UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2008/2009

November 2008

EBB 424/3 – Semiconductor Devices and Optoelectronics
[Peranti Semikonduktor dan Optoelektronik]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains FIFTEEN printed pages and ONE page APPENDIX before you begin the examination.
[Sila pastikan bahawa kertas peperiksaan ini mengandungi LIMA BELAS muka surat yang bercetak dan SATU muka surat LAMPIRAN sebelum anda memulakan peperiksaan ini.]

This paper contains SEVEN questions. ONE question from PART A, THREE questions from PART B and THREE questions from PART C.
[Kertas soalan ini mengandungi TUJUH soalan. SATU soalan dari BAHAGIAN A, TIGA soalan dari BAHAGIAN B dan TIGA soalan dari BAHAGIAN C.]

Instruction: Answer **FIVE** questions. Answer **ALL** questions from PART A, **TWO** questions from PART B and **TWO** questions from PART C. If candidate answers more than five questions only the first five questions answered in the answer script would be examined.
*[**Arahan**: Jawab **LIMA** soalan. Jawab **SEMUA** soalan dari BAHAGIAN A, **DUA** soalan dari BAHAGIAN B dan **DUA** soalan dari BAHAGIAN C. Jika calon menjawab lebih daripada lima soalan hanya lima soalan pertama mengikut susunan dalam skrip jawapan akan diberi markah.]*

Answer to any question must start on a new page.
[Mulakan jawapan anda untuk setiap soalan pada muka surat yang baru.]

You may answer a question either in Bahasa Malaysia or in English.
[Anda dibenarkan menjawab soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]

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PART A

BAHAGIAN A

1. [a] Why nanoelectronic devices are so important?

Mengapa peranti nanoelektronik sangat penting?

(25 marks/*markah*)

[b] Give a brief explanation on Coloumb blockade effect in nanoelectronic device especially in single-electron tunneling device.

Berikan penjelasan ringkas berkaitan pengepungan Coloumb dalam peranti nanoelektrik khasnya dalam peranti penerowongan elektron-tunggal.

(25 marks/*markah*)

[c] Describe the principle of operation of an avalanche photodiode. Use a sketch to show the structure of avalanche photodiode.

Terangkan prinsip operasi fotodiod avalanche. Gunakan lakaran untuk menunjukkan struktur fotodiod avalanche.

(20 marks/*markah*)

[d] A red homojunction laser diode can be fabricated by selecting appropriate material. Indicate a material that can be used for red laser emission and explain your choice. It is however known that homojunction laser has several problems associated to it. Explain what these problems are.

Simpang-sejenis diod laser merah boleh difabrikasi dengan memilih satu bahan yang sesuai. Nyatakan bahan yang boleh digunakan untuk penghasilan laser merah dan terangkan pemilihan anda. Telah diketahui bahawa simpang-sejenis diod laser mempunyai beberapa masalah berkaitan dengannya. Terangkan apakah masalah-masalah tersebut.

(30 marks/*markah*)

PART B

BAHAGIAN B

2. [a] Bipolar junction transistors (BJTs) are classified as 'minority-carrier' devices. Why? Explain briefly.

Transistor dwikutub (BJTs) diklasifikasikan sebagai 'peranti pembawa minoriti'. Mengapa? Jelaskan secara ringkas.

(25 marks/*markah*)

[b] How a BJT operated as active, saturation, cutoff, and inversion modes? Give a brief explanation.

Bagaimana BJT beroperasi sebagai mod aktif, mod pemutus, dan mod penyongsangan? Berikan penjelasan ringkas.

(20 marks/*markah*)

[c] Figure 1 shows a common base I-V characteristics at room temperature of a PNP BJT. The curves correspond to an emitter current of 0 mA (the bottom curve), 1 mA, 2 mA, 3 mA, 4 mA, 5 mA, 6 mA, 7 mA, 8 mA, and 9 mA (the top curve). The emitter area is 75 µm by 75 µm. Give a brief analysis to this BJT characteristics. Attention should be focused on transistor current and breakdown.

