ID Number	M

Graduate School of Advanced Sciences of Matter

Hiroshima University

Department of Semiconductor Electronics and Integration Science

Master Course

Entrance Examination for 2013 April Enrollment

August 27, 2012, 13:00~16:00

MAJOR SUBJECTS

Notices

(1) This booklet includes the following sheets.

Problem sheets (including this sheet)	6 pages
Answer sheets	3 pages
Memo sheet	1 page

(2) There are 5 problems I~V, the categories of which are indicated in the boxes [ ].

(3) Solve <u>three</u> problems, selecting from the 5 problems I~V.

(4) One answer sheet should be used for one problem. Write the problem number and its category name at the upper left corner of the answer sheets. The backside of the sheets can be used.

(5) Fill in your identification number on this cover sheet, all the answer sheets, and the memo sheet.

(6) Return all the sheets listed in (1) at the end of the test.

(7) Fill in the numbers of the answered problems in the boxes below.

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I	Electromagnetism

Q1. Show that the impedance of a capacitor $Z_C = \dfrac{1}{j\omega C}$ from electromagnetism laws as following steps, where j, ω, C are the imaginary unit, the angular frequency and the capacitance, respectively.

(1) Consider a parallel-plate capacitor with the area S, the distance d and the dielectric permittivity ε. Derive the equation $Q = CV$ expressing the total electron charge of the capacitor, from Gauss's law $\nabla \cdot \boldsymbol{D} = \rho$ and the relationship between electric field and potential $\boldsymbol{E} = -\nabla \phi$, where Q, V, $\boldsymbol{D}$, ρ, $\boldsymbol{E}$, ϕ are the total electron charge, the voltage of the capacitor, the electric flux density, the charge density, the electric field and the potential of the capacitor, respectively. Note that the end effect is ignored.

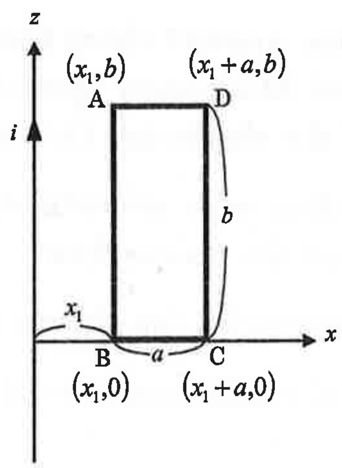
(2) Obtain the relationship between the voltage and the current of the capacitor using the current continuity equation $I = \dfrac{dQ}{dt}$, where t is time.

(3) Show the impedance of the capacitor $Z_C = \dfrac{1}{j\omega C}$, by using $I = |I|e^{j\omega t}$ for the current flowing into the capacitor.

Q2. A current i flows on z axis and a rectangular coil ABCD is located on x-z plane as schematically shown in the figure. Answer the following questions. Here, the magnetic permeability is μ_0.

(1) Obtain the density of magnetic flux $\boldsymbol{B}$ at position (x, z), where $x > 0$, and answer the direction.

(2) Obtain the induced electromotive force V in the coil when $i = i_0 \cos \omega t$, where i_0 is current amplitude, ω is angular frequency and t is time.



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II Circuit Theory

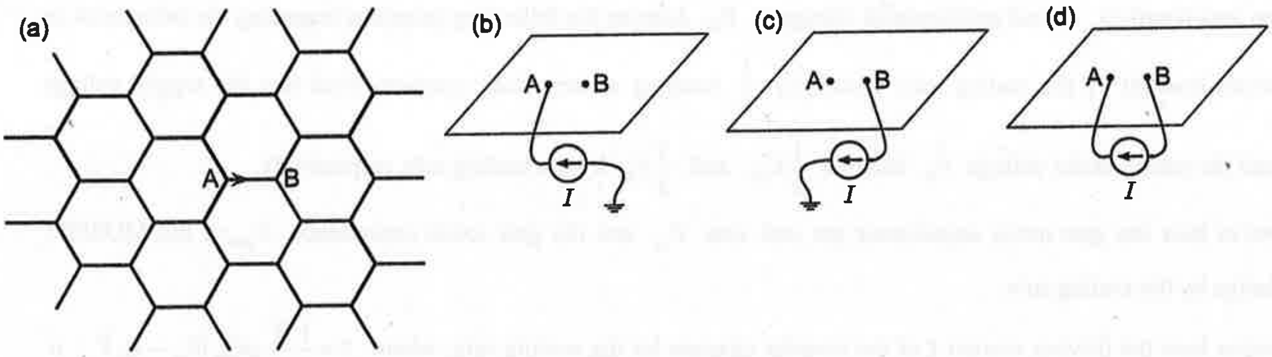
Q1. Consider an infinitely large honeycombed resistive network composed of linear resistors with a resistance R, shown in Figure 1(a). The resistance of each edge of the hexagons is R. Answer the following questions.

