

Homework 3 and Mid-term

ECE 4339 Spring 2014

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Choose a combination of problems so that the total ≥ 100 pts to submit as part 1.

Then the rest can be submitted a week later as part 2. Must follow numerical order in each part.

1. (15 pts) Basic review: frequency, photon quantum energy, and units.

1.1 (2 pts) Question 1: speed of light

The speed of light c is 2.99792458×10^8 meter/sec. Calculate the speed of light in the following units: cm/sec; $\mu\text{m}/\text{ps}$; where: ps = picosecond = 10^{-12} sec. Try to remember the value of c in $\mu\text{m}/\text{ps}$. It is a very useful unit.

1.2 (2 pts) Question 2: frequency

Calculate the frequency of light in unit of THz (Terahertz), which is 10^{12} Hz, using the result of c in the unit of $\mu\text{m}/\text{ps}$ from question 1 above, for the following wavelengths: $0.78 \mu\text{m}$ (the wavelength of CD laser), $0.65 \mu\text{m}$ (the wavelength of DVD laser), $0.633 \mu\text{m}$ (HeNe laser wavelength), $0.532 \mu\text{m}$ (the wavelength of doubled Nd:YAG, such as green laser pointer), and $0.405 \mu\text{m}$ (BluRay laser). What is the color of each wavelength? (search for pics that shows colors of these wavelength on the Internet).

1.3 (1 pt) Question 3: λ vs. f

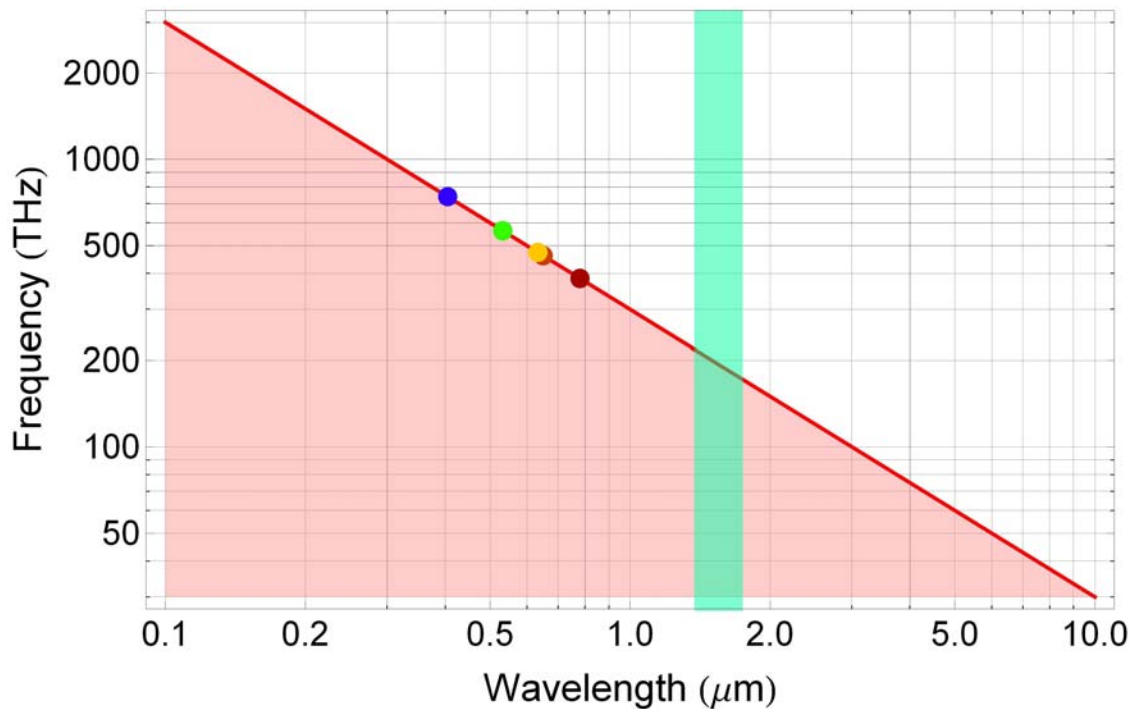
Plot lightwave frequency (in unit of THz) as a function of wavelength (in unit of μm) on log-log scale for λ (wavelength) from $10 \mu\text{m}$ to $0.1 \mu\text{m}$.

1.3 Answer given (but you must import and paste in your work - unless you use *Mathematica*)

```

c = 299.792458 ; laserλL = Log[{0.78, 0.65, 0.633, 0.532, 0.405} ] ;
laserfL = Log[c/{0.78, 0.65, 0.633, 0.532, 0.405} ] ;
LaserHue = {Hue[0., 1, 0.65, 1], Hue[0.05, 1, 0.8, 1], Hue[0.13, 1, 1, 1], Hue[0.3, 1, 1, 1], Hue[0.7, 1, 1, 1]} ;
λpoint = Table[{LaserHue[[i]], PointSize[0.02], Point[{laserλL[[i]], laserfL[[i]]}], {i, 1, Length[laserλL]}] ;
Show[LogLogPlot[ $\frac{c}{\lambda}$ , {λ, 0.1, 10}, PlotStyle → {{Thick, Red}}
, Filling → {1 → {Axis, Hue[0., 0.5, 1, 0.4]}}
, Frame → True, GridLines → Automatic,
FrameLabel → {Style["Wavelength (μm)", 20], Style["Frequency (THz)", 20]},
LabelStyle → {18, FontFamily → "Arial"}]
, Graphics[{Hue[0.44, 1, 1, 0.5], Thickness[0.05], Line[{Log[{1.55, 30}], Log[{1.55, 3000}]}], λpoint}
]
]

