EECS 2077 Test #4, Fall 2016 Name:____

#1 ____/25 pts **Allowed materials: 4 pages of 1-sided equation sheets, writing utensil, calculator.**
#2 ____/20 pts **Remember – we use cgs units! Centimeter/gram/second.**
#3 ____/30 pts $kT = 0.026$ eV (300K) $\varepsilon_0=8.854\times10^{-14}$ F/cm $\varepsilon_r(Si)=11.8$
#4 ____/25 pts $q= 1.6\times10^{-19}$ C $n_i(Si)=1.5\times10^{10}$ / cm^3 $\varepsilon_r(SiO_2)=3.9$

1) Lets start off by testing your contemporary knowledge… (5 pts. each)

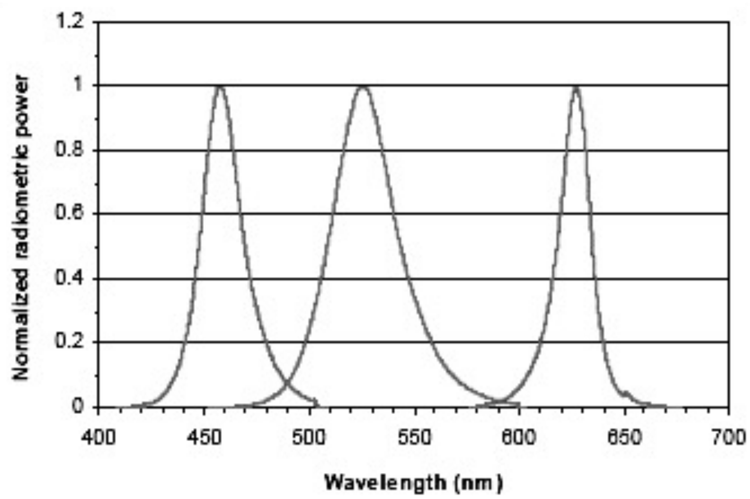
(a) For a modern CMOS chips, the main reason that the processor speeds have NOT increased is because:

__ of fundamental RC time constant limitations in switching of transistors
__ these days chip designers are too distracted by social media
__ the processors get too hot which causes too much thermal generation of carriers
__ none of the above, microprocessor speeds have been doubling every year recently

(b) The reason why transistors in CMOS chips are made smaller and smaller each year is because:

__ the processor speed can run faster and faster with smaller transistors
__ you can pack more transistors and computing power on the same chip size and therefore for similar cost
__ the world is running out of sources of pure silicon
__ we can

(c) Shown at right are 3 LED spectrums (blue, green, and red). If you assume ideal diode operation, and you only had a 2.14 V battery, which of the LEDs spectrums below would be possible?



__ all of them
__ none of them
__ blue and green
__ green and red
__ blue and red
__ blue
__ green
__ red
__ periwinkle

(d) next question, if we used the above 3 LEDs to make a white light source, in terms of the theoretically possible power effiency would that 3 LED light source be more or less power efficient than today's standard commercial white LEDs?

__ more efficient
__ less efficient
__ would be the same efficiency actually
__ it depends, there is not one dominate way in which modern white LEDs are made

(e) in modern telecommunication systems lasers and optical signals (0's and 1's) are modulated by:

__ verbal cues relayed to monkey in a cage who shines a laser into or out of an optical fiber on demand
__ some electronics that directly turn the laser ON and OFF
__ some electronics that directly turn multiple lasers ON and OFF and which feed into the same optical fiber
__ devices that cause optical interference of a laser beam that is split and then rejoined in phase or out of phase

2) [20 pts.] An ideal p+n junction at 300K, made out of an unknown material (is not Si) has the following parameters (you might not need them all).

p-side:	n-side:	General parameters
$Na=10^{18}/cm^3$	$Nd=10^{15}/cm^3$	$\varepsilon_r=6.3$
$Dn=40\ cm^2/sec$	$Dp=80\ cm^2/sec$	$n_i=10^{10}\ /\ cm^3$ ← again, is not Si!
$Ln=10^{-3}$ cm	$Lp=10^{-2}$ cm	$A = 500\ \mu m^2$

a) [8 pts] What are the DRIFT and DIFFUSION currents (A) across the junction at an applied reverse bias of -3V?

