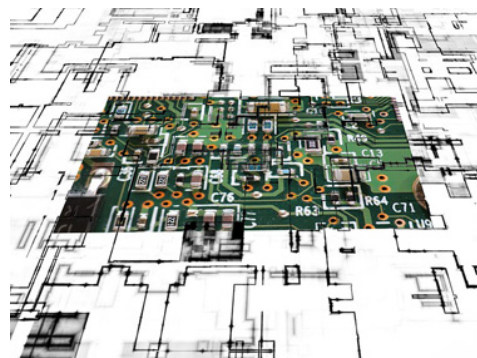
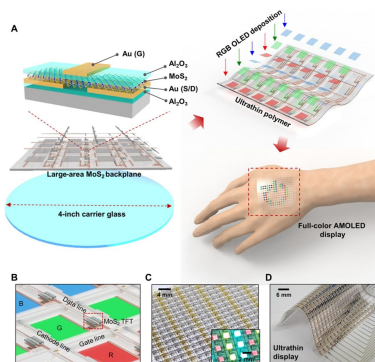


**PRAIRIE VIEW A&M UNIVERSITY
ROY G. PERRY COLLEGE OF ENGINEERING
DEPARTMENT OF
ELECTRICAL & COMPUTER ENGINEERING**

COURSE ASSESSMENT REPORT

**ELEG 3033 – PHYSICAL PRINCIPLES OF SOLID STATE
DEVICES – SPRING 2022**

NAME OF INSTRUCTOR: A. ANIL KUMAR



2020 – 2025 – 2030 quantum technologies forecast

(Source: Quantum Technologies report, Yole Développement, 2020)

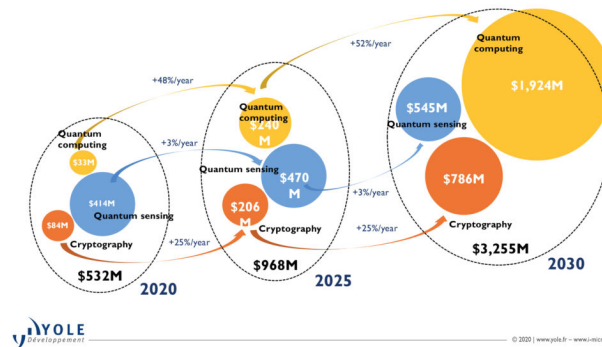


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I. COURSE SYLLABUS



PRAIRIE VIEW
A&M UNIVERSITY

SYLLABUS

1. **Course number and name:** ELEG 3303-Physical Principles of Solid State Devices
2. **Credits and contact hours:** Credit 3 semester hours. Contact hours 3.
3. **Instructor's name:** A. Anil Kumar, Ph.D., Professor

4. Text book, title, author, and year

Solid State Devices, 2nd Edition, by B.S. Nair and S.R. Deepa, PHI Mediamatics Publication, (2020) ISBN 978-9387472273.

a. other supplemental materials

Course Specific:

ECE 606 Solid State Devices L1.1: Solid State Devices

https://www.youtube.com/watch?v=cWE_M2_xjLE

Colorado State University <http://ecee.colorado.edu/~bart/book/>

Physics of Semiconductors and Nanostructures, Cornell University

<https://www.youtube.com/playlist?list=PLYWzPf87clvHHoXq9cZozCw-khGltqLAG>

Neil deGrasse Tyson Explains The Weirdness of Quantum Physics

<https://www.youtube.com/watch?v=SDxzZHSBhw0>

<https://www.allaboutcircuits.com/textbook/semiconductors/chpt-2/quantum-physics/>

Global Environment:

The global chip shortage, explained

<https://www.youtube.com/watch?v=IUfobGJVszs>

Why the Global Chip Shortage Is Hard to Overcome | WSJ

https://www.youtube.com/watch?v=FP_q-as29x0

Emerging Trends in Semiconductors

[https://www.youtube.com/watch?v=TzspmrkTT-](https://www.youtube.com/watch?v=TzspmrkTT-8&list=PLqYqvTonHe89deiFLhVSMmHYpdDEsBfnG)

[8&list=PLqYqvTonHe89deiFLhVSMmHYpdDEsBfnG](https://www.youtube.com/watch?v=TzspmrkTT-8&list=PLqYqvTonHe89deiFLhVSMmHYpdDEsBfnG)

Understanding The Global Semiconductor Industry

<https://www.youtube.com/watch?v=-RYSdUKxqaw>

The Future of Semiconductors <https://www.rambus.com/blogs/the-future-of-semiconductors/>

What's Ahead for the Semiconductor Industry? <https://www.industryweek.com/technology-and-iiot/article/22026855/whats-ahead-for-the-semiconductor-industry>

Silicon chips are reaching their limit. Here's the future

<https://www.techradar.com/news/silicon-chips-are-reaching-their-limit-heres-the-future>

Emerging Trends in the Semiconductor Industry

<https://halocarbon-es.com/emerging-trends-in-the-semiconductor-industry/>

Semiconductors – the Next Wave

<https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/technology-media-telecommunications/deloitte-cn-tmt-semiconductors-the-next-wave-en-190422.pdf>

5. Specific course information

- a. **brief description of the content of the course (catalog description):** Crystal structure, introduction to quantum concepts and discrete energy levels;

atomic bonding, solid state band theory, Fermi-Dirac statistics, charge carrier transport, and introduction to semiconductor device physics and operation.

- b. **prerequisites or co-requisites:** PHYS 2326, CHEM 1403 and MATH 2320
- c. **indicate whether a required, elective, or selected elective (as per Table 5-1) course in the program:** Required

6. Specific goals for the course

a. specific outcomes of instruction (e.g. The student will be able to explain the significance of current research about a particular topic.)

1. Demonstrate application of physics, chemistry, quantum concepts and statistical concepts to describe semiconductor physics phenomena and how these phenomena are related to device operations
2. Demonstrate their familiarity with some of the current scientific and engineering issues and limitations relevant to device operation and fabrication.
3. Demonstrate their ability to acquire and apply new knowledge as needed, using appropriate learning strategies about semiconductor and nanotechnology devices.