```



1.4 (2 pts) Question 4: quantum

We discuss Planck's light quantum, the smallest amount of energy that a light carries, as: $E = h \nu$ where h is Planck's constant and ν is light frequency. ($h = 6.62606896 \times 10^{-34}$ Joule/s). Find the photon energy for each light in question 2.

1.5 (2 pts) Question 5: Unit of eV

A most useful unit of energy is eV= electron-Volt: it is the energy to move an electron across a potential of 1 V.
What is one eV in the unit of Joule. (note the charge of an electron is: $e=1.602176487 \times 10^{-19}$ Coulomb.

1.6 (2 pts) Question 6: photon energy

What is the energy of each photon in question 5 in unit of eV?

1.7 (1 pt) Question 7: photon energy vs. λ

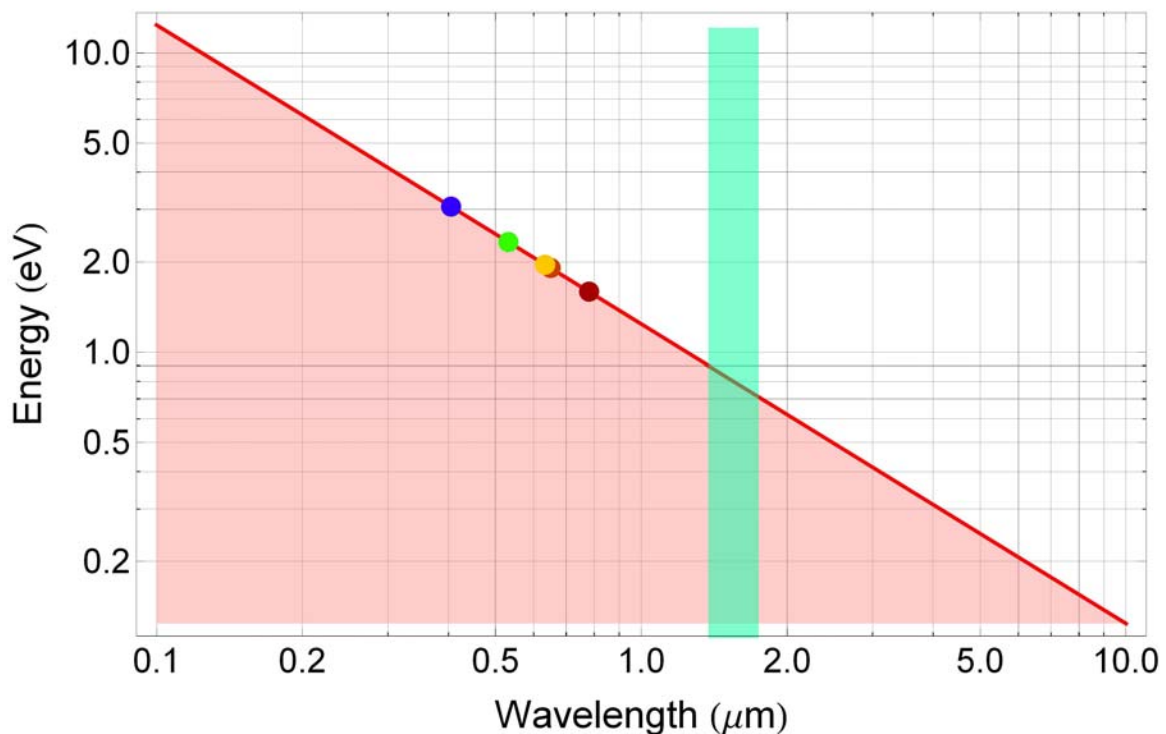
Plot the photon energy (in unit eV) as a function of wavelength on log-log scale for λ (wavelength) from $10 \mu\text{m}$ to $0.1 \mu\text{m}$.