Calculations:

Answer for DRIFT: __________

Answer for DIFFUSION: _________

b) [8 pts] What are the DRIFT AND DIFFUSION currents (A) across the junction at a forward bias of 0.8 V?

Calculations:

Answer for DRIFT: __________

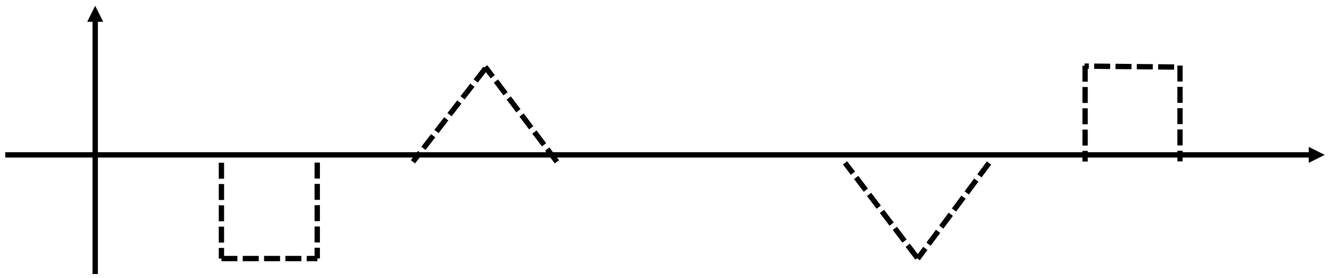
Answer for DIFFUSION: _________

c) [4 pts] Under zero bias (no voltage), what type of carriers dominates the flow of carriers across the junction?

Circle one: electrons / holes / neither

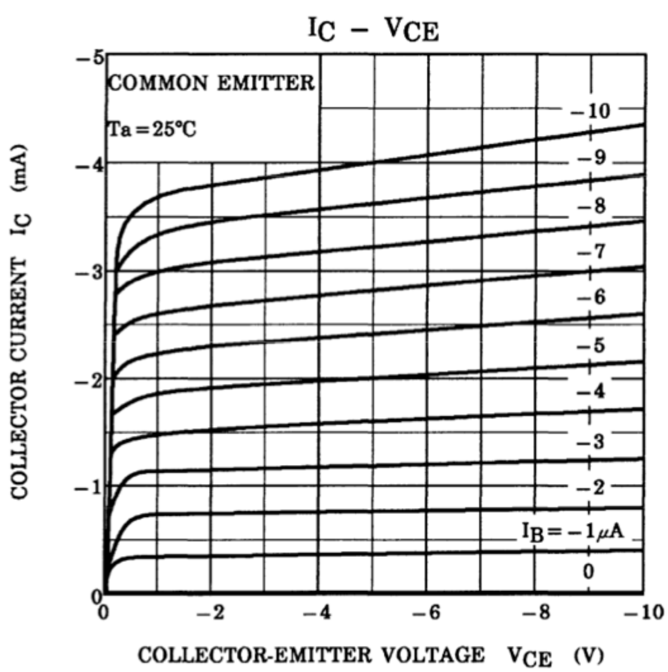
3) [30 points] Time for a mish-mash of problems…

a) [10 pts] Draw the band-diagram (just conduction and valance bands) for the following E-field profile. Draw the band-diagram directly below the E-field profile so I can match them up. (The dotted line is the E-field, Y-axis is E-field with positive E-field above the X-axis, X-axis is positive distance). Use the provided space below so I can clearly see how the band diagram changes…



b) [10 pts] a <u>cube</u> of light emitting material has a refractive index of n=1.8. Calculate the total light outcoupling percentage for the sheet (remember, what is not outcoupled, is trapped inside by total internal reflection). You may neglect Fresnel reflection.

c) [10 pts] for the BJT at right, assume you it is biased with -5V across Vce and that the BJT has zero base current (you cut the wire for example). If we shine 10^{14} photons/second on the base-collector depletion region and they have greater energy than the bandgap energy and are all absorbed, what will the resulting collector current be?



