Limpert / Nolte

Laser Physics - Fundamentals and Applications - summer semester 2015, 14.07.2015

# Exam

Only a calculator is allowed as help. You can obtain a maximum of 39 points. Good Luck!

## Problem 1 (5 points)

a) Define homogeneous broadening and name two physical effects responsible for it. (2 points)

b) Define inhomogeneous broadening and name two physical effects responsible for it. (2 points)

c) Which condition do you need to get stable multi-wavelength laser operation with an homogeneously broadened medium? (1 point)

## Problem 2 (3 points)

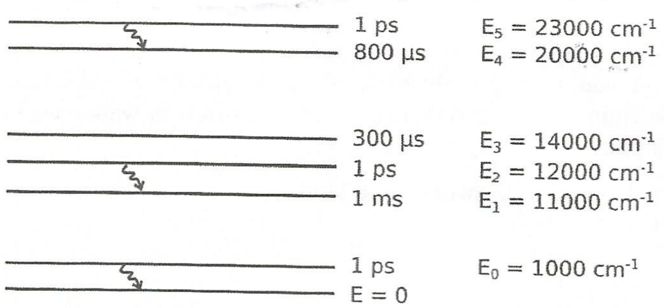
Assume three laser materials with the same emission cross-section ($\sigma = 3 \cdot 10^{-24}\,\mathrm{m}^2$), doping concentration ($n_{tot} = 1 \cdot 10^{25}\,\mathrm{ion/m}^3$), volume, lifetime of the excited state, emission wavelength and pump rate. The main characteristics of these materials are listed in the following table:

| Parameter | Material I | Material II | Material III |
|---|---|---|---|
| $g_o(1/\mathrm{m})$ | 30 | 30 | 15 |
| $I_{sat}(\mathrm{W/cm}^2)$ | $6 \cdot 10^4$ | $10^5$ | $10^5$ |

Identify which of the materials from the table above is a 4-level system, which a 3-level system and which an inverse 3-level system. Justify your answer.

## Problem 3 (7 points)

Imagine that we have a material with the following energy diagram:




a) Explain what quantum defect and quantum efficiency are. (1 point)

b) How would you choose the pump and signal wavelengths to get an efficient 4-level system with the smallest possible quantum defect? (1 point)

c) How would you choose the pump and signal wavelengths to get an efficient 3-level system with the smallest possible quantum defect? (1 point)

d) How would you choose the pump and signal wavelengths to get an efficient inverse 3-level system with the smallest possible quantum defect? (1 point)

e) Which of these configurations would you choose to build a high pulse-energy Q-switched laser? Why? (1 point)

f) Is it possible to get an emission wavelength shorter than the pump wavelength in this system without violating the energy conservation? If yes, how would this work? Which combination of signal and pump wavelength would you need? (2 points)

## Problem 4 (4 points)

a) An active medium with a quantum efficiency of 0.9 is optically pumped at 800 nm wavelength and emits at 1600 nm wavelength. Calculate the maximum optical to optical efficiency in this system! (1 point)

b) Calculate the quantum-defect-induced heat (in W) in the system for an extracted signal power ($P_{extr} = P_{out} - P_{in}$) of 100 W. (1 point)

c) Briefly describe two ways in which the generated heat can degrade the laser operation and propose a solution for each. (2 points)

**Problem 5** (4 points)

We assume a passive (no gain medium present) optical cavity of length $x = 2\,\text{m}$ consisting of two mirrors. The power enhancement factor of such a cavity is given by $V = P_{IC}/P_{in}$ with $P_{IC}$ being the power inside the cavity when the steady-state is reached and $P_{in}$ being the CW power incident in the cavity.

a) Assume that both cavity mirrors have a radius of curvature $R = 1.36\,\text{m}$. Draw the stability diagram for resonators indicating the stability regions in general and mark the position of the given cavity in it. (1 point)

b) Assuming a steady-state enhancement factor $V = 100$ and an input CW power $P_{in} = 50\,\text{W}$. How much energy can be stored in the given cavity? (1 point)

c) If it were possible to tilt the first cavity mirror instantly in order to couple the stored energy out of the cavity (once that the build-up of the energy inside it has reached its steady-state), which would be the temporal duration of the generated signal? Sketch its temporal evolution. (2 points)

**Problem 6** (5 points)

For an application we need a peak intensity (i.e. maximum intensity in both space and time) of $I_p = 102 \cdot 10^{11}\,\text{W/m}^2$ with a minimum average power of $P_{ave} = 25\,\text{W}$. Take into account that the $1/e^2$ radius of the gaussian beam at the focal point is $w_o = 25\,\mu\text{m}$ and that the maximum energy that can be launched in the material before damaging it is $E_{dam} = 500\,\mu\text{J}$

a) Explain the operating principle of Q-switching with the help of a graph showing the temporal evolution of the inversion, the losses and the output power. (2 points)

b) Assuming that for the application above we use pulses with the highest possible energy and that their temporal shape is gaussian, calculate: the peak power ($P_{peak}$), the FWHM pulse duration ($\tau_{pulse}$), the repetition rate of the pulse train and the FWHM spectral bandwidth in wavelength (consider an emission wavelength of $\lambda = 1\,\mu\text{m}$). (2 points)

c) Which kind of pulsed laser (Q-switched or Mode-locked) would you need for this application? Justify your answer. (1 point)

**Problem 7** (7 points)

Different media should be investigated by means of saturation spectroscopy. Assume that there is only one transition within the Doppler-broadened spectrum. Using a single laser source, sketch the setup in case of a medium showing strong absorption and explain the main components. Which physical quantity is detected? Sketch the detected signal.

**Problem 8** (4 points)

a) Draw a qualitative term scheme for spontaneous Raman scattering! Indicate between which levels the Raman scattered light is observed. Denominate the observed radiation. (2 points)

b) Draw a qualitative Raman spectrum (neglect higher harmonics). Where can the Raman transitions discussed in a) be found in the spectrum? (2 points)

*Physical constants and units:*

$h = 6.626 \cdot 10^{-34}$ Js

$c = 2.998 \cdot 10^{8}$ m/s

$e = 1.602 \cdot 10^{-19}$ C

$\epsilon_0 = 8.854 \cdot 10^{-12}$ F/m

$m_e = 9.1093 \cdot 10^{-31}$ kg

*Helpful formulas:*

$\lambda[\mathrm{m}] = 1/(100 \cdot \Delta E[\mathrm{cm}^{-1}])$

Gauss : $A \cdot e^{-2\left(\frac{x-x_0}{\Delta x}\right)^2}$

$\int_0^\infty e^{-2\frac{r^2}{w^2}} r dr = \frac{w^2}{4}$