- b. explicitly indicate which of the student outcomes listed in Criterion 3 or any other outcomes are addressed by the course. Outcome 7:** An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

7. Brief list of topics to be covered

1. Introduction to Solid-state Device Theory
2. Quantum Physics
3. Valence and Crystal Structure
4. Band Theory of Solids
5. Electrons and "Holes"
6. The P-N Junction
7. Junction Field-effect Transistors (JFETs)
8. Insulated-gate Field-effect Structures (MOS-C, MOSFET, IGFET)
9. Superconducting Devices
10. Nanotechnology

II. END OF SEMESTER CLASS ASSESSMENT REPORT

There are two separate assessments for:

- Electrical Engineering (EE) Majors
- Computer Engineering (CPEG) Majors

**END OF SEMESTER COURSE OUTCOME ASSESSMENT REPORT
ELEG 3033-Z01 – PHYSICAL PRINCIPLES OF SOLID STATE DEVICES
(ELECTRICAL ENGINEERING MAJORS)**

SPRING 2022 SEMESTER

Report Prepared by: Dr. A. Anil Kumar

Report Date: May 16, 2022

Outcome 7: "An ability to acquire and apply new knowledge as needed, using appropriate learning strategies."						
Semester	Analysis Type	# of Students	Expected Class Average	Expected Percent of students at or above average	Class Average	% Students meeting Expected Average
Spring 2021	Direct	23	70	70	70	65%
SPRING 2022	Direct	15	70	70	70	50%
Implementa- tion Summary	Items implemented from previous report or after meeting previous instructor	Topics covered were mostly the same as in the prior semester, with the exception of a less detailed discussion of MOS structures. More time was spent on the details of p-n junction diodes, including explicit device applications. A novel item included for the first time is a Panel Discussion on Global Issues pertaining to solid state devices – industrial, economic, political and social issues, in addition to the engineering and scientific aspects. The book used was–Solid State Devices, 2 nd Edition, by B.S. Nair and S.R. Deepa. While the book has an excellent set of worked out examples in each chapter as well as a large set of problems at the end, it lacked adequate introduction to the quantum principles. Will be searching for a different book.				
Perceived Problems	Perceived problems are directly related to the PC and the sub items under them	Problems related to principles of physics and chemistry continue to plague this course, especially: inability to recall Bohr's model, molecular formation, electronic structure of atoms, and basic quantum concepts such as quantization and spin. Reduced active participation during class as well as almost no show during office hours. More review sessions were conducted to compensate.				
Plans for Addressing Problems	Plans to address specific measures to address PC and their sub areas	Measures to be implemented: 1. Identified instructors in Chemistry and Physics teaching pre-requisites to work proactively address knowledge shortcoming. Make them aware of what is expected of EE majors to learn and retain. 2. Offer to cover 1-2 of their lectures on applications of concepts. 3. Seek another textbook to replace the current one.				
Overall Trend over Periods	Ascertain if there were improvements over previous semesters	A few improvements over the previous semester. The panel discussion on Global Issues relating to solid state devices was received with more enthusiasm. The session was more active and interactive. Political issues such as tariffs on China, reliance on global production of semiconductor chips, varied access to rare earth materials were among the topics discussed. Several relevant documents and videos were posted on the course website. However, since this course deals with non-intuitive quantum concepts, requiring a modern physics course as a prerequisite (ex. TAMU-CS) might make this course more approachable. The current practice of covering the quantum concepts and devices, all in one semester, results in an excess of cognitive load.				
Were Expectations Met?		YES				

**END OF SEMESTER COURSE OUTCOME ASSESSMENT REPORT
ELEG 3033-Z01 – PHYSICAL PRINCIPLES OF SOLID STATE DEVICES
(COMPUTER ENGINEERING MAJORS)**

SPRING 2022 SEMESTER

Report Prepared by: Dr. A. Anil Kumar

Report Date: May 16, 2022

Outcome 7: "An ability to acquire and apply new knowledge as needed, using appropriate learning strategies."						
Semester	Analysis Type	# of Students	Expected Class Average	Expected Percent of students at or above average	Class Average	% Students meeting Expected Average
Spring 2021	Direct	4	70	70	72	70%
Spring 2022	Direct	9	70	70	70	45%
Implementa- tion Summary	Items implemented from previous report or after meeting previous instructor	Topics covered were mostly the same as in the prior semester, with the exception of a less detailed discussion of MOS structures. More time was spent on the details of p-n junction diodes, including explicit device applications. A novel item included for the first time is a Panel Discussion on Global Issues pertaining to solid state devices – industrial, economic, political and social issues, in addition to the engineering and scientific aspects. The book used was–Solid State Devices, 2 nd Edition, by B.S. Nair and S.R. Deepa. While the book has an excellent set of worked out examples in each chapter as well as a large set of problems at the end, it lacked adequate introduction to the quantum principles. Will be searching for a different book.				
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Plans for Addressing Problems	Plans to address specific measures to address PC and their sub areas	Measures to be implemented: 1. Identified instructors in Chemistry and Physics teaching pre-requisites to work proactively address knowledge shortcoming. Make them aware of what is expected of EE majors to learn and retain. 2. Offer to cover 1-2 of their lectures on applications of concepts. 3. Seek another textbook to replace the current one.				
Overall Trend over Periods	Ascertain if there were improvements over previous semesters	A few improvements over the previous semester. The panel discussion on Global Issues relating to solid state devices was received with more enthusiasm. The session was more active and interactive. Political issues such as tariffs on China, reliance on global production of semiconductor chips, varied access to rare earth materials were among the topics discussed. Several relevant documents and videos were posted on the course website. However, since this course deals with non-intuitive quantum concepts, requiring a modern physics course as a prerequisite (ex. TAMU-CS) might make this course more approachable. The current practice of covering the quantum concepts and devices, all in one semester, results in an excess of cognitive load.				
Were Expectations Met?		YES				

III. OUTCOME ASSESSMENT PROJECT

**ELECTRICAL & COMPUTER ENGINEERING
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET
ELEG 3303 – PHYSICAL PRINCIPLES OF SOLID STATE DEVICES
SPRING 2022
Instructor: A. Anil Kumar**

Title of Assignment

Optimum Characteristics of a p-n Diode in a Half Wave Rectifier

Outcome Measured Using this Assignment

Outcome 7

“An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.”

