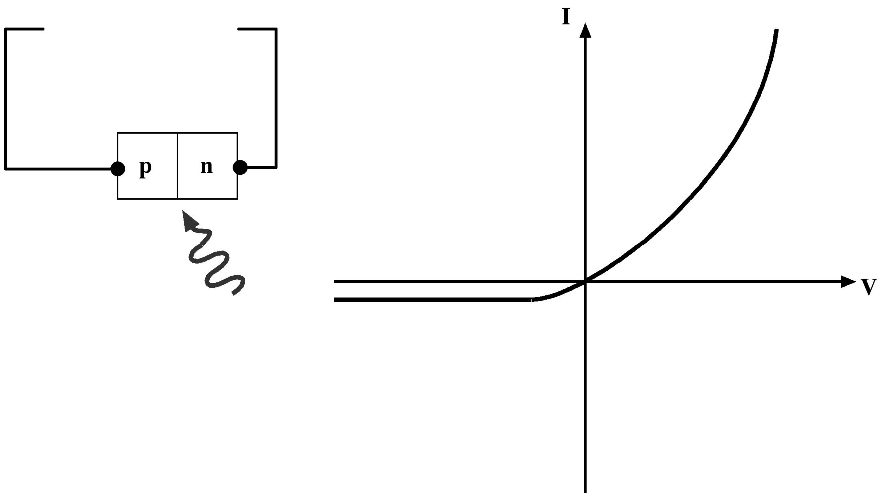
EECS 2077
Semiconductor Devices

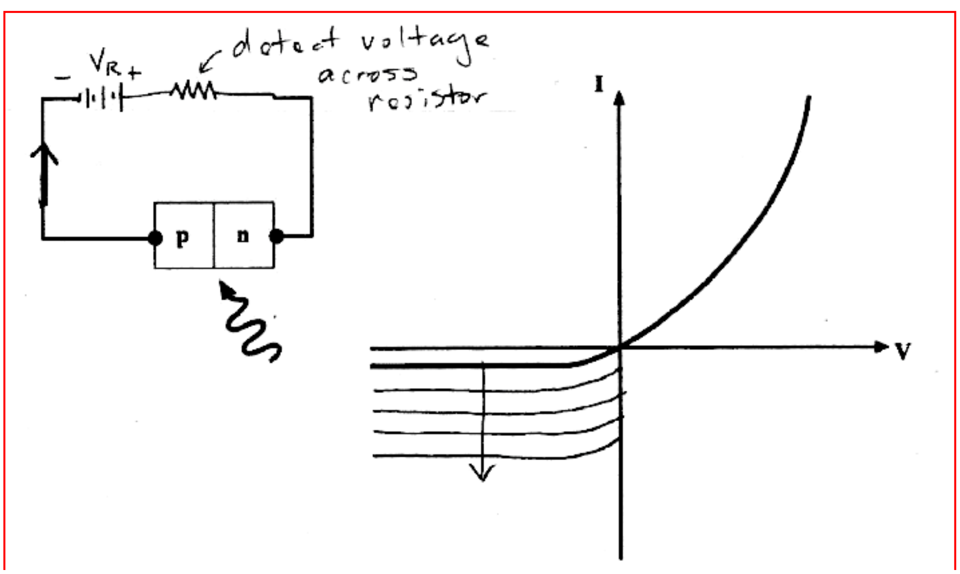
16 - Solar & Detectors   Name:____________________________

