SK2411, IO2659 Examination tasks

VT12, 2012 May 29

Task 1

(a) (1 point) In bulk semiconductors optical gain spectrum depends on the charge carrier concentration as shown in the Fig.1. Explain the physical reason for the most obvious features: the spectral gain broadening and shift of the gain peak to higher frequencies with increasing carrier concentration.

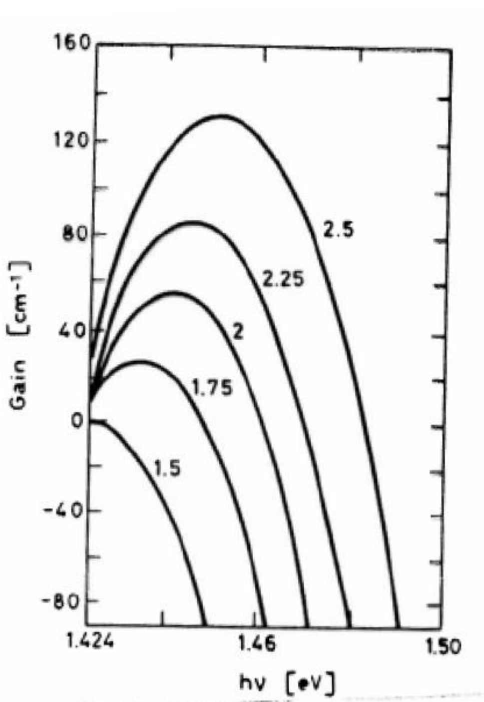


Fig. 1

(b) (1 point) Why is it beneficial to use quantum wells or quantum dots in semiconductor lasers?

(c) (2 points) Calculate radiation pressure exerted on a perfectly absorbing surface by a laser beam focused to a round spot with the spot radius of 100 µm. The absorbing surface is in vacuum (index of refraction =1). The laser pulse length is 100 fs and the pulse energy is 3.14 µJ. Compare this radiation pressure to the atmospheric pressure of about 10^5 Pa. 1 Pa=1 N/m^2. (Hint: from thermodynamics we know that pressure times volume is equal to energy, pV=kT, therefore the pressure is equal to energy density).

Task 2

(a) (2 points) You have two different species of ions which have dipole-allowed transitions with equal transition dipole matrix elements. The only spectroscopic difference between those ions is that one is emitting near-infrared radiation at 750 nm, while another is emitting in ultraviolet at 325 nm. You need to make lasers based on these transitions in the ions and the laser cavities at both wavelengths have identical losses. Which laser would require higher pump power to reach threshold? Estimate, approximately, how many times larger.

(b) (1 point) In He-Ne gas lasers a typical emission linewidth is about 1 GHz. Natural linewidth of the emitting atoms, is few MHz. What is the reason for this broadening? Is it homogeneous or inhomogeneous and why?

(c) (1 point) In optical communications there is increasing need to amplify multiple channels situated at slightly different wavelengths. The most economic option would be to amplify all channels in a single optical amplifier. The problem however can arise due to cross-talk between channels, i.e. when amplification of pulses at one wavelength, representing data in one channel, would affect amplification factor of optical pulses at another wavelength, representing simultaneous data in other channel. At the telecoms optical range around the wavelength of 1.55 µm you have two amplifier choices: a semiconductor diode optical amplifier or Er^{3+}-doped glass fiber amplifier. Which amplifier and why would you choose in order to minimize the cross-talk effect?

Task 3

(a) (2 points) Part of experimental absorption spectrum of CO_2 molecule is shown in Fig.2. On the horizontal axis the wavelength is given in microns. Explain why the spectrum has this shape and how the multiple narrow lines arise.

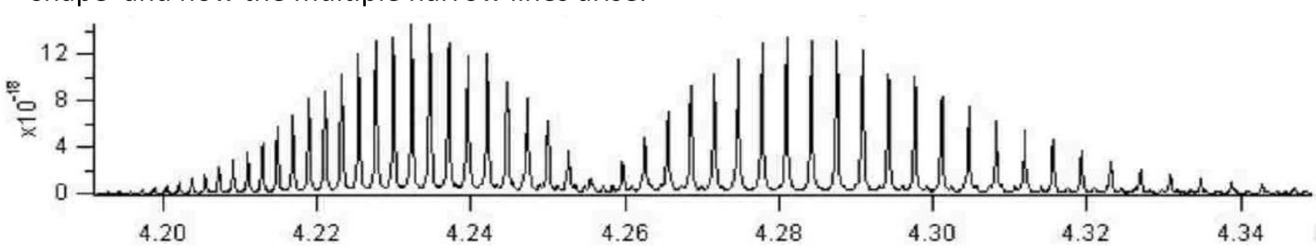


Fig.2

(b) (2 points). (1)From Fig.2 estimate the frequency of this particular vibrational mode in CO_2. (2) Propose a method based on a simple mathematical formula how moment of inertia of CO_2 molecule could be extracted from such spectrum.

