QE: Semiconductor-electronic devices (60 points) 2010년

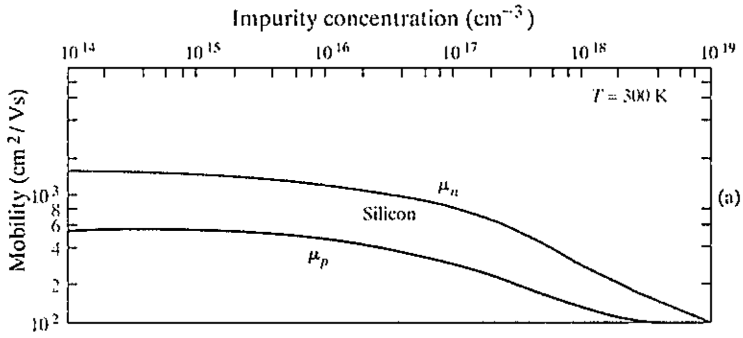
Physical Constants

Electronic charge, $q = 1.6\times10^{-19}$C

Electron mass, $m_0 = 9.11\times10^{-31}$kg

Effective mass of electrons in Si, $m^*_n = 0.26m_0$

Intrinsic carrier concentration n_i for Si = 1.5×10^{10}cm^{-3}



(Fig. 1)

1. (20 points) When an electric field with strength 1×10^3 V/cm is applied to a p-type uncompensated Si sample at room temperature, the electron drift velocity, v_d is 1×10^6 cm/sec.
   (Hint: if necessary, use the Fig. 1 and note that 1 kg cm^{2}V^{-1} s^{-1} C^{-1} = 10^{-4} sec)
   a) Find the electron mobility of this sample.
   b) Find the mean free time of an electron in this sample.
   c) Calculate the conductivity of this sample?

2. (20 points) Let us assume that excess holes are somehow injected into a semi-infinite p-type Si bar at x = 0. The Si bar has a cross-sectional area of 0.5 cm^2 and Na = 10^{17} cm^{-3}. The steady state hole injection maintains a constant excess hole concentration at the injection point $\delta p(x=0)=\Delta p=5\times10^{16}$ cm^{-3} . Assume that $\tau_p=10^{-10}$ s.
   a) Calculate the diffusion length for holes.
   b) How much is the excess stored hole charges?
   c) Find the steady state separation between E_i and F_p at x= 0.1 μm.
   d) Calculate the hole current at x=0.1 μm.

3. (20 points) Qualitatively explain the direction and the magnitude change of the diffusion and the drift current for each electron and hole particle at the following bias conditions in a pn junction.
   a) At equilibrium
   b) Forward bias
   c) Reverse bias

QE problem for 2010 semiconductor ex.

1. NMOS problem
   a) Draw $I_{ds} - V_{ds}$ curves as a function of V_{gs}
   b) Describe the physical reason to have the linear region and saturated region and indicate the region
   c) Output conductances at the two regions are quite different. Explain origin of the conductances and indicate the conductances on the I-V curve
   d) In the saturated region, Gm is almost constant. Why (explain physical reason)? Also indicate the Gm
   e) Below $V_{th,}$ current does not flow. Why (explain physical reason)?

2. NPN Bipoalr transistor

   Emitter: n-type $5*10^{18}$ /cm^3, 1um thick, L_D=0.1um, u_p=$6*10^2$ cm^2/V-s (long)

   Base: p-type $5*10^{17}$ /cm^3, 0.2um thick, L_D=1um, u_n=$3*10^3$cm^2/V-s (short)

   Collector: n-type $1*10^{16}$/cm^3, 2um thick, L_D=5um, u_p=$6*10^2$ cm^2/V-s (short)

   V_{be}= 1V, V_{bc}=3 V, kT=0.026eV
   a) Calculate emitter, base and collector currents
   b) Calculate bet, alpa, and gamma of the transistor
   c) Derive the Ebers-Moll equation of the transitor.

QE 2010 광전자 부문

1. Consider a semiconductor laser where electrons and holes are confined in an infinite quantum well where the quantum well width is d, the band gap of QW region is E_g, and electron and hole effective masses are m_e and m_h, respectively. What is the longest wavelength emitted from the semiconductor laser?

