UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Pertama
Sidang Akademik 1996/97

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EEE 327 - Fizik Peranti Semikonduktor

Masa : [3 jam]

ARAHAN KEPADA CALON :

Sila pastikan bahawa kertas peperiksaan ini mengandungi **SEPULUH (10)** 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.

Jawab semua soalan di dalam Bahasa Malaysia.

1. Satu sampel hablur silikon didop secara seragam dengan 3 x 10^{16} cm^{-3} atom arsenik (penderma) dan 2.3 x 10^{16} cm^{-3} atom boron (penerima). Pada keseimbangan haba 27°C, tentukan kuantiti-kuantiti berikut

A sample of silicon crystal is doped uniformly with 3 x 10^{16} cm^{-3} of arsenic atoms (donors) and 2.3 x 10^{16} cm^{-3} of boron atoms (acceptors). At thermal equilibrium at 27°C determine the following quantities

(a) Jenis keberaliran sampel
Conductivity type of the sample

(b) Kepekatan pembawa majoriti
Majority carrier concentration

(c) Aras Fermi, E_f
Fermi level, E_f

(d) Aras Fermi intrinsik, E_i, dalam silikon
Intrinsic Fermi level, E_i in silicon

(e) Kepekatan pembawa intrinsik n_i
Intrinsic carrier concentration n_i

(f) Kepekatan pembawa minoriti
Minority carrier concentration

(g) Ketumpatan cas-cas tetap dalam sampel
Density of fixed charges in the sample

Gunakan data berikut
Use the following data

N_C = 2.9 x 10^{19} cm^{-3}, N_V = 1.1 x 10^{19} cm^{-3}

kT = 0.0259 eV, E_G = 1.11 eV

(100%)

2. Satu sampel silikon didop dengan $N_D = 5 \times 10^{15}$ cm^{-3} dan $N_A = 3 \times 10^{15}$ cm^{-3}.
A silicon sample is doped with $N_D = 5 \times 10^{15}$ cm^{-3} and $N_A = 3 \times 10^{15}$ cm^{-3}.

(a) Apakah kepekatan pemderma terion dan penerima terion dalam sampel pada 300°K?
What are the concentrations of ionized donors and ionized acceptors in the sample at 300°K?

(b) Apakah kepekatan penderma terion dan penerima terion pada 0°K?
What are the concentrations of ionized donors and ionized acceptors at 0°K?

(c) Tentukan n dan p pada 0°K.
Find n and p at 0°K.

(d) Kirakan kebarangkalian Fermi-Dirac bagi satu aras tenaga di E_c dalam sampel ini diduduki pada 300°K..

Calculate the Fermi-Dirac probability that an energy level at E_c is occupied in this sample at 300°K.

(e) Kira kebarangkalian bagi satu aras tenaga di E_v tidak diduduki pada 300°K.
Calculate the probability that an energy level at E_v is empty at 300°K.

(f) Apakah aras pendopan maksimum bersih bagi Si jenis-n pada 300°K, supaya persamaan bentuk tertutup yang digunakan bagi pengiraan kepekatan pembawa kekal sah. (anggarkan nilai yang hampir).

What is the net maximum doping level for n-type Si at 300°K , so that the closed form equations used for carrier concentration calculations remain valid? (estimate an approximate value).

(g) Satu silikon jenis-n didop dengan $N_D = 10^{16}$ penderma/ cm^3 dan kuantiti penerima, $N_A(cm^{-3})$. yang tidak diketahui $n_i = 1.1 \times 10^{10}\ cm^{-3}$, $\mu_n = 0.1\ m^2/v.s$ dan $\mu_p = 0.03\ m^2/v\text{-}s$. Tentukan N_A jika sampel mempunyai keberintangan 1Ω cm.

[Guna : $E_g = 1.11$ eV, $kT = 0.0259$ eV, $N_C = 2.9 \times 10^{19}\ cm^{-3}$, $N_V = 1.1 \times 10^{19}\ cm^{-3}$, semuanya pada 300°K]

An n-type silicon is doped with $N_D = 10^{16}$ donors/cm^3 and an unknown quantity of acceptors, $N_A(cm^{-3})$. $n_i = 1.1 \times 10^{10}\ cm^{-3}$, $\mu_n = 0.1\ m^2/v.s$ and $\mu_p = 0.03\ m^2/v\text{-}s$. Find N_A if the sample has resistivity 1Ω cm.

