Optoelectronics – Photonics Lab Description, Guidelines, & Grading Checklist

Due Date: Monday, December 2, 2013 by 5pm
Deliverable: (1) Email MSWord electronic copy with all hand written data scanned with it – <u>File Name</u>: *First Name-Last Name LED Lab-Year*.

Objectives:
- To gain familiarity with characterizing light emitting devices and relating electrical properties to test and measurement data
- To determine the energy, wavelength and frequency range of optical power
- To determine the turn-on voltage of the device from the I-V characteristics.
- To examine the relationship of Planck's constant with regard to the data
- To use energy band diagrams to conceptualize device structure, properties, processing, and performance (SP^3) as related to Band gap engineering

Introduction:
Light emitting diodes (LEDs) are solid state devices consisting of two (or more) different semiconductor materials – hence, they are comprised of several heterojunctions. Some common materials for LEDs include InGaN (near UV and blue), GaN (blue and green), AlGaP (green), AlGaInP (green, yellow, and orange), AlAs & GaAs (red and near infrared), InGaAsP (near infrared).

Band gap engineering and SP^3 toward a given device performance parameter is the goal for devices such as LEDs. For heterostructure LEDs, the performance parameter is light of a nearly specific wavelength (usually a range) that is produced in response to the flow of the current at the heterojunctions between these materials. The LED can be made by a *p-n* heterostructure junction. LEDs can also be grown and fabricated using semiconductor quantum wells (figure 1) and are much more efficient. In this case, the active region (i.e., where e$^-$-h$^+$ recombination occurs and the light is produced) is sandwiched between the cladding (i.e., outside) layers which then have ohmic contacts for current injection of the proper carrier and Schottky for rectifying the unwanted carrier (figure 1). The materials of the cladding layer have a wider energy band gap than the active region (figure 1b). One cladding layer is doped p-type for hole injection and the other cladding layer is doped n-type for electron injection. The applied voltage must exceed a minimum
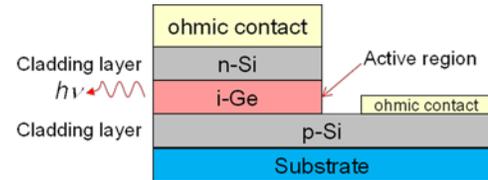

Figure 1a: Schematic of a double heterostructure, single quantum well LED where the cladding layer is the larger band gap semiconductor and the active region is the smaller band gap semiconductor. Note: the semiconductors chosen in this example are not used in LEDs because they are not very efficient light producers. Why is this the case?
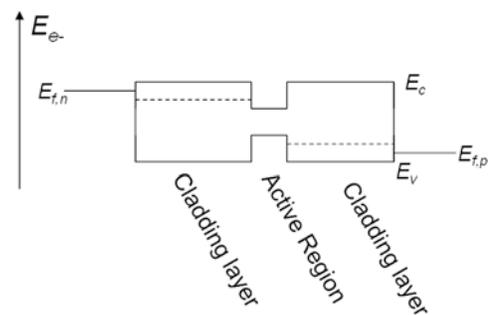

Figure 1b: Energy band diagram at flatband condition of the device structure shown in figure 1a. What would the band diagram look like at the equilibrium condition? You will need to draw both.

voltage in order for the current to flow. It is approximately equal to the magnitude of the energy band gap of the active region semiconductor. The magnitude of the energy band gap is related to the energy of the emitted photon by $E=h\nu$ where h is Planck's constant and ν is the frequency of the emitted photon.

Equipment and Materials:
- Optical spectrum analyzer
- Optics table
- Power supply with cables with Labview data acquisition and control software and computer
- LEDs – use only those with clear lenses. Do not use the color lens LEDs

Procedure and Data Analysis:
The lab will be performed in **Professor Wan Kuang's** research lab. Hence, please treat the facilities and instrumentation with care. **Dr. Paul Davis** will set up the experiment in which several light emitting devices are to be characterized. Each group is responsible for measuring the measured current versus input voltage (I-V curve) characteristics (figure 2) and the output power versus wavelength (figure 3). Thus, it is important that you save all the data from the lab and keep a copy of the data for yourself and the group. From each set of measurements, you are to calculate the following:

(1) Determine the turn-on voltage of the device from the *I-V* characteristics (figure 2).

(2) Determine the energy, wavelength and frequency range and maximum of the optical power of the LEDs measured (see figure 3).