2. Consider a single transverse mode semiconductor laser where the cavity length is L, the field reflectivities of two mirrors are R_1 and R_2, the mode confinement factor of active region is Γ, and the internal loss coefficient of cladding region is α. Find the material threshold gain G_{th}.

QE: semiconductor (2009.8.12)

[물리전자] (60 점)

1. 폭 L [um] 의 무한 장벽 potential well 에 트랩된 전자의
quantized energy level 값을 유도하시오.

2. 상기 무한 장벽 potential well 의 폭 L [um] 이 어떤 경우
quantum effect 가 발생할지, 또 그 효과의 예를 논하시오.

3. Energy band 가 발생하는 이유는? 자유전자론이 energy gap (Eg)을
설명할 수 있는가? Eg 가 발생하는 원인은 무엇인가?

4. pn junction 의 depletion 영역 발생과정을 설명하시오.

5. Graphene 이란 무엇인지 기술하시오.

[electronic devices (40 points)]

physical constants

electronic charge, $q=1.6\times10^{-19}$C	$\varepsilon_0=8.8\times10^{-14}$F/cm
relative dielectric constant of Si $\varepsilon_{r,Si}=11.7$	relative dielectric constant of SiO_2 $\varepsilon_{r,SiO2}=3.9$

1. Consider a MOS capacitor with the n^+ poly-silicon gate. The device area is 100×100 nm^2, the insulator is a thermally grown SiO_2 with a thickness of 2 nm and the substrate is silicon with a N_A=5E18 cm^{-3}.

   a) **(5 points)** What is the amount of the effective oxide charge when the threshold voltage is +0.2[V]?
   b) **(5 points)** Draw the energy band diagram and calculate the charge distribution when the V_{GS} is -1.0[V].
   c) **(5 points)** Find a number of the implanted ions if we need a threshold voltage of +0.3[V].
   d) **(5 points)** Discuss the leakage current when the V_{GS} is +1.2[V].

2. Consider a Si p-n abrupt junction with N_A=1E17 cm^{-3} and N_D=1E20 cm^{-3} (device area is 100×100 nm^2).

   a) **(5 points)** Calculate the value of the maximum field E_0 at equilibrium.
   b) **(5 points)** What is the reverse voltage for the breakdown if the critical field E_c=3E5 V/cm?
   c) **(10 points)** Sketch the small signal junction capacitance C_j (vs. V_D) and calculate the values at V_D= -1.0 and V_D= +0.3 [V].

[광소자] (40 점)

1. inhomogeneous laser 의 gain clamping 을 설명하시오.

2. external quantum efficiency (Q.E.)에서 internal Q.E.를 구할 방법을 설명하시오.[첨부 참조]

(2009)

Power Output of Injection Lasers

The considerations of saturation and power output in an injection laser are basically the same as that of conventional lasers, which were described in Sections 5.6 and 6.4. As the injection current is increased above the threshold value, the laser oscillation intensity builds up. The resulting stimulated emission shortens the lifetime of the inverted carriers to the point where the magnitude of the inversion is clamped at its threshold value. Taking the probability that an injected carrier recombine radiatively within the active region as η_i,[2] we can write the following expression for the power emitted by stimulated emission:

$$P_e = \frac{(I - I_t)\eta_i}{e} h\nu \qquad (15.4\text{-}1)$$

Part of this power is dissipated inside the laser resonator, and the rest is coupled out through the end reflectors. These two powers are, according to (15.3-4), proportional to the effective internal loss $\alpha \equiv \alpha_n\Gamma_n + \alpha_p\Gamma_p + \alpha_s$ and to $-L^{-1} \ln R$, respectively. We can thus write the output power as

$$P_0 = \frac{(I - I_t)\eta_i h\nu}{e} \frac{(1/L) \ln (1/R)}{\alpha + (1/L) \ln (1/R)} \qquad (15.4\text{-}2)$$

The external differential quantum efficiency η_{ex} is defined as the ratio of the photon output rate that results from an increase in the injection rate (carriers per second) to the increase in the injection rate:

QE-2008 반도체 기본

(Use kT=0.026eV, $E_g^{Si}=1.11$eV, and $n_i=1.5\times10^{10}/cm^3$)

