EE 232	**<u>Midterm Examination-2</u>**	Fall 2006
11/8/2006	**EE 232 – Lightwave Devices**	Prof. Ming Wu

- If you need additional conditions to solve a problem, please write down your assumptions.
- There are problems on both sides of this sheet.

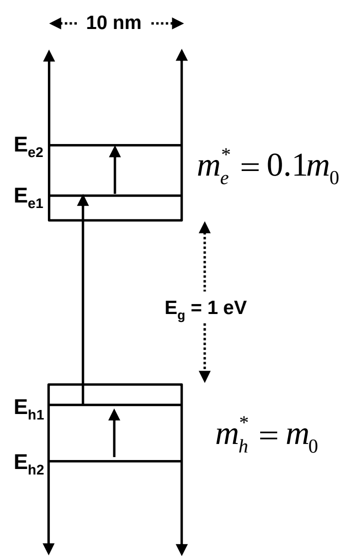
Global Parameters:

Unless stated otherwise in the problem, use the following values for all problems:

Optical matrix element:	$\left\|\hat{e}\cdot\vec{p}\right\|^2 = M_b^2 = (m_0/6)E_p$, and E_p = 24 eV
Bandgap energy:	E_g = 1 eV
Relative dielectric constant:	$\varepsilon_r = 9$
Refractive index:	$n_r = 3$

30 pts.

1. Consider the quantum well show on the right. The width of the well is 10 nm. Assume infinite potential well for both electrons and holes. The lineshape of the inter-subband transitions have a FWHM of 10 meV.



a) Find the photon energy corresponding to

i) $E_{e1} \rightarrow E_{e2}$ transition

ii) $E_{h2} \rightarrow E_{h1}$ transition

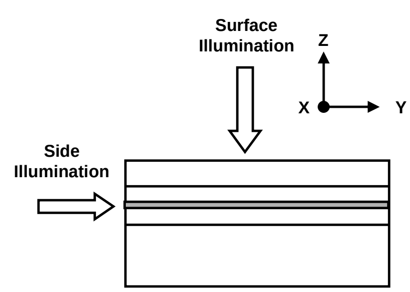
iii) $E_{h1} \rightarrow E_{e1}$ transition

b) What is the maximum absorption coefficient for $E_{h2} \rightarrow E_{h1}$ transition? What doping condition (type, concentration) is necessary to achieve this maximum value?

c) What is the maximum absorption coefficient for $E_{h1} \rightarrow E_{e1}$ transition? What bias condition is necessary to achieve this maximum value?

20 pts.

2. A quantum well is embedded in a separate confinement waveguide, as shown on the right. The quantum well parameter is the same as in the figure of Problem 1. Consider all six possible transitions among the first two quantum levels in conduction and valance bands, i.e.,



$E_{h2} \rightarrow E_{h1}$, $E_{h2} \rightarrow E_{e1}$, $E_{h2} \rightarrow E_{e2}$,

$E_{h1} \rightarrow E_{e1}$, $E_{h1} \rightarrow E_{e2}$,

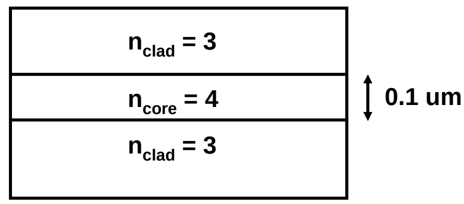
$E_{e1} \rightarrow E_{e2}$,

a) What transitions have zero matrix elements for surface-illumination? List all such transition. Justify your answer. For simplicity, you can consider the case with zero transverse wavevector.

b) What transitions have zero matrix elements for side-illumination with TM polarization? List all such transition. Justify your answer. For simplicity, you can consider the case with zero transverse wavevector.

20 pts.

3. Consider a double heterostructure (DH) waveguide as shown on the right. Optical wavelength is 1 μm.



a) How many transverse modes does this waveguide support?

b) Find the confinement factor of the fundamental mode.

c) If a 10-nm-wide quantum well is embedded in the middle of the core layer of the DH waveguide (i.e., separate confinement structure), what is the confinement factor for the quantum well?

30 pts.

4. For a single quantum well laser with a well width of 10 nm, a confinement factor of 1%, an internal loss of 1 cm^{-1}, and uncoated facets with power reflectivity of 30%. The quantum well material has an electron effective mass of 0.1 m_0, and a hole effective mass of 0.2 m_0. The quantum well is tensile-strained. The optical emission wavelength is 1.24 μm. Use E_P = 24 eV for the calculation of the matrix element.

a) Find the maximum available gain for the quantum well.

b) Find the minimum length of the laser such that the laser will lase between first sub-bands.

c) If a laser length of 10 μm is desired, what is the minimum number of quantum wells needed if we like to keep the laser lasing in the first sub-bands? Assume that adding quantum wells does not change the field profile, and the confinement factor for *each* quantum well remains the same (1%).