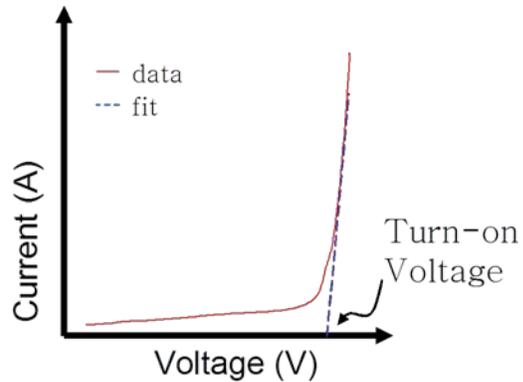(3) Determine Planck's constant (mean and standard deviation) from the

Figure 2: Current versus voltage plot of an LED showing the turn-on voltage where the fit intersects with the voltage axis (red = data, dashed blue = linear fit).
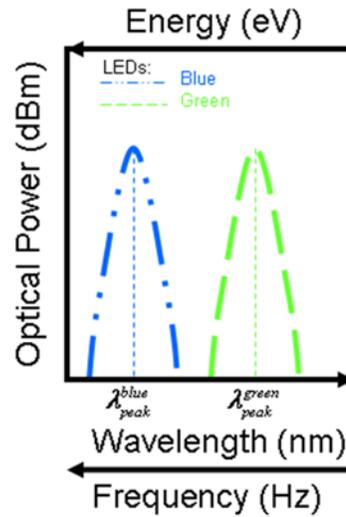

Figure 3: Optical power spectrum versus wavelength, frequency and energy of two LEDs of different colors. You must have all 3 x-axes on your plot.
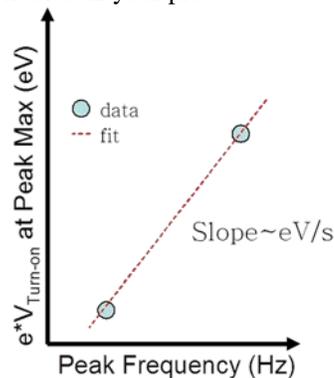

Figure 4: The data (points) of $V_{turn\text{-}on}$ as a function of maximum Peak Frequency. $V_{turn\text{-}on}$ is obtained from figure 2 and the peak frequency is obtained from figure 3. The slope of the fit (dashed line) provides a number that should be close in value to a very famous constant.

turn-on voltage and the peak emission wavelength. Perform a statistical analysis (i.e., a minimum of % difference for accuracy, and coefficient of variation = R^2 or adjusted R^2 to examine the goodness of fit) to show the error involved in the measurement and fit (figure 4). Be sure to define, both mathematically and written description the statistical approaches you use and reference your sources.

(4) Determine the energy band gap engineered structure of the device. That is, theorize the semiconductor material for each region of the device structure (figures 1a & 1b). Using SP^3, you will need to theorize the identity of the substrate material and growth method. Draw the energy band diagram of the cladding layer, the active region and the metal contacts for the following conditions:
   a. Flatband condition
   b. Equilibrium conditions.

The minimum number of data plots for the report is 3 and the report should include (at least) the following data plots (this does not include band diagram and other figures):
1. Current versus voltage with data fit (see figure 2)
2. Optical Power (dBm) versus wavelength, energy and frequency (see figure 3)
3. Turn-on voltage versus maximum peak frequency with data fit (see figure 4)
In order to plot your data and perform the fits of your data, use software including Origin, JMP, Mathematica or MatLab (not Excel). Any fitting should accompany an assessment (e.g., R^2, adjusted R^2, data regression, etc.) of your fits. Be sure to define, both mathematically and written description the statistical approaches you use and reference your sources. You may use your calculator as long as it generates electronic plots that can be electronically pasted into your report. There are freeware programs available on the web for plotting data (see for example www.freedownloadmanager.org or www.freewarehome.com).

Due Date & Deliverables:
*Due Date***:** See the top of the first page of this document
*Deliverables***:** (1) Email MSWord electronic copy with all hand written data scanned with it –
            File Name: *First Name-Last Name LED Lab-Year.*
You will submit (electronic copy via email) a brief report on your findings. In your report, identify the semiconductor materials system and show step-by-step how you identified the semiconductor materials system. Thoroughly describe and discuss your results. Describe your results and state or theorize the reasons behind the results (i.e., discussion) using your knowledge of *energy band gap engineering*, *band theory*, *SP^3* (*structure, properties, processing and performance*) and other aspects of Materials Science and Engineering. All figures should have captions and figure numbers (e.g., see template at end of this document). Include all plots, sketches, calculations, equations (with equation numbers) and other aspects of your analysis such as data, data regression, energy band diagrams (equilibrium & and biased conditions), cross-section sketches of LED materials structure (semiconductors, substrate & contacts), etc. Include references (including class handouts) used to identify the material. **The report must have the format given at the end of this document otherwise it will not be accepted.**

Formatting and organization of your report should follow the template included at the end of this document.