1.7 Answer (but you must import and paste in your work - unless you use *Mathematica*)

```

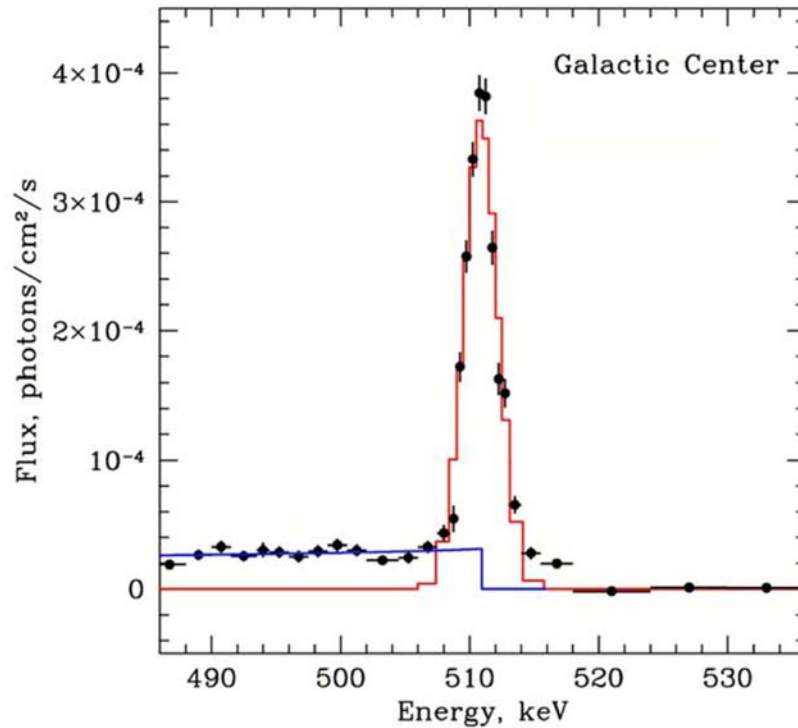
c = 299.792458 ; h = 4.135667333632515 * 10^-3 ; laserλL = Log[{0.78, 0.65, 0.633, 0.532, 0.405} ] ;
laserEL = Log[c h / {0.78, 0.65, 0.633, 0.532, 0.405} ] ;
LaserHue = {Hue[0., 1, 0.65, 1], Hue[0.05, 1, 0.8, 1], Hue[0.13, 1, 1, 1], Hue[0.3, 1, 1, 1], Hue[0.7, 1, 1, 1]} ;
λpointE = Table[{LaserHue[[i]], PointSize[0.02], Point[{laserλL[[i]], laserEL[[i]]}], {i, 1, Length[laserλL]}] ;
Show[LogLogPlot[ $\frac{c h}{\lambda}$ , {λ, 0.1, 10}, PlotStyle -> {{Thick, Red}}
, Filling -> {1 -> {Axis, Hue[0., 0.5, 1, 0.4]}},
, Frame -> True, GridLines -> Automatic,
FrameLabel -> {Style["Wavelength (μm)", 20], Style["Energy (eV)", 20]},
LabelStyle -> {18, FontFamily -> "Arial"}]
, Graphics[{Hue[0.44, 1, 1, 0.5], Thickness[0.05], Line[{Log[{1.55, 0.10}], Log[{1.55, 10}]}]}]
, λpointE]
]
]

```



1.8 (3 pts) Question 8: astronomical photon energy

This is an exercise in unit conversion. Below is the plot of gamma ray intensity as function of photon energy from the center of our galaxy (Milkyway) obtained by Max Planck Institute for Astrophysics. (γ -ray is photon with very high energy.)



Using the formula: $E = mc^2$, and the electron rest mass is $9.10938215 \times 10^{-31}$ Kg, guess what nature of the peak at 511 keV (kilo eV) in the graph is. Calculate the 511-keV-line intensity (the peak of the graph) in unit of W/m^2 . Hint, look up matter-antimatter, and electron its anti-matter.

2. (25 pts) Carrier density and Fermi level in GaAs

2.1 (5 pts)

Go to lecture: <http://www0.egr.uh.edu/courses/ece/ece4339-4119/Class%20Notes/Chapter%203%20-%20Carriers%20in%20semiconductor%20-Part%202.html>. See calculation of 6.3.1 (the default parameters are for GaAs).

For $T=300K$, vary the conduction band Fermi level from -0.2 eV to 0.2 eV (the value is relative to the conduction band edge) in 5 steps (your choice of the steps, but the 2 endpoints have to be -0.2 and 0.2 eV, for example: $-0.2, -0.15, 0, 0.75, 0.2$ etc... don't follow this example). Record the calculated the carrier density. Then, use the approximated formula:

$$n_0 = N_C e^{-(E_c - E_f)/k_B T} \quad \text{which was already given for GaAs: (cf. Chapter 3, 7.1)}$$

$$N_C(300 K) = 4.3034 \times 10^{17} \text{ Cm}^{-3}$$

to calculate the carrier densities for the same Fermi levels. Plot the carrier density by both approaches vs Fermi levels on Log-Linear scale. (Carrier density on log scale, Fermi level on linear scale). **What do you think of the approximated formula? (Is it reasonable?)**

2.2 (4 pts)

Do the same as above for $T=500 K$. But here, you don't have to do the part with approximated formula. Make a log-

linear plot of carrier density for both 300 K you find in 1.1 and 500 K you find here.

2.3 (4 pts)

Let a GaAs crystal be Te-doped at $1 * 10^{17} \text{ cm}^{-3}$ (and no other dopants). At 300K, all Te donors are ionized, in other words, all Te-electrons are free. Find the Fermi level relative to the conduction band. (You can use the web lecture calculator and if so, no need to show your calculation, but show a screen view that you did it - it is also OK to do your own calculation).