1. $N_a=1\times10^{17}/cm^3$, $N_d=3\times10^{17}/cm^3$로 doping 된 Silicon 에서

가) one-sided step p-n junction 일때;

1) electron 의 농도를 구하시오. [linear plot 과 semi-log plot] (5 점)

2) hole 농도, N_a^- 농도, N_d^+ 농도, total charge 농도에 대하여 구하시오(15 점)

나) graded doping 되었을 경우에 대해서 1), 2)를 반복하시오. (10 점)

2. Effective mass 에 대하여 논하시오 (15 점)

3. Forward bias 된 pn junction 에서 quasi-fermi level 을 그리고 의미를 논하시오 (15 점)

(2008)

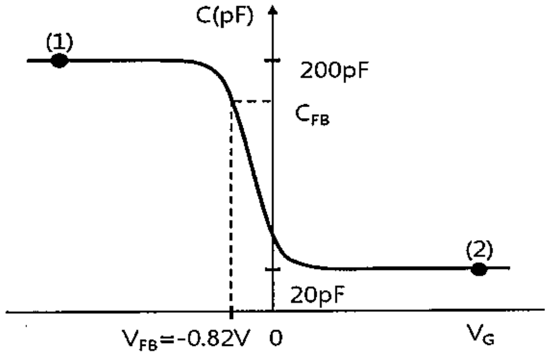
QE: Semiconductor-electronic devices (40 points)

Physical Constants

Electronic charge, $q=1.6\times10^{-19}C$ — $\varepsilon_0 = 8.85\times10^{-14}F/cm$

Relative Dielectric constant of Si $\varepsilon_{r,Si} = 11.8$ — Relative Dielectric constant of SiO_2 $\varepsilon_{r,SiO2} = 3.9$

1. The high-frequency C-V curve of an MOS capacitor is shown below. The device area is 1×10^{-3} cm^2, the work function difference (ϕ_{ms}) is -0.5V, the insulator is SiO_2, and the substrate is silicon.



a) **(5 points)** Is the substrate is n or p type? Explain how you arrive at your answer.
b) **(5 points)** Draw the energy band diagram corresponding to point (1) and (2)
c) **(5 points)** Find the equivalent trapped oxide charge density.
d) **(10 points)** Determine the maximum value of the depletion width. Using the depletion approximation and neglect the width of inversion layer.

2. Consider a uniformly doped p-n-p BJT. Assume emitter doping>> base doping>collector doping.

a) **(5 points)** Draw the energy band diagram at equilibrium.
b) **(5 points)** Draw the energy band diagram (showing quasi-Fermi levels) at normal active bias.
c) **(5 points)** Explain the Early effect.

(2008년2)

QE 반도체 광소자 문제 (40점)

[1] Dielectric optical waveguide에서 존재하는 mode의 종류에 대하여 설명하고 각각에 대한 특징과 차이점을 ray optics 관점에서 논하시오. [20점]

[2] 길이가 L이고 반사율이 R_1과 R_2인 resonator로 이루어진 semiconductor laser가 있다. gain이 존재하는active region의 mode confinement factor가 Γ이고 cladding을 포함한 나머지 영역에서의 internal loss coefficient가 α일 때 주어진 active region의 material threshold gain G_{th}를 구하시오. [20점]

QE; 반도체-공통 (60 점) 2007년

Use: kT/q =0.026 V, $E_g^{Si} = 1.11$ eV, $n_i = 1.5 \times 10^{10} / cm^3$; Si 의 intrinsic carrier concentration, $q = 1.602 \times 10^{-19} C$, $n_0 = n_i \exp[(E_F - E_i)/kT]$, $p_0 = n_i \exp[(E_i - E_F)/kT]$

1. p+-n junction 의 순방향 전류 I 가 흐르고 있을 경우
   1) Band diagram 을 그리시오(5 점)
   2) Band diagram 상에 electron 과 hole 의 quasi-Fermi level 들을 각각 그리시오 (10 점)
   3) 또한, 1-2)에서 본인이 그린 quasi-Fermi level 들이 왜 그러한 형태를 취하여야 하는지 그 이유들을 설명하시오 (5 점)
   4) n-영역에 축적된 hole 의 총 전하 Q 를 구하시오 (5 점)
   5) Depletion edge 로부터 거리에 따른 hole 농도의 변화를 도시하시오. (5 점)

