EV-A (Advanced Course in Experimental Physics): Lasers, Atomic Physics and Quantum Optics
Universität Erlangen–Nürnberg
Winter Term 2018/2019

Exercise Sheet 8 (13.12.2018)

Lecture: Tuesday, Thursday 12:00 - 14:00, lecture hall HH
Tutorial: Wednesday: 10:00 - 12:00, SRLP 0.179 | Thursday 08:00 - 10:00, SR 00.732, SR 01.779, SRLP 0.179
Hompage: www.qoqi.nat.fau.de/teaching/lectures

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1) Gas laser

As a consequence of the Doppler broadening, the gain coefficient γ_0 of a gas laser is given by:

$$\gamma_0(\nu) = \gamma_0(\nu_0) e^{-\frac{(\nu-\nu_0)^2}{2\sigma_D^2}} ,$$

where the full width at half maximum (FWHM) of the gain coefficient is given by $\Delta\nu_D = \sqrt{8\,\ln(2)}\sigma_D$.
(a) Derive the bandwidth B, inside which laser operation sets in, as a function of $\Delta\nu_D$ and the ratio $\frac{\gamma_0(\nu_0)}{a_\gamma}$. Here, a_γ is the loss coefficient of the resonator.
(b) A He-Ne-laser has a Doppler broadening of $\Delta\nu_D = 1,5$ GHz and a gain coeffcient of $\gamma_0(\nu_0) = 2 \times 10^{-3}$ cm^{-1}. The resonator has a length of $L = 10\,$cm and its mirrors have reflectivities of $R_1 = 1$ and $R_2 = 0.97$, respectively. Assume that there are no other losses in the resonator and that the refractive index inside the laser is $n = 1$. Determine the number of lasing modes inside the resonator.
(c) The active medium in a gas laser has a length of 68 cm and a so-called small signal gain of G_0 (i.e., the gain $G_0 = \kappa\, n_{st} = \kappa\, R/\gamma$ below the lasing threshold) of $G_0 = \frac{0{,}08}{m}$ c. Determine the photon flux density of the outcoupled light in units of the saturated flux density γ/κ, if the transmission coefficient of the outcoupling mirror is 3.7%. The second mirror has a transmission coefficient of 4%. Other losses can be neglected. Determine the optimal transmission coefficient of the outcoupling mirror in order to maximize the outcoupled laser power.

2) Thermal lensing

Let us look at a cylindrical homogeneous laser crystal of length L and radius R heated by a pump light with thermal power P of spatially and temporally constant power density. Both end facets of the crystal are thermally isolated, while the surface of the cylinder is kept at a constant temperature T_0 by contact to a cooler. Hereby, a temperature distribution is created, which depends only on the radial position r.
(a) Determine the function $T(r)$ from the stationary heat equation $\Delta T = -Q/K$, where Δ is the Laplace operator, $Q = P/V = P/(\pi R^2 L)$ is the thermal power per volume and K is the heat conduction coefficient of the crystal (in units of W/Km).
Hint: Use the Laplace operator in cylindrical coordinates and the ansatz $T(r) = ar^2 + br + c$, where a, b and c are coefficients to be determined.
(b) The radial distribution of the temperature $T(r)$ creates via $n = n(T)$ a refractive index profile that implicitly depends on the radius r. This will lead to a “thermal lens”. Calculate the refractive power (inverse value of the

focal length) of the corresponding lens.
Hints:
- The action of a thin lens with focal length f reads $\exp(ikr^2/2f)$.
- Simply assume $\partial n/\partial T \approx const.$
- Additional temperature effects such as mechanical tensions shall be neglected (although these can be relevant)
(c) Discuss which implications the formation of a thermal lens might have for a laser.