(1) A current I is injected into the resistive network from the node A as shown in Figure 1(b). The current spreads out from A toward infinity. Find the current that flows in the branch AB, shown in Figure 1(a), in terms of I.

(2) A current I is injected into the resistive network uniformly from inifinity and is drained out from the node B, as shown in Figure 1(c). Find the current that flows in the branch AB in terms of I.

(3) A current I is injected into the resistive network from the node A and is drained out from the node B, as shown in Figure 1(d). Find the voltage drop V along the branch AB in terms of I and R.

(4) Find the resistance between the nodes A and B in terms of R.



Q2. Figure 2 shows the circuit consisted of the switch S, resistor R, capacitor C and alternating voltage $e(t) = E_m \sin(\omega t + \theta)$, where E_m is voltage amplitude, ω is angular frequency, t is time and θ is phase. Answer the following questions.

(1) The switch S is connected to the node B and C is discharged when $t < 0$. The switch S is connected to the node A at $t = 0$. Find the current $i(t)$ for $t \geq 0$.

(2) Find a charge $Q_S(t)$ stored in C when the circuit is in a periodic steady state.

(3) The circuit is in a periodic steady state. The switch S is connected to the node B at $t = t_1$. Find the current $i(t)$ for $t \geq t_1$.

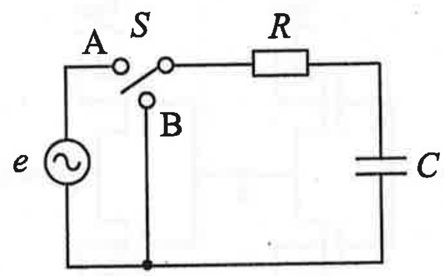


Figure 2

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Ⅲ Integrated Circuit

Q1. Convert the complex logic gate shown in Figure 1 into the transistor-level schematic diagram implemented in the static CMOS integrated circuit.

Q2. Draw the waveform of the output voltage V_Y shown in Figure 2(a), when the input voltage V_X in Figure 2(b) is applied to the circuit. Here V_{DD} is applied to the gate of the NMOSFET, the threshold voltage is assumed to be $\frac{V_{DD}}{4}$, and the capacitance C is assumed to be small enough. The substrate bias effect can be ignored and the subthreshold leakage current is assumed to be zero.

Q3. Figure 3 shows a two-stage circuit consisting of the same two inverters, where the gate width of the MOSFETs is W, the gate length is L and subthreshold voltage is V_{th}. Answer the following questions regarding the influences on this circuit brought by the scaling rule: shrunk by $\frac{1}{S}$ keeping electric field constant. Note that the supply voltage V_{DD} and the subthreshold voltage V_{th} become $\frac{1}{S}V_{DD}$ and $\frac{1}{S}V_{th}$ by the scaling rule, respectively.

(1) Derive how the gate oxide capacitance per unit area C_{ox} and the gate oxide capacitance C_{gate} of the MOSFET change by the scaling rule.

(2) Derive how the driving current I of the inverter changes by the scaling rule, where $I = \frac{1}{2}\frac{W}{L}\mu C_{ox}(V_{gs} - V_{th})^2$, μ is the mobility, V_{gs} is the gate-source voltage, and V_{th} is the threshold voltage.

(3) Derive how the delay time t_{AB} of the inverter input/output (between the node A and B) changes by the scaling rule.

