EECS 2077 Test #4, Fall 2014 Name:____

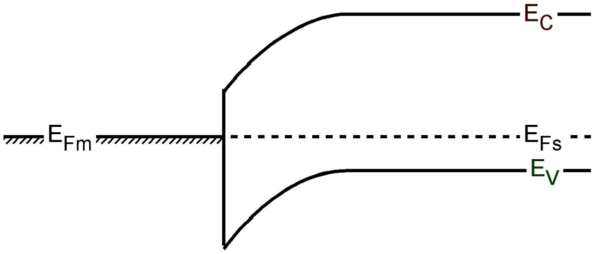
#1 ____/25 pts	**Allowed materials: 4 pages of 1-sided equation sheets, writing utensil, calculator.**		
#2 ____/25 pts	**Remember – we use cgs units! Centimeter/gram/second.**		
#3 ____/22 pts	kT = 0.026 eV (300K)	ε_0=8.854x10^{-14} F/cm	ε_r(Si)=11.8
#4 ____/28 pts	q= 1.6x10^{-19} C	n_i(Si)=1.5x10^{10} / cm^3	ε_r(SiO_2)=3.9

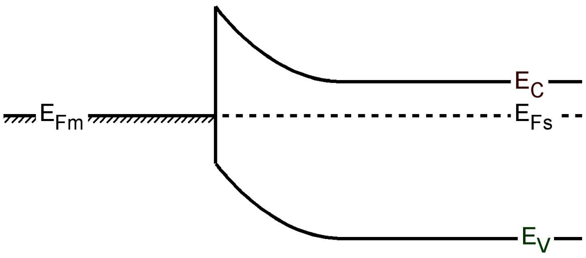
1.) 25 pts. Two metal/semiconductor junctions are given below. For both junctions:

a) [9 pts] draw the IV diagram for both positive and negative voltage applied to the junctions, **with respect to voltage applied to the metal** (assume semiconductor is grounded);

b) [8 pts] on each plot, for **positive voltage** label the **carrier type** that dominates the current flow on the semiconductor side of the junction;

c) [8 pts] on each plot, for **negative voltage** label the **carrier type** that dominates the current flow on the semiconductor side of the junction.





2.) 25 pts. A challenging diode question. Remember, for the real diode, up in the exponential you need to subtract contact potential from the applied voltage. Lets calculate the REAL diode characteristics (including contact potential) for a pure p+n+ GaN LED doped to 10^{18}/cc on both sides, and 100 μm x 100 μm diode area.

For simplicity, assume the contact potential is 90% of bandgap energy (because is heavily doped). For simplicity, use the parameters shown below which are for lightly doped material (mobility, diffusion length, etc. all decrease with increased doping, but lets keep it simple). Note, some key equations are shown below the table too.

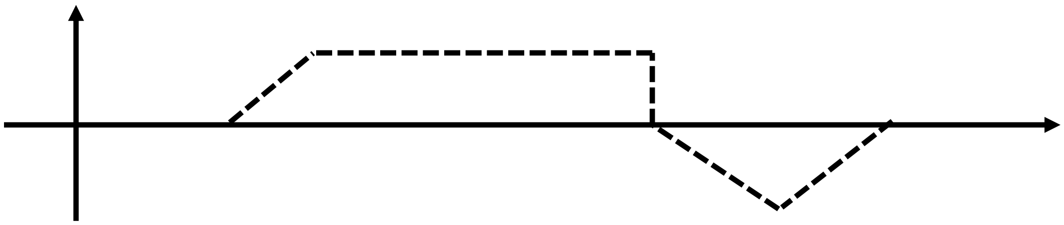
(a) [15 pts] What is the drift current across the junction at an applied reverse bias of -4V?

(b) [10 pts] How much voltage would be needed to obtain 20 mA of forward bias current through the diode (which is a common spec for small individual LEDs). Remember, assume the REAL case.

