EE 232 12/14/2010	**<u>Final Examination-2</u>** **EE 232 – Lightwave Devices**	Fall 2010 Prof. Ming Wu

- If you need additional conditions to solve a problem, please write down your assumptions.
- Answer in the space below the problem. If you need additional space, you can use the overflow pages in the back. Please indicate which page the answer continues in the lower-right corner.
- Please put a square box around your final answers for each problem.

Commonly used constants:

$\hbar = 1.054 \times 10^{-34}$ J·s	$q = 1.6 \times 10^{-19}$ C	$m_0 = 9.11 \times 10^{-31}$ kg
$k_B T = 0.026$ eV at 300K	$k_B = 1.38 \times 10^{-23}$ J/K	$\varepsilon_0 = 8.854 \times 10^{-12}$ F/m
1 eV $= 1.6 \times 10^{-19}$ J		

Your Name	
Student ID #	
Signature	

Problem	Points	Pt. Earned
1	15	
2	15	
3	15	
4	15	
5	12	
6	15	
7	13	
Total	100	

1. Consider the following 3 photoreceivers: (1) p-i-n photodiode, (2) APD with 10dB gain and 10dB noise figure, (c) APD with 20dB gain and 20dB noise figure. Assume all photodetectors have the same quantum efficiency of 100% (APD's quantum efficiency is measured in the absorption only, before multiplication). The load resistance is 50Ω. The photon energy is 1.24eV.

   a) Which receiver is best to pick up extremely weak optical signal, and why?

   b) Which receiver is best for very strong optical signal, and why?

   c) Find the best ranges of optical powers for the second receiver (APD with 10dB gain and 10dB noise figure).

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2. You are asked to design a surface-illuminated p-i-n photodiode with a 3dB bandwidth of 100GHz using a semiconductor material with an absorption coefficient of 10^4 cm^{-1}, an electron velocity is 10^7 cm/sec, and a hole velocity is 10^6 cm/sec. The photodiode is connected to a load resistance of 50Ω. For ease of optical coupling, the area of the photodiode should be as large as possible. The photon energy is 1.24eV. The dielectric constant of the semiconductor is $\varepsilon_r \varepsilon_0 = 10^{-12}$ F/cm.

a) Find the dimensions of the photodiode such that the optimum frequency is 100 GHz.

b) What is the quantum efficiency of your photodiode? Assume the surface is fully anti-reflection coated, and the internal quantum efficiency is 100%.

c) If we use the photodiode to detect simple ON-OFF modulated optical signal at 100Gb/s (assume 100 GHz bandwidth for simplicity), what optical power is needed to achieve a signal-to-noise ratio of 1000?

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3. Intersubband photodetectors can be realized in either N-type or P-type quantum wells. Consider a quantum well with a bandgap energy of 1 eV, an electron effective mass of $m_e^* = 0.1m_0$ and a hole effective mass of $m_h^* = 1m_0$. The intraband scattering time is 0.1 ps.

a) Using infinite well approximation, what is the quantum well width of the N-type and P-type intersubband photodetectors if the peak absorption wavelength of both detectors is 12.4 µm?

b) What is the *ratio* of their absorption coefficients if they have the same doping concentration (assume the second subband is completely empty)?

c) If we optimize the doping for each detector, what is the *ratio* of the maximum absorption coefficients for N-type and P-type intersubband photodetectors?

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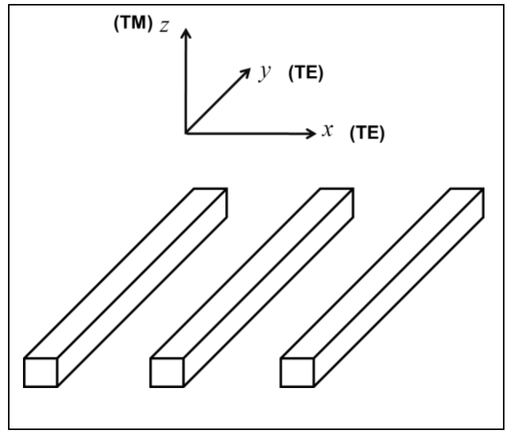
4. For the quantum wire sample shown on the right. The quantum wire has a square cross section.



a) What polarizations are allowed for the *interband* transition (i.e., from the first hole subband to the first electron subband)? Explain why.

b) What polarizations are allowed for the *intraband* transition in conduction band (i.e., from the first electron subband to the second electron subband)? Explain why.

c) What are the functional forms of the absorption spectra for the *interband* and *intrasubband* absorptions, respectively? Draw the qualitative shape of the absorption spectra.

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5. Consider two semiconductors with effective masses of the electrons and holes of (A) $0.1m_0$ and $0.2m_0$ and (b)) $0.2m_0$ and $0.4m_0$.

a) Find the ratio of their transparency carrier concentrations if these semiconductors are in bulk forms.

b) Find the ratio of their transparency carrier concentrations if these semiconductors are quantum wells with the same width?

c) Under the same carrier concentration (above transparency), find the ratio of peak optical gains for bulk semiconductor (assume T = 0K).

d) Repeat c) for quantum wells with the same well width.

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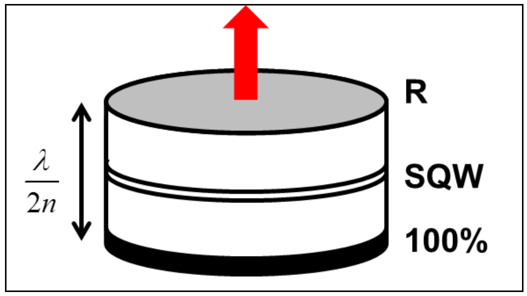
6. A single quantum well (SQW) vertical cavity surface-emitting laser (VCSEL) has a back mirror reflectivity of 100% and a front mirror reflectivity of R. The diameter of the VCSEL pillar is 2µm. For simplicity, ignore the thickness of the reflectors. The shortest cavity, obtained when the two mirrors are spaced by half wavelength in the semiconductor. To maximize the gain, the quantum well is inserted in the middle of the two mirrors. For simplicity, ignore the residue loss of the cavity, and assume all optical energy are within the semiconductor pillar. The wavelength of the laser is 1µm, and the refractive indices of all semiconductors are 3.33. Both the electron and the hole effective masses are 0.5 m_0. For calculating the matrix element, E_p = 24 eV.



a) If the quantum well width is 10 nm, find the maximum available gain from the quantum well (from the first hold subband to the first electron subband).

b) What is the minimum front reflectivity, R, that the SQW VCSEL can achieve lasing?

c) What is the cavity Q corresponding to the condition in b)?

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7. This problem concerns with the optimization of high speed lasers. Assume the active layer has a linear gain, $g(N) = a(N - N_{tr})$, and the residue loss is negligible. The laser under consideration here is a double heterostructure (DH) laser with a confinement factor of 20% and cleaved facets (reflectivity = 30%). The relaxation oscillation frequency of the laser is measured to be 10GHz when the output power is 1 mW. In the following, find the new relaxation oscillation frequencies of the laser when the following parameters are modified (while all other parameters remain the same). In all cases, the relaxation oscillation frequency is measured with *the laser output power is fixed at 1 mW.*

a) Reduce the cavity length by 4 times.

b) Increase the reflectivity of both mirrors to 90%.

c) Increase confinement factor to 80%.

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