Photonics, Spring 2025

Submit your answers as a PDF file via Google Classroom before deadline (14.04.2025 at 10.00). If problems, contact the course assistant joonas.mustonen@helsinki.fi.
If you utilize LLM models as assistance in solving the task, please specify their usage at the end of your submission.

Exercise 10, 14.4.2025

1. **Electrons in GaAs** (3 points)

As a conduction band electron travels freely within the crystal lattice, it encounters a periodic potential energy that effectively manifests an inertial resistance to acceleration. The effective mass m_e^* is a quantum mechanical quantity that takes into account this resistance. The average kinetic energy of an electron is then simply $K = \frac{1}{2}m^*\langle v\rangle^2$. The root mean square velocity $\sqrt{\langle v^2\rangle}$ is called the thermal velocity v_{th}.

Recall that in Exercise 8 Problem 2c we derived, from the electron concentration distribution $n(E)$, that the average CB electron energy is $\frac{3}{2}k_BT$.

Consider then a nondegenerately doped GaAs semiconductor at room temperature (300 K). Let the electron effective mass m_e^* be 0.067 m_e, and the electron drift mobility $\mu_e = 8500\ \mathrm{cm^2V^{-1}s^{-1}}$.

a) Calculate the thermal velocity of the electrons in the CB.

b) Given τ_e is the mean free time between electron scattering events (between electrons and lattice vibrations) and if $\mu_e = e\tau_e/m_e^*$, calculate τ_e.

c) Calculate the drift velocity $v_d = \mu_e E$ of the CB electrons in an applied field E of $10^5\mathrm{Vm^{-1}}$. What is your conclusion?

2. **LED output spectrum** (2 points)

a) The typical width of LED output spectrum in units of energy is $\approx 3k_BT$. Show that the linewidth $\Delta\lambda$ is approximately:

$$\Delta\lambda \approx \lambda^2 \frac{3k_BT}{hc}$$

Hint: What is the energy of a photon in terms of its wavelength? What does the spectral distribution of a single color LED look like? What would the derivative of the spectral distribution look like near the half maximum? Could you then make an educated approximation of $d\lambda/dE$?

b) Keeping in mind that conduction band electrons have an energy distribution, the lowest conduction band energy level and the highest valence band energy level form the familiar bandgap energy E_g. The maximum electron concentration in the CB is at $\frac{1}{2}k_BT$ above E_g.
In LEDs, the higher energy photons corresponding to this maximum can become reabsorbed in the material producing high energy electrons and holes. These photogenerated high energy electrons and holes can recombine, emitting secondary photons with lower energies. For this reason, the photon emission spectrum of LEDs is wider ($\approx 3k_BT$) than what would be expected from the electron density distribution.
The bandgap of a GaAs LED is 1.42 eV at 300 K. The bandgap energy decreases with temperature as $dE_g/dT \approx -4.5 \times 10^{-4}\mathrm{eVK^{-1}}$. Compute the change in the peak (central) wavelength of emitted photons if the temperature changes 10°C.

3. **Active Hyperspectral Imager (AHI)** (3 points)

Read an article: *Teemu Kääriäinen and Timo Dönsberg, "Active hyperspectral imager using a tunable supercontinuum light source based on a MEMS Fabry–Perot interferometer," Opt. Lett. 46, 5533-5536 (2021)*

a) Why do supercontinuum lasers generate broadband infrared emission, eventhough lasers are monochromatic light sources?

b) What is MEMS Fabry-Perot interferometer and what is the benefit to use it with broadband light source?
c) MEMS Fabry-Perot interferometer changes its wavelength by adjusting the air gap between mirrors without any mechanical parts. How much the distance between mirrors needs to be changed that from the minimum wavelength to its maximum wavelength?