OC Problem Set 6

Friday, June 5, 2015

Which statements are correct (more than one answer might be correct, give the reason for your decision)? (this part is optional)

1. Induced absorption is
   a) the process underlying optical amplification.
   b) the process underlying optical detection.
   c) nonsensical.
   d) a reason for optical loss.
   e) a source of optical noise.

2. Induced emission is
   a) the process underlying optical amplification.
   b) the process underlying optical detection.
   c) nonsensical.
   d) a reason for optical loss.
   e) a source of optical noise.

3. Spontaneous absorption is
   a) the process underlying optical amplification.
   b) the process underlying optical detection.
   c) nonsensical.
   d) a reason for optical loss.
   e) a source of optical noise.

4. Spontaneous emission is
   a) the process underlying optical amplification.
   b) the process underlying optical detection.
   c) nonsensical.
   d) a reason for optical loss.
   e) a source of optical noise.

5. Population inversion
   a) is impossible with systems in thermal equilibrium.
   b) can be achieved with a two-level system.
   c) can be achieved with a three-level system.
   d) can be achieved with a four-level system.
   e) causes difficulties in paying pensions.
   f) can be achieved in semiconductor structures.
   g) is natural with systems in thermal equilibrium.
   h) needs a pump mechanism which transfers energy to the system.

6. Laser radiation is
   a) more powerful than LED radiation for the same input electrical power.
   b) possibly harmful for the eye.
   c) spectrally broad.
   d) spatially widely divergent.
   e) always visible.
   f) efficiently coupled to singlemode fibers.
   g) efficiently coupled to multimode fibers.

7. In a semiconductor pn-diode laser, population inversion occurs if
   a) the energy $hf^{(e)}$ of emitted photons is larger than the bandgap energy W_G.
   b) the energy $hf^{(e)}$ of emitted photons is smaller than the difference of the quasi Fermi levels $W_{Fn}-W_{Fp}$.
   c) the energy equivalent eU of junction voltage U is larger than the energy $hf^{(e)}$ of emitted photons.
   d) a sufficiently large reverse current is applied.
   e) a sufficiently large forward current is applied.

8. Compound materials are used
   a) for adjusting the bandgap.
   b) for adjusting the lattice constant.
   c) for adjusting bandgap and lattice constant independently.
   d) for an improved carrier lifetime.
   e) for avoiding the development of crystal defects.
   f) for creating direct semiconductors.
   g) for all of the above reasons.

9. Compound semiconductors
   a) can also contain metal atoms.
   b) have a composition, where all the constituents contribute in equal parts.
   c) are always direct semiconductors.

10. Heterojunctions
    a) confine carriers.
    b) have a larger refractive index where the bandgap is larger
    c) confine light.
    d) are essential for achieving a high radiation efficiency.

11. Optical emission from a heterojunction is observed
    a) if the diode is reverse-biased.
    b) at photon energies below the bandgap energy.
    c) only at photon energies smaller than the difference of the quasi Fermi levels.
    d) basically at all photon energies larger than the bandgap energy.

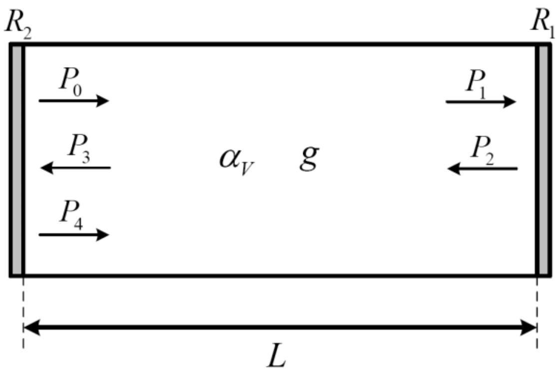
12. Band-to-band transitions can occur
    a) radiatively through Auger recombination.
    b) nonradiatively via recombinations via impurities in the forbidden band.
    c) radiatively by recombinations of CB electrons and VB holes.

Problem: Fabry-Perot Resonator

A laser oscillator consists of an active medium that is capable of providing optical amplification. Placed around the amplifying medium there is an optical resonator that provides the necessary optical feedback. A simple resonator is the Fabry-Perot resonator as depicted below. Between the two parallel mirrors (power reflection coefficients R_1, R_2) there is the active medium (length L = 500 µm, modal power gain g; loss constant $\alpha_V = 25\ \text{cm}^{-1}$) where longitudinal modes exist according to the Fabry-Perot resonance condition.

For stationary laser oscillation both the amplitude condition and the phase condition must be fulfilled: After a complete round-trip of the lightwave in the resonator (after 2L), all losses are compensated and no phase shift occurs, i.e.

$$\exp\left(\mathrm{j}\omega_0\tau\right)\exp\left[\frac{1}{2}\left(\Gamma G-\frac{1}{\tau_P}\right)\tau\right]=1.$$



a) Neglecting phase shifts at the mirrors, what is the resonance condition for longitudinal modes? Estimate the number of half-waves for a Fabry-Perot resonator in GaAs: λ_0 = 850nm and n ≈ n_g ≈ 3.65! What is the frequency spacing Δf between two adjacent longitudinal modes?

b) Calculate the optical powers P_n (n = 1, 2, 3) at the mirrors during one round-trip as well as the optical power P_4 at the beginning of the subsequent round-trip as a function of P_0, R_1, and R_2, if $P(z) \propto \exp\left[\left(\Gamma g-\alpha\right)z\right]$.

c) The losses at the mirrors can be distributed over a round-trip through the resonator. Rewrite the expression for P_4 from b) accordingly, and determine the equivalent loss coefficient α_R for $R_1 = R_2 = R$ (GaAs – air interface)!

d) At stationary laser oscillation, the lightwave in the resonator is neither amplified nor attenuated, i.e. $P_4 = P_0$ (we assume that also the phase condition is fulfilled). How big is the threshold value of the modal power gain constant g_S of the power gain at lasing threshold?

e) The modal power gain g in semiconductors is proportional to the carrier concentration n_T. For GaAs it holds that

$$g = g_0\cdot\left(n_T/n_t-1\right), \text{ where } g_0 = 330\ \text{cm}^{-1},\ n_t = 1.1\times10^{18}\ \text{cm}^{-3}.$$

At the transparency carrier concentration n_t the power gain constant is $g = 0$. Determine the threshold carrier concentration n_{TS} for the calculated threshold values g_S from d)!

For questions and suggestions on the OC tutorial please contact:

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