2.4 (4 pts)

Do the same as in 1.1 but for holes and use section 6.3.3 calculation. Vary the Fermi level from 0.2 to -0.1 eV (relative to the valence band edge). (You must calculate $N_V(300 K)$). Plot the carrier density vs -Fermi (not Fermi, just change the sign to get -Fermi to plot, in other words, if Fermi valence is -0.1 eV, plot the point as +0.1 eV).

2.5 (4 pts)

Plot the electron density you find in 1.1 (neglect the approximation formula results) and the hole density found in 1.4 vs Fermi Level on the same graph and compare (note: the Fermi level will be kept the same sign for electrons, and reversed sign for holes). **Discuss why carrier density for holes is so much larger than electrons for the same Fermi level.**

2.6 (4 pts)

Another GaAs crystal layer is Mg-doped at $2 * 10^{18} \text{ cm}^{-3}$ (and no other dopants). This layer and the layer in 1.3 are joined together to form a junction and at thermal equilibrium. Draw the conduction and valence bands of each layer relative to each other. (For this question, you need not be concerned with what happens at the interface region between the 2 layers. Just plot the band structure of one layer on the right and that of the other layer on the left (see lecture Chapter 3, section 9.1)

3. (15 pts) Intrinsic vs. doped carriers in GaSb

Refer to this web site: <http://www.ioffe.ru/SVA/NSM/Semicond/> for various parameters of GaSb. **Use the calculation in Chapter 3, 6.3.4, but make sure with GaSb parameters for the following questions.** Neglect the light hole, use only the heavy hole effective mass.

For band gap dependence of temperature, use the formula:

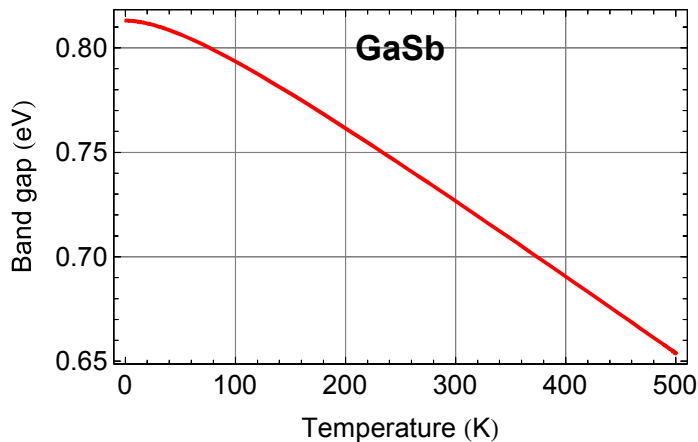
$$E_g = 0.813 - 3.78 * 10^{-4} \frac{T^2}{T+94} \text{ (eV)}$$

This is a plot for your reference:

```

Plot[0.813 - 3.78 * 10^-4  $\frac{T^2}{T + 94}$ , {T, 1, 500}, PlotRange -> All
, PlotStyle -> {Thick, Red}
(*, Filling->{1-> { Axis, Hue[0.43,1,1,0.5]}} *)
, Frame -> True
, GridLines -> Automatic, FrameLabel -> {"Temperature (K)", "Band gap (eV)"}
, LabelStyle -> Directive[14, FontFamily -> "Arial"]
,
Epilog -> Inset["GaSb", {250, 0.8}, BaseStyle -> {18, Bold, FontFamily -> "Arial"}]]

```



3.1 Question 1 (5 pts)

Find the intrinsic carrier density and Fermi level at $T=100, 200, 300, 400, 500$ K. Then plot the intrinsic Fermi level as a function of temperature. Use the midgap as the reference point. (see 6.4.1 as an example).

3.2 Question 2 (4 pts)

Plot the intrinsic carrier density obtained in 2.1 vs. temperature on a log-linear scale. **Discuss.**

3.3 Question 3 (4 pts)

Let $T=300$ K. Plot the carrier density product $n_0 p_0$ as a function of Fermi level from -0.4 to 0.4 eV on a log-linear scale with a minimum of 6 values of Fermi level. What do you observe? **Discuss.**

3.4 Question 4 (2 pts)

An GaSb crystal is Mg-doped with $3 * 10^{18} \text{ cm}^{-3}$. Find the **minority carrier concentration** at 300 K.

4. (20 pts) Carriers relaxation and luminescence

4.1 (2 pts)

When electrons and holes are injected or generated in a semiconductor with energy much higher above conduction band and valence band, respectively, what will happen to them? and draw a diagram to explain. Note: by convention for holes, the energy scale is inverted, in other words, if a hole with energy that appears to be below the valence band edge in a diagram, it means its energy is high above the valence band edge. (Think of it as the mirror image of electron energy diagram across the horizontal line).

4.2 (2 pts)

When electrons and holes relax to the bottom of conduction bands, what relaxation process shown in the class demonstration?