Rajah 1 menunjukkan ciri tapak-biasa I-V bagi PNP BJT pada suhu bilik. Lengkok berkaitan dengan arus pemancar 0 mA (lengkok bawah), 1 mA, 2 mA, 3 mA, 4 mA, 5 mA, 6 mA, 7 mA, 8 mA, dan 9 mA (lengkok atas). Luasan pemancar ialah 75 µm × 75 µm. Buat analisis ringkas ke atas ciri BJT ini. Perhatian sepatutnya ditumpukan ke atas arus dan pecahtebat transistor.

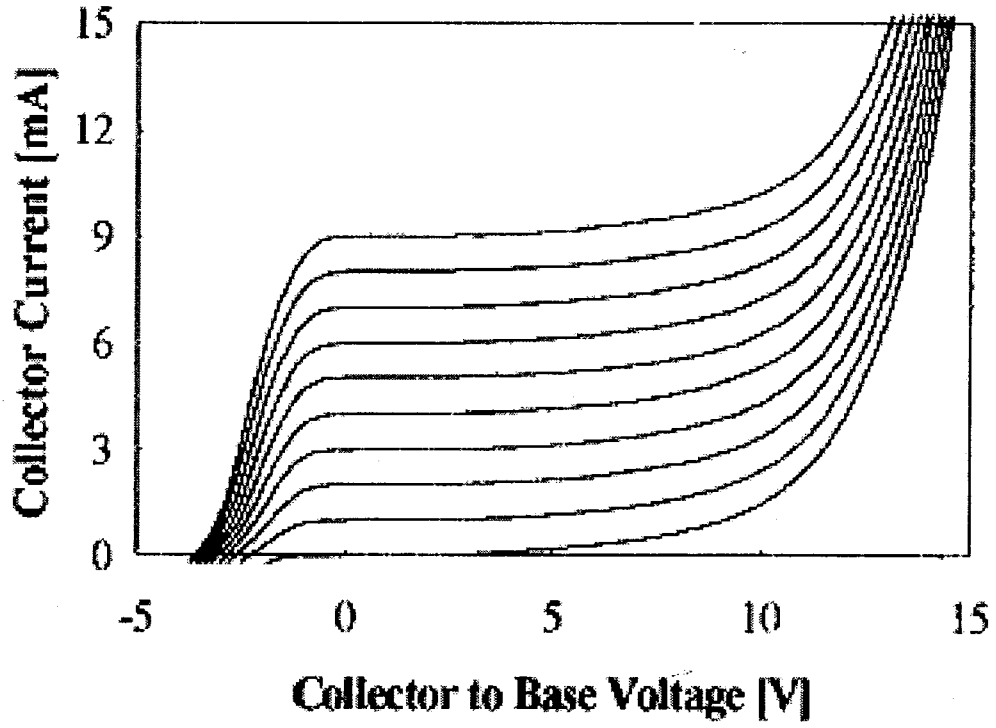

Figure 1

Rajah 1

(25 marks/*markah*)

[d] Suppose BJT at Question 1(c) has emitter efficiency of 0.96, a base transport factor of 0.99, and a depletion layer recombination factor of 0.98. Calculate the base current for each curves.

Andaikan BJT pada Soalan 1(c) mempunyai kecekapan pemancar 0.96, faktor pengangkutan tapak 0.99 dan faktor kombinasi semula lapisan kosong 0.98. Kira arus tapak bagi setiap lengkok.

(30 marks/*markah*)

3. [a] The field effect transistor (FET) was known as a unipolar transistor. What does it means?

Transistor kesan medan (FET) dikenali sebagai transistor sekutub. Apa yang dimaksud dengan ayat ini?

(10 marks/*markah*)

[b] A typical I-V characteristic of JFET is shown in Figure 2.