4) [25 pts] Question related to a NMOS device with the following parameters:

The gate electrode 'metal' is n+ poly Silicon.

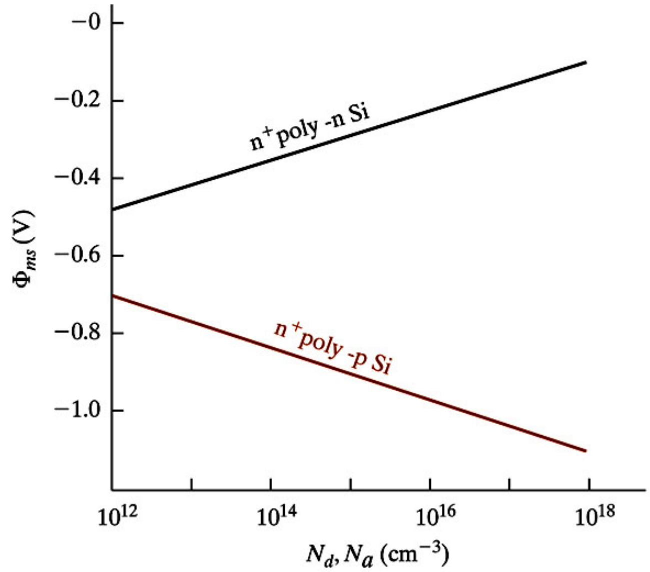
The substrate is doped with Boron to the level of Na=10^{17}/cm^3.

In the plot shown at right, the curves are labeled as 'gate material – substrate material'.

The gate oxide is has a thickness of 15 nm and a dielectric constant of 4.

There is an interface charge (Qi) of -20 nC/cm^2.

$$V_T = \phi_{ms} - \frac{Q_i}{C_i} - \frac{Q_{D,\max}}{C_i} + 2\phi_f$$



a) provide the value for how much the Fermi level in the substrate has been shifted from the intrinsic Fermi level due to doping (deeper into the substrate, where the bands are flat) [5 pts]:

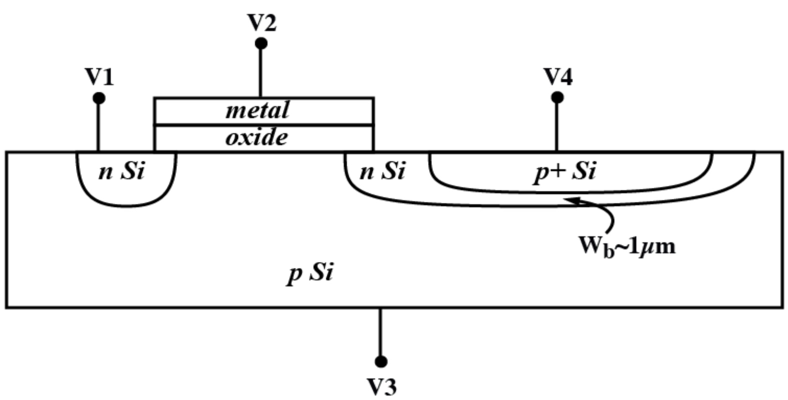
b) the interface charge. Does it increase or decrease your threshold voltage?

INCREASE / DECREASE [5 pts]

c) the difference between the metal (gate electrode) work function and the semiconductor workfunction, does it increase or decrease your threshold voltage?