Email me a digital copy of your report and turn in a hard copy of your report.

You may work together to help each other analyze data and understand the lab, but you should submit your own report that is your own work. Feel free to ask the TA lab assistant(s) and Dr. Wan Kuang questions during the lab to help you understand the lab and provide clarification.

Note: Do <u>not</u>:
- use pronouns (e.g., we, they, I, you, one, etc.)
- cite websites

References that might be helpful to you are:

[1] K.O. Kasap, *Principles of Electronic Materials and Devices*, 3rd Ed. (McGraw Hill, 2006)
    a. Ch. 3.9, p. 258-267
    b. Ch. 5.7, p.427-430
    c. Ch. 6.9, p. 543-547
[2] Alfonso Franciosi and Chris G. Van de Walle, *Heterojunction band offset engineering*, Surface Science Reports 25 (1996) p. 1-140
[3] Jasprit Singh, *Electronic and Optoelectronic Properties of Semiconductor Structures* (Cambridge Press, 2003) Ch. 3.2, p. 118
[4] V. Mitin, V. Kochelap, M. Stroscio, *Quantum Heterostructures: Microelectronics and Optoelectronics*, (Cambridge University Press, 2005)
[5] Anderson & Anderson, *Fundamentals of Semiconductor Devices*, (McGraw Hill, 2005) Ch. 6.3 p. 317-331
[6] K.F. Brennan, *The Physics of Semiconductors – with Applications to Optoelectronic Devices*, (Cambridge University Press, 1999) Ch. 11.2, p. 554
[7] Jasprit Singh, Physics of Semiconductors and Their Heterostructures, (McGraw Hill, 1993) Ch. 6
[8] Larry A. Coldren and Scott W. Corzine, *Diode Lasers and Photonic Integrated Circuits*, (Wiley-Interscience, 1995)
[9] S.O. Kasap, *Optoelectronics and Photonics – Principles and Practices* (Prentice Hall, 2001) Ch. 3-4
[10] Chin-Lin Chen, *Elements of Optoelectronics & Fiber Optics*, (Irwin, 1996) Ch. 4
[11] S.M. Sze, *Physics of Semiconductor Devices*, 2nd Ed. (Wiley-Interscience, 1981)
[12] K.K. Ng, *Complete Guide to Semiconductor Devices*, 2nd Ed. (Wiley-Interscience, 2002)

I have some of the textbooks available in my office if you would like to check them out for a time not greater than half a day.

The template for the report for you to follow is on the next page. I will not accept any lab reports that do not conform to the template.

Help with writing – See *Course Notes* on the website:
http://coen.boisestate.edu/bknowlton/courses/mseecembe-478-578/

Title of Report (font 14)
Lab Report for MSE 310-ECE 340 – Electrical Properties of Materials (font 11)

U.R. Dirac[1], E.T. Compton[2], and O.U. Moseley[1,2] (font 10)
[1]Department of Materials Science and Engineering, Boise State University
[2]Department of Electrical and Computer Engineering, Boise State University

Date

I. SUMMARY (font 11)

(1/4-1/2 page; max. ½ page) Summarize your most important findings. The audience for your summary is a manager (e.g., your manager or your bosses' boss) that might only read the summary. Note: use third person for the entire report. Do not use pronouns such as I, we, you, etc.. (font 10)

Use following numbers for grading:

Significantly = 3; Moderately = 2; Minimally = 1

o Succinct writing style: 2
o High-quality grammar & spelling: 2
o Summarized most important Findings: 3
o Audience is your manager: 3
o No use of pronouns: 3
o Meet page requirements: 2

II. PURPOSE

(1/4-1/2 page; max. 1 page) Describe the purpose and objectives of the lab as related to you the student. The purpose can describe whether or not the objectives have been met, how this lab is useful to you as an engineering student and soon to be engineer, and the insight you have gained that supplements/compliments the course lectures by performing the lab.

