EECS 2077
Semiconductor Devices

15 - Opto Semicond. **Name:______________________________**

In-Class Problems

(1) A semiconductor with $n_i=10^9$/cc is doped n-type to $Nd=10^{15}$/cc, and we optically generate 10^{17} electron-hole pairs. If the electron and hole mobility is the same, for a given voltage applied to the semiconductor how much will the drift current increase due to the optical generation?

200X

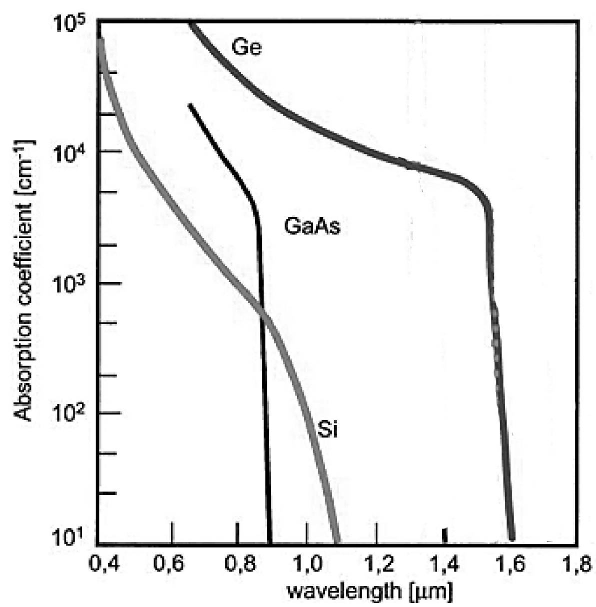
(2) Same semiconductor, $n_i=10^9$/cc is doped n-type to $Nd=10^{15}$/cc, if the carrier lifetime is 1 ns for <u>holes</u>, and we increase the doping to $Nd=5x10^{15}$/cc, what will be the new lifetime for (a) <u>electrons</u> and (b) for <u>holes?</u>

(a), (b) : same answer … 1 ns / 5 = 0.2 ns (200 ps)

(3) You are making an infrared camera using an imaging chip made with narrow band-gap semiconductors (narrower than Si). You would like to block visible light coming into the camera, otherwise the visible light could wash out the infrared image. You decide that a real simple solution might be to place a Silicon wafer in front of the camera.

If you want to attenuate all the light that is ~1 µm or less in wavelength, by at least 30 dB attenuation, what is the minimum thickness you need for the Silicon wafer?

Notes: remember db = 10 log (X/Xo), for units like intensity of light or power. Only in a circuit do you use db = 20 log (V/Vo) or db = 20 log (I/Io) because power is $IV=V^2/R=I^2R$ and the square just comes out (if you did P/Po, you would again use 10 log).



30 dB = -10 log (I/Io)

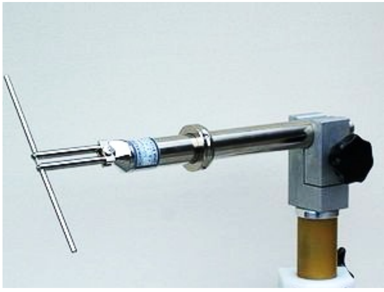
$I/Io=10^{-3}$ (99.9% of visible light is absorbed).

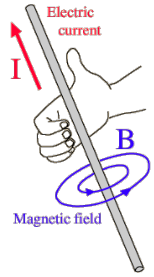
$I/Io=10^{-3}=e^{(-\alpha * t_{Si})}$, α ~ 100 / cm for 1 µm light (from the graph)

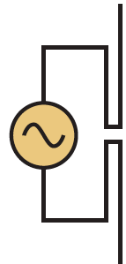
Therefore t_{Si} ~ 0.069 cm ~ 690 µm.

