and the beam radius is 0.15mm (much smaller than the Nd:YAG crystal transverse size). Calculate the photon number in the cavity and the laser output power.
b. (1 pt) (Continued from Task 4a) If the laser is now fundamentally mode-locked through the amplitude-modulation technique, calculate modulation frequency, temporal

separation of two adjacent pulses, and temporal duration of one pulse. Neglect the effect of spatial hole burning.

c. (1 pt) Explain how the Ti:Sapphire laser illustrated in the following figure achieves mode-locking.

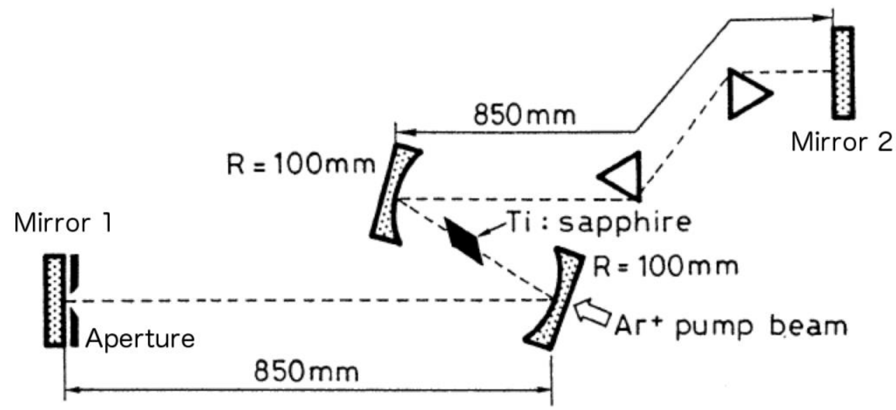

Fig.2. Mode-locked Ti-Sapphire laser