Task 4:

(a) (1 point). Explain what Brewster angle is. Give one scenario, preferably with drawing, how it can be used in a laser cavity design.

(b) (1 point). You are very famous in making customized lasers. A customer wants a single-mode 0.5m-long continuous-wave (CW) Nd:YAG laser (λ=1064nm) whose Gaussian output should have a divergence angle of 0.05 degree. You decide to construct the laser using the symmetric near-planar resonator scheme. What will be the size of the beam waist in the resonator? Assume there is no additional lens inside the cavity. What is the Rayleigh range of the beam? What is the curvature of the wavefront at the Rayleigh-range position?

(c) (2 points). [Continued from (b)] If you put a thin lens with a focal length of 5cm at 19.5cm away from the output-end of the laser, what will be the beam spot size and the wavefront curvature just after the lens? Assume the lens has a large enough aperture.

Task 5:

(a) (1 point). What is the value of the M^2 factor of a perfect Gaussian beam? When you buy a relatively high-power (>5W) CW Nd:YAG laser, you will mostly likely find that its beam quality (usually defined in M^2 factor) worsens in the specification sheet as compared to the values for lower-power lasers. What are the possible reasons?

(b) (2 points). [Continued from 4(b)] The 0.5m-long resonator for constructing the Nd:YAG laser (λ=1064nm) has two mirrors with reflectances R_1=100% and R_2=98%. Assume that the resonator suffers no additional loss other than the mirror loss. Calculate the cavity life time τ_c and the quality factor of the resonator. How many round trips a group of photons can travel before the photon number decays to 1/e of the original value?

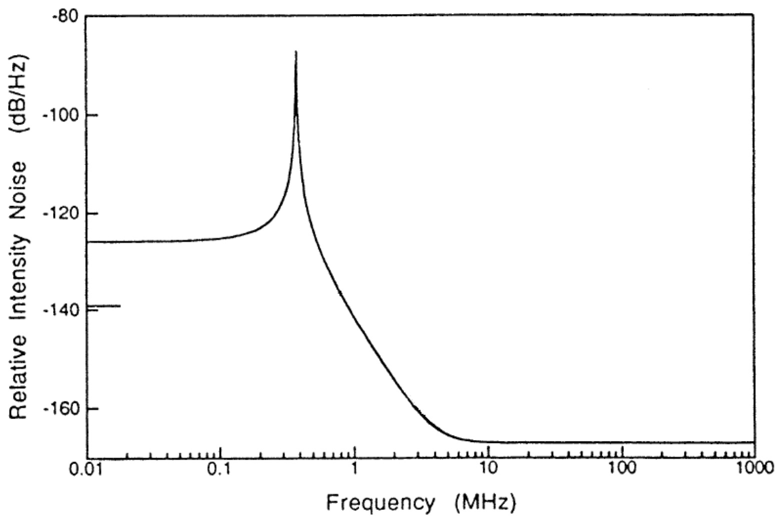
(c) (1 point). What pumping methods are appropriate for gas lasers? Why?

Task 6:

(a) (1 point). [Continued from 4(b)] Apple now wants you make a laser which can be used to engrave characters on the backside (made of “liquidmetal”, a kind of metal alloy) of their iPhone5. You remember the CW Nd:YAG laser which you made for the previous customer. It has a CW output power of 2W. Although a bit low, and you have no money for additional pump sources, you think you can increase drastically the power of the laser to make it suitable for engraving on a liquidmetal surface. Of course you have to do some further customization. What will you do to the CW laser exactly before you make a first trial on a liquidmetal surface?

(b) (1 point). A shutter is placed inside the cavity of a 4-level laser system. The active medium in the laser has an effective upper-level life time of τ. With the shutter closed, the laser is pumped continuously with a pump rate R_p. What is the maximally achievable population inversion N? At a time instance $t_0 >> \tau$, the shutter is suddenly opened. Show schematically the variations of the population inversion and the photon number as a function of time, starting from time 0 when pumping started.

(c) (1 point). A single-transverse-mode CW Nd:YAG laser shows a relative intensity noise spectrum (obtained by Fourier transform of the time-domain relative intensity noise signal) as in the following figure. Explain the existence of the sharp peak. What parameters determine its frequency?



(d) (1 point). How do you achieve mode-locking with a Pockels cell?