   (여기서 minority carrier lifetime 은 τ_p, junction 의 단면적은 A, n 영역에서 hole 의 diffusion length 는 L_p로 둘 것)

2. Zener breakdown 과 Avalanche breakdown mechanism 을 각각 기술하고 중요한 차이점을 기술하시오 (10 점)

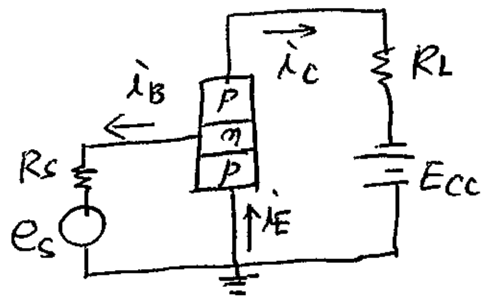
3. 1) Ideality factor 를 포함한 p-n junction diode 의 전류 전압 방정식을 적은 후, (5 점)
   2) I-V 특성 곡선을 그린 후, 특성 곡선상에서 ideality factor 의 변화와 그 이유를 설명하시오. (5 점)

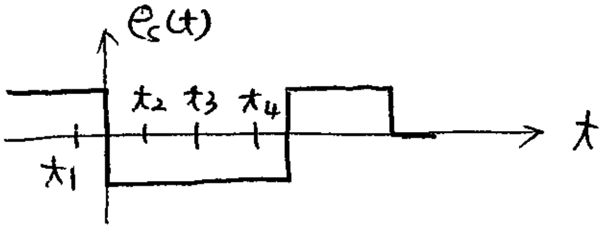
4. 만약 workfunction 이 $q\Phi_m = 6\,\text{eV}$ 인 금속과 $N_d = 1 \times 10^{18} / cm^3$ 로 doping 된 n-type Si 을 사용하여 metal-semiconductor contact 을 형성시켰다. 이 metal-semiconductor contact 이 Ohmic contact 인지 Schottky 인지를 판단하고 그 이유를 설명하시오. (10 점) (Si 의 electron affinity $q\chi = 4\,\text{eV}$ 로 가정할 것)

QE; 반도체-전자소자 (40 점)

2007년

1. pnp BJT amplifier 에서 그림과 같은 입력전압에 대하여





(1) i_B vs. time (3 점)
(2) i_C vs. time (3 점)
(3) Q_b vs. time (3 점)
(4) $t = t_1, t_2, t_3, t_4$ 일때 base 영역에서의 Q_b (3 점)를 각각 sketch 하시오

t_1 ; cut off
t_2 ; active
t_3 ; beginning of saturation
t_4 ; end of saturation

2. I C 에서 사용되는 BJT 중에서 vertical type 과 lateral type 의 장단점을 비교설명하시오 (8 점)

3. MOSFET 와 MESFET 의 동작원리를 비교 설명하시오. (8 점)

4. 다음 용어의 의미와 원리를 설명하시오

(1) work function engineering (3 점)
(2) LDD (3 점)
(3) I^2L (3 점)
(4) STI (3 점)

QE; semiconductor-basic (60 point) 200X년EL

Use: kT/q =0.026 V, $E_g^{Si} = 1.11$ eV, $n_i = 1.5 \times 10^{10}/cm^3$; intrinsic carrier concentration of Si, $q = 1.602 \times 10^{-19} C$, $n_0 = n_i \exp[(E_F - E_i)/kT]$, $p_0 = n_i \exp[(E_i - E_F)/kT]$

1. For a forward biased p+-n junction diode at a current I, answer the followings:
   1) Draw the band diagram. (5 point)
   2) Draw the quasi-Fermi levels for electrons and holes on the band diagram. (10 point)
   3) Also, explain the reason why you draw the quasi-Fermi levels as they appear on your answer. (5 point)
   4) Calculate the total hole charge Q which is accumulated in the n-region of the diode. (5 point)
   5) Plot the hole concentration in the n-region versus the distance from depletion edge. (5 point)

   (Here, you can assume that the minority carrier lifetime is τ_p, the cross-sectional area of junction is A, and the diffusion length for holes in the n-region is L_p)