(i) Determine the drain-source current saturation (I_{DSS}) value from the I-V curves with V_{GS} = 0 V, -1.0 V, -2.0 V, respectively.

(ii) Plot the transconductance curves for the three selected curves (V_{GS} = 0 V, -1.0 V, -2.0 V).

Ciri tipikal I-V JFET ditunjukkan pada Rajah 2.

(i) Tentukan nilai arus sumber-saliran tepu (I_{DSS}) daripada lengkok I-V dengan masing-masing V_{GS} = 0 V, -1.0 V, -2.0 V.

(ii) Lakarkan lengkok transkonduktans bagi ketiga-tiga lengkok terpilih tersebut (V_{GS} = 0 V, -1.0 V, -2.0 V).

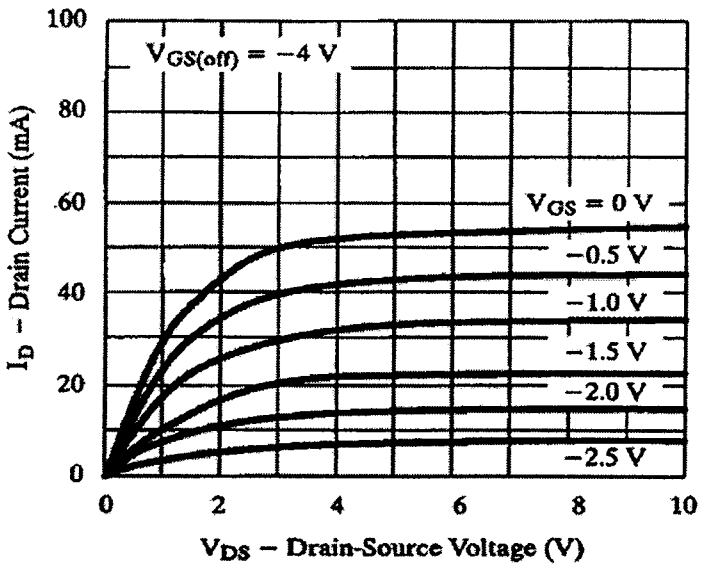

Figure 2

Rajah 2

(50 marks/*markah*)

[c] A biasing circuit of n-channel JFET is shown in Figure 3. If pinch off voltage, $V_{GS(off)}$ = -5 V and drain-source current saturation, I_{DSS} = 12 mA, plot transconductance curve and determine the Q-point value for V_{GG} = -0.5 V.

Litar pincang suatu JFET saluran-n ditunjukkan dalam Rajah 3. Jika voltan jepitan, $V_{GS(off)}$ = -5 V dan arus sumber-saliran tepu, I_{DSS} = 12 mA, lakarkan lengkok transkonduktans dan tentukan nilai "Q-point" bagi V_{GG} = -0.5 V.

(40 marks/*markah*)

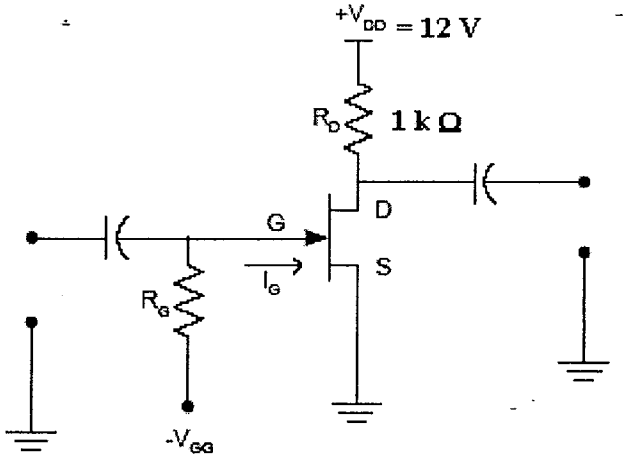

Figure 3

Rajah 3

4. [a] C-V characteristics of MOS capacitor at low and high frequencies shown in Figure 4.

