UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Pertama
Sidang Akademik 1997/98

September 1997

EEE327 - Fizik Peranti Semikonduktor

Masa : [3 jam]

ARAHAN KEPADA CALON :

Sila pastikan bahawa kertas peperiksaan ini mengandungi **EMPATBELAS (14)** muka surat bercetak dan **LAPAN (8)** soalan sebelum anda memulakan peperiksaan ini.

Jawab **LIMA (5)** soalan.

Agihan markah bagi soalan diberikan di sut sebelah kanan soalan berkenaan.

Semua soalan hendaklah dijawab di dalam Bahasa Malaysia. Jika pelajar memilih menjawab di dalam Bahasa Inggeris sekurang-kurangnya satu soalan mesti dijawab di dalam Bahasa Malaysia.

...2/-

Persamaan-Persamaan Bagi Rujukan

Equations For Reference

$$n = N_c \exp\left(-\frac{E_C - E_F}{kT}\right) = n_i \exp\left(\frac{E_F - E_i}{kT}\right)$$

$$p = N_v \exp\left(-\frac{E_F - E_V}{kT}\right) = n_i \exp\left(\frac{E_i - E_F}{kT}\right)$$

$$n_i = \sqrt{N_C N_V} \exp\left(-\frac{E_G}{2kT}\right) = 2.51x10^{19} \left(\frac{m_n^* m_p^*}{m_o^2}\right)^{3/4} \left(\frac{T}{300}\right)^{3/2} e^{-E_G/2kT}$$

$np = n_i^2$ at thermal equilibrium
pada keseimbangan haba

$$\mu = \frac{q \tau_c}{m^*}$$

$$J_N = nq \mu_n \varepsilon + q D_N \frac{dn}{dx}$$

$$J_p = Pq \mu_p \varepsilon - q D_p \frac{dp}{dx}$$

$$\bar{\varepsilon} = -\bar{\nabla} V \left(= -\hat{a}_x \frac{dV}{dx} \quad \text{in} \quad 1-D\right);$$

$E = Q.V$ (Joule = Coulomb x Volt)

$$\frac{D_N}{\mu_n} = \frac{D_P}{\mu_p} = \frac{kT}{q}$$

$$\frac{\partial n}{\partial t} = \frac{1}{q} \cdot \frac{\partial J_N}{\partial x} + G_n - R_n$$

$$\frac{\partial p}{\partial t} = \frac{1}{q} \cdot \frac{\partial J_P}{\partial x} + G_p - R_p$$

...3/-

1. (a) Satu sampel GaAs didop ringan dengan sejenis bendasinya bagi meningkatkan keberintangan. Tentukan jenis dan aras pendopan yang diperlukan bagi mencapai keberintangan maksimum bahan tersebut. Apakah nilai keberintangan maksimum? GaAs pada 300°K mempunyai $\mu_n = 8400\ cm^2/V\text{-}s$, $\mu_p = 400\ cm^2/V\text{-}s$ dan $n_i = 2 \times 10^6\ cm^{-3}$.
(Nota: pada aras pendopan rendah, kepekatan bendasing ≠ kepekatan pembawa majoriti).

A GaAs sample is lightly doped with single type of impurity to increase its resistivity. Determine the type and the level of doping required to achieve maximum resistivity of the material. What is the value of maximum resistivity? GaAs at 300°K has $\mu_n = 8400\ cm^2/V\text{-}s$, $\mu_p = 400\ cm^2/V\text{-}s$ and $n_i = 2 \times 10^6\ cm^{-3}$.
(Note: at low daping level, impurity concentration ≠ majority carries concentration).

