University of California, Santa Barbara
Dept. of ECE

Name Solutions

ECE 228B
Midterm Exam
Spring 2011

This is a closed book exam. You are allowed to use both sides of a single 8.5"x10" sheet of paper for formula and constants. Calculators are only allowed for numerical computation only and not for storage of formulae. Clearly state all approximations and assumptions. You will only be graded for work shown. **Good Luck!**

Problem 1	Problem 2	Total
50 pts	50 pts	100 pts

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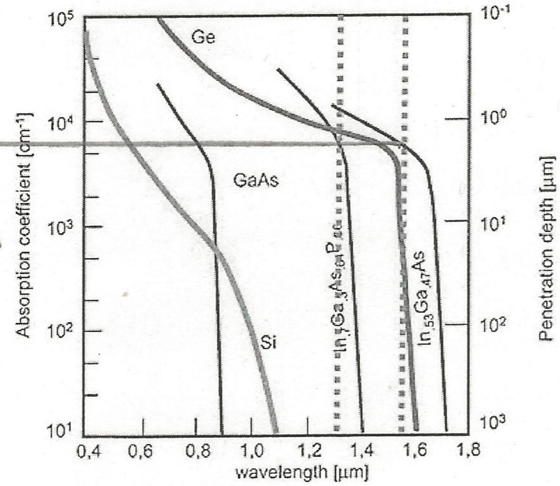
Problem 1 (50 pts)

An $In_{.53}Ga_{.47}As$ p-i-n photodiode, with a 90% anti-reflection coating (at 1.55 μm), illumination region thickness of 3.3 μm, 7.5GHz bandwidth and 2nA dark current is illuminated with +3dBm 1.55 μm CW light.

α $In_{.53}Ga_{.47}As$ $= 8000\ cm^{-1}$



Part A: 25 pts

Determine the SNR due to shot noise only.

from above $\alpha = 8000\ cm^{-1}$

Shot Noise Limited SNR

$$\frac{I_p^2}{\sigma_{sh}^2} = \frac{(R P_{in})^2}{2q(R P_{in} + I_d)\Delta f}$$

Responsivity

$$R = \frac{\eta q}{h\nu} = \frac{(1-R)(1-e^{-\alpha L})\,q}{h\nu} = \frac{(1-0.1)(1-e^{-8000\,cm^{-1}\cdot 3.3\mu m})\,q}{1.28\times10^{-19}\ J}$$

$$= 1.12\ A/W$$

$$SNR\Big|_{shot} = \frac{(2.25\ mA)^2}{2q(2.25mA + 2nA)(7.5\times10^9)}$$

$$= 9.36\times10^5 = 59.7\ dB$$

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Part B: 25 pts

Calculate the minimum received optical power for an SNR of 15dB when shot noise is the only noise source and the detector is cooled to drive the dark current down to 0.1nA.

$$(R P_{in})^2 = SNR\, 2q\,(R P_{in} + I_d)\,\Delta f$$

Since I_d is so low

$$R P_{in} \cong SNR\, 2q\, \Delta f$$

$$P_{in} \cong \frac{SNR\, 2q\, \Delta f}{R}$$

$$= \frac{(31.6)\, 2q\, \Delta f}{1.12}$$

$$= 67.\ nW$$

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Problem 2 (50 pts)

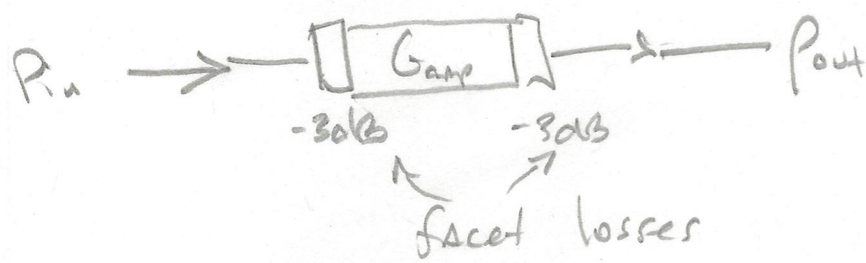
In this problem we first consider a semiconductor gain medium used as an optical amplifier, then embedding this gain medium in a cavity to realize a tunable laser. An InGaAsP-InP 350μm long active waveguide with zero reflection at the facets (AR coated), has a peak gain coefficient that can be approximated by

$$g_p \approx a\left(\frac{\Delta n}{\Delta n_T} - 1\right)$$

Assume a = 120 cm^{-1}, $\Delta n_T \approx 1.75 \times 10^{18}$ cm^{-3}, α = 600 cm^{-1}, a FWHM gain bandwidth of approximately 5nm, the gain peak at 1565nm, and a mode refractive index of $n'_{eff} = 4$.

Part A (25 pts)

Calculate the unsaturated total optical gain when the amplifier is biased to $\Delta n = 1.5\Delta n_T$ and optical coupling losses into and out of the amplifier are 3dB each facet.



$$P_{out} = (P_{in} - 3dB) + G_{amp} - 3dB$$

Total unsaturated gain $\quad P_{out} - P_{in} = G_{amp} - 6dB$

For $\frac{\Delta n}{\Delta n_T} = 1.5 \qquad g_p = 120\,(0.5) = 60\ cm^{-1}$

Total $G_{amp} = e^{(g_p + \alpha)L}$

$= e^{(60)(350 \times 10^{-4} cm)}$

$= 8.17$

$= 9.12$ dB $\qquad$ *

$G_{unsat} = 9.12\text{ dB} - 6\text{ dB} = 3.12$ dB

* ignoring α, which we should in principle use. Sorry it was confusing.

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Part B (25 pts)

Next, this active optical waveguide is fabricated into a DBR laser with a Bragg mirror on one end and a cleaved un-coated facet on the other end. Calculate the tuning current for a Bragg reflector that operates based on the free-carrier plasma effect so that the peak aligns with the gain peak of the semiconductor gain medium. Assume the lasing wavelength is set solely by the location of the Bragg mirror peak (i.e there is a Fabry-Perot resonance located at the gain peak). The mirror region is fabricated in a semiconductor waveguide with bandgap λ_g = 1300nm with an un-tuned Bragg peak at λ_B = 1550nm, β_{pl} = -1.3 x 10^{-20} cm^3, L=400 μm, d = 0.3μm, w = 2μm and an optical mode confinement factor Γ_t = 0.3. For the material assume an infinite spontaneous recombination time constant, bimolecular recombination constant B = 10^{-10} cm^3/s and Auger recombination constant C = 3 x 10^{-29} cm^6/s.

$V = 400\,\mu m \times 0.3\,\mu m \times 2\,\mu m = 2.4\times10^{-10}\ cm^3$

$I_g = qV(BN^2 + CN^3)$

We need to move the Bragg Mirror from 1550nm to the gain medium peak 1565nm.

$$\Delta\lambda = 15\,nm = \frac{\beta_{pl}\,\lambda_g\,\Gamma_t\,N}{n_{eff}}$$

$$|N| = \frac{(15\,nm)(n_{eff})}{\beta_{pl}\,\lambda_g\,\Gamma_t} = \frac{(15\,nm)(4)}{(-1.3\times10^{-20}\,cm^3)(1550\,nm)(0.3)}$$

$= -9.925\times10^{18}\ cm^{-3}$

$I_g = qV(BN^2 + CN^3)$

$= 1.5$ Amps.