Figure 1

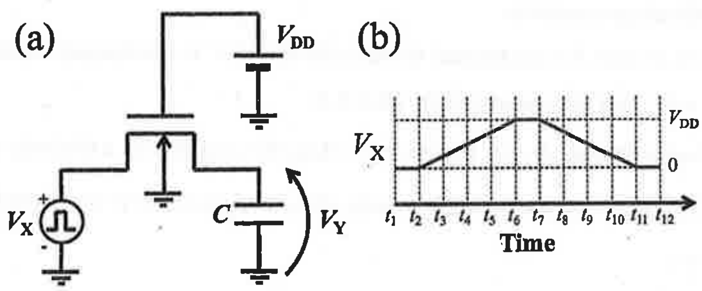

Figure 2

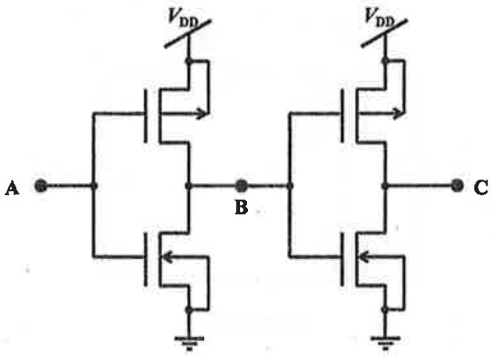

Figure 3

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Ⅳ Semiconductor Engineering

Q. Consider a semiconductor with band gap energy E_g and Fermi energy E_F. The energy level of the valence-band top shall be zero.

(1) Draw a schematic of the energy band diagram of the intrinsic semiconductor with positions of valence band, conduction band and Fermi level.

(2) Assume that the semiconductor is doped with donors of binding energy E_d. Draw a schematic of the energy band diagram with valence band, conduction band, Fermi level and position of the donor states.

(3) Write down the equation for the Coulomb force F_{Coul} between donor ion and donor electron. Use the symbols r_d, q, ε and ε_0 for distance between ion and electron, electron charge, dielectric constant of the semiconductor and vacuum dielectric constant, respectively.

(4) Calculate the allowed orbital radii r_d for electrons bound to the donor ion. Assume additionally the equations $F_{cent} = \frac{m_e \cdot (v_e)^2}{r_d}$ and $m_e \cdot v_e \cdot r_d = n \cdot \hbar$ for the centrifugal force of an orbiting electron and the angular-momentum quantization, respectively. Here $\hbar$, m_e, v_e and n are Plank constant, effective electron mass of the semiconductor, electron velocity and a positive integer, respectively.

(5) Derive the equation for the potential energy E_{Coul} of the orbiting electron from the Coulomb force F_{Coul} determined in (3).

(6) Derive the possible donor binding energies E_d from the allowed orbital radii r_d determined in (4) and the potential energy E_{Coul} of the orbiting electron determined in (5). How big is the largest possible donor binding energy?

V | Quantum Mechanics

Q. Find the ground state energy for a particle bound in an infinite walled one-dimensional box of length L, where electron mass is $m = 9.1\times10^{-31}$ kg, electron charge is $e = 1.6\times10^{-19}$C, Plank's constant is $h = 6.6\times10^{-34}$ Js, $\hbar = h/2\pi = 1.1\times10^{-34}$ Js, Boltzmann's constant is $k = 1.4\times10^{-23}$ JK^{-1}, and wave function is ϕ. A significant figure is two digits.

(1) Write Schroedinger's equation.

(2) Solve Schroedinger's equation and find solutions.

(3) Find the particle energy E.

(4) Assuming that the particle is an electron and $L = 10\,\text{mm}\,(=10^{-2}\,\text{m})$, find the ground state energy in [eV].

(5) Assuming that the particle is an electron and the quantum size $L = 0.3\,\text{nm}\,(=3.0\times10^{-10}\,\text{m})$, find the ground state energy in [eV].

(6) Assuming that the particle is an alpha particle and the box L corresponds to the dimension of a uranium nucleus $L = 1.0\times10^{-14}$ m, find the ground state energy in [eV]. Mass of alpha particle is $m_\alpha = 6.7\times10^{-27}$ kg.