[Use : $E_g = 1.11$ eV, $kT = 0.0259$ eV, $N_C = 2.9 \times 10^{19}\ cm^{-3}$, $N_V = 1.1 \times 10^{19}\ cm^{-3}$, all at 300°K]

(100%)

3. (a) Kira keberintangan sampel-sampel GaAs berikut pada 300°K. Guna $\mu_n = 8500\ cm^2/v\text{-}s$, $\mu_p = 400\ cm^2/v\text{-}s$, cas elektronik, $q = 1.6 \times 10^{-19}$ coulomb.

Calculate the resistivities of the following samples of GaAs at 300°K. Use, $\mu_n = 8500\ cm^2/v\text{-}s$, $\mu_p = 400\ cm^2/v\text{-}s$, electronic charge, $q = 1.6 \times 10^{-19}$ coulomb.

(i) GaAs intrinsik; $n_i = 2 \times 10^6\ cm^{-3}$
intrinsic GaAs; $n_i = 2 \times 10^6\ cm^{-3}$

(ii) GaAs; $N_D = 5 \times 10^{14}\ cm^{-3}$
n-type GaAs; $N_D = 5 \times 10^{14}\ cm^{-3}$

(iii) GaAs; $N_A = 5 \times 10^{14}\ cm^{-3}$
p-type GaAs; $N_A = 5 \times 10^{14}\ cm^{-3}$

(25%)

(b) Kebolehgerakan elektron μ_n dalam GaAs tulin (intrinsik) pada 300°K ialah 8500 cm^2/v-s. Apabila GaAs terdop jenis-n dengan $N_D = 2 \times 10^{17}$ cm^{-3}, μ_n turun ke 5000 cm^2/v-s. Tentukan kuantiti-kuantiti berikut;

Electron mobility μ_n in pure (intrinsic) GaAs at 300°K is 8500 cm^2/v-s. When GaAs is doped n-type with $N_D = 2 \times 10^{17}$ cm^{-3}, μ_n drops to 5000 cm^2/v-s. Determine the following quantities;

(i) τ_L, min masa perlanggaran serakan disebabkan oleh getaran haba atom-atom kekisi.

τ_L, mean collision time of scattering due to thermal vibration of lattice atoms

(ii) μ_I, kebolehgerakan disebabkan serakan elektron oleh penderma terion.

μ_I, mobility due to scattering of electrons by ionized donors.

(iii) τ_I, min masa perlanggaran disebabkan penyerakan oleh penderma terion.

τ_I, mean collision time due to scattering by ionized donors.

(iv) Purata halaju hanyut elektron dalam GaAs terdop pada 300°K jika satu medan luaran, ε = 100V/cm dikenakan.

Average drift velocity of electrons in doped GaAs at 300°K if an external field, ε = 100V/cm is applied.

(v) Purata bilangan perlanggaran yang dialami oleh satu elektron semasa melalui kawasan sepanjang 5 μm.

Average number of collisions experienced by an electron in traversing a region 5 μm long.

[Guna/*Use*: $m_n^* = 0.067\ m_o$, $m_p^* = 0.48\ m_o$, $m_o = 9.11 \times 10^{-31}$ kg].

(75%)

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4. (a) Kira panjang gelombang terpanjang sinaran yang boleh diserap oleh GaAs.
Calculate the longest wavelength of radiation that can be absorbed by GaAs.

(10%)

(b) Pekali serapan GaAs ialah 10^4 cm^{-1}. Kira ketebalan minimum sampel GaAs, yang akan meresap 90% sinaran, tertuju secara normal padanya.

The absorption coefficient of GaAs is 10^4 cm^{-1}. Calculate the minimum thickness of GaAs sample, which will absorb 90% of radiation, incident normally on it.

(15%)

(c) 10 mw sinaran 1.73 eV tertuju ke atas sampel di atas. Berapakah kuasa yang dipancar semula daripada hablur GaAs, jika kecekapan kuantum dianggap 100%?

10 mw of 1.73 eV radiation is incident on the above sample. How much power is re-emitted from the GaAs crystal, if quantum efficiency is assumed to be 100%?