INCREASE / DECREASE [5 pts]

d) the NMOS device can be further used to create a BiCMOS amplifier as shown below. Using only two arrows, across the semiconductor regions draw the two dominant current directions that would exist between the terminals if the device were setup for maximum amplification. [10 pts]



EXTRA SPACE

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#5 ____/25 pts
#6 ____/15 pts
#7 ____/35 pts
#8 ____/25 pts

Allowed materials: 4 pages of 1-sided equation sheets, writing utensil, calculator.
Remember – we use cgs units! Centimeter/gram/second.

$kT = 0.026$ eV (300K)	$\varepsilon_0=8.854\text{x}10^{-14}$ F/cm	$\varepsilon_r(Si)=11.8$
$q= 1.6\text{x}10^{-19}$ C	$n_i(Si)=1.5\text{x}10^{10}$ / cm^3	$\varepsilon_r(SiO_2)=3.9$

(5) [25 pts] Let's design a JFET. An ideal Si p+n junction at 300K has the following parameters (you may or may not need them all).

p-side:	n-side:	General parameters
$Na=10^{17}/cm^3$	$Nd=10^{15}/cm^3$	Total JFET gate area $A=10^{-6}$ cm^2
$Dn=18$ cm$^{2/}$sec	$Dp=25$ cm$^{2/}$sec	$\varepsilon_{Si}=11.8$
$Ln=10^{-3}$ cm	$Lp=10^{-2}$ cm	
$\mu p=200$ cm2/V-s	$\mu n=1300$ cm2/V-s	
$\mu n=700$ cm2/V-s	$\mu p=450$ cm2/V-s	

$\mathbf{V_o}=0.0259*\ln(10^{32}/2.25\text{x}10^{20})=0.695$ V
$\mathbf{I_o}=1.6\text{x}10^{-19}\text{x}10^{-6}\text{x}(25/10^{-2})*2.25\text{x}10^{5}=9\text{x}10^{-17}$ A

(a) [5 pts.] What is the total current across the gate during operation of the JFET.

(b) [10 pts.] Calculate the width of the depletion region (W) at no applied bias (0V).

(c) [5 pts.] You use the above materials to make a JFET. If you want a conducting portion of the channel that is at least 2 μm thick, what is the distance you will need between the semiconductor regions making up the gate?

(d) [5 pts.] How much gate voltage then will it require to turn this JFET fully OFF?

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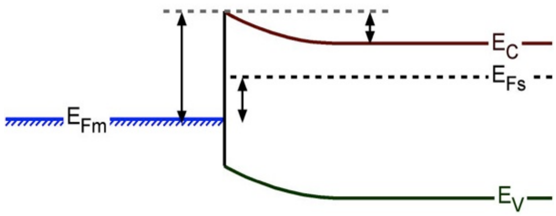
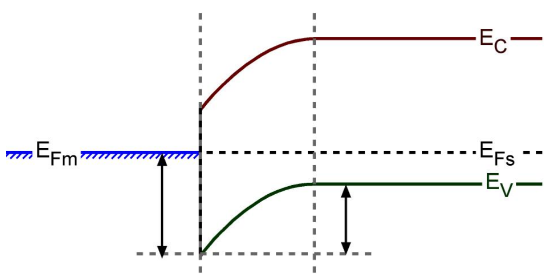
6) Metal-semiconductor Diodes! [15 pts.] For each device state shown below, circle from each list which carrier type dominates (electrons, holes, neither) and the relative magnitude of the current (large, small, zero). <u>Assume in all cases the metal is electrically grounded and that the voltage is applied to the semiconductor side.</u>



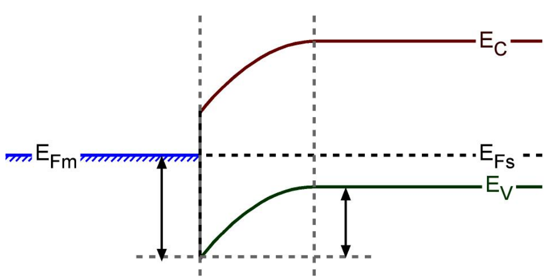
POSITIVE VOLTAGE ON THE SEMICONDUCTOR

electrons holes neither / large small zero



POSITIVE VOLTAGE ON THE SEMICONDUCTOR

electrons holes neither / large small zero



ZERO VOLTAGE ON THE SEMICONDUCTOR

electrons holes neither / large small zero

7) [35 pts, 3 points each] Drift vs. diffusion game!