(60%)

(b) Kebolehgerakan elektron dalam satu bahan semikonduktor pada 300°K, disebabkan oleh getaran kekisi dan serakan ion bendasing, adalah seperti berikut:

The mobilities of electrons in a semiconductor material at 300°K, due to lattice vibration and impurity ion scattering, are obtained independently as follows:

$\mu_L = 1.57\ T^{3/2}\ (cm^2/v\text{-}s)$ dan

and

$\mu_I = 4.157 \times 10^7\ T^{-3/2}\ (cm^2/v\text{-}s)$

...4/-

di mana, T ialah dalam $^{\circ}$K. Tentukan suhu apabila kebolehgerakan keseluruhan μ_n ialah maksimum. Apakah nilai maksimum μ_n?

where, T is in $^{\circ}$K. *Find the temperature at which overall mobility* μ_n *is maximum. What is the maximum value of* μ_n*?*

(40%)

2. Silikon didop secara tak seragam dengan ciri pendopan berikut:
Silicon is doped non-uniformly with the following doping profiles:

$$N_D(x) = 10^{19} \exp(-10^7 x^2) \quad cm^{-3}$$
$$N_A(x) = 10^{14} \quad cm^{-3}$$

bagi $0 < x < 10^{-3}$ cm
for

Pada 300°K, bahan mempunyai $n_i = 10^{10}$ cm^{-3} dan kT = 0.0259 eV. Tentukan kuantiti-kuantiti berikut:

At 300°K, *the material has* $n_i = 10^{10}$ cm^{-3} *and kT = 0.0259 eV. Determine the following quantities:*

(a) Kepekatan bendasing terion $N_D^+(x)$ dan $N_i(x)$ pada 0°K.
Ionized impurity concentrations $N_D^+(x)$ *and* $N_i(x)$ *at* 0°K.

(20%)

(b) Kepekatan pembawa bebas n(x) dan p(x) pada 300° K. Silikon berada pada keseimbangan haba. Anggap keadaan adalah kuasi-neutral.

Free carrier concerntrations n(x) and p(x) at 300° K. *Silicon is at thermal equilibrium. Assume quasi-neutrality candition holds.*

(20%)

(c) Medan elektrik dalaman $\varepsilon(x)$ pada keseimbangan haba bagi $0 < x < 10^{-3}$ cm dengan menganggap keadaan kuasi-neutral. Apakah $\varepsilon(0)$ dan $\varepsilon(10^{-3}$ cm)?

The electric field $\varepsilon(x)$ *that develops internally at thermal equilibrium, for* $0 < x < 10^{-3}$ cm, *assuming quasi-neutrality. What are* $\varepsilon(0)$ *and* $\varepsilon(10^{-3}$ cm)*?*

(35%)

(d) Keupayaan (voltan) dalaman yang terbina merintang panjang bahan, daripada x = 0 sehingga x = 10^{-3} cm, pada keseimbangan haba, pada 300° K.

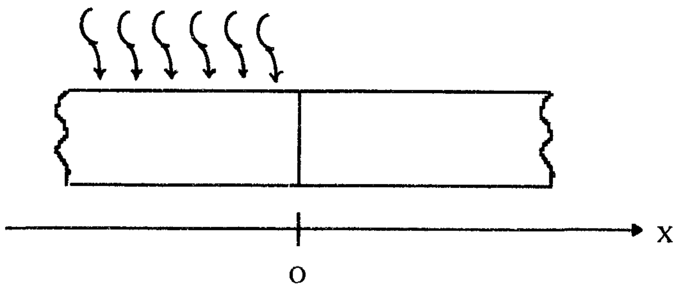
The built-in potential (voltage) that develops across the length of the material, from x = 0 to x = 10^{-3} *cm, at thermal equilibrium, at* 300° K .

(25%)

...6/-

3. Sebahagian daripada satu pupuk semikonduktor panjang dicahayakan. Cahaya menjanakan $G_L = 10^{15}$ EHP/(cm^3 - sec) secara seragam sepanjang kawasan $x < 0$. $G_L = 0$ bagi $x > 0$. Keseluruhan pupuk didop seragam dengan $N_D = 10^{17}/cm^3$. Diberikan masa hayat pembawa minoriti, $\tau_p = 10^{-6}$ saat, $n_i = 10^{10}/cm^3$ dan kT = 0.0259 eV .

A portion of a long semiconductor slab is illuminated with light. The light generates, G_L = 10^{15} EHP's/(cm^3 - sec) uniformly throughout the $x < 0$ region. $G_L = 0$ for $x > 0$. The entire slab is doped uniformly with $N_D = 10^{17}/cm^3$. It is given that the minority carrier lifetime, $\tau_p = 10^{-6}$ sec, $n_i = 10^{10}/cm^3$ and kT = 0.0259 eV .