In-Class Problems

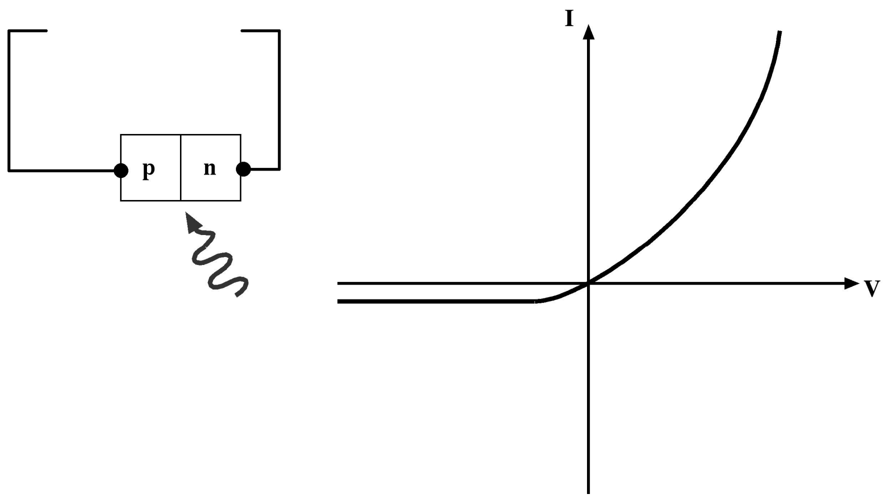
(1) Consider a diode…

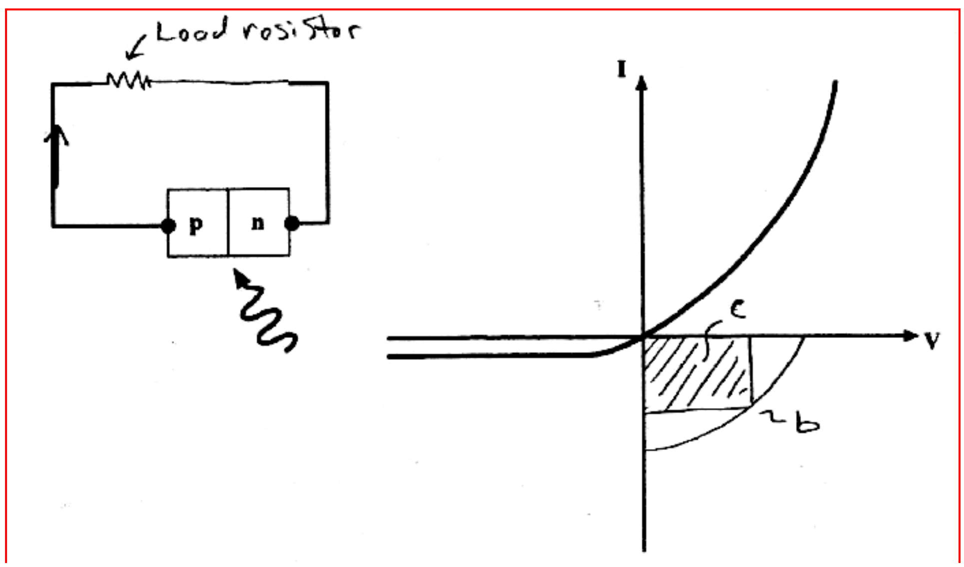
(a) Draw the new I-V characteristics for the diode when used as a photodetector. You only need to draw your new I-V characteristic <u>in the quadrant of operation as a photodetector</u>. Also, draw the additional basic components needed in the circuit diagram and label the photo-generated current direction in the circuit.



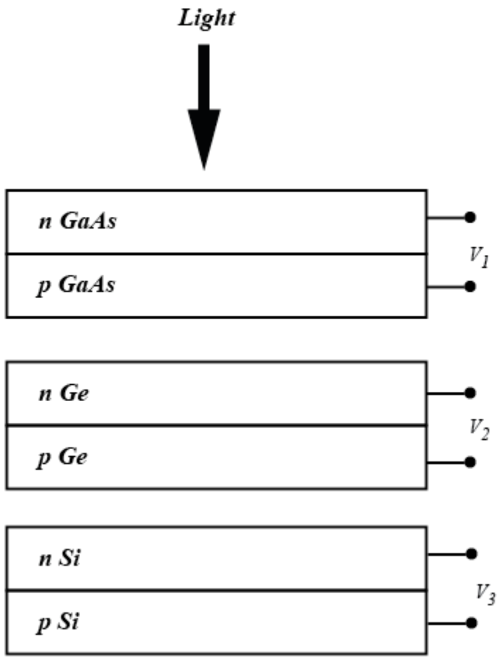


(b) Draw the new I-V characteristics for the diode when used as a photovoltaic device (solar-cell). You only need to draw your new I-V characteristic <u>in the quadrant of operation as a photovoltaic</u>. Also, draw the additional basic components needed in the circuit diagram and label the photo-generated current direction. On the diagram label how you can calculate the power generation achieved by the photodiode.