(a) [3 pts] Determines the source and drain current for a MOSFET that that is turned OFF (no inversion).

DRIFT DIFFUSION BOTH NEITHER

(b) [3 pts] Reduces as you decrease doping for a forward biased PN junction.

DRIFT DIFFUSION BOTH NEITHER

(c) [3 pts] How carriers transport across the base-collector depletion region of a normal forward active mode BJT.

DRIFT DIFFUSION BOTH NEITHER

(d) [3 pts] Separates photogenerated carriers inside a solar cell so that they can be collected.

DRIFT DIFFUSION BOTH NEITHER

(e) [3 pts] Drives the source to drain current in a MOSFET.

DRIFT DIFFUSION BOTH NEITHER

(f) [3 pts] Is the current that will dominate in a laser in order to get population inversion.

DRIFT DIFFUSION BOTH NEITHER

(g) [3 pts] A solar cell with 0V and no light, drives current flow at thermal equilibrium (think before you answer).

DRIFT DIFFUSION BOTH NEITHER

(h) [3 pts] A JFET would have an current-to-current amplification factor of infinity if it were not for this.

DRIFT DIFFUSION BOTH NEITHER

(i) [3 pts] What drives current from the emitter to the base in a pnp BJT in normal forward active mode.

DRIFT DIFFUSION BOTH NEITHER

(j) [3 pts] Requires particles that have electrical charge and electric field.

DRIFT DIFFUSION BOTH NEITHER

(k) [3 pts] Requires a concentration gradient.

DRIFT DIFFUSION BOTH NEITHER

(l) [2 pts] Before taking this course, is what you thought that made BJTs and MOSFETs work.

MAGIC GHOSTS PHYSICS VOODOO PHYSICS

8.) [25 pts, 5 pts each] Magnus opus lab accident! This one was so bad they will either shut us down permanently or maybe we will finally put in place some lab safety procedures. A bunch of cubes of semiconductors (GaN = 3.4 eV, GaAs = 1.42 eV, Si = 1.12 eV), metals, and oxides have been fused together.

