Midterm 1

● Graded

Student

Guan-Shi Chen

Total Points

81 / 100 pts

Question 1

Q1

16 / 20 pts

– 0 pts Correct

✔ **– 4 pts** Missed 1 item

– 8 pts Missed 2 items

Question 2

Q2

15 / 20 pts

– 0 pts Correct

✔ **– 5 pts** Does not rank based on lower resistivity (that is preferable in this case).

– 10 pts Incorrect rank and no explanation.

Question 3

Q3

20 / 20 pts

✔ **– 0 pts** Correct

– 5 pts No opinion on what the pitfalls

Question 4

Q4

10 / 20 pts

Q4.1

− 0 pts Correct

✔ **− 5 pts** Wrong

Q4.2

− 0 pts Correct

✔ **− 5 pts** Wrong

Q4.1higher doping density higher potential
Q4.2lower threshold voltage higher on-current

Question 5

Q5

20 / 20 pts

✔ **− 0 pts** Correct

− 5 pts 5.2 wrong

− 5 pts 5.1 wrong

− 2.5 pts 5.1; need to account for sub-threshold current

No questions assigned to the following page.

ECE 3030: Physical Foundations of Computer Engineering

Spring 2024

Midterm 1

March 4, 2024

Time: 1 hr 15 min

Instructor: Asif Khan

Instructions:

1. There are 8 pages in this test.

2. Read all the problems carefully and thoroughly before you begin working.

3. This is an OPEN note, OPEN internet exam.

4. A list of constants and equations is provided on pages 7, and 8.

5. There are a total of 5 problems that you are required to answer.

Q1	20 pts
Q2	20 pts
Q3	20 pts
Q4	20 pts
Q5	20 pts
Total	100 pts

6. Show all your work and circle/underline your final answer. For numerical answers, write the units. Write legibly. If I cannot read it, it will be considered a wrong answer. Do all work on the space provided; use scratch paper when necessary. Turn in all scratch paper, even if it did not lead to an answer.

7. Download this template and write on your electronic device or print this template and write on the print if you can. Writing on a blank paper and clearly marking each questions is also fine. You are required to upload PDF/pictures of either the completed template or just your answers.

8. Report any and all ethics violations to the instructor/proctor.

Sign your name on ONE of the two following cases (or write one of the cases on the paper with your answers):

I DID NOT observe any ethical violations during this exam:

I observed an ethical violation during this exam:

Question assigned to the following page: 1

Q1 Circle the correct answer. [Total 20 pts (5 × 4 pt)]

[Q1.1] Group IV materials are used as acceptor dopants to make silicon n-type. **(True/False)** Group IV is Si, Group III is the acceptor dopant.

[Q1.2] In a p-type semiconductor, the Fermi level is closer to **(Valence band/Conduction band)**.

[Q1.3] In a semiconductor, the mobile electrons and holes exist in the conduction and the valence band, respectively. **(True/False)** At 0K, valence band is full of e^-, while conduction band is full of holes.

[Q1.4] What is the number of transistor in an iPhone 15? Choose the closest answer. **(1 Billion/10 Billion/100 Billion/1 Trillion)**

[Q1.5] When the input voltage to a CMOS inverter is 0 V, the N-MOSFET is in the OFF-state, the P-MOSFET is in the ON-state, and the output voltage is V_{DD}. **(True/False)**

Question assigned to the following page: 2

Q2 **Physics of resistors:** The following table lists different properties of different interconnect metals. Rank them in terms of your preference for their use of as interconnect metals in a chip. Provide a brief explanation of your answer. [20 pts]

Material	Electron density (m^{-3})	Electron mobility (m^2/Vs)
Al	1.98×10^{29}	1.2×10^{-3}
Cu	8.5×10^{28}	4.32×10^{-3}
W	6×10^{28}	1.8×10^{-3}
AB	5×10^{28}	3×10^{-3}

Most preferred to least: Cu > AB > W > Al

Cu has the highest electron mobility than all the rest. Compared to Al, Cu has lower electron density, but way higher electron mobility (2.33 times less electron density but 3.6 times higher electron density.

Comparing W and AB, while W has a higher electron density, it has comparably less electron mobility than AB (1.2 times more electron density, but 1.67 times less electron mobility), making it a worse material than AB.