Use following numbers for grading:

Significantly = 3; Moderately = 2; Minimally = 1

o Succinct writing style: 2
o High-quality grammar & spelling: 2
o Describe purpose & objective related to student: 3
o How the lab is useful to student, soon to be engineer: 3
o Insight gained that supplements/compliments course lectures: 3
o Discuss whether or not objective of lab have been met: 3
o No use of pronouns: 2
o Meet page requirements: 2

III. EXPERIMENTAL

(1/4-1/2 page; max. ½ page) Describe the instrumentation, devices and the methods used to perform for each measurement. Do not use lists and/or bullet points.

Use following numbers for grading:

Significantly = 3; Moderately = 2; Minimally = 1

o Succinct writing style: 2
o High-quality grammar & spelling: 2
o Details of the desired data to be acquired: 3
o Instrumentation described in terms of the desired data: 3
o Data acquisition described in detail: 3
o Data figures NOT referred to: 3
o No use of pronouns: 2
o Meet page requirements: 2

IV. DATA ANALYSIS APPROACH

(1/4-1/2 page; max. 1/2 page) Describe and define the data analysis approach. Include software used, statistics & error analysis used, fitting method (e.g., linear regression & how it is done) etc. Equations should be on a separate line and numbered and all variables are defined. For instance, the energy of a photon is described by:

$$E = h\nu \tag{1}$$

where h is Planck's constant and ν is the frequency of the photon. **DO NOT** introduce your figures with data or any results from your measurements in this section. They are to be introduced in the Results section.

Use following numbers for grading:

Significantly = 3; Moderately = 2; Minimally = 1

o Succinct writing style: 2
o High-quality grammar & spelling: 2
o No use of pronouns: 2
o Meet page requirements: 2
o Software used in analysis: 3
o Fitting and error analysis: 3
o Equations used: 3

V. DATA ANALYSIS RESULTS AND DISCUSSION

(minimum 1 page; max. 2 pages) Thoroughly describe and discuss your results and the trends observed in your results. Include data (e.g., figures, tables, schematics, photographs, etc.), data regression, energy band diagrams (equilibrium & and biased conditions), cross- section sketches of LED materials structure (semiconductors, substrate & contacts), etc. You may include your figures and tables here and or in the **DATA SECTION**. Describe your results and relate them to one another (i.e., tie the observed trends in the results

together) state or theorize the reasons behind the results (i.e., discussion) using your knowledge of energy band gap engineering, band theory, SP^3 (structure, properties, processing and performance) and other aspects of Materials Science and Engineering. Figures should have captions and figure numbers (e.g., see figures used in this document).

Use following numbers for grading:

Significantly = 3; Moderately = 2; Minimally = 1

o Succinct writing style: 2
o High-quality grammar & spelling: 2
o Referred to all data figures and tables: 3
o All data figures complete: 3
o Referred to all band diagrams: 3
o All band diagrams complete: 3
o Referred to sketches of the device: 3
o All sketches complete: 3
o No use of pronouns: 2
o Connecting trends in the data: 3
o Trends described in terms of:
    o Band gap engineering: 3
    o SP^3: 3
    o Band Theory: 3
o Meet page requirements: 2

VI. SUMMARY AND CONCLUSION

(minimum: 1/4 page; max. 1/2 page) Summarize your findings and state your conclusions.

Use following numbers for grading:

Significantly = 3; Moderately = 2; Minimally = 1

o Succinct writing style: 3
o High-quality grammar & spelling: 2
o No use of pronouns: 2
o Meet page requirements: 2
o Summarize findings & state conclusions: 3

VII. ACKNOWLEDGMENTS

(minimum: 1 sentence; max. 1 paragraph) Acknowledge anyone that helped you.

Use following numbers for grading:

Significantly = 3; Moderately = 2; Minimally = 1

o Succinct writing style: 2
o No use of pronouns: 2
o Meet page requirements: 2

VIII. REFERENCES

List Journal and Conference papers, books, and course notes. <u>Refrain from citing websites unless it is for software purposes</u>. If you really feel that you want to use a website as a reference, please talk to me about it. Use a minimum of THREE references. References should be cited within the body of your report.

Reference Formatting Examples:
[1] Author list, *Title of journal paper*, Volume (Year) page numbers.
[2] Author list, *Title of conference paper*, Conference Name (Year) page numbers.
[3] Author list, *Title of Book*, Edition (Publisher, Year) pages used.

Please use fonts between 10 – 12 (Title can be 14). Please use 1 inch margins and page numbers.

VIII. DATA SECTION

Place your data here. All the necessary figures are described in the lab description. Formatting of tables and figures are described on the next page.