Check the complex engineering problem characteristics related to this assignment

Assignment problem	
x	involves wide-ranging or conflicting technical issues
x	has no obvious single solution
x	involves diverse groups of stakeholders
x	includes many component parts or sub-problems
x	has significant consequences in a range of contexts
Assignment problem involves the application of the principles of	
x	engineering
x	science
x	mathematics

Brief justification of the suitability of assignment for the outcome

This assignment sets the student in the role of a solid state device consultant. Based on a customer's requirement for a low cost rectifier, there is a need for a circuit that satisfies the following conflicting criteria: (i) a diode with capacitance in a given range, (ii) a low forward resistance to keep power consumption by the diode to a minimum, (iii) an output voltage less than the peak input value, (iv) a reverse bias not exceeding the breakdown voltage and (v) an 50 Hz – 60 Hz input frequency. The student is expected to investigate a potential diode that meets these requirements. This assignment will assess the student's comprehension of the physics of p-n diodes, ability to compare and contrast their differing characteristics, identify the material parameters that contribute to them, and recommend at least one set of parameters that meets the required criteria. A confluence of learning strategies – analytical thinking, ability to conduct independent literature survey, ability to present findings in a clear fashion, among others.

**ELEG 3303 – PHYSICAL PRINCIPLES OF SOLID STATE DEVICES
SPRING 2022**

ASSIGNMENT STATEMENT/QUESTIONS

One of the major applications of p-n diodes discussed in class is rectification – conversion of AC to DC. A large signal diode – with a large p-n junction (depletion) region – that allows for increased forward current carrying capacity (forward resistance of a few Ohms) and reverse blocking resistance of few Mega Ohms is needed. Such diodes are useful for low frequency applications such as rectifiers, inverters, battery charging devices, etc. For typical ratings of a diode visit this link:

<https://www.allaboutcircuits.com/textbook/semiconductors/chpt-3/diode-ratings/>

Consider the following scenario. You are a solid state device expert working for ACME International Microelectronics Establishment (AIME). A customer approaches you to seek your advice on a low cost circuit that provides for a 'reasonable' rectification of an AC signal. From your experience, you know that she probably needs a half wave rectifier (low cost) that operates under the following conflicting criteria: (i) a diode with capacitance in a given range, (ii) a low forward resistance to keep power consumption by the diode to a minimum, (iii) an output voltage less than the peak input value, (iv) a reverse bias not exceeding the breakdown voltage and (v) an 50 Hz – 60 Hz input frequency. You are expected to investigate a potential diode that meets these requirements.

Your task is to explore the optimum characteristics of such a diode.

Submit a brief report on your approach to addressing this task. What you plan to do, how you would interpret the customer's need and how you would proceed to find at least one choice of a diode that meets her requirements.

To facilitate analysis, consider the following steps:

1. List the general characteristics of p-n junction diodes – forward current, forward voltage, reverse resistance, capacitance, temperature stability, among others.
2. Investigate the literature to explore at least three different diodes that, when a diode is made out of it, provides the optimum range of capacitance values.
3. Compute the relevant quantities for these diodes that meet the customer's requirements.
4. Write a concise but detailed report of your findings along with a summary and a rationale for your choice(s)/recommendations.

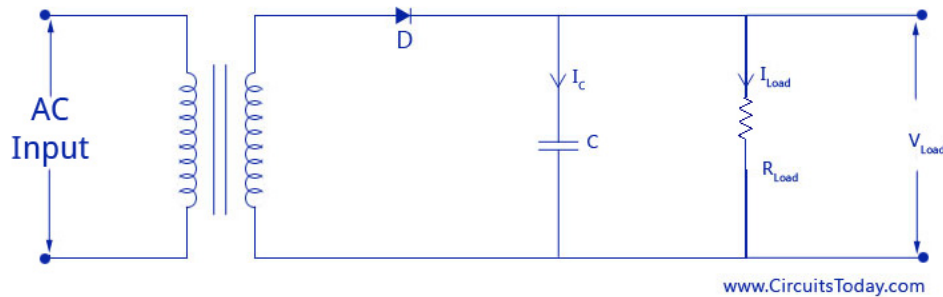
The attached rubric will be employed to assess your submission. Your report should be properly formatted, and should include, at a minimum: Title Page, Abstract, Introduction and Motivation, Proposed Approach to the Assigned Project, Relevant Equations and Computations, Analysis of Results, Conclusions and References/Bibliography. Identify specific learning strategies employed in your deliberations.

Included after the Rubric is a learning Styles Survey.

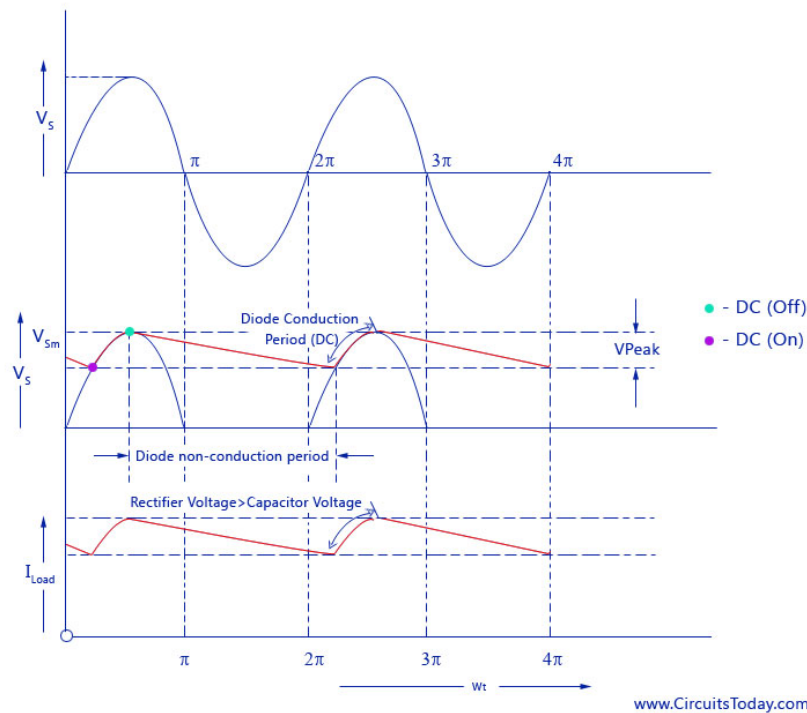
PROJECT DESCRIPTION

As discussed in class, a typical half wave rectifier and its output are shown in the figures below. (<https://www.circuitstoday.com/filter-circuits>)

Half wave Rectifier with Capacitor Filter



Half wave Rectifier with Capacitor Filter - Waveform



To get a 'reasonable' DC output, you need V_{Peak} difference as small as possible. As long as the RC time constant is much greater than the period (inverse of the frequency of the input signal), the capacitor will stay mostly fully charged thus delivering a near DC output. If the load resistor is small, a higher current will flow through the circuit resulting in a faster capacitor discharge. So, to maintain a large time constant, a high load resistance as well as a high capacitance are needed. However, there are limits on the size and cost of the capacitor. Typical capacitance range is between 10 pF to 100 pF. A high resistance will also result in a high power dissipation, adding to the already existing power loss due to no output in the negative half cycle.

