

Note 1: Verify that you have good Internet connectivity for the Final Exam!!!

Note 2: I will post the Final Exam at 10:00 am, Monday 13 December, on the ~sburns WEB site.

Note 3: I will remove the posting at 11:50 am.

Note 4: Use either a printed download from the WEB page or separate sheets of paper or a combination. Be sure your name is on each sheet of the submitted material. Be sure your solutions are legible; do recognize the capabilities of your scanner and imaging systems.

Note 5: Your audio and video must be turned on during the exam. This is to facilitate responding to any questions you might have.

Note 6: Submit a pdf and/or jpgs of your solutions as attachments to an e-mail to me sburns@d.umn.edu by 12:10 pm.

Note 7: Open Book, Laptop, WEB access OK, Tablet, etc. and Notes. All of these sources are what you might be expected to exploit as an engineer in an industrial environment. Watch your time management if you surf the WEB!

Note 8: As appropriate, explain the use of any graphs or charts to justify answers.

Note 9: WATCH YOUR UNITS AND UNIT CONVERSIONS!!!

PROBLEM	TOPIC	POINTS	SCORE
1	Semiconductor Pot-Pourri	20	
2	Diffusion Doping Profiles and Concepts	25	
3	Oxidation	25	
4	Related to Photonics	30	
5	From Your Technical Presentations	100	
TOTAL		200	

PROBLEM 1 (20 Points, 5 Points) Semiconductor Pot-Pourri

(a) There are _____ Si atoms/cm³ and a lattice spacing of about _____.

(b) List two basic properties you can ascertain from the size and location of the “flats” on a silicon wafer. _____ and _____

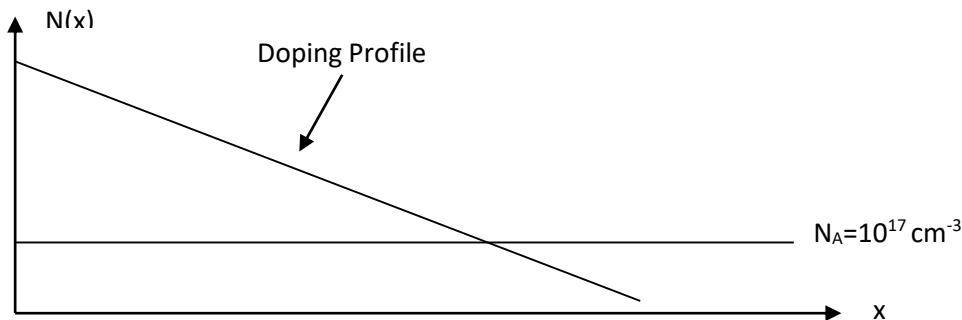


(c) One of your friends, attending at a large university in the Twin Cities, wants to **donor** dope a Si wafer with **2 x 10²³ boron atoms/cm³**. Briefly explain (two reasons) why this student is probably doing very poorly in their equivalent EE 5621 course.

(d) For Si, List two non-metallic donor elements: _____ and two non-metallic acceptor elements: _____.

PROBLEM 2 (25 Points, 5 Points each) Diffusion Doping Profiles and Concepts

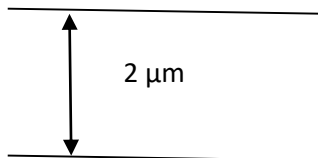
Assume a **linear** donor doping profile defined by $n(x) = [6.0 \times 10^{19} - (1.5 \times 10^{23})x] \text{cm}^{-3}$ as sketched. The substrate is doped at $N_A = 1 \times 10^{17} \text{cm}^{-3}$.



- (a) Compute a value for the junction depth, x_j .
- (b) What is the resultant dose, Q_0 ? [You can make your algebraic life easier by utilizing the linear nature of the doping profile!]
- (c) This deposition step is now capped and we proceed with a limited source diffusion for time t_1 and temperature T_1 . During the time, t_1 , used for this finite (limited source) drive diffusion, the surface concentration will **(INCREASE, REMAIN THE SAME, DECREASE)**, the junction depth, x_j , will **(INCREASE, REMAIN THE SAME, DECREASE)**, and the dose, Q_0 will **(INCREASE, REMAIN THE SAME, DECREASE)**. Circle your choices.
- (d) Suppose the finite (limited) source diffusion in Part (c) was done at temperature T_2 , where $T_2 > T_1$ and the time remains the same. Comparing to the results from Part (c), the surface concentration would be **(LOWER, ABOUT THE SAME)**, the junction depth, x_j , would be **(DEEPER, ABOUT THE SAME, NOT AS DEEP)**, and the dose, Q_0 would be **(LARGER, ABOUT THE SAME, SMALLER)**. Circle your choices.
- (e) Mathematically, a deposition diffusion is described by an **(Exponential, Error Function, Complementary Error Function, Gaussian)** and the limited source diffusion sometimes called the drive diffusion is described by an **(Exponential, Error Function, Complementary Error Function, Gaussian)**