(i) Identify the type of capacitor (n-MOS or p-MOS).

(ii) Mark or determine the accumulation region, depletion region, inversion region, flatband voltage (V_{FB}) and threshold voltage (V_T).

(iii) Determine the total capacitance for curve (a) and curve (b).

Ciri C-V bagi kapasitor MOS pada frekuensi rendah dan tinggi ditunjukkan dalam Rajah 4.

(i) Tentukan jenis kapasitor (n-MOS atau p-MOS)

(ii) Tandakan atau tentukan kawasan penumpukan, kawasan kesusutan, kawasan penyongsangan, voltanjalur rata (V_{FB}) dan voltan ambang (V_T)

(iii) Tentukan kapasitans keseluruhan bagi lengkok (a) dan lengkok (b)

(50 marks/*markah*)

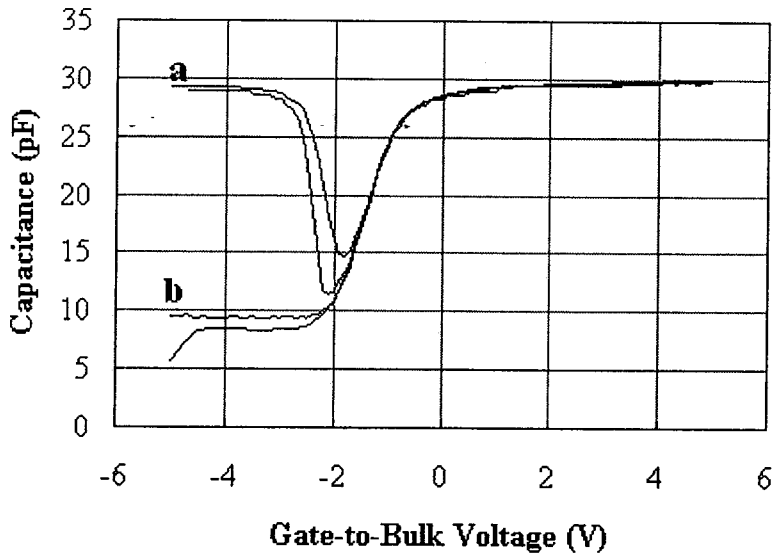

Figure 4

Rajah 4

[b] Identify and give a brief explanation about the source of MOSFET capacitances including intrinsic capacitance and parasitic capacitances. How to minimize the parasitic capacitances?

Kenalpasti dan berikan penjelasan ringkas berkaitan dengan punca-punca kapasitans pada MOSFET termasuk kapasitans instrinsik dan kapasitans parasitik. Bagaimana mengurangkan kapasitans parasitik?

(30 marks/*markah*)

[c] Sketch a cross-section view of metal semiconductor field effect transistor (MESFET) and give a brief explanation why GaAs MESFET is better than Si MESFET.

Lakarkan keratan rentas logam semikonduktor transistor kesan medan (MESFET) dan berikan penjelasan ringkas mengapa GaAs MESFET lebih baik dibandingkan dengan Si MESFET.

(20 marks/*markah*)

PART C

BAHAGIAN C

5. [a] For an optical fibre communication, wavelength of 1.1 to 1.6μm is required. A laser diode can be used for such application. State and explain a material that can be used to produce laser which could emit such wavelength.

Untuk komunikasi fibre optikal, panjang gelombang 1.1 hingga 1.6μm di perlukan. Diod laser boleh digunakan untuk aplikasi ini. Nyatakan dan terangkan apakah bahan yang sesuai untuk digunakan bagi meghasilkan laser yang mempunyai panjang gelombang yang dinyatakan.

(20 marks/*markah*)

[b] In a laser diode, population inversion is a precondition for lasing action. Describe how population inversion can be achieved in a diode laser. You must use energy band diagrams to demonstrate your answer.