For this project, focus on the diode capacitance that depends on a set of parameters, such as: the doping concentrations, the dielectric used for the diode and the temperature. Hence choose the appropriate circuit parameters that meet the stated requirements.

Project Requirements and Grading:

Task	Excellent (85-100)	Average (70-84)	Below Average (55-69)	Score
1. Identify and Formulate the technical problem using principles of engineering/mathematics/science Formulate an optimized approach to choosing a diode that meets the requirements. Create a functional block diagram that displays relevant factors to be considered, such as material and device parameters, stability at high temperatures, costs, etc.	• Demonstrates ability to learn independently. • Demonstrates ability to go beyond the minimum of what is required to complete the assignment and shows resourcefulness by seeking information from outside sources into the assignment.	• Demonstrates ability to learn independently but requires confirmation and reassurance. • Completes minimum required tasks efficiently and without direction.	• Requires detailed step-by-step instructions to complete a task. • Has trouble completing even the minimum required tasks. • Is unable to recognize own shortcomings or deficiencies.	
2. Solve the technical problem Develop a relevant database of material parameters and device characteristics, and perform needed computations. Show quantitatively your choice of the chosen material for the proposed diode.	• Demonstrates ability to learn from mistakes and practices continuous improvement. • Demonstrates ability to understand, interpret, and apply concepts learned in a format different from that taught in class (e.g. different nomenclature, equations in different form).	• Recognizes own shortcomings or deficiencies but fails to address these issues. • Applies resources from outside of what is covered in class.	• Assumes all learning takes place within the confines of the classroom. • Is unable to use materials outside of what is covered in class.	

**IV. PROJECT – OUTCOME #7 ASSIGNMENT
GRADE SHEET SHOWING STUDENT AND CLASS PERFORMANCE**

ELECETRICAL ENGINEERING MAJORS

STUDENT NAME	EE	SCORE	POINTS
		MAX 4/4	MAX 100
<u>Ahmed, Faisal A.</u>	X	2/2	70
<u>Anderson, Spenser D.</u>	X	2/2	70
<u>Coronado, Ivan</u>	X	4/4	100
<u>Evans, Hunter P.</u>	X	3/2	80
<u>Grant, Jade A.</u>	X	1/1	60
<u>Hall, Zhaniriua L.</u>	X	2/2	70
<u>Neco, Donte C.</u>	X	1/1	60
<u>Shy, Cymon</u>	X	1/1	60
<u>Simmons, Jaden A.</u>	X	1/1	60
<u>Washington, Tyreese D.</u>	X	1/1	60

COMPUTER ENGINEERING MAJORS

STUDENT NAME	CEP	SCORE	POINTS
		MAX 4/4	MAX 100
<u>Edgar, Danario J.</u>	X	1/1	60
<u>Hall, Tarjae S.</u>	X	1/1	60
<u>Joubert, Jordan D.</u>	X	2/2	70
<u>Knight, Anthony D.</u>	X	2/2	70
<u>Mannings, Tyler B.</u>	X	4/4	100
<u>Robinson, Roderick R.</u>	X	1/1	20
<u>Turner, Roshaan L.</u>	X	2/2	70

V. INNOVATIONS IN SPRING 2022

Two innovations were incorporated in this course for Spring 2022.

Formative Assessment: Previously, all assessments have been conducted at the end of the semester. While such an assessment – Summative Assessment – might impact the instructor in terms of enhancing the quality of instruction for a following semester, it does not impact the learning of students in the current semester. Assessment during the semester – Formative Assessment – is needed to address the latter. During Spring 2022, this was achieved by assigning a project after the mid-term. The purpose of the Project 1 was to prepare the students for the type of thinking necessary to meet Criterion 7. For more details, see Section V.1.

Panel Discussion: This session will focus on the national and global environments impacting solid state devices, the subject of this course. You will find, on the next page, an illustrative list of articles on these issues, from technical and economic journals, as well as several web links with videos that address global issues, such as the U.S.-China Decoupling, semiconductor chip wars, wireless technology wars, etc. You are also expected to find your own resources. The goal is for the students to have a truly global perspective of what they study in this course as well as develop an ability to transfer their learning to other related subjects. For more details, see Section V.2.

V.1 PROJECT 1 – SEMICONDUCTOR DESIGN

This is a design project. By nature, it is open-ended. You are given overall requirements and you are expected to explore multiple approaches towards meeting those requirements.

A SCENARIO

Imagine you have just been hired by Intel for the following job. For more details, visit the link at the end of this document.

Physical Design Engineer Lead, Intel

\$123k-155k yearly est.

Brief Job description: As a Physical Design Lead, you will be involved in challenging projects and drive it to completion in record time. You will quickly ramp on the existing flow, understand the challenges, and produce the work plan. Your expertise in deep submicron technology, processor design, and teamwork skills will be highly leveraged to guide activity across the entire cross-discipline, multi-site team. You will work with others to identify the issues, get buy-in on proposed solutions, and implement the solutions in time for the team to execute to schedule.

PROJECT DESCRIPTION

Your project is to design a semiconductor that has the following requirements:

1. It should be able to absorb radiation in the frequency range – 5×10^{14} Hz and 6×10^{14} Hz.
2. It should produce a current density of at least 100 kA/cm².

A FEW HINTS

From our class discussions, you know the expression for current density in a semiconductor and the parameters the expression has. You must make an initial estimate of a specific bandgap, compute the required carrier (electron and hole) concentrations, utilize the appropriate carrier mobilities, and hence compute the current density. Then you should try to optimize all these parameters to meet the requirements as closely as possible.

REPORT TO BE SUBMITTED

You must prepare and submit a short report that has, at the very least, the following sections:

1. Cover Page – Project Title, Your Name, Your Major, Course Number, Semester /Year
2. A Brief Summary of the Project
3. Details of the Project
4. Conclusions
5. References

Develop your report in the tone that you are trying to market your product to your division head – why he/she should fund you to do this research and how Intel might profit from it.