2. Describe the Zener and avalanche breakdown mechanisms, respectively, and list major differences in these two breakdown mechanisms. (10 point)

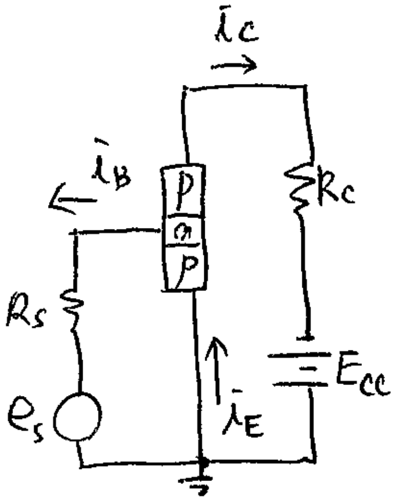
3. 1) Give the current equation of a non-ideal p-n junction diode, which includes an ideality factor. (5 point)
   2) Draw a typical I-V characteristic curve of the p-n junction diode, mark separate regions where the ideality factor of diode is different, and explain the reason why the ideality factor changes. (5 point)

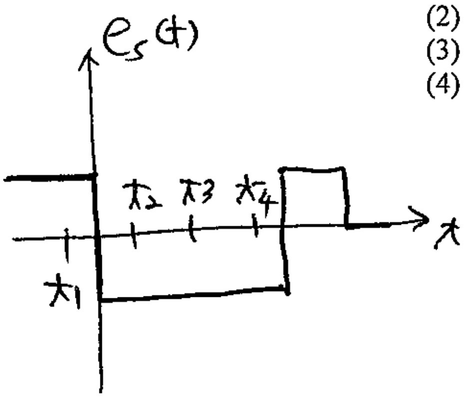
4. You made a metal-semiconductor contact using a metal with a workfunction $q\Phi_m = 6$ eV and an n-type Si doped to $N_d = 1 \times 10^{18}/cm^3$. Judge whether this metal-semiconductor contact would form an Ohmic or Schottky contact? Justify your answer.
   (Assume the electron affinity $q\chi$ of Si is 4 eV) (10 point)

(2007)

QE; semiconductor- electronic devices (40 point)

1. for an pnp BJT amplifier, sketch





(1) i_B vs. time (3 point)
(2) i_C vs. time (3 point)
(3) Q_b vs. time (3 point)
(4) Q_b in the base area (3 point)
(at $t = t_1, t_2, t_3, t_4$)
t_1 ; cut off
t_2 ; active
t_3 ; beginning of saturation
t_4 ; end of saturation

2. Compare and discuss the vertical type BJT with the lateral type BJT (8 point)

3. What is the difference of the operating principles between MOSFET and. (8 point)

4. Explain the meaning and the key factor of the followings

    (1) work function engineering (3 point)
    (2) LDD (3 point)
    (3) I^2L (3 point)
    (4) STI (3 point)

2006. 8. 14

QE 반도체 공통기초 (60 점)

[1] Potential energy 가 $V(x)=0$, $0<x<L$, $V(0)=V(L)=\infty$ 로 주어지는 양자우물 (quantum well)에 속박된 전하 q, 질량 m 을 가진 전자의 에너지와 파동함수를 구하시오. [20 점]

[2] 반도체에서 전자(electron)로 가득 채워진 completely filled band 의 경우 전류가 흐를 수 없고, 전자가 부분적으로 비어 있는 band 의 경우에만 전류가 흐를 수 있다는 것을 보이고, 이를 바탕으로 정공(hole)의 개념을 설명하시오. [20 점]

[2] $N_d - N_a = Gx$, dielectric constant 가 ε, junction 단면적이 A 인 linearly graded p-n juntion 의 junction capacitance 를 구하시오. [20 점]

QE 반도체 전자소자 문제 (40 점)

[1] Schottky Diode Clamped BJT 소자에 대하여
(1) Schottky Diode 가 BJT 의 deep saturation 을 방지하는 원리를 설명하시오 [10 점]
(2) 제작된 Schottky Diode 의 단면도를 도시하시오 [5 점]

