PHYC 564, Laser Physics II

Homework #4, Due Wed. March 24, 2021

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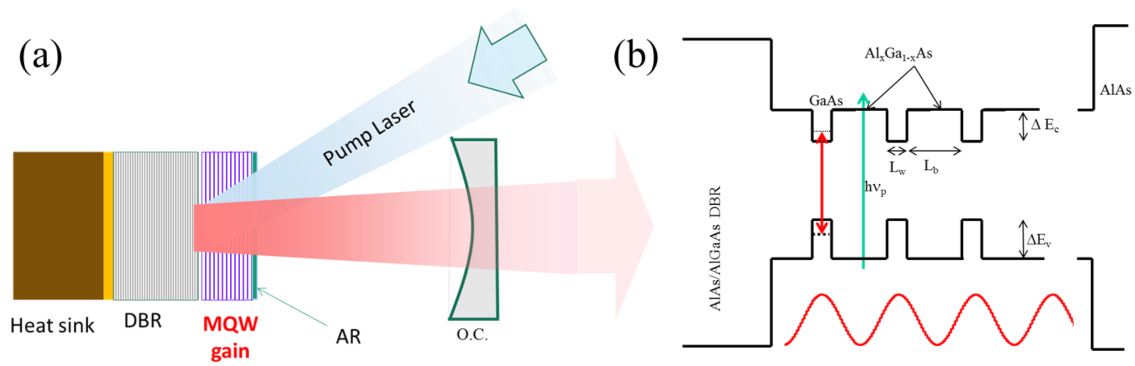
Design of an Optically –Pumped Semiconductor Laser (OPSL)

You are asked to design and analyze a MQW gain structure for an OPSL as depicted in Fig.(a) below.



The QWs are made from GaAs and the barriers are $Al_xGa_{1-x}As$ which is lattice matched to GaAs. Assume the operation is at room temperature (T=300K) where

$$E_g^{GaAs} = 1.424 \text{ eV} \quad \text{and} \quad E_g^{AlGaAs}(x) = E_g^{GaAs} + 1.247x$$

Furthermore, the QW spacing should satisfy resonant-periodic-gain (RPG) structure; thus each QW should be placed at the antinode of the standing-wave laser field inside the cavity (Fig. b).

(a) This laser is to be pumped in the barrier of MQW by a laser at λ_p=750 nm. Therefore, choose the barrier bandgap to be 1.5kT below the photon energy of the pump.

(b) Knowing ΔE_C (see next page) choose the largest QW thickness (L_w) that allows only one QW bound state (n=1) in its conduction band. What is the energy of this level (relative to the top of the GaAs conduction band)

(c) Knowing L_w from part b), obtain the number of bound-states (m) in the valence band for both heavy-hole (hh) and light-holes (lh). Find the energy of each bound state. Note: For parts b and c you may have to use simple numerical/graphical solutions.

(d) Qualitatively plot equilibrium absorption coefficient (i.e. no pumping) versus wavelength of the QW structure assuming the transition selection rule follows the infinite barrier case: $I_{nm}=\delta_{nm}$. Please be quantitative in your wavelength axis.

(e) Calculate the carrier density required to bring this structure to transparency (F_c-F_v=$E_e^{n=1}$-$E_{hh}^{m=1}$). For this part, first set-up the equations considering all sub-bands (levels). For numerical estimation, however, only take into account one sub-band in the valence band corresponding to m=1 heavy-hole level.

(f) Pick a reasonable laser wavelength and then design the separation of QWs to satisfy RPG condition. Assume an effective index of refraction n=3.4 for the MQW structure, and a DBR reflection coefficient r_{DBR}~ -1 (i.e. a node at the DBR interface)

$$E_g(\mathrm{Al}_x\mathrm{Ga}_{1-x}\mathrm{As}) = 1.424 + 1.247x \text{ eV} \quad (300\text{ K})$$

$$\Delta E_g(x) = 1.247x \text{ eV}$$

$$\Delta E_c = 0.67\,\Delta E_g \qquad \Delta E_v = 0.33\,\Delta E_g$$

Table K.3 Important Band Structure Parameters for $\mathrm{Al}_x\mathrm{Ga}_{1-x}\mathrm{As}$, $\mathrm{In}_{1-x}\mathrm{Ga}_x\mathrm{As}$, $\mathrm{Al}_x\mathrm{In}_{1-x}\mathrm{As}$, and $\mathrm{Ga}_x\mathrm{In}_{1-x}\mathrm{As}_y\mathrm{P}_{1-y}$ Compounds[a–e]

General Interpolation Formula for Ternary Compound Parameters P: $P(A_xB_{1-x}C) = xP(AC) + (1-x)P(BC)$			Ref.
$\mathrm{Al}_x\mathrm{Ga}_{1-x}\mathrm{As}$			
$E_g(\Gamma) = 1.424 + 1.247x$ (eV)	at 300 K	for $x < 0.4$	a
$1.519 + 1.447x - 0.15x^2$ (eV)	at 0 K	for $x < 0.4$	b
$m_e^*/m_0 = 0.067 + 0.083x$			a
$m_{hh}^*/m_0 = 0.50 + 0.29x$ (Density of states mass)			interpol.
$m_{lh}^*/m_0 = 0.087 + 0.063x$			f
$m_{so}^*/m_0 = 0.15 + 0.09x$			a
$\gamma_i(x) = x\gamma_i(\mathrm{AlAs}) + (1-x)\gamma_i(\mathrm{GaAs})$	(for calculating transport masses)		interpol.
$\mathrm{In}_{1-x}\mathrm{Ga}_x\mathrm{As}$			
$E_g(\Gamma) = 0.36 + 0.505x + 0.555x^2$ (eV)	at 300 K		c
$0.324 + 0.7x + 0.4x^2$ (eV)	at 300 K		a
$0.422 + 0.7x + 0.4x^2$ (eV)	at 2 K		
$m_e^*/m_0 = 0.025(1-x) + 0.071x - 0.0163x(1-x)$			
or			
$1/m_e^*(x) = x/m_e^*(\mathrm{GaAs}) + (1-x)/m_e^*(\mathrm{InAs})$			
$\mathrm{In}_{0.53}\mathrm{Ga}_{0.47}\mathrm{As}$			
$E_g(\Gamma) = 0.813$ (eV) at 2 K			a
0.75 (eV) at 300 K			
$m_e^*/m_0 = 0.041$			
$m_{hh}^*/m_0 = 0.465$ //[001]			
0.56 //[110]			
$m_{lh}^*/m_0 = 0.0503$			
$\mathrm{Al}_x\mathrm{In}_{1-x}\mathrm{As}$			
$E_g(\Gamma) = 0.36 + 2.35x + 0.24x^2$ (eV)	at 300 K		a
$0.357 + 2.29x$ (eV)	at 300 K	for $0.44 < x < 0.54$	
$0.447 + 2.22x$ (eV)	at 4 K	for $0.44 < x < 0.54$	
$\mathrm{Al}_{0.48}\mathrm{In}_{0.52}\mathrm{As}$			
$E_g(\Gamma) = 1.508$ (eV) at 4K			a
1.450 (eV) at 300 K			
$m_e^*/m_0 = 0.075$			d
$m_{hh}^*/m_0 = 0.41$			
$m_{lh}^*/m_0 = 0.096$			