Job Description

<https://www.zippia.com/intel-careers-6055/jobs/?leftpanel=true&dlp=ad53c56b3c963fdfba034ef3d6af801e7ce3eec1>

As the Programmable Solutions Group (PSG) Business Unit within Intel, we will continue to drive the future of field-programmable gate array (FPGA) technology. PSG continues to deliver industry-leading custom logic solutions to customers, and take advantage of the many opportunities that we see in the future for FPGA's, the Custom Logic Engineering group is seeking a Physical Design Lead to join our team.

The Custom Logic Engineering group is responsible for creating and delivering the best custom logic solutions that transform and accelerate a smart and connected world.

As a Physical Design Lead, you will be involved in challenging projects and drive it to completion in record time. You will quickly ramp on the existing flow, understand the challenges, and produce the work plan. Your expertise in deep submicron technology, processor design, and teamwork skills will be highly leveraged to guide activity across the entire cross-discipline, multi-site team. You will work with others to identify the issues, get buy-in on proposed solutions, and implement the solutions in time for the team to execute to schedule.

Physical Design Lead will be responsible for, but not limited to:

- Oversees definition, design, verification, and documentation for SoC (System on a Chip) development.
- Determines architecture design, logic design, and system simulation.
- Defines module interfaces/formats for simulation.
- Performs Logic design for integration of cell libraries, functional units and subsystems into SoC full chip designs, Register Transfer Level coding, and simulation for SoCs.
- Contributes to the development of multidimensional designs involving the layout of complex integrated circuits.
- Performs all aspects of the SoC design flow from high level design to synthesis, place and route, timing and power to create a design database that is ready for manufacturing.
- Analyzes equipment to establish operation infrastructure, conducts experimental tests, and evaluates results.
- Reviews vendor capability to support development.



V.2 ELEG 3303 – Panel Discussion Session – Global Issues – April 18,2022

B-GLOBAL Learning Outcome	General Issues of Concern	Your Report Should Contain
<i>Global Awareness:</i> Students will be able to describe important issues that impact local and international communities and begin to connect local actions to global contexts.	The course deals with the fundamental physical principles and materials that determine the functioning of solid state devices that are the basis of practically all systems in use today. These issues are truly global in the sense that the materials, design and fabrication involve multiple countries – the U.S., China, Hong Kong, Taiwan, Israel, Malaysia, Japan, to mention a few. The recent tariffs imposed on China and the ongoing war on Ukraine by Russia, for instance, create a global need to revisit the needed collaborations that in turn require an understanding of the cultural, economic and commercial aspects of the subject material.	What are the Major Issues of Concern to You?
<i>Cultural Knowledge:</i> Students will be able to demonstrate a comparative understanding of another culture's history, values, politics, communication styles, economy or beliefs and practices	As discussed a few times during the class sessions, the business interaction of the U.S. with another country depends upon a mutual understanding of the culture, history, values, politics, communication styles, economy or beliefs and practices of both countries. For instance: (i) The Chinese believe in longer term interactions and collaborations and take longer to establish those, while the U.S. focuses more on "event-based" collaborations; (ii) The changing policies of China – her political actions, actions to make her more self-sufficient such as building her own chip factories, impact the U.S. and her allies; and (iii) Specifically, the potential impact on the U.S. semiconductor industry due to the intervention from China in Taiwan, where the biggest semiconductor manufacturing company TSMC (a major supplier of chips to the U.S.) is located; (iv) In contrast to several fabless companies (the design is done in the U.S. but the manufacturing is done elsewhere), Israel, for instance, has IDMs (Integrated Device Manufacturing) that do both.	What Can You Learn About Those Countries' History, Values, etc.? How do they compare with those of the U.S.?

Your Assignment:

1. Pick one or more of such global issues and bring your knowledge and point(s) of view to the class discussion.
2. Submit a 1-2 page report on how you will approach towards addressing such an issue.

Relevant Resource Materials for the Discussion:

Semiconductor Shortages End an Era of Globalization

<https://daily.jstor.org/semiconductor-shortages-end-an-era-of-globalization/>

The Global Shortage in Semiconductor Chips

<https://www.mckinsey.com/il/podcast/the-global-shortage-in-semiconductor-chips>

Top 5 trends to impact the semi industry in 2022

<https://www.accenture.com/us-en/blogs/high-tech/top-5-trends-to-impact-the-semi-industry-in-2022#:~:text=The%20demand%20for%20semiconductors%20has,energy%20consumption%20and%20water%20usage.>

The global chip shortage, explained

<https://www.youtube.com/watch?v=IUfobGJVszs>

Why the Global Chip Shortage Is Hard to Overcome | WSJ

https://www.youtube.com/watch?v=FP_g-as29x0

Emerging Trends in Semiconductors

<https://www.youtube.com/watch?v=TzspmrkTT-8&list=PLqYqvTonHe89deiFLhVSMmHYpdDEsBfnG>

Understanding The Global Semiconductor Industry

<https://www.youtube.com/watch?v=-RYSdUKxqaw>

The Future of Semiconductors

<https://www.rambus.com/blogs/the-future-of-semiconductors/>

What's Ahead for the Semiconductor Industry?

<https://www.industryweek.com/technology-and-iiot/article/22026855/whats-ahead-for-the-semiconductor-industry>

Silicon chips are reaching their limit. Here's the future

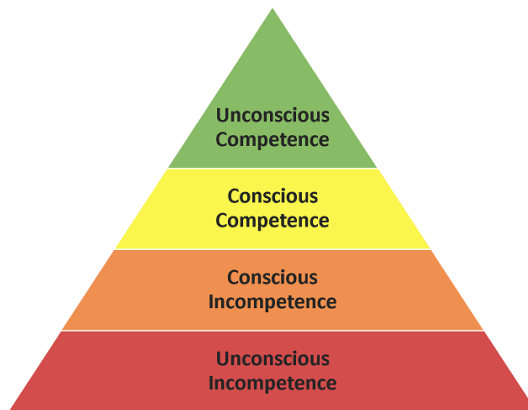
<https://www.techradar.com/news/silicon-chips-are-reaching-their-limit-heres-the-future>

Semiconductors – the Next Wave

<https://www2.deloitte.com/tw/en/pages/technology-media-and-telecommunications/articles/semiconductor-next-wave.html>