Tentukan kuantiti-kuantiti berikut pada keadaan mantap
Determine the following quantities at steady state -

(a) bagi $x << 0$ (i.e., jauh daripada sempadan $x = 0$) kepekatan pembawa lebihan, aras-aras kuasi Fermi (merujuk kepada E_i) dan kepekatan pusat-pusat R-G. ($C_p = C_n = 10^{-8}$ cm^3/saat)

for $x << 0$ (i.e., far from the boundary at $x = 0$) the excess carrier concentrations, quasi Fermi levels (w.r.t. E_i) and the concentration of R-G centers. ($C_p = C_n = 10^{-8}$ cm^3/sec.)

(30%)

...7/-

(b) taburan kepekatan lubang sebagai fungsi x bagi semua x.
the distribution of hole concentration as a function of x for all x.

(70%)

4. Pertimbangan satu sampel Germanium terdop seragam yang mempunyai masa hayat pembawa minoriti 10^{-3} saat. Sampel dicahayakan oleh satu sumber cahaya berkeamatan tetap yang menjanakan G_{LO} pasangan elektron-lubang/(cm^3 - saat) secara seragam sepanjang isipadu. Pada keadaan mantap, sampel Ge yang tercahaya mempunyai $n = 5 \times 10^{16}\ cm^{-3}$, $p = 10^{13}/cm^3$. Pada suhu bilik bagi Ge, $\mu_n = 3900\ cm^2/V$-saat, $\mu_p = 1900\ cm^2/V$-saat, $n_i = 2.4 \times 10^{13}\ cm^{-3}$.

Consider a uniformly doped germanium sample having minority carrier lifetime 10^{-3} sec. The sample is illuminated by a constant intensity light source which generates G_{LO} electron-hole pairs/(cm^3-sec) uniformly throughout the volume. At steady-state, the illuminated Ge sample has $n = 5 \times 10^{16}\ cm^{-3}$, $p = 10^{13}/cm^3$. At room temperature for Ge, $\mu_n = 3900\ cm^2/V$-sec, $\mu_p = 1900\ cm^2/V$-sec, $n_i = 2.4 \times 10^{13}\ cm^{-3}$.

(a) Kirakan kepekatan elektron dari lubang pada keseimbangan haba, n_o dan p_o.
Calculate the thermal equilibrium electron and hole concertrations, n_o and p_o.

(20%)

(b) Kirakan kepekatan pembawa lebihan pada keadaan mantap.
Calculate the excess carrier concentrations at steady state.

(10%)

(c) Kirakan keamatan penjanaan optik, G_{LO}.
Calculate optical generation intensity, G_{LO}.

(10%)

...8/-

(d) Kirakan keberintangan sampel Ge.

Calculate the resistivity of the sample of Ge.

(10%)

(e) Setelah mencapai keadaan mantap dengan kadar penjanaan G_{LO} (EHP/cm^3-saat), keamatan cahaya dikurangkan kepada satu pertiga daripada nilai mulanya pada t = 0, iaitu

After reading steady-state condition with generation rate G_{LO} (EHP/cm^3-sec), the light intensity is reduced to one-third its initial value at t = 0, i.e.,

$$G_L(t) = \begin{cases} G_{LO} & , \quad t < o \\ \frac{1}{3} G_{LO} & , \quad t \geq o \end{cases}$$

Tentukan kepekatan lubang p(t) bagi $t \geq o$.

Find the hole concentration p(t) for $t \geq o$.

(50%)

5. (a) Gunakan anggaran susutan bagi menganalisa satu diod p-n simpang mendadak pada pincang balikan dan tentukan ungkapan-ungkapan bagi keupayaan terbina dalam serta lebar kawasan susutan.

Use depletion approximation to analyze an abrupt junction p-n diode at reverse bias and find expressions for built-in potential and the depletion region width.