(15%)

(d) Satu sampel GaAs jenis-p homogen dicahayakan pada 300°K bagi satu masa yang lama ($t < 0$). Aras pendopan ialah $N_A = 10^{12}$ cm^{-3}, $N_D = 0$. Kadar penjanaan pembawa lebihan ialah $G_{op} = 10^{18}$ cm^{-3} s^{-1}. Masa hayat pembawa minoriti lebihan (masa hayat gabungan semula) ialah $\tau = 0.01$ μsaat. Pencahayaan dipadamkan pada $t = 0$. Terbitkan ungkapan bagi kuantiti-kuantiti berikut dan kirakan nilainya:-

A homogeneous p-type GaAs sample is illuminated at 300°K for a longtime ($t < 0$). Doping levels are $N_A = 10^{12}$ cm^{-3}, $N_D = 0$. The excess carrier generation rate is $G_{op} = 10^{18}$ cm^{-3} s^{-1}. The excess minority carrier lifetime (recombination lifetime) is $\tau_n = 0.01$ μsec. The illumination is turned off at $t = 0$. Develop expressions for and evaluate numerically the following quantities:-

(i) Kepekatan pembawa minoriti lebihan pada keadaan mantap ($t \leq 0$).
Excess minority carrier concentration at steady state ($t \leq 0$).

(ii) Perubahan dalam keberaliran sebagai fungsi masa, selepas pencahayaan dipadamkan ($t \geq 0$).

The change in conductivity as a function of time, after illumination is turned off ($t \geq 0$).

Guna/*Use* : $E_g = 1.43$ eV; $n_i = 2 \times 10^6$ cm^{-3}; $h = 6.626 \times 10^{-34}$ J-s

$\mu_n = 8500$ cm^2/v-s; $\mu_p = 400$ cm^2/v-s; $q = 1.6 \times 10^{-19}$ coulomb

(60%)

5. (a) Kepekatan elektron dalam sekeping silikon jenis-n terdop ringan dan seragam pada 300°K berubah secara lelurus daripada 10^{17} cm^{-3} pada $x = 0$ ke 10^{16} cm^{-3} pada $x = 5$ µm. Elektron dibekalkan supaya profil kepekatan akan kekal tetap. Kirakan ketumpatan arus resapan elektron J_{diff}. Anggap medan elektrik sifar $\mu_n = 1000$ cm^2/v-s, kT = 0.0259 eV. Anggap μ_n tetap.

The electron concentration in a piece of uniform, lightly doped, n-type silicon at 300°K varies linearly from 10^{17} cm^{-3} at $x = 0$ to 10^{16} cm^{-3} at $x = .5$ µm. Electrons are supplied to keep the concentration profile constant. Calculate the electron diffusion current density J_{diff}. Assume electric field to be zero. $\mu_n = 1000$ cm^2/v-s, kT = 0.0259 eV. Assume μ_n to remain constant.

(40%)

(b) Kepekatan penderma $N_D(x)$ dalam satu silikon terdop tak seragam pada 300°K diberikan oleh

Donor concentration $N_D(x)$ in a non-uniformly doped silicon at 300°K is given by

$$N_D(x) = 10^{16} - 10^{19}\,x \quad (\text{cm}^{-3})$$

x dalam cm/*x is in cm* bagi/*for*, $0 < x \leq 1$ µm

Tentukan medan elektrik terbina-dalam $\mathcal{E}(x)$ di dalam sampel semikonduktor jika tiada arus mengalir. Kira $\mathcal{E}(0)$.

Find, the built-in electric field $\mathcal{E}(x)$ in the semiconductor sample if no current flows. Evaluate $\mathcal{E}(0)$.

(40%)

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(c) Tentukan pekali resapan bagi elektron dalam silikon pada 300°K pada satu medan elektrik tinggi 100 KV/cm di mana halaju elektron tepu ke 10^7 cm/s.

Find the diffusion co-efficient for electrons in silicon at 300°K at a high electric field of 100 KV/cm where electron velocity saturates to 10^7 cm/s.

(20%)

6. Satu simpang p-n mendadak dibentuk dalam silikon dengan $N_A = 10^{15}$ cm^{-3} dan $N_D = 2 \times 10^{17}$ cm^{-3} masing-masing pada bahagian p dan n.

An abrupt p-n junction is formed in silicon with $N_A = 10^{15}$ cm^{-3} and $N_D = 2 \times 10^{17}$ cm^{-3} on p- and n- sides respectively.