VI. RECOMMENDATIONS FOR SPRING 2023

1. Repeat the innovations incorporated from Spring 2022. In particular:
 - a. Expand on the Global Issues relating to the course material. Update the global status of the semiconductor industry for the discussion. Explore the possibility of an invited speaker (even by Zoom) who is active in the industry.
 - b. Improve upon the Formative Assessment. Assign a project before the mid-term to assess the students' preparedness for the final project. Provide to students more periodic assessments of their progress throughout the semester. Allow and assist students in assessing their own progress on the extent to which they acquire knowledge and to effectively implement it. This might be difficult if the class size is too large, however, innovative and effective approaches will be explored.
 - c. Conduct a "pre-assessment" during the first week of class to assess the students' preparation for the course in terms of the required pre-requisites.
2. Redo the course expectations and outcomes for the course from the point of view of learning assessment. Generate a rubric that addresses four levels of competence.
<https://trainingindustry.com/wiki/strategy-alignment-and-planning/the-four-stages-of-competence/>
 - a. **Unconscious Incompetence**
In unconscious incompetence, the learner isn't aware that a skill or knowledge gap exists.
 - b. **Conscious Incompetence**
In conscious incompetence, the learner is aware of a skill or knowledge gap and understands the importance of acquiring the new skill. It's in this stage that learning can begin.
 - c. **Conscious Competence**
In conscious competence, the learner knows how to use the skill or perform the task, but doing so requires practice, conscious thought and hard work.
 - d. **Unconscious Competence**
In unconscious competence, the individual has enough experience with the skill that he or she can perform it so easily they do it unconsciously.



<https://effectiviology.com/the-stages-of-learning-how-you-slowly-become-more-competent-at-new-skills/>

Table: Pertinent measures of competence in the course

	UC	CC	CI	UI
Able to perform basic computations of macroscopic quantities given a formula.				X
Able to perform basic computations of macroscopic quantities by being resourceful to find the relevant formula(e).			X	X
Able to apply the techniques taught to a given problem, assess the effectiveness of each technique.		X	X	X
Able to comprehend all concepts and techniques taught. Example Measure: Able to analyze a given a complex, composite problem, propose an alternative solution and provide a clear discussion of the of the entire process.	X	X	X	X

3. Continue to make students aware of the importance of linking their technical knowledge to the real world of business and commerce. This is done by demonstrating with examples of past technology inventions and innovations and their evolutions in time, and how international politics might impact the local industries.
4. Address three major issues, impacting students' performance – time management, learning strategies and a “high school mindset.”
 1. Time Management: Most students do not have any training in time management. This results in poor preparation for tests and projects. Carnegie-Mellon University in 1995 noticed that the first-year attrition rate was very high. An analysis showed that time management was a serious problem. A freshman level course was then instituted to make students aware of this issue. A great discussion can be found here: <https://www.cs.cmu.edu/~pausch/Randy/Randy/TMenglishTranscript.pdf>
 2. Learning Strategies: Students tend to possess poor retention of the knowledge gained from previous courses, especially chemistry and physics. This is partly due to poor note taking, not reading ahead the assigned portion of the text, not utilizing active listening and involved in multi-tasking such as checking their phone or working on the computer to mention just a few of such activities. I will be requesting meetings with the instructors of these courses, so that I can share my perceptions about my previous students' performance and explore ways to improve the situation. I can meet their classes and deliver one to two lectures for them in which I will discuss the relevance of the concepts in future courses.
 3. Another major issue is the “high school mindset.” Students tend to expect that college level problems will also be multiple choice questions, that can be answered simply by plugging into a formula or even worse, by making a guess. This is clear by the way they approach a composite problem, wherein one is expected to analyze the entire problem before proceeding to the solution and even realizing that some information required for the solution is not available readily – either it needs to be looked up or needs to be computed at one of the several stages of the problem.

These practices severely limit the performance of students anytime they are assigned an open-ended, composite problem that requires multiple levels of analysis.

VII. SAMPLES OF STUDENT WORK

Name: Kymon Odunoye

**DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING
ROY G. PERRY COLLEGE OF ENGINEERING
PRAIRIE VIEW A&M UNIVERSITY
ELEG 3303 – PHYSICAL PRINCIPLES OF SOLID STATE DEVICES
EXAMINATION 3
THURSDAY, APRIL 7, 2022**

30

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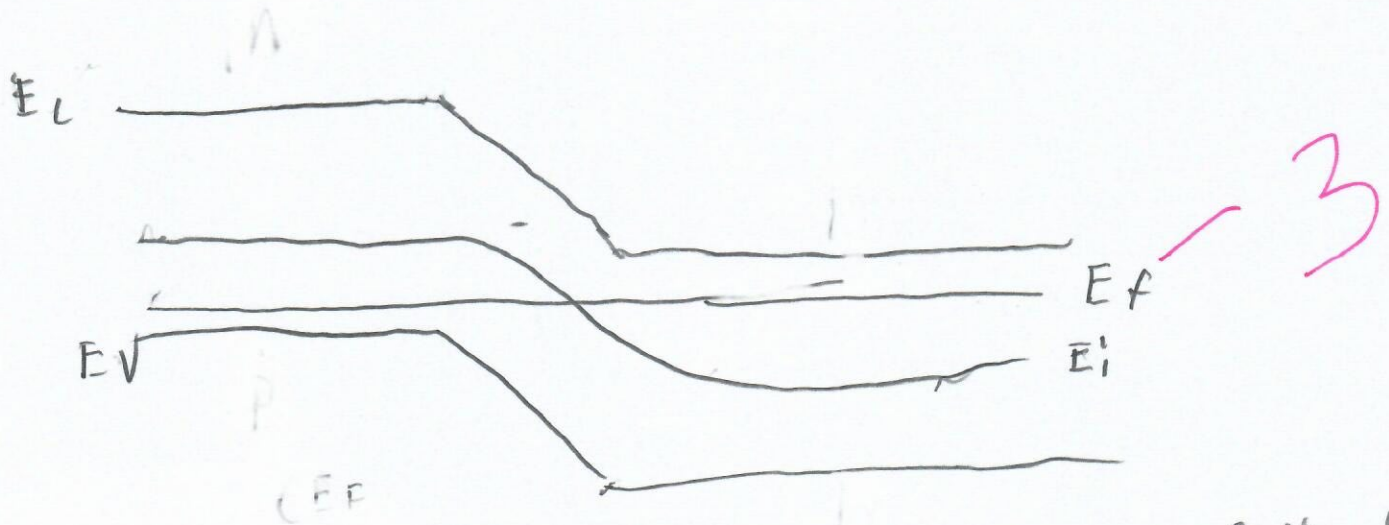
Name: Kymon Odunoye