4.3 (4 pts)

In the class demonstration, when the red (650 nm) laser light is shone of various materials, only scattered laser light of the same color was seen. But when the blue laser (405 nm) was used, lights of different colors appeared: greenish, yellowish, orange, even white (with a tint of blue that was from the original laser light). Did the laser light change its color? Explain the phenomenon. Why did it happen only with the blue laser but not the red laser (Remember what discussed in class). Explain if the following statement is true or false and why: ***The observed colors, (greenish, yellowish, orange, white) is a function of both the blue laser light and the material properties; if the blue laser wavelength is changed to, for example, 390 nm instead of 405 nm, the emitting color will also change.***

4.4 (4 pts)

$\text{Al}_x \text{Ga}_{1-x} \text{As}$ is an alloy of GaAs and AlAs, of which the direct bandgap is given by the formula:

$$E_g [\text{Al}_x \text{Ga}_{1-x} \text{As}] = E_g [\text{GaAs}] + 1.55x + 0.37x^2$$

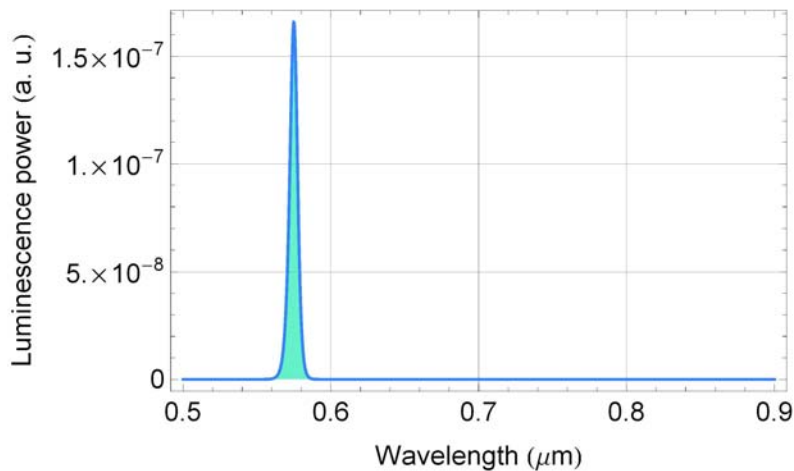
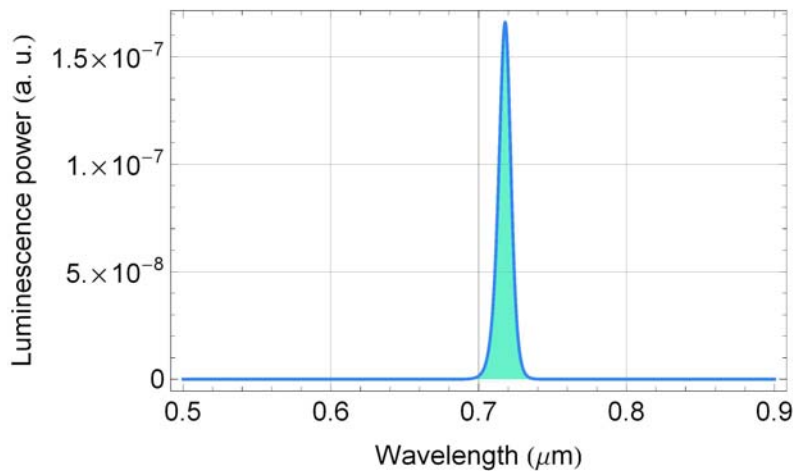
Let $E_g [\text{GaAs}] = 1.42 \text{ eV}$ (at 300 K), Plot the bandgap $E_g [\text{Al}_x \text{Ga}_{1-x} \text{As}]$ as a function of alloy fraction x , for x from 0 to 0.4

4.5 (3 pts)

A person has 2 wafers with an epitaxial layer of $\text{Al}_x \text{Ga}_{1-x} \text{As}$ on it with two different values of x . But he/she doesn't remember what the x values are, and cannot tell which and which. If you have a blue laser and an optical spectrum analyzer (which is also called a spectrometer, an instrument that can measure the spectrum of light - you can look it up and read more), what will be a simple measurement you can do to help the person determine x and tell which and which wafer? (Hint: see the next question). Do not just use a name for the experiment, you must also identify the physical process and explain why your experiment can help solving the problem.

4.6 (5 pts)

The experiment was done at liquid N_2 temperature, $T=77 \text{ K}$, and you obtained 2 spectra below: wafer A gave the left spectrum and wafer B gave the right spectrum. Determine the Al x concentration for each wafer, and describe the emission color from each wafer (e. g. red, green,...). You are welcome to find online the closest hue for each wavelength and submit for extra credit. You can also obtain a graph of the visible spectrum vs wavelength and use arrows to point to the color of the luminescence from each wafer.



To solve this problem, you should use this calculation of luminescence spectrum in lecture: http://www0.egr.uh.edu/courses/ece/ece4339-4119/Class%20Notes/Chapter%204%20-%20Excess%20carriers_html_Part1.html in section 2.2.2. However, note that the plot there is luminescence vs. photon energy (eV), not wavelength, hence you must convert wavelength to photon energy. Make sure you set the temperature at 77 K. Vary x concentration such that you obtain a spectrum with the peak emission photon energy best matched the measured spectra above. You should obtain x with an accuracy better than 5% for full credit.