(60%)

...9/-

(b) Satu diod silikon p^+n digunakan sebagai satu varaktor. Kepekatan pendopan berkesan bagi sebelah p dan n adalah masing-masing $N_A = 10^{19}$ cm^{-3} dan $N_D = 10^{15}$ cm^{-3}. Tentukan kapasitan diod sebagai fungsi voltan pincang balikan jika luas diod, $A = 7 \times 10^{-4}$ cm^2, $ni = 10^{10}$ cm^{-3}, pemalar dielektrik $K_s = 11.7$, $\epsilon_0 = 8.854 \times 10^{-14}$ F/cm dan $kT = 0.0259$ eV. Kirakan kapasitan diod pada $V_R = 1$ V dan 5V.

A p^+n silicon diode is used as a varactor. The effective doping concentrations of the p and n sides are $N_A = 10^{19}$ cm^{-3} and $N_D = 10^{15}$ cm^{-3} respectively. Find the diode capacitance as a function of reverse bias voltage V_R if diode area, $A = 7 \times 10^{-4}$ cm^2, $ni = 10^{10}$ cm^{-3}, dielectric constant $K_s = 11.7$, $\epsilon_0 = 8.854 \times 10^{-14}$ F/cm and $kT = 0.0259$ eV. Compute the diode capacitance at $V_R = 1$ V and 5V.

(40%)

6. (a) Tentukan ungkapan bagi arus ke depan bagi satu diod p-n simpang mendadak tapak panjang. Anggapkan kawasan-kawasan di luar kawasan susutan adalah kuasi-neutral dengan

Find an expression for the forward current in a long base, abrupt junction p-n diode. Assume the regions outside the depletion region are quasi-neutral with

$$\Delta p_n(x_n) = \frac{\eta_i^2}{N_D}(e^{V_A/V_T} - 1) \equiv p_n - p_{no}$$

$$\Delta n_p(-x_p) = \frac{\eta_i^2}{N_A}(e^{V_A/V_T} - 1) \equiv n_p - n_{po}$$

di mana x_n , $-x_p$ adalah sempadan-sempadan kawasan muatan dengan pincang yang dikenakan $V_A \cdot \left(V_T \equiv \frac{kT}{q}\right)$.

where x_n , $-x_p$ are the boundaries of the depletion region with applied bias $V_A \cdot \left(V_T \equiv \frac{kT}{q}\right)$.

(60%)

...10/-

(b) Satu diod p-n silikon tapak panjang mempunyai spesifikasi-spesifikasi berikut:

A long bases silicon p-n diode has the following specifications:

bahagian p: $N_A = 10^{16}\ cm^{-3}$, $\mu_n = 1200\ cm^2 / v-s$, $\tau_n = 10^{-8}$ saat/*sec*
p-side

bahagian n: $N_D = 10^{18}\ cm^{-3}$, $\mu_p = 150\ cm^2 / v-s$, $\tau_p = 10^{-8}$ saat/*sec*
n-side

$n_i = 10^{10}\ cm^{-3}$, $Ks = 11.7$, $\epsilon_o = 8.854 \times 10^{-14}\ F/cm$, $q = 1.6 \times 10^{-19}$ coulomb

kT = .0259 eV. Luas diod, A = 10^{-4} cm^2.

Tentukan arus ketepuan I_0, kapasitans resapan C_D, kealiran resapan G_D bagi pincang ke depan V_A = +0.5 V pada frekuensi rendah.

$n_i = 10^{10}\ cm^{-3}$, $Ks = 11.7$, $\epsilon_o = 8.854 \times 10^{-14}\ F/cm$, $q = 1.6 \times 10^{-19}$ coulomb

kT = .0259 eV. Diode area, A = 10^{-4} cm^2.

Find the saturation current I_0, the diffusion capacitance C_D, the diffusion conductance G_D for a forward bias V_A = +0.5 V at low frequencies.