Quantity	***Symbol***	***AlN***	***GaN***	***InN***	***(Unit)***
Crystal structure		W	W	W	–
Gap: Direct (*D*) / Indirect (*I*)		*D*	*D*	*D*	–
Lattice constant	$a_0 =$	3.112	3.191	3.545	Å
	$c_0 =$	4.982	5.185	5.703	Å
Bandgap energy	$E_g =$	6.28	3.425	0.77	eV
Intrinsic carrier concentration	$n_i =$	9.4×10^{-34}	1.9×10^{-10}	920	cm^{-3}
Effective DOS at CB edge	$N_c =$	6.2×10^{18}	2.3×10^{18}	$9{:}0\times10^{17}$	cm^{-3}
Effective DOS at VB edge	$N_v =$	4.9×10^{20}	1.8×10^{19}	5.3×10^{19}	cm^{-3}
Electron mobility	$\mu_n =$	300	1800	3200	cm^2/Vs
Hole mobility	$\mu_p =$	14	30	–	cm^2/Vs
Electron diffusion constant	$D_n =$	7	39	80	cm^2 / s
Hole diffusion constant	$D_p =$	0.3	0.75	–	cm^2 / s
Electron affinity	$\chi =$	1.9	4.1	–	V
Minority carrier lifetime	$\tau =$	–	10^{-8}	–	s
Electron effective mass	$m_e^* =$	0.40 m_e	0.20 m_e	0.11 m_e	–
Heavy hole effective mass	$m_{hh}^* =$	3.53 m_e	0.80 m_e	1.63 m_e	–
Relative dielectric constant	$\varepsilon_r =$	8.5	8.9	15.3	–
Refractive index near E_g	$\bar{n} =$	2.15	2.5	2.9	–
Absorption coefficient near E_g	$\alpha =$	3×10^5	10^5	6×10^4	cm^{-1}

- D = Diamond. Z = Zincblende. W = Wurtzite. DOS = Density of states. VB = Valence band. CB = Conduction band
- The Einstein relation relates the diffusion constant and mobility in a non-degenerately doped semiconductor: $D = \mu\,(k\,T\,/\,e)$
- Minority carrier diffusion lengths are given by $L_n = (D_n\tau_n)^{1/2}$ and $L_p = (D_p\tau_p)^{1/2}$
- The mobilities and diffusion constants apply to low doping concentrations ($\approx 10^{15}$ cm^{-3}). As the doping concentration increases, mobilities and diffusion constants decrease.
- The minority carrier lifetime τ applies to doping concentrations of 10^{18} cm^{-3}. For other doping concentrations, the lifetime is given by $\tau = B^{-1}\,(n+p)^{-1}$, where $B_{GaN} \approx 10^{-10}$ cm^3/s.

3a) [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 up all the provided space below so I can clearly see hope band diagram changes…



3b) [12 pts] A Si bar is 0.4 cm long and 100 μm^2 in cross-sectional area is doped with 10^{17} boron, resulting a mobility for holes of 500 (cm/s)/(V/cm). What is the DRIFT current (current I_p, not current density J_p) with 3V applied? *Problem is similar from the homework and the 1st test!*

4) 28 pts (4 pts each) Drift or diffusion!

(a) Exists at 300K for a diode in thermal equilibrium (with no voltage applied to it).

DRIFT DIFFUSION BOTH NEITHER

(b) Increases as you increase doping for a diode with any sort of voltage on it.

DRIFT DIFFUSION BOTH NEITHER

(c) Is how carriers are transported across the base-collector of a BJT.

DRIFT DIFFUSION BOTH NEITHER

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

DRIFT DIFFUSION BOTH NEITHER

(e) Drives the source to drain current in a MOSFET.

DRIFT DIFFUSION BOTH NEITHER

(f) Is the type of current consumed at the gate of a JFET when the JFET is turned OFF.

DRIFT DIFFUSION BOTH NEITHER

(g) Exists for a forward biased Schottky diode.

DRIFT DIFFUSION BOTH NEITHER

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#5 ____/25 pts **Allowed materials: 4 pages of 1-sided equation sheets, writing utensil, calculator.**
#6 ____/25 pts **Remember – we use cgs units! Centimeter/gram/second.**
#7 ____/20 pts kT = 0.026 eV (300K) $\varepsilon_0=8.854\text{x}10^{-14}$ F/cm $\varepsilon_r(\text{Si})=11.8$
#8 ____/30 pts $q= 1.6\text{x}10^{-19}$ C $n_i(\text{Si})=1.5\text{x}10^{10}$ / cm^3 $\varepsilon_r(\text{SiO}_2)=3.9$

5.) [25 pts, 5 pts each] True or false, for a PNP BJT setup for normal amplification, assume an amplification factor of 100. Circle your answer.

(a) TRUE / FALSE : Collector current changes exponentially with change in base current.

(b) TRUE / FALSE : Hole drift across the base-collector increases exponentially with voltage across the emitter-base.

(c) TRUE / FALSE : If 400 holes are collected, then we know that 400 holes were emitted.

(d) TRUE / FALSE : By having the emitter more heavily doped than the base it increases the required base current for operation (compared to having base and emitter at the same doping levels).

(e) TRUE / FALSE : I_C saturation with increasing V_{CE} occurs because once you have the base-collector reverse biased the collector is all setup to collect holes as drift current.