5. (25 pts) Mobility and diffusion illustration

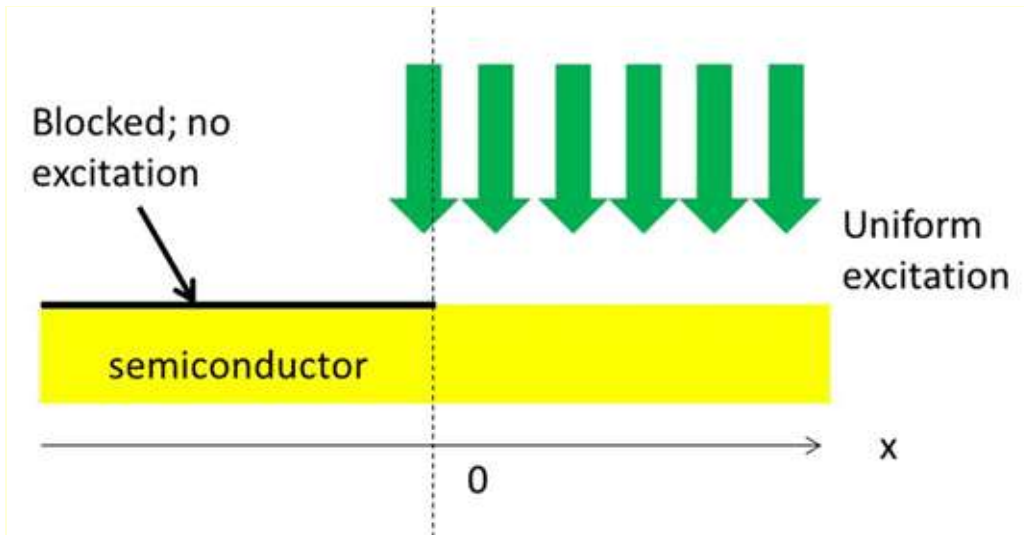
As we learn, excess carriers diffuse and at the same time decay via recombination, resulting in an effective “spread distance” called diffusion length: $L = \sqrt{D\tau}$ where τ is the carrier lifetime, D is the diffusion coefficient or diffusivity for short, which is related to the mobility by the Einstein relation:

$$D = k_B T \frac{\mu}{e}$$

The larger L is, the farther do carriers spread out.

In the following, refer to Chapter 4, part 2, Section 5.4

5.1 (5 pts) Consider example 5.4.1 of Chapter 4



Set $P=2$, $\mu=1$, Find the values of n_0 and n_1 such that you have a physically valid solution. Copy and paste the 3 plots: carrier density, carrier flux, and light emission intensity. If you obtain a proof for what n_0 and n_1 should be as a function of pump rate P , you will get extra credit.

5.2 (5 pts) Vary μ

Obtain the image of light emission intensity for $\mu=0.1$ and 5. Compare the two cases and discuss how they are different

5.3 (5 pts) Consider example 5.4.2 of Chapter 4

Do the same thing as 5.1, and set $a=1$. Obtain the value of n_0 , n_1 , n_A and n_B (hint, $n_0=n_1$ and $n_A=n_B$).

5.4 (5 pts) Larger gap

Do the same as above with $a=4$. Compare the peak carrier density for the case in 5.3 and 5.4 and discuss their difference (why the peak carrier population density for $a=4$ is larger than that for $a=1$?)

5.5 (5 pts) Vary μ

Let $a=1$, obtain results for 2 cases: $\mu=0.001$ and 5. (for $\mu=0.001$, just type in the number, the slider won't go lower than 0.1). Note what the peak carrier density is for $\mu=0.001$ (it is essentially the same as the pump rate), then compare the peak carrier density again for $\mu=5$. Explain why so in simple terms. (Use your intuition, if you have the same amount of money but spread out more, how much is left?).

6. (50 pts) Technical reading and analytical interpretation

Read the paper: "Time-resolved imaging of radiative recombination in 4H-SiC p-i-n diode" by A. Galeckas et al.,

Appl. Phys. Lett. Vol. 74, pp. 3398-3400, 1999. It is available on the last section of lecture Chapter 4, part 2.

To answer the questions below, you need to read the paper. Looking at a figure alone will NOT be enough. Read those paragraphs pertaining to each figure to answer them. You do NOT need to understand 100% of what in the paper to answer all these questions below.

5 points each question.

6.1

Label on Fig. 1 (copy and use some software such as ppt drawing to show) where the substrate is, the epilayers and their thickness, the mesa and its dimension.

6.2

What does figure 2 describe? What color do you think it looks like?

6.3

look at Fig. 3. Look at the black-white inset photo. What is the bright streak at the top? Why does it get darker as you go to the bottom?

6.4

Look at Fig. 3 again. What does it plot? Is the vertical axis on log scale or linear scale? If we assume that the emitting light intensity is proportional to the electron-hole (EH) density, how do you express the spatial variation of the EH density along these layers? Look at the curve for 100 A/cm², if you approximate the carrier density profile as e^{-x/L_D} where x is the distance and L_D is the diffusion length, what are the diffusion length values for n- and n+ region?

6.5

Recalling that diffusion length $L_D = \sqrt{D\tau}$ where D is the diffusivity and τ is the effective carrier lifetime, let's assume that the D is the diffusivity is approximately the same for both n- and n+ region, which region, n- or n+, has a longer carrier lifetime? Can you speculate why so?