PROBLEM 3 (25 Points; 5 Points each) Oxidation

- (a) The chemical formula for a wet oxidation is: _____ and the chemical formula for a wet oxidation is: _____.
- (b) For a given oxidation time and temperature, the oxide thickness using a wet oxidation is **(THICKER, THINNER, ABOUT THE SAME)** compared to a dry oxidation. Circle your choice.
- (c) A FET gate oxide is best accomplished using a **(WET, DRY)** oxidation process because a gate oxide is **(THICKER, ABOUT THE SAME, THINNER)** than a field or masking oxide and the defect trap state density is **(HIGHER, ABOUT THE SAME, LOWER)** than a field or masking oxide. Circle your choices.
- (d) Wet chemistry etching of SiO_2 uses **(Acetone, HF, H_2SO_4 , Sand slurry, DI H_2O , Vodka)** and a dry etching process uses **(MBE, Sand blasting, Plasma, High intensity UV photons)**.
- (e) The silicon $2 \mu\text{m}$ layer shown below is subject to a 3 hour wet oxidation at 1050° from the top only. Sketch and label the resultant cross-section layers and approximate dimensions.



PROBLEM 4 (30 Points; 6 Points each) Related to Photonics

- (a) To generate electron-hole pairs, you need a material with a **(ZERO, LOW, HIGH)** absorption coefficient which means that incoming photons have **($h\nu = 0$, $h\nu < E_g$, $h\nu > E_g$)**. Circle your choices.
- (b) Even though a crystalline silicon LED could emit light with a wavelength = _____, the emission efficiency is very low because crystalline silicon is a **(Direct, Indirect, Excessive Trap State)** material. Calculate the Si wavelength and circle your choice.

- (c) For a high output solar cell or LED, the Diffusion Length should be (**Zero, Low, High**) and the concomitant Minority Carrier Lifetime should be (**Zero, Low, High**). Circle your choices.
- (d) Typically, white light LED light bulbs with the standard A-19 Form Factor use _____ as the semiconductor material coated with a (**blue, red, green, yellow**) phosphor. These products have an efficacy typically of about (**10-15, 25-50, 100, 500**) lumens/watt. Fill in the blank and circle your choices.
- (e) Refer to the three density of state diagrams. Fill in the blanks with either A, B, or C:
 (i) This material would yield the highest quantum (conversion) efficiency. _____
 (ii) This material is representative of a-Si:H _____
 (iii) This material would yield the lowest conversion efficiency when used in a solar panel. _____
 (iv) This material is probably polycrystalline silicon. _____

