2007 PhD Quals Question, James Harris

1. Si MOSFET

A. Can you sketch the cross-section of a MOSFET?
B. Below your sketch, can you sketch the energy band diagram at thermal equilibrium with no gate or drain voltage?
C. Using a different color, can you show how the band diagram is changed if I apply a sufficient gate bias to reach inversion under the channel?
D. Can you now show how the band diagram is changed when I apply a drain bias?
E. Draw the drain I-V characteristic and briefly describe the 2 or 3 most important regions of the I-V characteristic and how these are related to the three band diagrams you've sketched.

2. Single Electron Transistor

The above characteristics look pretty useful, so I'm going to SNF and fabricate some of these devices. I go down to the e-beam system to make very small gate length devices and find my line drawing skills are pretty good, but my alignment skills are somewhat lacking and so I have produced a series of devices in which the gate length is less than the source-drain spacing, so draw that on the cross-section schematic of your earlier device to make sure we are both clear what kind of device my inept skills have produced.

A. Would this device work by the normal processes by which we describe MOSFETs? Why not?
B. If I apply a gate bias, can I still create an inversion layer under the gate of this device?
C. Is there anything different about the inversion layer in this device and the normal MOSFET?
D. If I apply a drain bias to this device, would I expect to get any drain current? By what mechanism?
E. I made 25 of these devices in SNF with gate lengths from 100nm down to 5 nm and they all had the same degree of mis-alignment at source and drain, i.e., the barriers at each end were all exactly the same. As I measure the drain I-V characteristics of these devices, would I expect to see anything different about the characteristics as the gate length became shorter and shorter?
F. What do you imagine the characteristics might look like compared to the normal MOSFET characteristics and what would this be due to?
G. If I said that I measured a voltage step of 25mV for the tunneling of a SINGLE electron onto the inversion layer island of my device, how might you go about estimating how small such an island would have to be?

2008 PhD Quals Questions
J. S. Harris

1. (I have a LED demo with Red, Green & Blue LEDs which I show to the student) Can you first draw a band diagram for light emitting diode (LED) and describe how it works?

2. What is different about the 3 LEDs I showed you, what is important? Does the semiconductor have to be a direct bandgap semiconductor?

3. I then show a white LED and ask, how can I get white light from a LED?

4. Can you draw the I vs V characteristic for the 3 diodes and label R, G, B? How would the LEDs differ and what insight can you gain about the material from the I-V characteristic?

5. Can you draw the emission spectrum for one of the diodes and compare it to that of an incandescent light bulb and explain the key features of the LED?

6. If you now compare the emission spectrum with the I-V characteristic, it seems that I'm getting a "free lunch" since I am able to get 2.5eV photons out with about 2V of applied bias. How is this possible? What is missing in this picture?

7. If we thermally isolate the diode, but have a window in which the photons can escape, what will happen to the LED and how does this effect the I-V and emission characteristics of the LED as a function of time (temperature)?

8. (I now show the student a Red semiconductor laser pointer) The semiconductor parts of this laser and the red LED are quite similar, but not identical. How does this semiconductor laser differ from the LED and in particular, why is the light emission so strongly directional in the laser compared to the LED?

9. On your graph of the LED spectral output, draw a similar curve for the laser? What are the notable differences?

10. If I were to put both the laser and LED in my thermally isolated environment so the temperature decreases, would you expect the optical output of the LED and laser to behave differently as a function of temperature? Explain.

2009 PhD Quals Questions
J. S. Harris

1. What is the Depletion Approximation for a p/n junction?

2. Can you draw the charge distribution, electric field and potential for an abrupt p/n junction under the depletion approximation?

3. Can you draw an energy band diagram for the p/n junction, including the vacuum level?

4. What happens to the above sketches if I now insert a plane of positive charge right at the p/n junction interface which is exactly $1/2(N_d x_n)$ of the original depletion region. Go back to your original drawings for the idealized p/n junction and using a different color pen, draw in the charge distribution, electric field and potential for the new situation.