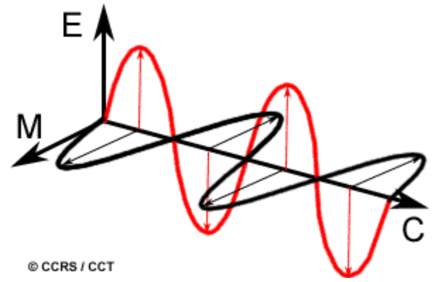
(4) Photons are created by some sort of movement or transition of charge. A photon is nothing more than an electromagnetic disturbance that is propagating forwards (electric field and magnetic field feeding into each other based on Maxwells equations). Sometimes the movement or energy transition of the charge is in an atom, sometimes in a material (like a semiconductor), and sometimes charge moving in a physical object like a wire. Draw out all 5 phases of photon generation created by moving charge in

two wires (simple dipole antenna). Make sure you understand WHY the fields are in the directions they are. This is a good refresher on E&M!









(5) The future is solid-state lighting (LEDs), and as of right now, they will ALL be made with GaN semiconductor for the blue portion of the white light in a lamp. GaN has a band-gap energy of 3.4 eV.

(a) Why does that bandgap not make sense regarding blue light emission?

E=hc/lambda   lambda = 1240/3.4 or 365 nm… UV light!

(b) Now, you can tune the emission of of a semiconductor by 'alloying' it with another semiconductor that has the same crystal structure and a similar lattice constant (spacing between atoms). The emission you get is determined simply by the ratio of the two mixed semiconductors. InN has a bandgap of 0.7 eV. How much % of InN do you need to mix with GaN to make a blue LED that emits light at 470 nm (blue light)?

470 nm = 1240 / Eg   Eg = 2.64 eV   2.64/3.4 eV = 0.776   Still fairly wide bandgap so is mainly GaN, right? So 1-0.776 = 0.224 or 22.4% InN.

A full length way to do this is $E_{gGaN}(X) + E_{gIn}(1-x) = Eg_{InGaN}$

(6) Who really needs a Professor?! Learn ahead on your own (figure out how solar cells work, which is the next lecture)!!!

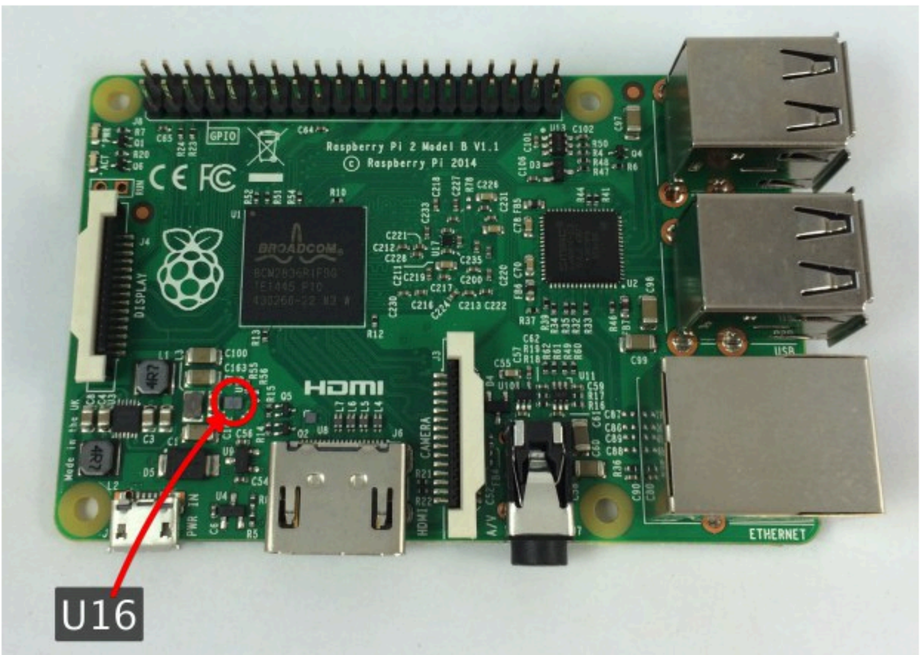
Draw a band diagram for a PN junction. Have a few photons come in and be absorbed in the depletion region. Draw arrows in the direction of any current flow for generated electrons and holes. Then figure out how this is different than if photons were absorbed by a slab of uniformly doped semiconductor!