6.6

Recalling that the diffusivity D is also proportional to the mobility. Which region, n- or n+ do you think the mobility is higher? Do you think that both mobility and carrier lifetime contribute to the difference in the diffusion length between the two regions?

6.7

Look at Fig. 4. What does the top photo (Fig. 4(a)) show? Copy and paste the figure and draw a arrow to show where you think there is an **excess electron-hole population**. Do you think that this is a spatially uniform diode along the horizontal direction? In Fig. 4(a), which part, left or right, is more efficient as an LED? What does Fig. 4(b) show? Is the vertical scale logarithmic or linear?

6.8

Look at Fig. 5. What do the researchers claim the effective carrier lifetime they measured for each region, n- and n+? How did they measure these values?

6.9

Go back to questions (6.4) and (6.5), use the lifetime given in the paper you that you find in question (6.8) above, use the value of diffusion length you find in (6.4), infer what you think the diffusivity for each region are, using appropriate relations.

6.10

Comment on what you learn from this paper

7. (50 pts) Real life application

Suppose you want to build something that requires an optical detector. Attached at the end is a technical brochure from a company selling Si detectors. The purpose of this problem is to ask you to read, apply what you learn to understand, so that you will be an informed user of these products.

7.1 (5 pts)

In a few words, summarize: What does the brochure describe? Explain in simple words how these detectors work. If you have 1.5- μm laser (it means the laser wavelength is 1.5 μm), would you buy these detectors to detect your laser light? (hint: read the brochure carefully)

7.2 (10 pts)

The brochure mentions these features:

- low capacitance: explain what good is low capacitance?
- low dark current: what is dark current and what good is dark current? (remember discussion in class)
- high responsivity: what is responsivity? What is its unit? Why high responsivity is good?

Extra note: The function of a photodetector (PD) is to detect light (photons). When a photon whose energy is above a semiconductor bandgap impinges on the semiconductor and is absorbed, it generates an electron hole pair, which can be collected with electrodes. The merit of a PD is a measure that determines how strong it can give a current signal for a given light power input. Think of this: What is the light input unit? What is the detector output unit? How would one determine the proportionality between the output vs. input? This proportionality coefficient is called responsivity. If a detector gives 1 mA output current for 3-mW light input, what is its responsivity? If a detector gives 0.1 mA current output without any light input- i. e. in total darkness, is this 0.1 mA signal useful? can it be detrimental?)

7.3 (10 pts)

Look at the chart labeled “Typical Dark Current vs Temperature”. Write an expression that describes the relationship of dark current (relative unit only) and temperature. Suppose you plan to use this detector in a system that detects the ambient light level around a car and automatically turns on the car headlight if it senses darkness. For winter in Bismarck, North Dakota (-40 C) this system typically has a signal current/dark current ratio of 1000 during bright sunshine daytime. You bring this system to Houston for the summer (~ 80 C under the hood of a car

with engine on). What is your signal current/dark current ratio now? Do you think the circuit will work reliably?

7.4 (15 pts)

Review Chapter 3, Section 7.5.1 about intrinsic carrier density in Si as a function of temperature. This detector has an intrinsic drift region sandwiched between lightly doped regions. Use the same method in 7.5.1, calculate the intrinsic carrier concentration for temperature from -40 C to 100 C. Then, calculate and plot the drift current density as a function of temperature:

$$J = e(\mu_n[T] n[T] + \mu_p[T] p[T]) E$$

where symbol n and p represent electron and hole density respectively.

Plot the drift current in relative unit (no need for absolute unit). If you wish, you can assume for simplicity that mobility is constant vs. temperature and carrier density. (Of course, we learn in HW 1 that mobility does depend on temperature, but just neglect it here for approximation). Compare your plot qualitatively with the data on dark current vs. temperature (Note: the calculation for realistic dark current is a bit more complicated with impurity effects and leakage current included).

7.5 (10 pts)

Look at the data for D-series detectors, metal package. Plot (scatter plot) the detector typical dark current vs. the detector active area (Active area of a detector is the area that responds to light). Any comments on the relationship? Why would you want large area detector if the dark current is higher?

Technical brochure

PHOTOCONDUCTIVE SERIES

PLANAR DIFFUSED SILICON PHOTODIODES



APPLICATIONS

- Pulse Detectors
- Optical Communications
- Bar Code Readers
- Optical Remote Control
- Medical Equipment
- High Speed Photometry

FEATURES

- High Speed Response
- Low Capacitance
- Low Dark Current
- Wide Dynamic Range
- High Responsivity