5. Please draw the I-V characteristic for the first "ideal" junction at room temperature. What would the I-V characteristic look like at -100°C and explain the differences based upon the physical processes for current in the diode.

6. Would there be any significant differences between the I-V characteristic for the "ideal" diode and the one where we introduced the sheet of charge? Why or why not?

7. If I have a p/N heterojunction in which the bandgap of the n-region is 1.5 eV and that of the p-region is 1.0 eV and both materials have exactly the same electron affinity. Draw the energy band diagram for this p/N heterojunction, including the vacuum level. Why is there a discontinuity in the valence band and not the conduction band?

2010 PhD Quals Questions
J. S. Harris

1. I have several LEDs here of different colors. Can you first briefly tell me how an LED works and what is different about the devices that produce different colors of light?

2. Can you draw the Current-Voltage and Light-Current (L-I) curves for me for say two different color LEDs and identify which is which?

3. Can you sketch the characteristic spectral distribution for one of the LEDs? Why can you have photons with $\lambda < E_g$, but not greater than E_g?

4. There is a lot of effort today to produce solid state lighting. How can I produce a White LED?

5. I now have a red laser. Can it be made of the same materials as a red LED? What is different about the laser compared to the LED?

6. Can you draw the I-V and L-I curves and spectral distribution for the laser? How do they differ from the LED and why?

7. If I now change the temperature of the LED and laser, how do the spectral characteristics change and why?

8. I have a polarizing filter and when I put it in front of the LED, it has virtually no effect, but when I put it in front of the laser, and rotate it, it changes from virtually zero transmission to unchanged transmission. What does this tell you about the fundamental recombination processes occurring in the laser vs. the LED?

9. If stimulated emission and absorption are reciprocal processes, can I use a LED or laser as a solar cell? What might I do differently to optimize the solar cell vs. a laser or LED?

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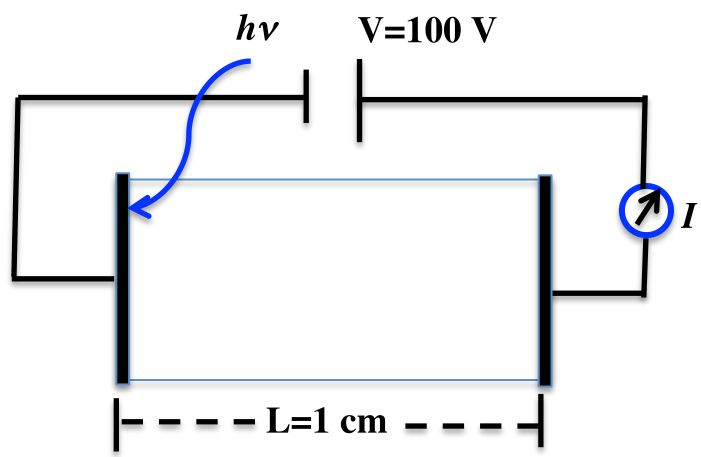
2013 PhD Qualifying Exam Questions—J. Harris

1. I have the structure illustrated here with two metal electrodes separated by 1cm and I put it into vacuum. I then illuminate the cathode with a pulse of light.



   a. Is there any requirement on the threshold energy of the photons to measure a current at the anode?
   b. When I measure a current, what is the current density as a function of time? Plot it.
   c. Since the external circuit requires current continuity, how do I explain the current through vacuum?
   d. What is the maximum current density?
   e. What is the length of time (known as the transit time) that there will be a measurable current?

2. I now fill the void between the electrodes with a semiconductor and the electrodes form Ohmic contacts to the semiconductor and I illuminate it with a pulse of light.
   a. Is there any difference in the photon energy from the prior case? Why?
   b. What is the current density in this case? Plot it as a function of time. Why is it different than the prior case?
   c. What is the transit time in this case?

3. The Einstein Relationship is used extensively in describing the transport of carriers in semiconductors.
   a. Do you know what physical foundation or assumptions are to derive this relationship?
   b. Can you derive of describe how to simply derive the Einstein Relationship?
   c. Would this apply in the description of transport at very high electric fields?