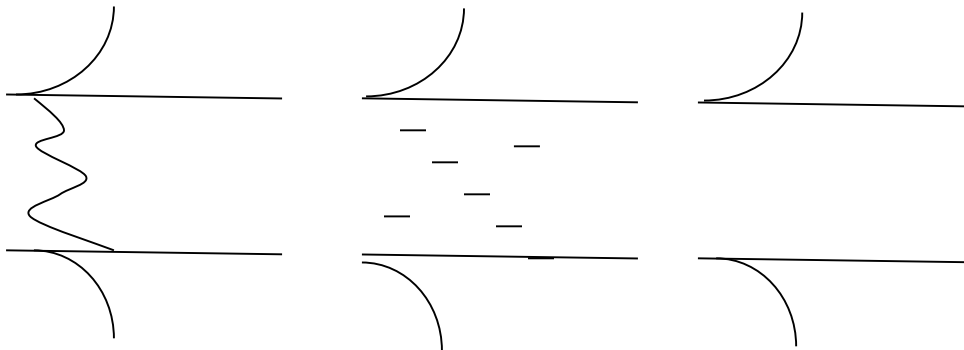


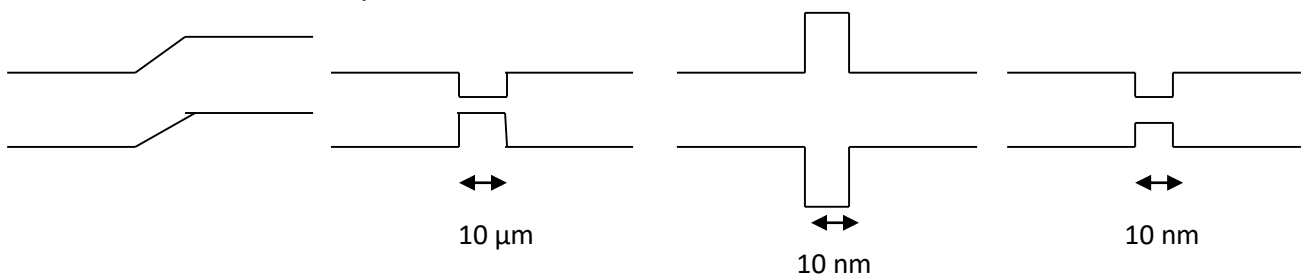
Figure A

Figure B

Figure C

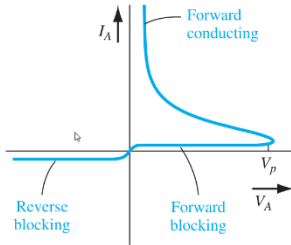
Problem 5 (100 Points, 10 Points each) Extracted From Your Technical Presentations and amalgamated with related course material. Short Answer and Circle Your Choice(s). Even though the questions are of varying length and difficulty, they will be valued equally at 10 Points each. Be sure you answer all parts of multi-part questions!!!

- (a) Which one of the following band-gap diagrams illustrates a **quantum well** structure for photonic applications such as a LASER diode? Circle your choice.



- (b) All OLEDs displays include (**Si, GaAs, C, Al**) and are (**EMISSIVE, BACKLIT**) compared to a liquid crystal LED display. OLED displays are (**THICKER, THINNER**) compared to an LED display; and currently are (**LESS EXPENSIVE, ABOUT THE SAME COST, MORE EXPENSIVE**) than a liquid crystal display. The useable operating lifetime is limited by the OLED used for (**Red Green Blue, Yellow, IR**) output.

- (c) The I-V diagram is for what type of device? _____ and **draw the circuit symbol** labeling the terminals. An important application is in _____



- (d) So called “soft errors” in an IC which you may encounter on the surface of the Earth or in an airplane trip are often the result of (**Neutrinos, Cosmic Rays, Ionizing Radiation, Neutron Flux**) and errors induced are (**Threshold voltage shifts, Increased leakage current, Changes in the electron-hole recombination rate**). The possibilities for an error are most likely if the devices are (**Relatively Large, Relatively Small, Size Makes No Difference**) and performance degradation is often the result of an (**Increase, Decrease**) of (**n and p Concentrations, τ_n and τ_p , μ_n and μ_p**)
- (e) Rank the efficiency of a solar panel from 1 through 4 where 1 is the highest efficiency.
 _____ GaAs; _____ Amorphous Silicon; _____ Hydrogenated Amorphous Silicon; _____ Crystalline Silicon;
 _____ Polycrystalline Silicon,
- (f) SiC, AlN, GaN, BN, ZnO, Diamond, and ZnSe are considered to be (**Narrow, Wide, Zero**) bandgap materials, consequently the intrinsic concentration, n_i , is (**Much Lower, About the Same, Much Higher**) than the intrinsic concentration in Si and these materials are especially suited for devices operating at $T =$ (**0K, Liquid N₂ Temperatures, 300K, 600K, 1812K**).
- (g) Flexible solar panels fabricated on polyimide (plastic) substrates use (**x-Si, Poly-Si, a-Si:H, GaAs**) but the most common solar panels installed for grid support or on top of Malosky stadium or at the Bagley Pond Building most likely use (**x-Si, Poly-Si, a-Si:H, GaAs, Perovskite**).
- (h) MEMS are a key component of (**Pressure Sensors, Wii Video Game Controllers, Smart Phone Pedometers, Air Bag Sensors, Smart Phone Screen Rotation Hardware, All of these components**)
- (i) All OLEDs include (**Si, GaAs, C, Al**) and OLED displays are (**THICKER, THINNER, ABOUT THE SAME**) compared to an LCD/LED display; are considered to be an example of an (**LCD, AMLCD, EMISSIVE**) display and currently are (**LESS EXPENSIVE, ABOUT THE SAME COST, MORE EXPENSIVE**) than a comparable large screen displays and use (**MORE, LESS, ABOUT THE SAME**) power than a comparable large screen displays
- (j) OSHA Hazard Communication Standard (HCS) Pictograms, relevant to the semiconductor industry, include (**Health Hazards, Flammables, Gases Under Pressure, Acute Toxicity, Skin Corrosion/Burns, Oxidizers, Gas Environmental Hazards, Organics Environmental Hazards, All of the Items listed**).