(2) The bandgap of GaAs is ~1.4 eV, Ge is ~0.8 eV, and Si is ~1.1 eV. Assume the semiconductor layers are thin enough to act as good photodiodes. What wavelengths of light can cause the Ge photodiode to provide a voltage at V_2?



Answer: E=hc/lambda=1240/lamda (nm).

Lamda (GaAs) = 1240 / 1.4 = 886 nm
Lamda (Si)= 1240 /1.1 = 1127 nm
Lamda (Ge) = 1240/0.8 = 1550 nm

Therefore Ge will respond to Lamda <1550 nm (so had enough energy to create e-h pairs) and Lamda > 886 nm (so it can get through the GaAs).

(3) A Si solar cell that is 2 x 2 cm^2 has a reverse saturation current of 32 nA in the dark, a depletion width of 1 μm, and has electron and hole diffusion lengths of 2 μm. If the solar cell is exposed to light and the optical generation rate is 10^{18}/cc-s:

(a) calculate the short circuit current

From Equation 8-1,

$$I_{sc} = I_{op} = q \cdot A \cdot g_{op} \cdot (L_p + L_n + W) = 1.6 \cdot 10^{-19} C \cdot 4cm^2 \cdot 10^{18} \tfrac{1}{cm^3} \cdot (2\mu m + 2\mu m + 1\mu m) = 0.32mA$$

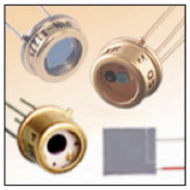
(b) also calculate the open circuit voltage

From Equation 8-3,

$$V_{oc} = \frac{kT}{q} \cdot \ln\left(1 + \frac{I_{op}}{I_{th}}\right) = 0.0259V \cdot \ln\left(1 + \frac{0.32 \cdot 10^{-3} A}{32 \cdot 10^{-9} A}\right) = 0.24V$$

(4) Consider the FDSO2 photodiode part listing below from ThorLabs with the following specifications: Active Area Diameter: 250 μm, Capacitance: 0.94 pF at 5V, Dark Current (5V): 35 pA, Optical Power Damage Threshold CW: 18 mW.

Si Photodiodes - VIS Wavelengths



The **FDS02** is a high-speed, fiber-coupled photodiode with a low junction capaci

The **FDS010** features a fast 1ns small area in a Si TO-5 Detector package with provide sensitivity down to 200 nm.

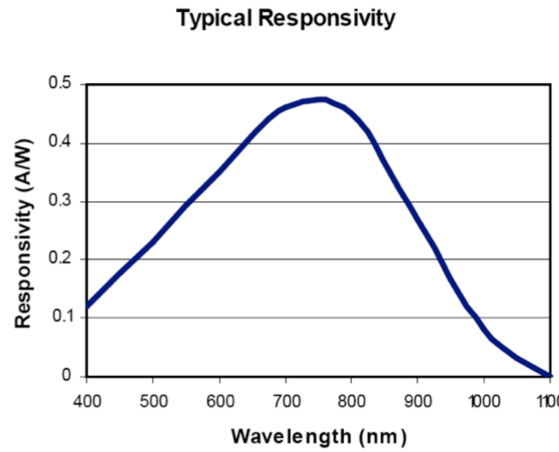
The **FDS100** is a large area Si Detector packaged in a TO-5 can.

The **FDS1010** is a large 100 mm^2 Detector, mounted on an insulating ceramic s

Order

Based on your currency / country selection, your ord

+1QTY	Part Number - Imperial
0	FDS02 - Si Photodiode, 47 ps Rise Time, Ø0.25 mm Active Area
0	FDS010 - Si Photodiode, 1 ns Rise Time, Ø1 mm Active Area, 200 - 1100 nm
0	FDS100 - Si Photodiode, 10 ns Rise Time, 3.6 mm x 3.6 mm Active Area, 350 - 1100 nm
0	FDS1010 - Si Photodiode, 40 ns Rise Time, 10 mm x 10 mm Active Area, 400 - 1100 nm



(a) what is the minimum current the photodiode will exhibit during operation?

35 pA (the dark current which is reverse saturation current).

(b) what is the maximum current that can be generated at a wavelength of 750 nm?