Populasi songsang adalah pre-kondisi untuk penghasilan diod laser. Terangkan bagaimana populasi songsang ini boleh diperolehi untuk laser diod. Anda perlu menggunakan gambarajah jalur tenaga untuk menerangkan jawapan anda.

(30 marks/*markah*)

[c] For an optical fibre communication, a heterojunction laser diode can be achieved by multi-layer thin film growth on a suitable substrate. You need to design a device that can emit blue laser. Answer the following question to help you in deciding on the best design.

Heterosimpang diod laser boleh dihasilkan dengan menggunakan lapisan-berbilang yang ditumbuhkan di atas substrat yang sesuai. Anda perlu merekabentuk laser yang menghasilkan cahaya biru. Jawab soalan di bawah untuk menolong anda merekabentuk peranti anda.

(i) State and explain a suitable material as a substrate for your blue laser diode.

Nyatakan dan terangkan bahan yang sesuai sebagai substrat untuk penghasilan diod laser biru anda.

(10 marks/*markah*)

(ii) For your laser diode, carrier and photon confinement must be achieved. How do these two properties can be obtained?

Untuk laser diod anda, pengurungan pembawa dan foton mesti diperolehi. Bagaimanakah kedua-dua ciri-ciri ini boleh diperolehi?

(10 marks/*markah*)

(iii) Sketch your blue laser diode and indicate the type of configuration you choose. You must label each layer clearly.

Lakarkan diod laser biru anda dan nyatakan apakah jenis konfigurasi pilihan anda. Anda perlu melabel setiap lapisan dengan jelas.

(30 marks/*markah*)

6. [a] State a III-V semiconductor compound that can be used to emit red, yellow and green light. Justify your answer by plotting an energy band for the compound you selected and explain all the necessary dopants that can be used to yield the colours you desired.

Nyatakan satu bahan sebatian semikonduktor III-V yang boleh digunakan untuk menghasilkan cahaya merah, kuning dan hijau. Sokong jawapan anda dengan lakaran gambarajah jalur tenaga dan terangkan dopant-dopant yang diperlukan untuk menghasilkan warna cahaya yang anda kehendaki.

(30 marks/*markah*)

[b] Group II-VI materials can be used to produce blue light emitting diode (LED). State some examples of group II-VI compounds that can emit blue light. Why do you think the use of group II-VI materials is not preferred if compared to group III-V materials for blue light emission.

Bahan kumpulan II-VI boleh digunakan untuk menghasilkan LED biru. Berikan contoh-contoh sebatian kumpulan II-VI yang boleh menghasilkan cahaya biru. Pada pandangan anda kenapakah bahan kumpulan II-VI tidak begitu diminati jika dibandingkan dengan bahan kumpulan III-V untuk menghasilkan cahaya biru.

(20 marks/*markah*)

[c] You are given a silicon solar cell absorption coefficient, $\alpha = 1 \times 10^6 m^{-1}$. The solar cell has an area of 10cm x 10cm with length, n, $l_n = 0.5\mu m$, width, W = $1\mu m$ and length e, $L_e = 50\mu m$. At $\lambda = 1.1\ \mu m$ the photogeneration rate, $G_o = 1 \times 10^{20}\ cm^{-3}s^{-1}$. Answer the following questions.

Anda diberikan sel suria silikon dengan pekali penyerapan, $\alpha = 1 \times 10^6 m^{-1}$. Sel suria ini mempunyai kawasan 10cm x 10cm dengan kepanjangan, n, $l_n = 0.5\mu m$, kelebaran, $W = 1\mu m$ dan kepanjangan, e, $L_e = 50\mu m$. Pada $\lambda = 1.1\ \mu m$ kadar fotogenerasi, $G_o = 1 \times 10^{20}\ cm^{-3}s^{-1}$. Jawab soalan-soalan seterusnya.

(i) Sketch the most possible configuration of this solar cell and indicate how photocurrent can be produced.