Al is the least preferred material becuase while it has the highest electron density, it has by far the least electron mobility compared to the rest of the materials in the table.

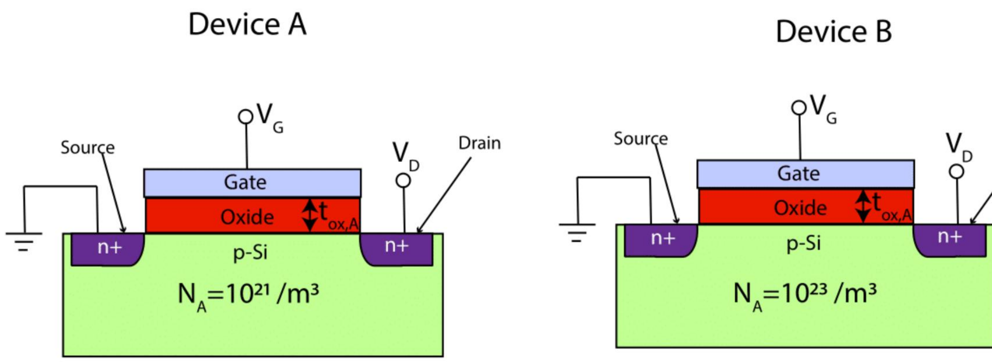
Question assigned to the following page: 3

Q3 **Semiconductors for AI:** Watch this youtube video. `https://www.youtube.com/watch?app=desktop&v=JrOgRQFqhbM` Based on the information presented in this video, write a short paragraph why such a trillion-dollar investment is sought for implementing Sam Altman's vision of artificial general intelligence (AGI) and/or artificial superintelligence. Write a brief opinion on what the pitfalls of this argument are. [Total 20 pts]

I think the reason Sam Altman is putting such a big effort and investment into the semiconductor industry is because of the lack of processing power for his needs. In order to have chance at creating his vision of artificial general intelligence, there has to be the processing power behind it to train the model and run inference based on those training to create new information and generate new ideas beyond what is was trained on. As of now, most companies that operate AI language models are based on NVIDIA for their GPU and processing power. Altman does not want to depend on others for his own models and seeks opportinuty at semiconductors. While I do think that the investment will bring competition to the market, I do also think that there is not much to improve on given our current technology. The technology Altman envision may be too far to reach for.

Question assigned to the following page: 4

Q4 **MOSFET:** Consider two n-type MOSFETs with acceptor doping densities $N_A = 10^{21}$ /m^3 and 10^{23} /m^3. All other physical parameters are the same for these two devices.



[Q4.1] Which device has a lager threshold voltage and why? [Total 10 pts]

A, lower doping concentration means larger depletion region, which means greater threshold voltage.

[Q4.2] Which device will you choose as the technology for high performance applications, such as microprocessor for data centers? [Total 10 pts]

B, Want lower threshold voltage so less voltage needed to reach ON current. Device with lower threshold voltage can reach higher current, which means higher performance.

Question assigned to the following page: 5

Q5 **Temperature dependence of MOSFET characteristics:** In this problem, you are asked to analyze the temperature dependence of the behavior of a MOSFET. All variables cited in this problem have their usual meaning. [Total 20 pts]

[Q5.1] What regime of operation (cut-off, linear, or saturation) is the MOSFET in, when $V_G = V_D = V_{DD}$. Write the down the equations for the on-current I_{ON} for an n-type MOSFET based on the square law model with corrections for sub-threshold current (see page 7 and 8). I_{ON} is defined as follows. [10 pts]

$$I_{ON} = I_D(V_G = V_D = V_{DD}) \tag{1}$$

Here, V_{DD} is the power supply voltage.

[Q5.2] The mobility μ decreases with the increase of temperature T. How does I_{ON} change if T increases. [10 pts]

5.1) Since $V_G = V_D$, the MOSFET is in the saturation region.
$V_G - V_t < V_D \rightarrow V_D - V_t < V_D \Rightarrow -V_t < 0$ ($V_t > 0$, so statement is true)

I_{ON} for saturation:

$$I_{ON} = \left(I_{sub-V_t}\left(1 - e^{\frac{-qV_D}{k_BT}}\right) + \mu C_{ox}\frac{1}{2L}(V_G - V_t)^2\right)W$$

5.2) Since temperature increases, mobility decreases, which decreases the ON current I_{ON}.