Signature: Kymon

Name: _____

PROBLEM 1 (5+10 Points)

A silicon p-n junction has $N_a = 10^{16} \text{ cm}^{-3}$ on the p side, and $N_d = 10^{17} \text{ cm}^{-3}$ on the n side. At 300K, draw the equilibrium band diagram, quantitatively specifying the position of the Fermi level. Find the built-in potential V_{bi} . Draw in a neat and tidy manner.



$$V_{bi} = \frac{k_B T}{q} \ln \frac{N_D N_A}{n_i^2} = \frac{(8.62 \cdot 10^{-5}) (300) (10^{16} \cdot 10^{17})}{1.602 \cdot 10^{-19} \ln 10^{10}}$$

$$= 0.778 \text{ eV}$$

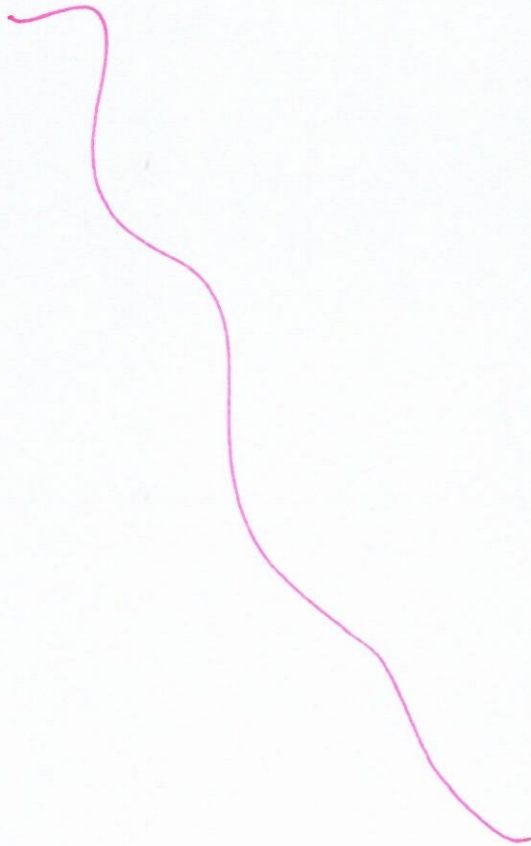
10

Name: _____

PROBLEM 2 (10+10+5 Points)

Consider a p-n junction in GaAs with doping densities of $N_a = 8 \times 10^{15}/\text{cm}^3$ in the p-region and $N_d = 1 \times 10^{17}/\text{cm}^3$ in the n-region. Calculate the built-in potential V_{bi} , total depletion region width W , and the depletion region capacitance C_j , at a reverse bias of -5 V. Assume that the cross-sectional area of the pn-junction is $25 \mu\text{m}^2$.

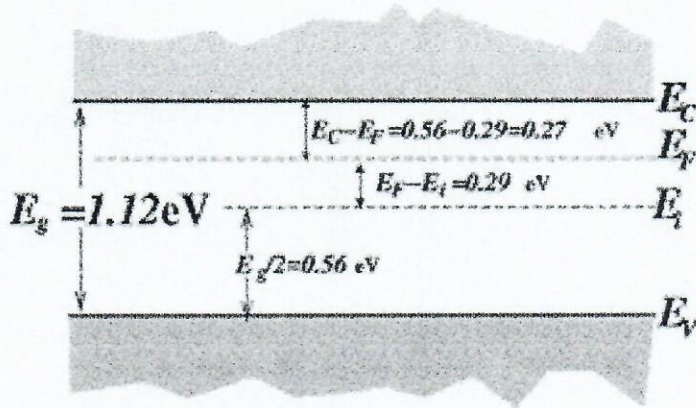
$$x_p = \frac{N_D}{N_A + N_D} W \quad x_n$$



Name: _____

PROBLEM 3 (8 Points)

Consider the following energy level diagram for a doped Si crystal. What type of material is it – n-type or p-type? Compute the electron and hole concentrations from the information in the diagram.



it is n type why?

$$n =$$

1

Name: _____

PROBLEM 4 (15 Points)

Calculate the drift current density in a semiconductor for a given electric field. Consider a germanium sample at $T = 300^\circ\text{K}$ with doping concentration of $N_d = 10^{17} \text{ cm}^{-3}$ and $N_a = 10^{16} \text{ cm}^{-3}$. The intrinsic carrier concentration is 10^{11} cm^{-3} . Assume complete ionization and electron and hole mobilities are $3900 \text{ cm}^2/\text{V}\cdot\text{sec}$ and $1900 \text{ cm}^2/\text{V}\cdot\text{sec}$. The applied electric field is $\mathcal{E} = 50 \text{ V/cm}$.

$$n = \frac{10^{17} - 10^{16}}{2} + \left[\left(\frac{10^{17} - 10^{16}}{2} \right)^2 + 10^{22} \right]^{\frac{1}{2}} = 1.602 \cdot 10^{16} \text{ cm}^{-3}$$

$$n = 1.6 \cdot 10^{16} \quad p = \frac{n_i^2}{n} \quad p = \frac{10^{22}}{1.6 \cdot 10^{16}} = 6250000000000000$$

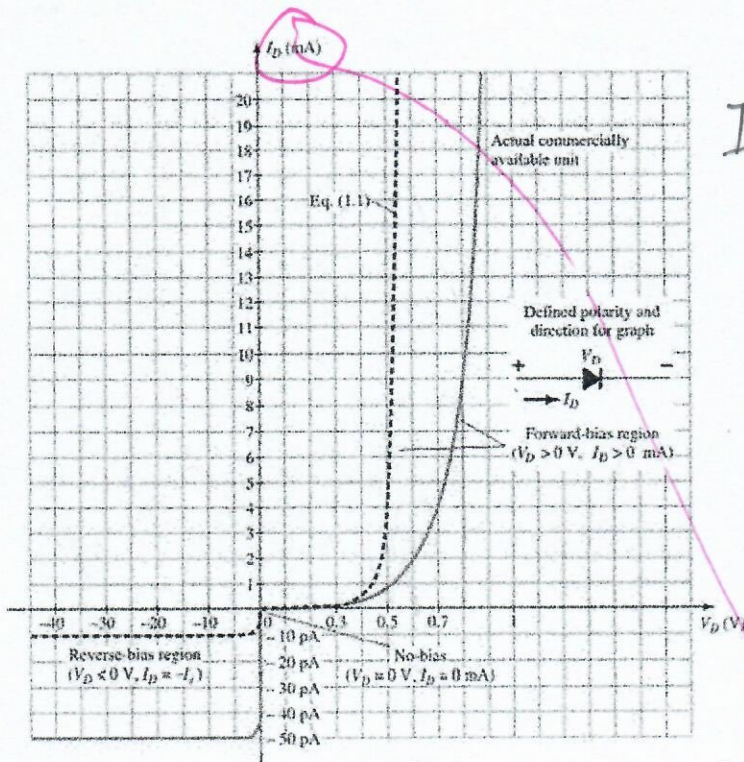
$$J = (1.602 \cdot 10^{-19} \text{ C} \cdot 1.6 \cdot 10^{16} \text{ cm}^{-3} \cdot 3900 \text{ cm}^2/\text{V}\cdot\text{sec} + 6250000000000000 \text{ cm}^{-3} \cdot 1900 \text{ cm}^2/\text{V}\cdot\text{sec}) \cdot 50 \text{ V/cm}$$