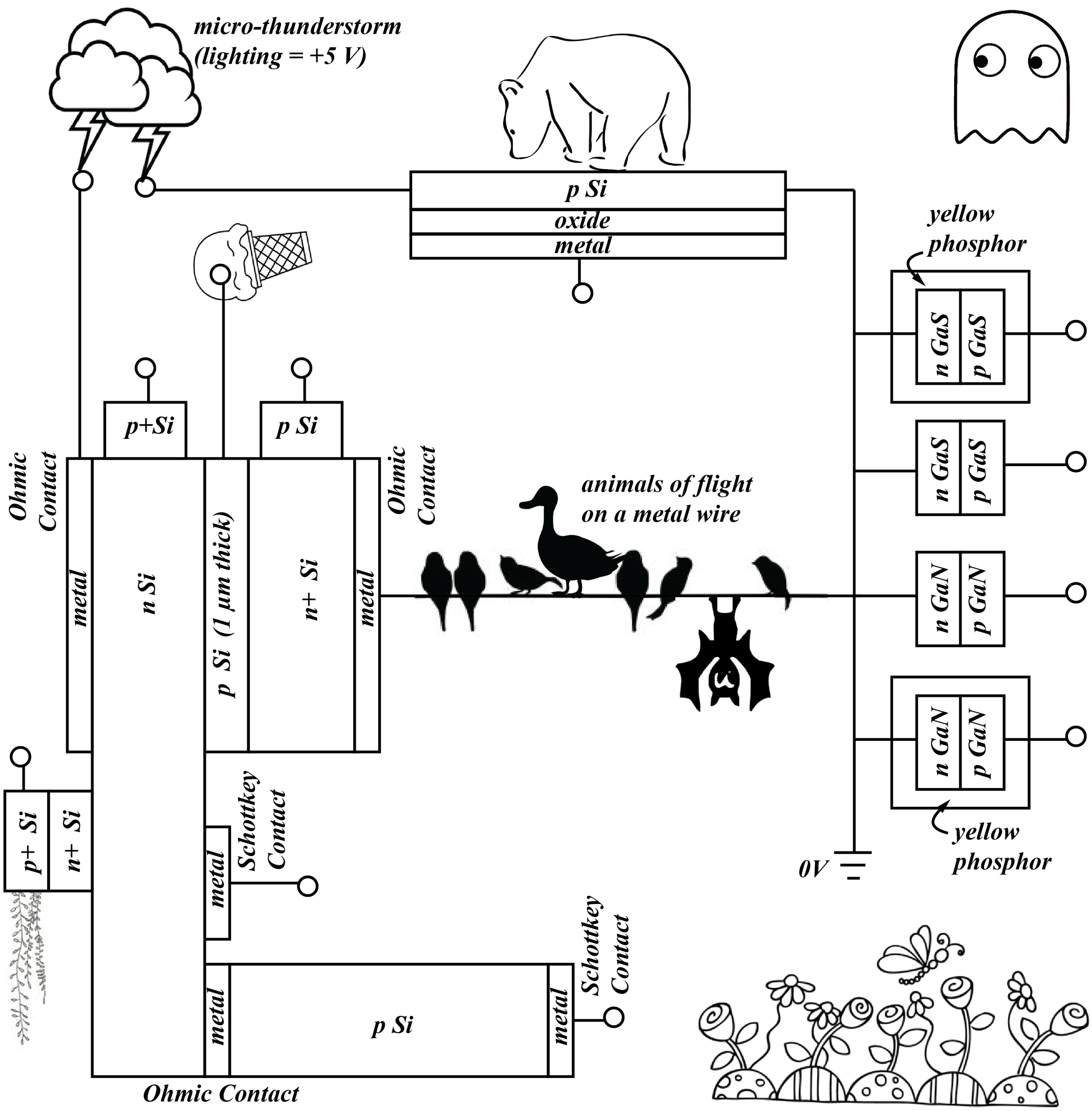
(a) There are no lights in the room. We can't clean up without some light. Label which terminal that needs voltage to give us the brightest light source so we can start to clean up.

(b) We also can't clean up until the animals of flight leave. Label the ice-cream cone with a voltage of 1V, 0V, or -1V with a goal of having current flow through the wire to scare off the birds of flight.

(c) The lights are on now... Holy smokes… there is a bear in the room! He is standing on the thin sheet of p Si semiconductor because it is nice and warm due to current flow. Label what type of small voltage you will put on the MOS metal contact to decrease the current flow (label it as positive, negative, or zero volts).

(d) Ugh, the animals of flight are back! And the micro-thunderstorm is starting to go crazy. You want to keep the current going through the wire so if the animals of flight land on it, they won't stay for too long. What you really need is a way to short-circuit the voltage from the micro-thunderstorm in case it goes too high. Put a ground electrode on terminal to achieve this extra safety feature for the birds of flight.

(e) Finally, all done. But your phone is dead and needs a safe +5V charging source so you can call in a ride home using Uber. Label the best terminal as 'cell-phone charger' and we are all done!



EXTRA SPACE FOR CALCULATIONS OR FOR GENERAL DEEP THOUGHTS ABOUT LIFE