(a) Guna anggaran susutan bagi menganalisa diod pada pincang sifar dan dapatkan ungkapan bagi keupayaan terbina dalam serta lebar kawasan susutan.

Use depletion approximation to analyze the diode at zero bias and find expressions for the built-in potential and the depletion region width.

(70%)

(b) Tentukan keupayaan terbina-dalam dan lebar kawasan susutan pada pincang sifar. Guna, $\varepsilon_r = 11.7$, $\varepsilon_o = 8.854 \times 10^{-14}$ F/cm, $n_i = 1.1 \times 10^{10}$ cm^{-3} dan kT = 0.0259 eV.

Determine the built-in potential and depletion region width at zero bias. Use, $\varepsilon_r = 11.7$, $\varepsilon_o = 8.854 \times 10^{-14}$ F/cm, $n_i = 1.1 \times 10^{10}$ cm^{-3} and kT = 0.0259 eV.

(30%)

7. Ketumpatan pembawa minoriti lebihan di luar kawasan susutan satu diod simpang p-n, dengan voltan V_a dikenakan merintanginya, diberikan oleh

Excess minority carrier densities outside the depletion region of a p-n junction diode, with voltage V_a applied across it, are given by

$$\Delta p_n(x) = p_{no}\left(e^{V_a/V_T} - 1\right)e^{-(x - x_n)/L_p}, \qquad x \geq x_n$$

$$\Delta n_p(x) = n_{po}\left(e^{V_a/V_T} - 1\right)e^{+(x + x_p)/L_n}, \qquad x \leq -x_p$$

di mana $V_T = \frac{kT}{q}$; x_n dan $-x_p$ adalah sempadan-sempadan kawasan susutan. L_p dan L_n adalah panjang resapan pembawa minoriti.

$V_T = \frac{kT}{q}$; x_n and $-x_p$ are the boundaries of the depletion region. L_p and L_n are diffusion lengths of minority carriers.

(a) Dengan menganggap diod tapak panjang, tentukan ungkapan bagi ketumpatan arus dalam diod p-n apabila voltan dikenakan.
Assuming long-base diode, find an expression for the current density in the p-n diode under an applied voltage.

(60%)

(b) Kira I_o bagi satu diod yang mempunyai spesifikasi berikut
Calculate I_o for a diode having the following specifications.

bahagian-n *n-side*	:	$N_D = 10^{16}$ cm^{-3};	$\mu_n = 1200$ cm^2/v-s;	$\mu_p = 430$ cm^2/v-s
bahagian-p *p-side*	:	$N_A = 5 \times 10^{18}$ cm^{-3};	$\mu_n = 120$ cm^2/v-s;	$\mu_p = 80$ cm^2/v-s
		$\tau_n = \tau_p = 1$ μsec,	A = 0.01 cm^2;	kT = 0.0259 eV

(40%)

8. Parameter pembikinan bagi satu transistor npn terdop seragam adalah seperti berikut:-
The fabrication parameters for a uniformly doped npn transistor are as follows:-

E : $N_{DE} = 10^{19}$ cm^{-3},	$X_E = 1$ μm,	$\mu_p = 100$ cm^2/v-s
B : $N_{AB} = 10^{17}$ cm^{-3},	$X_B = 0.7$ μm,	$\mu_n = 500$ cm^2/v-s
C : $N_{DC} = 10^{15}$ cm^{-3},	$L_{pc} = 50$ μm,	$\mu_p = 500$ cm^2/v-s

...10/-

di mana L ialah panjang resapan, X ialah panjang kawasan neutral yang berpadanan.
where L is the diffusion length, X is the length of the corresponding neutral region.

Tentukan yang berikut dengan anggapan T = 300°K.
Determine the following assuming T = 300°K.

(a) γ, kecekapan suntikan pemancar
γ, *the emitter injection efficiency.* (40%)

(b) β_T, faktor pengangkutan tapak Panjang resapan elektron dalam kawasan tapak, L_{nB} = 22.5 μm.
β_T, *the base transport factor. Diffusion length of electrons in base region,* L_{nB} = 22.5 μm.

(40%)

(c) α_F, gandaan arus ke depan dan $\beta \equiv \frac{i_C}{i_B}$.
α_F, *the forward current gain and* $\beta \equiv \frac{i_C}{i_B}$. (20%)

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