(40%)

7. (a) Tentukan jumlah cas yang disimpan dalam tapak sempit satu transistor npn. Panjang kawasan tapak kuasi-neutral ialah X_B, luas ialah A dan nilai-nilai sempadan pembawa minoriti dalam tapak ialah

Find the total charge stored in the narrow base of a npn transistor. The length of the quasi-neutral base region is X_B, area is A and the boundary values of minority carriers in base are

$n_{po}e^{V_{BE}/V_T}$ dan $n_{po}e^{V_{BC}/V_T}$

and

...11/-

Juga, kirakan arus gabungan semula pembawa minoriti dalam kawasan tapak bagi suntikan aras rendah dan pincang aktif. Anggap masa hayat pembawa minoriti ialah τ_n dan $X_B << \sqrt{D_n \tau_n}$.

Also, calculate the minority carrier recombination current in the base region for low level injection and active bias. Assume minority carrier lifetime is τ_n *and* $X_B << \sqrt{D_n \tau_n}$.

(30%)

(b) Tentukan kecekapan suntikan pemancar (τ) dan faktor pengangkutan tapak (α_T) jika arus pemancar diberikan oleh

Determine the emitler injection efficieney (τ) *and the base transport factor* (α_T) *if the emitter current is given by*

$$I_E = Aqn_i^2 \left(\frac{D_{NB}}{N_{AB} X_B} + \frac{D_{PE}}{N_{DE} X_E}\right) e^{V_{BE}/V_T}$$

(30%)

(c) Kirakan α_{dc} (gandaan arus dc CB) dan β_{dc} (gandaan arus dc CE).

Calculate α_{dc} *(CB dc current gain) and* β_{dc} *(CE dc current gain).*

(10%)

...12/-

(d) Tentukan voltan tebuk-tembus, dengan V_{BE} = 0 volt. Spesifikasi transistor adalah

Find the punch through voltage, with V_{BE} = 0 volt. The transistor specifications are

pemancar : $N_{DE} = 10^{19}\ cm^{-3}$, $X_E = 1\,\mu m$, $\mu_p = 70\ cm^2/v-s$
emitter

tapak : $N_{AB} = 10^{17}\ cm^{-3}$, $X_B = 0.7\,\mu m$, $\mu_n = 350\ cm^2/v-s$
base

pengumpul : $N_{DC} = 10^{16}\ cm^{-3}$, $L_{pc} = 50\,\mu m$, $\mu_p = 450\ cm^2/v-s$
collector

$n_i = 10^{10}\ cm^{-3}$, $kT = 0.0259\ ev$, $\tau_n = 10^{-4}$ saat/sec

$A = 10^{-4}\ cm^2$, $V_{BE} = +0.5$ volt, $K_S = 11.7$, $\epsilon_o = 8.854 \times 10^{-14}\ F/cm$

(30%)

8. Jawab mana-mana dua daripada yang berikut:
Answer any two:

(a) Terangkan dengan ringkas, dengan bantuan lakaran-lakaran, proses penjanaan-gabungan semula yang mungkin berlaku dalam satu semikonduktor.

Explain briefly, with the help of sketches, the generation-recombination processes which may occur in a semiconductor.

(50%)

...13/-

(b) Apakah pemodulatan lebar tapak? Bincangkan dengan ringkas kesan-kesan fenomena berikut ke atas prestasi keseluruhan transistor dwikutub:

What is base-width modulation? Discuss briefly the effects of the following phenomena on the overall performance of a bipolar transistor:

(i) Pemodulatan lebar tapak,
Base-width modulation,

(ii) Penjanaan-gabungan semula dalam kawasan tapak,
Generation-recombination in the base region,

(iii) Rintangan tapak, dan
Base resistance, and

(iv) Suntikan aras tinggi.
High level injection.

(50%)

(c) Apakah lubang?
Apakah cas dan jisim lubang? Terangkan jawapan anda menggunakan gambar rajah E-k. Bagaimanakah lubang bergerak, di bawah pengaruh medan elektrik yang dikenakan,

What are holes?
What charge and mass are assigned to holes? Explain the deductions using E-k diagram. How does a hole move-under an applied electric field,

(i) dalam satu hablur sempurna

in a perfect crystal

(ii) dalam satu hablur semikonduktor sebenar.

in a real semiconductor crystal?

(50%)

oooOooo