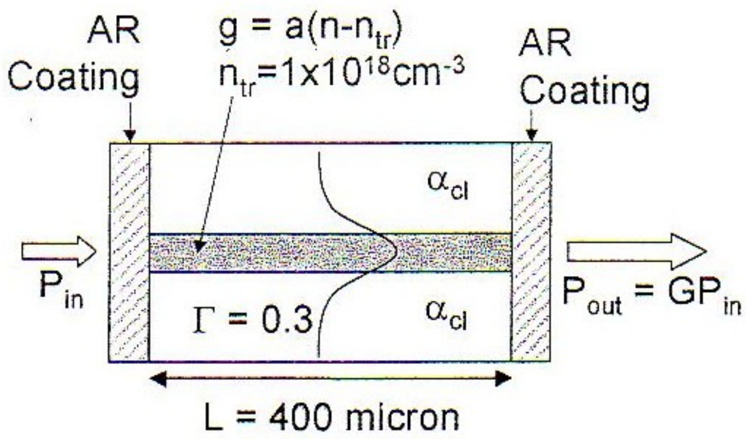
S-104.3310 Optoelectronics Feb 7, 2019

Exercise 4: Lasers III, SOAs and modulators

1. Let's study a heterojunction laser for optical telecommunication. The laser threshold current is 100 mA and the electron lifetime is 6 ns. a) What is the response time of the laser if the injection current is raised abruptly from 0 to 1.3 A? b) If the length of a pulse should be at least 0.4 ns, what is the maximum frequency at which the laser can be pulsed if the laser is unbiased (minimum injection current = 0 A) and the maximum injection current is 1.3 A? Assume that the pause time between pulses is also 0.4 ns. c) What is the maximum frequency, if the laser is biased with a current of 80 mA?

2. A GaAs laser has a resonance frequency of f_r = 3 GHz. The other relevant parameters of the laser are τ_p = 2 ps, $\Gamma = 0.9$ and $\bar{\varphi} = 10^{18}$ cm^{-3}. The photon lifetime in the cavity is τ_p = 2 ps. Let us also assume that the thickness of the active layer is d = 0.1 μm. a) Calculate the differential gain in the laser. b) Calculate the angular frequency ($\omega = \omega_{max}$) at which the transfer function $H(\omega)$ attains the maximum. c) Calculate the ratio of the transfer function $H(\omega_{max})$ to its direct current value $H(0)$.

3. A Fabry-Perot semiconductor laser (spatially single-mode) can be turned into a semiconductor optical amplifier (SOA) by preventing the feedback by coating the facets with antireflection (AR) coatings (sketched below). Estimate the carrier density needed for an overall optical gain of G = 20 dB, using the SOA parameters: an active region length of 400 μm, carrier density at transparency $n_{tr} = 1\times10^{18}$ cm^{-3}, and optical confinement factor 0.3. Assume small signal conditions with no output power or gain saturation. Gain coefficient is given by $g = a(n - n_{tr})$ with a gain constant of $a = 2.5\times10^{-16}$ cm^2. Losses in the cavity are mainly caused by free carrier absorption in the doped cladding regions; use the absorption coefficient of $\alpha_{clad} = 50$ cm^{-1} for the cladding layers.



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4. a) Calculate the change in refractive index in GaAs for an applied electric field of 2×10^5 V/cm. b) Calculate the value of V_π for a transverse GaAs modulator (see updated lecture slides for the difference in longitudinal/transverse EOMs) when the wavelength of incoming light is 1.1 μm (use electro-optic coefficient of 1.6×10^{-12} m/V). The waveguide is 1 μm thick and 1.5 mm long. c) A phase shift of π is needed to produce in a longitudinal electro-optical modulator having a length of 150 μm. Calculate the linear electro-optical coefficient the active material has to have in order to achieve the required phase shift with a bias voltage of 10 V. The refractive index of the material is about 3.5, the thickness of the active layer is 1 μm and the operation wavelength is 1.55 μm.

5. The absorption coefficient due to excitonic absorption in a quantum well is given by

$$\alpha_{ex}(\ \omega) \cong \frac{2.9\times10^3}{\Delta\varepsilon L_z}\exp\left[-\frac{\left(\varepsilon^{ex} - \ \omega\right)^2}{\sqrt{q}\left(\Delta\varepsilon\right)^2}\right],$$

where Δε is the linewidth of the absorption peak and the well width L_z is in Å. Calculate the on-off ratio of a 100Å GaAs/$Al_{0.2}Ga_{0.8}As$ QCSE modulator under an applied field of 100 kV/cm. The active region consists of 100 periods of the MQW. The heavy-hole exciton resonance has a linewidth of 2.5 meV and the incident photon energy coincides with the exciton energy at zero bias.