6) [30 pts] Question related to an p-MOS transistor with the following parameters:

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

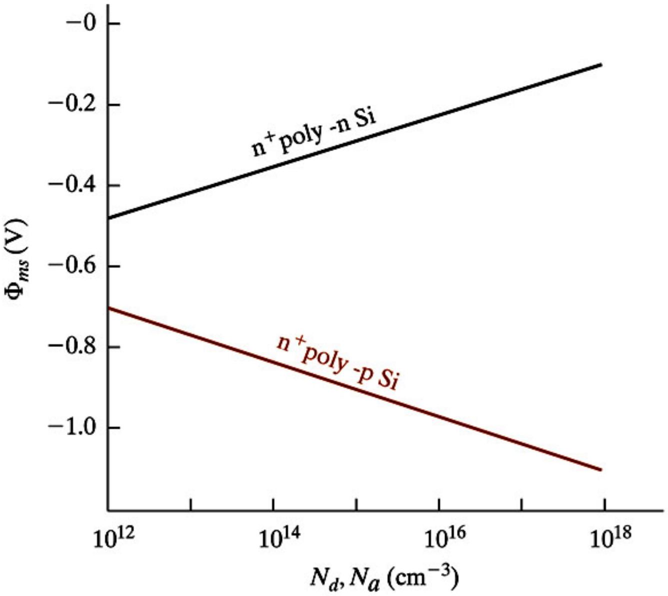
The substrate is doped with Phosphorus to the level of Nd=10^{17}/cm^3.

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

The gate oxide is has a thickness of 20 nm and a dielectric constant of 4.

There is an interface charge (Qi) of -35 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) calculate the capacitance per unit area of the gate oxide [5 pts]:

c) provide the value for the maximum depletion charge [5 pts]

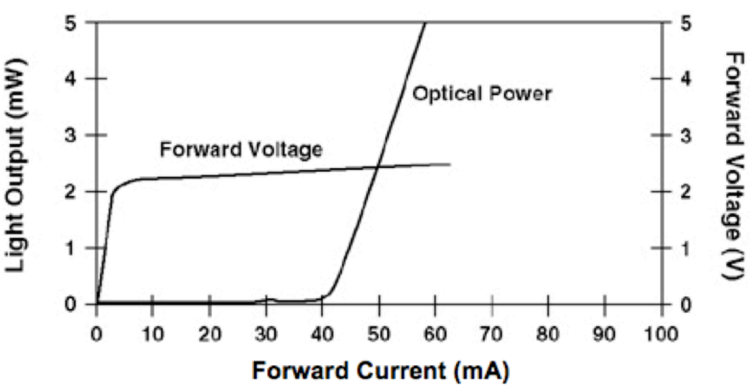
d) 10 pts, for each of your answers above for (a) and (c), tell me if they increase OR decrease the required threshold voltage (in terms of magnitude):

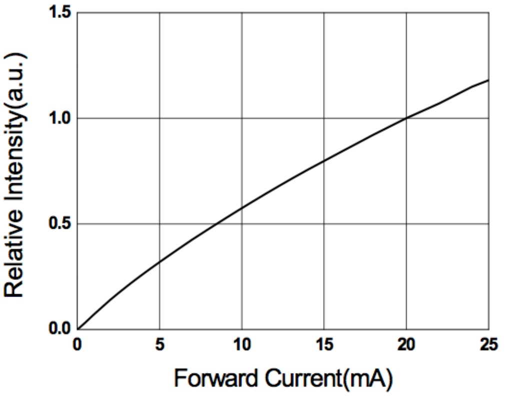
a – INCREASE / DECREASE

c – INCREASE / DECREASE

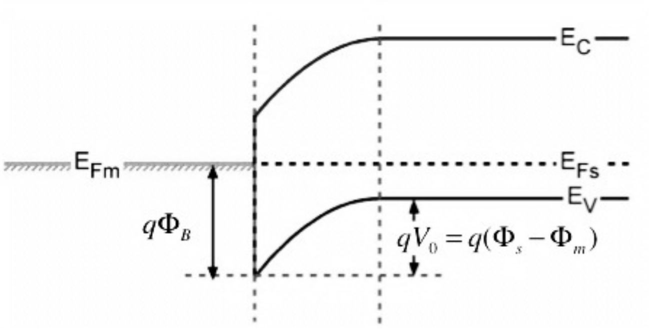
7) 20 pts. Some opto problems.

a) 10 pts. Here are two light emitting semiconductor devices. Label on each diagram where any of the following are occurring: no emission (N), spontaneous emission (S), lasing (L):





b) 10 pts. Modify the equation below by crossing out ALL terms we can eliminate for using the Schottky diode shown below as a photodetector (not a solar cell).