Lakarkan konfigurasi sel suria yang paling sesuai dan tentukan bagaimana fotoarus dihasilkan.

(25 marks/*markah*)

(ii) Calculate the photocurrent.

Kirakan fotoarus.

(25 marks/*markah*)

7. [a] A plot of photon energy vs. absorption coefficient is given in Figure 5. Given a p-i-n photodiode with intrinsic width, W = 40μm with p^+ layer of 0.1μm. The diode is illuminated with optical pulse with wavelength of 900nm and incident light intensity, I_{ph} of 0.1mWcm^{-2}. Given that the drift velocity of the electrons in the intrinsic layer is 10^6ms^{-1} whereas drift velocity for holes is 10^5ms^{-1}. Answer the following questions.

Plot tenaga foton melawan pekali penyerapan diberikan pada Rajah 5. Diberikan satu fotodiod p-i-n dengan kelebaran intrinsik, W = 40μm dengan lapisan p^+ = 0.1μm. Diod ini disinarkan dengan denyutan optikal berpanjang gelombang 900nm dan keamatan cahaya, I_{ph} bersamaan dengan 0.1mWcm^{-2}. Diberikan kelajuan hanyutan elektron pada lapisan intrinsik bersamaan dengan 10^6ms^{-1} dan kelajuan hanyutan lohong ialah 10^5ms^{-1}. Jawab soalan-soalan seterusnya.

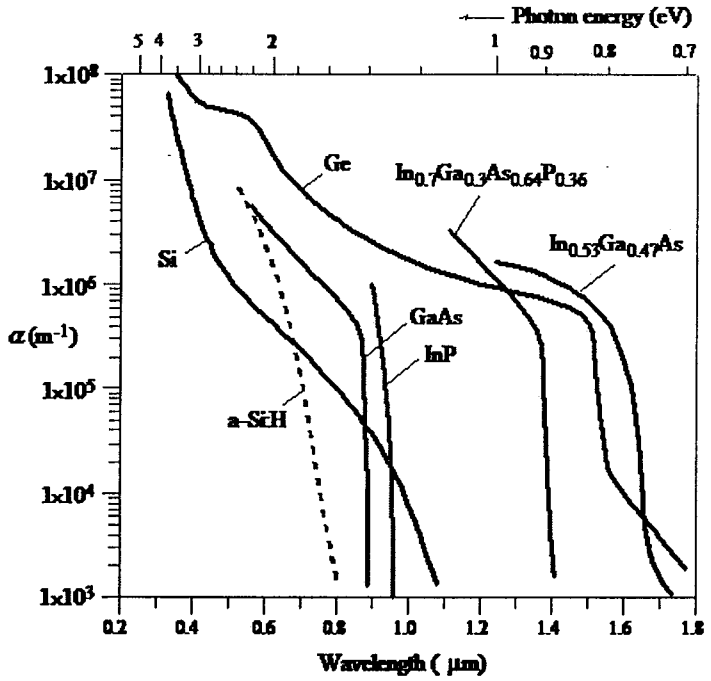

Figure 5

Rajah 5

(i) Calculate the absorption depth of Si at 900nm? Do you think the photogeneration will occur across the intrinsic layer entirely?

(ii) Calculate the electric field, E_o in the intrinsic layer.

(iii) What is the time taken for the electrons and holes to move across the intrinsic layer?

(iv) Calculate the efficiency of the photodiode. Comment on your answer.

(v) Based on the graph in Figure 5, suggest a material which could be suitable to detect infra-red radiation. Explain your answer.

(i) Kirakan kedalaman penyerapan Si pada 900nm? Adakah anda fikir bahawa fotogenerasi akan berlaku di sepanjang lapisan intrinsik keseluruhnnya?

(ii) Kirakan medan elektrik, E_o pada lapisan intrinsik.

(iii) Apakah masa yang dambil oleh elektron dan lohong untuk bergerak sepanjang lapisan intrinsik?