[2] $N_a = 1\times10^{18}/cm^3$, Qo /q = 5 E10 cm2, Tox = 5 nm, N+ poly silicon gate 인 n-type Si 반도체에서
(1) threshold voltage 를 계산하시오 [10 점]
(2) threshold voltage 에 관련되는 각 항목에 doping level 이 주는 영향을 설명하시오 [5 점]

[3] p-n-p-n switching diode 의 동작원리를 two transistor analogy 로 설명하시오 [10 점]

QE 반도체 광소자 문제 (40 점)

[1] Dielectric waveguide 에서 guided mode 와 radiation mode 에 대해 설명하고 그 차이점에 대해 논하시오. [20 점]

[2] Semiconductor quantum well laser 와 semiconductor bulk laser 의 gain curve 를 개략적으로 그리고 차이점에 대해 설명하시오. [20 점]

2005.10.26

반도체 및 물리전자 공통분야 (60 점)

Use: $kT/q = -0.026$ V at 300°K

$n_i = 1.5\times10^{10}/\text{cm}^3$: Si 의 intrinsic carrier concentration at 300°K

$q\chi = 4.01$ eV: electron affinity of Si

$E_g = 1.12$ eV: bandgap of Si

$q\phi_m = 5.1$ eV: workfunction for Au.

1. For a forward biased p^+- n junction diode
   a) Draw the band diagram (5 점),
   b) Draw the quasi-Fermi levels for electrons and holes on the band diagram (10 점).
   c) Also, explain the reason why you draw the quasi-Fermi levels as they appear on your answer (5 점).

2. A silicon at $T = 300$ °K is homogeneously doped with $N_D = 5\times10^{15}/\text{cm}^3$.
   a) Determine the thermal equilibrium concentrations of electrons and holes (5 점)
   b) Determine the hole and electron concentrations at $T = 400$ °K (10 점)

3. Consider a gold Schottky diode at $T = 300$ °K formed on n-type Si doped at $N_D = 1\times10^{15}/\text{cm}^3$. Determine the followings:
   a) Workfunction $q\phi_s$ of the n-type Si (10 점)
   b) The equilibrium contact potential V_0 (10 점)
   c) Thickness of the depletion region W (5 점)

반도체 (전자소자 부문: 40 점)

[1] p-n-p BJT 에서 사용되는 다음의 식에서

$$i_C = B\, i_{Ep}$$

$$\gamma = \frac{i_{Ep}}{i_{En} + i_{Ep}}$$

$$\frac{i_C}{i_E} = \frac{B \cdot i_{Ep}}{i_{En} + i_{Ep}} = B \cdot \gamma \equiv \alpha$$

$$i_B = i_{En} + (1 - B) \cdot i_{Ep}$$

$$\frac{i_C}{i_B} = \frac{B \cdot i_{Ep}}{i_{En} + (1-B)\, i_{Ep}} = \frac{B \cdot \left[i_{Ep} / (i_{En} + i_{Ep}) \right]}{1 - B \left[i_{Ep} / (i_{En} + i_{Ep}) \right]}$$

$$\frac{i_C}{i_B} = \frac{B \cdot \gamma}{1 - B \cdot \gamma} = \frac{\alpha}{1 - \alpha} \equiv \beta$$

B, γ, α, β 의 명칭과 의미는? (15점)

[2] IC 에 사용되는 BJT n-p-n isoplaner 구조의 단면을 도시 하시오. (10점)

[3] CIS (CMOS Image Sensor) 와 CCD (Charge Coupled Device) 의 Pixel 구조와 동작원리를 비교하고 장단점을 논하시오. (15점)

<2005 7

<u>반도체 및 물리전자 광소자분야 (40 점)</u>

다음 4 문제에서 <u>2 문제를 선택</u>하시오.

1. Fabry-Perot laser 의 free spectral range 를 설명하시오 (20 점).
2. Fabry-Perot laser 가 single frequency 로 발진하는 과정을 보이며 설명하시오 (homogeneous laser medium 의 경우) (20 점).
3. Dielectric waveguide 에서 photon 의 <u>guided mode</u> 와 semiconductor quantum well 에서 electron 의 <u>bound state</u> 에 대하여 비교하여 설명하시오 (20 점).
4. DFB(distributed feedback) 레이저의 동작원리를 설명하시오 (20 점).