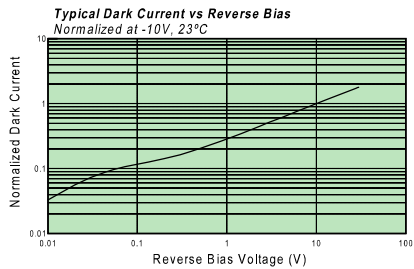
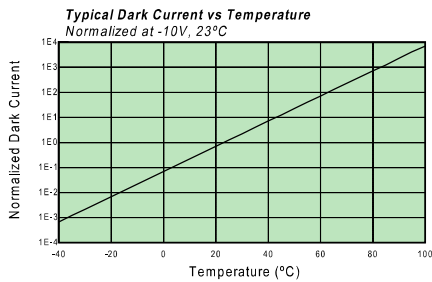
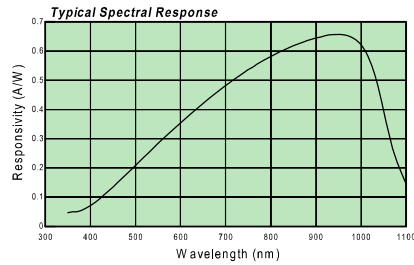
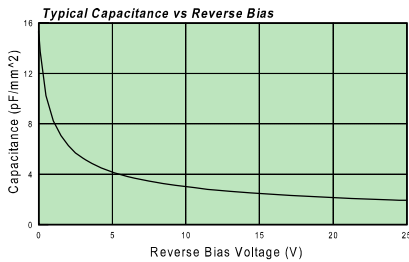
The Photoconductive Detector Series are suitable for high speed and high sensitivity applications. The spectral range extends from 350 to 1100 nm, making these photodiodes ideal for visible and near IR applications, including such AC applications as detection of pulsed LASER sources, LEDs, or chopped light.

To achieve high speeds, these detectors should be reverse biased. Typical response times from 10 ns to 250 ns can be achieved with a 10V reverse bias, for example. When a reverse bias is applied, capacitance decreases (as seen in the figure below) corresponding directly to an increase in speed.

As indicated in the specification table, the reverse bias should not exceed 30 volts. Higher bias voltages will result in permanent damage to the detector.

Since a reverse bias generates additional dark current, the noise in the device will also increase with applied bias. For lower noise detectors, the Photovoltaic Series should be considered.

Refer to the *Photoconductive Mode (PC)* paragraph in the Photodiode Characteristics section of this catalog for detailed information on electronics set up.



PHOTOCONDUCTIVE SERIES

TYPICAL ELECTRO-OPTICAL SPECIFICATIONS AT TA=23°C

Model No.	Active Area		Responsivity (A/W)						Capacitance (pF)		Dark Current (nA)		NEP (W/√Hz)	Reverse Voltage (V)	Rise Time (ns)	Temp Range (°C)	Package Style †	
	Area (mm ²)	Dimension (mm)	400 nm		632 nm		970 nm		0 V	-10 V	-10 V		-10V 970 nm	max	-10 V 632 nm 50-ohm	Operating		Storage
			min	typ	min	typ	min	typ	typ	typ	typ	max						
D SERIES, METAL PACKAGE																		
PIN-020A	.20	0.51φ							4	1	.01	.15	2.8 e-15	30	26	-40 → +100 -55 → +125		1 / TO-18
PIN-040A	.81	1.02φ						8	2	.05	.50	6.2 e-15	24		4 / TO-18			
PIN-2DI*	1.1	.81 x 1.37						25	5	.10	1.0	8.7 e-15	13		7 / TO-18			
PIN-3CDI	3.2	1.27 x 2.54						45	12	.15	2	1.1 e-14	12		2 / TO-5			
PIN-3CD															5 / TO-5			
PIN-5DI	5.1	2.54φ						85	15	.25	3	1.4 e-14	14		2 / TO-5			
PIN-5D															5 / TO-5			
PIN-13DI	13	3.6 sq	.07	.12	.33	.40	.60	.65	225	40	.35	6	1.6 e-14		17			2 / TO-5
PIN-13D															5 / TO-5			
PIN-6DI	16.4	4.57φ						30	60	.5	10	1.9 e-14	24		3 / TO-8			
PIN-6D															6 / TO-8			
PIN-44DI	44	6.6 sq						700	130	1	15	2.8 e-14	43		3 / TO-8			
PIN-44D															6 / TO-8			
PIN-10DI	100	11.28φ						1500	300	2	25	3.9 e-14	250		10 / Lo-Prof			
PIN-10D														11 / BNC				
PIN-25D	613	27.9φ						9500	1800	15	1000	1.1 e-13		12 / BNC				
D SERIES, PLASTIC PACKAGE §																		
FIL-3C	3.2	1.27 x 2.54							45	12	.15	2	1.1 e-14	30	13	-10 → +60 -20 → +70		14 / Plastic
FIL-5C	5.1	2.54φ						85	15	.25	3	1.4 e-14	12					
FIL-20C	16.4	4.57φ	.08	.12	.33	.40	.60	.65	330	60	.5	10	1.9 e-14		17			
FIL-44C	44	6.6 sq						700	130	1	15	2.8 e-14	24					
FIL-100C	100	11.28φ						1500	300	2	25	3.9 e-14	43					
PIN-220D	200	10 x 20						3200	600	5	100	6.2 e-14	75		15 / Plastic			
															26 / Plastic			

* The I suffix on the model number is indicative of the photodiode chip being isolated from the package by an additional pin connected to the case.
 § The photodiode chips in FIL series are isolated in a low profile plastic package. They have a large field of view as well as in line pins.

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