(iv) Kirakan kecekapan fototdiod ini. Berikan komen terhadap jawapan anda.

(v) Berdasarkan graf pada Rajah 5, cadangkan satu bahan yang paling sesuai untuk mengesan radisi infra-merah. Terangkan jawapan anda.

(50 marks/*markah*)

[b] Dye sensitized solar cell, Si:H solar cell and passivated emitter rear locally diffused (PERL) solar cell are three examples of photovoltaic devices. Compare these cells by stating the definition and the advantages and disadvantages of use.

Sel suria tersentisais dai, sel suria Si:H dan sel suria 'passivated emitter rear locally diffused (PERL)' adalah tiga contoh peranti fotovoltik. Bandingkan ketiga-tiga peranti ini dengan menyatakan defnisi setiap peranti dan kebaikan dan keburukkan penggunannya.

(30 marks/*markah*)

[c] Describe the principle of operation of a solar cell. Use an appropriate diagram to support your answer.

Terangkan prinsip operasi sel suria. Gunakan gambarajah untuk menyokong jawapan anda.

(20 marks/*markah*)

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Appendix

Lampiran

Equations

$$I_D = -\frac{Q_{inv} W L}{t_r}$$

$$I_{D,sat} = \mu C_{ox} \frac{W}{L} \frac{(V_{GS} - V_T)^2}{2} (1 + \lambda V_{DS}), \quad \text{for } V_{DS} > V_{GS} - V_T$$

$$V_T = V_{FB} + V_C + 2\phi_F + \frac{\sqrt{2\varepsilon_s q N_a (2\phi_F + V_{SB} + V_C)}}{C_{ox}}$$

$$V_{DS,sat} = V_{GS} - V_{FB} - 2\phi_F - \frac{q N_a \varepsilon_s}{C_{ox}^2} \left(\sqrt{1 + 2 \frac{C_{ox}^2}{q N_a \varepsilon_s} (V_{GB} - V_{FB})} - 1 \right)$$

$$V_T = V_{FB} + 2\phi_F + \frac{\sqrt{2\varepsilon_s q N_a (2\phi_F + V_{SB})}}{C_{ox}}$$

$$V_{FB} = \Phi_{MS} - \frac{Q_f}{C_{ox}} - \frac{1}{C_{ox}} \int_0^{t_{ox}} \frac{x}{x_{ox}} \rho_{ox}(x) dx$$

$$\Phi_{MS} = \Phi_M - \Phi_S = \Phi_M - \left(\chi + \frac{E_g}{2q} + \phi_F \right)$$

$$\phi_F = V_t \ln \frac{N_a}{n_i}, \text{ p - substrate}$$

$$V_T = V_{FB} - |2\phi_F| - \frac{\sqrt{2\varepsilon_s q N_d (|2\phi_F| - V_{SB})}}{C_{ox}}$$

$$V_{FB} = \Phi_{MS} - \frac{Q_f}{C_{ox}} - \frac{1}{C_{ox}} \int_0^{t_{ox}} \frac{x}{x_{ox}} \rho_{ox}(x) dx$$

$$\Phi_{MS} = \Phi_M - \Phi_S = \Phi_M - \left(\chi + \frac{E_g}{2q} - |\phi_F| \right)$$

$$|\phi_F| = V_t \ln \frac{N_d}{n_i}, \text{ n - substrate}$$

$$V_T = V_{FB} + 2\phi_F + \frac{\sqrt{2\varepsilon_s q N_a (2\phi_F + V_{SB})}}{C_{ox}}$$

$$\alpha = \gamma_E \alpha_T \delta_T$$

$$I_D = I_{DSS} \left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2$$

$$\beta = \frac{\alpha}{1 - \alpha}$$

$$I_C = \alpha I_E$$

$$I_B = I_E - I_C$$

$$C = \frac{C_{ox} C_d}{C_{ox} + C_d}$$