Simple! With a PN junction the depletion region has E-field which separates the carriers (sloped bands!). These carriers have opposite charges and move in opposite directions which gives a net current flow from the n-side to the p-side!

Is The New Raspberry Pi 2 Camera Shy?

Camera Flashes Can Cause the New Raspberry Pi To Crash. Here's The Quick Fix

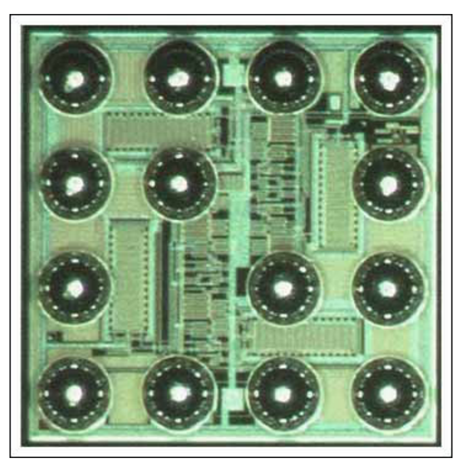
By Alasdair Allan February 9th, 2015 4:06 am Category Raspberry Pi



The new Raspberry Pi 2 with the problem SMPS chip (labelled U16) shown.

(7) See the story header shown above (thx to Andrew Krew, EECS 2077 student in 2014). Great example of why we need to keep light away from general semiconductor electronics and circuits if you want them to work properly!

- When light hits a semiconductor it can generate electron hole pairs and make it more electrically conductive.
- When light hits a reverse biased diode (like those found in rectifiers, CMOS source-channel-drains, BJT base-collectors) it can cause a significant increase in current compared to the VERY small reverse saturation current. We will learn more about this next week :)



More info from the article: “The problem was first discovered when an owner attempted to take some flash photographs of the new board and found that taking its picture caused the board to instantly power off.”

“The problem is caused by the switched mode power supply (SMPS) chip on the board, labelled U16 on the silkscreen, which appears to be photosensitive. Too much light causes fluctuation in the power supply and the board resets.”

And from another story: “This component that’s causing the issue is in a WL-CSP package: a bare silicon die which has solder balls attached. This is a picture of the underside of a similar package (enormously magnified) – each circle is a minuscule ball of solder" See the image at right.

<u>So for this problem, show in a diagram what is happening….</u>

Light is getting underneath the U16 chip because it stands away from the PCB with a small gap (due to the solder connections). If you look at the U16 packaging in the photo, the underside has EXPOSED silicon! Electron hole pairs are optically generated and mess up the chip's electronic state.

(8) Quick calculations of photon energy and power….

(a) Calculate the energy in Joules of 1 photon of green light (2.3 eV, ~550 nm wavelength). This is easy… eV is also Joules if you multiply out the charge of one electron accelerated through 1 V.

E=2.3*Q*V = 2.3x1.6E-19x1 = 3.68E-19J

(a) A lightbulb typically will typically emit 10 W or more. How many green photons per second is that?

W=J/s 1/s=W/J=10W/3.68E-19J = 2.7E19 photons/second

(9) A big area of semiconductor research is to make LEDs and detectors with emissions WAY out in the infrared. These are used for imaging, for medical applications, and for military defense applications. However, there is a significant major challenge with some of these devices, in that they have to be actively cooled during operation. Why? *Hint – thing of bandgap energy and related effects on the device with temperature…*

Thermal generation! Is a big issue. So much thermal generation (because of narrow bandgap, easy to get energy needed from valence to conduction band). The thermal generation can cause so many carriers to appear that you lose doping differences or you can't detect photons because the thermally generated carriers…