FORMATTING
<u>Formatting in General:</u>
Font: Times New Roman
Font Size: Titles in body: 11; Body of text: 10;
<u>Formatting of Numbers:</u>
- Do not use an over abundance of significant figures or digits
- Use of scientific notation: Do use: $5\text{x}10^{19}$ cm^{-3}; Do not use: 5*10^19 cm^-3 or 5*E19 cm^-3
- Do not use "*" as a multiplication symbol, use "x"
- Do not use "^" for an exponent

<u>Formatting of Tables:</u>

TABLE I
UNITS FOR MAGNETIC PROPERTIES

Symbol	Quantity	Conversion from Gaussian and CGS EMU to SI [a]
Φ	magnetic flux	$1 \text{ Mx} \rightarrow 10^{-8} \text{ Wb} = 10^{-8} \text{ V·s}$
B	magnetic flux density, magnetic induction	$1 \text{ G} \rightarrow 10^{-4} \text{ T} = 10^{-4} \text{ Wb/m}^2$
H	magnetic field strength	$1 \text{ Oe} \rightarrow 10^3/(4\pi) \text{ A/m}$
m	magnetic moment	$1 \text{ erg/G} = 1 \text{ emu} \rightarrow 10^{-3} \text{ A·m}^2 = 10^{-3} \text{ J/T}$
M	magnetization	$1 \text{ erg/(G·cm}^3) = 1 \text{ emu/cm}^3 \rightarrow 10^3 \text{ A/m}$
$4\pi M$	magnetization	$1 \text{ G} \rightarrow 10^3/(4\pi) \text{ A/m}$
σ	specific magnetization	$1 \text{ erg/(G·g)} = 1 \text{ emu/g} \rightarrow 1 \text{ A·m}^2/\text{kg}$
j	magnetic dipole moment	$1 \text{ erg/G} = 1 \text{ emu} \rightarrow 4\pi \times 10^{-10} \text{ Wb·m}$
J	magnetic polarization	$1 \text{ erg/(G·cm}^3) = 1 \text{ emu/cm}^3 \rightarrow 4\pi \times 10^{-4} \text{ T}$
χ, κ	susceptibility	$1 \rightarrow 4\pi$
χ_ρ	mass susceptibility	$1 \text{ cm}^3/\text{g} \rightarrow 4\pi \times 10^{-3} \text{ m}^3/\text{kg}$
μ	permeability	$1 \rightarrow 4\pi \times 10^{-7} \text{ H/m} = 4\pi \times 10^{-7} \text{ Wb/(A·m)}$
μ_r	relative permeability	$\mu \rightarrow \mu_r$
w, W	energy density	$1 \text{ erg/cm}^3 \rightarrow 10^{-1} \text{ J/m}^3$
N, D	demagnetizing factor	$1 \rightarrow 1/(4\pi)$

Vertical lines are optional in tables. Statements that serve as captions for the entire table do not need footnote letters.

[a]Gaussian units are the same as cgs emu for magnetostatics; Mx = maxwell, G = gauss, Oe = oersted; Wb = weber, V = volt, s = second, T = tesla, m = meter, A = ampere, J = joule, kg = kilogram, H = henry.
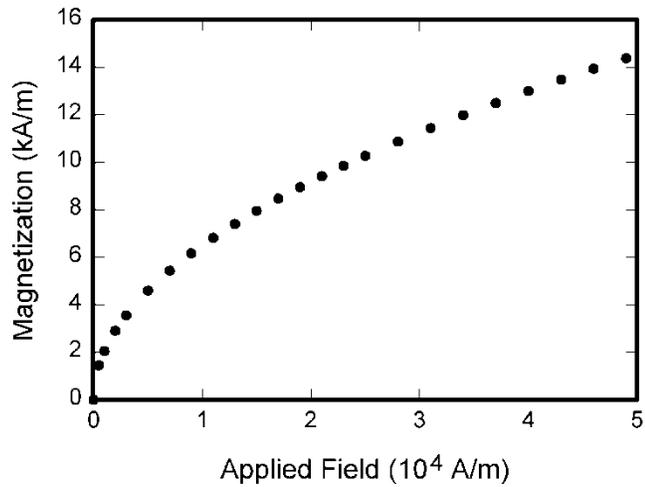
Formatting of Figures:

Fig. 1. Magnetization as a function of applied field. Note that "Fig." is abbreviated. There is a period after the figure number, followed by two spaces. It is good practice to explain the significance of the figure in the caption. That is, what is it that you want to convey to your reader.

- For multiple curves on one plot, a Legend or labeling of each curve is required.
- Do not use titles on your plots.
- Data should be points and fits should be lines.