~0.47 A/W x 18 mW = 10 mA (roughly)

(c) roughly, what is the absolute minimum optical power this could detect?

roughly, two ways to interpret and answer (precise answer depends on sensing circuit, noise etc..)

35 pA / 0.48 A/W = 73 pW

or

35 pA * 5V = 175 pW

if you take into consideration responsivity (A/W) then an acceptable answer would be 2x175 pW or 350 pW.

(5) Lets finish by making sure you really understand the main equation for current in a photodiode or solar cell...

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

(a) If I increase doping, the optically generated current will

___ increase
___ decrease
___ stay the same
___ frighten me.

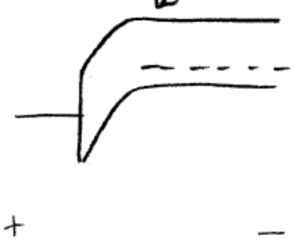
If you increase doping Lp, Ln, and W all decrease, so the optically generated current will decrease! *Time and time again in this course you find that increased dopings decrease current or cause an increase in required operating voltage (think about all the devices!).*

(b) A metal and a p-type semiconductor are joined together to make a Schottky diode. The metal work function is LESS than the semiconductor work function. Above is an equation predicting the current value generated by a pn junction photodiode. Please rewrite the current equation using only the remaining terms needed *for this Schottky photodiode that is reverse biased and which has light illumination on it.*

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

only photo-generated e's within L_n

reverse bias so $V<0$



(6) You apply +40 V to the emitter of a pnp heterojunction bipolar transistor (HBT), the collector is grounded. The base terminal is left floating. The HBT has an amplification factor of ~1000 and perfect emitter injection efficiency (~1). Ideally, how may total charges (q) will flow through the external bias circuit if:

(a) ten photons are absorbed in the emitter region

_X_ 0 charges, the charges will just recombine.
___ 10 charges, the charges will be transported through the BJT
___ 10,000 charges, the charges will be amplified by the BJT
___ how the heck would I know? I did not pay attention in class this week and will pay dearly for it on the final…

(b) ten photons are absorbed in the base-collector depletion region

___ 0 charges, the charges will just recombine.
___ 10 charges, the charges will be collected by the BJT
___ 10,000 charges, the charges will be amplified by the BJT
_ X _ 10,010 charges, the charges will be collected and amplified by the BJT

You will get 10 photo-generated electrons into the base (that just stay there until they recombine). You will get 10 photo-generated holes that drift out to the collector (and are collected). Before the electrons in the base recombine, you will get 10,000 more holes that diffuse across the base, and drift out to the collector. Therefore your total charge that flows through the circuit is 10+10,000 or 10,010 electrons total.

(c) Lets think about the same problem differently, you bias the same HBT in normal forward active mode and measure and measure a collector current of Ic=100 mA and a base current Ib of 0.1 mA. These measurements were made in the dark. You turn the lights on in the room and find that the collector current jumps to 120 mA. Calculate the *photo-generated* current in the depletion region. You may assume the effects of photogeneration is negligible in all other device areas.

$B = \frac{I_C}{I_B} = 1000$ $120mA - 100mA = 20\ mA$

$\therefore\ 20mA/1000 = 0.02\ mA$ of electrons into the base!

however, we have photogenerated holes going into the collector so our total photogenerated current is $I_{electrons} + I_{holes} = 0.02\ mA \times 2 = 0.04\ mA$

Sorry, scanned solution got cut-off. It says "is $I_{electrons}$ + I_{holes} = 0.02 mA x 2 = 0.04 mA total.

(7) Why do we rarely use simple uniformly doped semiconductor (a photoconductor) to detect light?

___ they don't generate as many electron-hole pairs
_X_ their background (dark) current level is huge compared to the small dark current for a photodiode (rev. sat.)
___ they require more voltage
___ we ran out of beach sand

(8) See the file on blackboard for this lecture title: "Lecture 16 - Suppl 1.pdf".

(a) in the future, what is the highest efficiency we can expect to achieve for real commercial solar cells?

>50% is expected!

(b) The highest efficiency solar cells will be multi-junction and will be EXPENSIVE, and you can't afford to make large area panels with them. What technology is added to make them more economical?

A solar concentrator to take a large area of light and focus onto a smaller area solar cell.