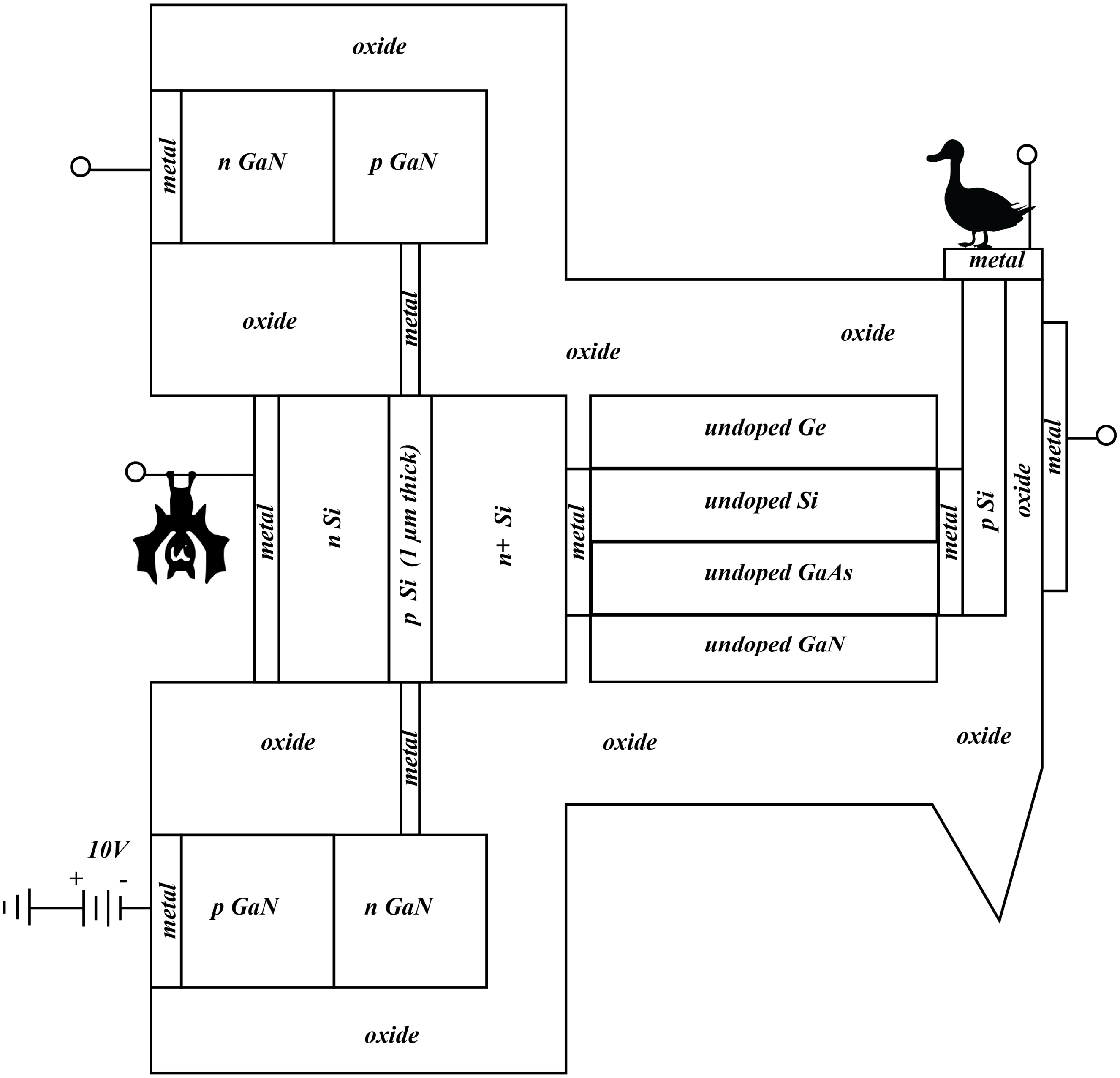


$$qA\left(\frac{L_p}{\tau_p}p_n+\frac{L_n}{\tau_n}n_p\right)\left(e^{qV/kT}-1\right)-qAg_{op}\left(L_p+L_n+W\right)$$

8.) [30 pts] A never-before-seen type of lab accident! A bunch of cubes of semiconductors, metals, and oxides have been fused together. The lab is destroyed, you are bored with nothing to do, so you set out to play with what is left…

Label the diagram to get maximum current flow between the bat and duck terminals. Use only what survived the lab accident. The only things that survived other than the mega device below, are a +10V voltage source, a +5V voltage source, a -5 V voltage source, a -10V voltage source, an ultra-violet LED mini flashlight, and red LED mini flashlight. The LEDs have the same optical power output of 100 mW.

Assume: Eg (Ge) ~0.7 eV, Eg (Si) ~ 1.1 eV, Eg (GaAs) ~1.4 eV, Eg (GaN) ~3.4 eV
Assume: all metal contacts are OHMIC



EXTRA SPACE