$$= 4.67 \cdot 10^{13} \text{ A cm}^{-2}$$

Name: _____

PROBLEM 5 (12 Points)

Examine the current-voltage characteristic of a p-n diode below. Compute its forward resistance for $V_D = 0.5 \text{ V}$, 0.6 V , 0.7 V and 0.8 V .



$\frac{V}{I} = R$

$$V_D = 0.5 \text{ V} = \frac{0.5}{1} = 0.5 \text{ } \Omega$$

$$V_D = 0.6 \text{ V} = \frac{0.6}{2} = 0.3 \text{ } \Omega$$

$$V_D = 0.7 = \frac{0.7}{4} = 0.175 \text{ } \Omega$$

$$V_D = 0.8 = \frac{0.8}{8} = 0.1 \text{ } \Omega$$

$\frac{V}{I} = R$
4

Name: _____

PROBLEM 6 (4+4+5 Points)

Consider a p-n diode made up of GaAs doped with $4 \times 10^{17} \text{ cm}^{-3}$ Si atoms, in which 70% of Ga atoms are replaced with Si atoms and 30% of As atoms replaced with Si atoms.

(a) What is the value of donor concentration, N_D ?

(b) What is the value of acceptor concentration, N_A ?

(c) What is the value of the built-in potential?

Name: _____

PROBLEM 7 (12 POINTS)

Consider a uniformly doped GaAs p-n junction with doping concentrations $N_a = 5 \times 10^{17} \text{ cm}^{-3}$ and $N_d = 10^{17} \text{ cm}^{-3}$. Calculate V_{bi} at $T = 300 \text{ K}$ and $T = 400 \text{ K}$. Refer to the Appendix for intrinsic carrier concentrations. What is the fractional increase/decrease in the V_{bi} ?

$$V_{bi} = \frac{kT}{q} \ln \frac{N_A N_D}{n_i^2}$$

$$T = 300 \quad \frac{(8.62 \cdot 10^{-5})(300)}{1.602 \cdot 10^{-19}} \ln \frac{(5 \cdot 10^{17} \cdot 10^{17})}{(2.4 \cdot 10^6)^2} = 0.107408$$

$$T = 400 \quad \frac{(1.38 \cdot 10^{-23})(400)}{1.602 \cdot 10^{-19}} \ln \frac{(5 \cdot 10^{17} \cdot 10^{17})}{(5.98 \cdot 10^6)^2} = 0.177331$$

T

51.0

~~scribbles~~

Name: _____

BONUS PROBLEM (10 points)

As you are aware, the I_D - V_D curve for a diode is as follows:

$$I_D = I_s [e^{\frac{qV_D}{kT}} - 1].$$

Rearrange this equation to derive the following equation for V_D :

$$V_D = \frac{k_B T}{q} \ln \frac{I_D + I_s}{I_s}.$$



Name: Tyler Mannings

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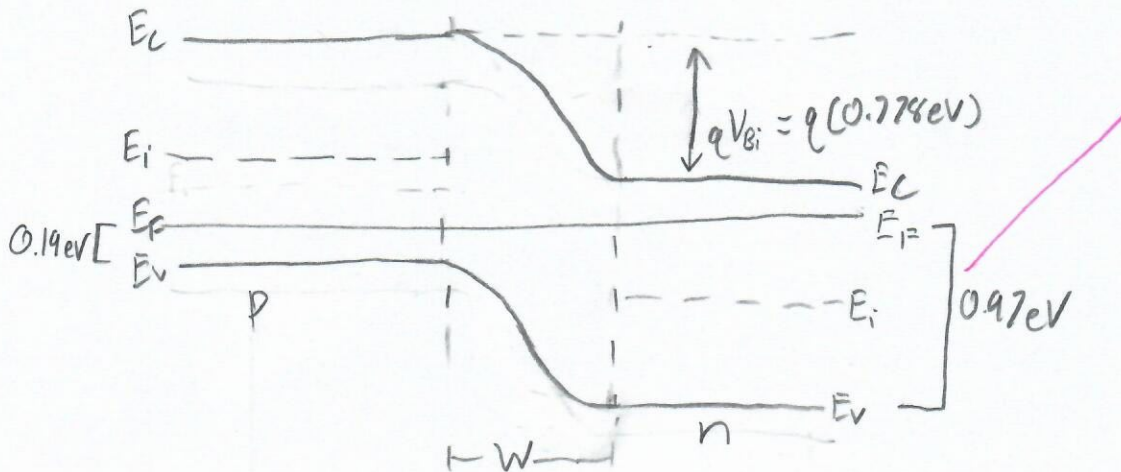
Signature: 

Name: _____

PROBLEM 1 (5+10 Points)

A silicon p-n junction has $N_a = 10^{16} \text{ cm}^{-3}$ on the p side, and $N_d = 10^{17} \text{ cm}^{-3}$ on the n side. At 300K, draw the equilibrium band diagram, quantitatively specifying the position of the Fermi level. Find the built-in potential V_{bi} . Draw in a neat and tidy manner.

Si $\Rightarrow E_g = 1.12, E_i = 0.56, n_i = 1 \times 10^{10}$

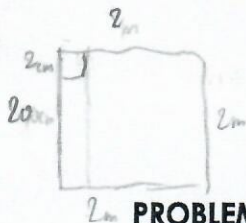


$$n = N_D = n_i e^{(E_f - E_i)/kT} \Rightarrow \frac{10^{17}}{10^{10}} = e^{(E_f - E_i)/kT} \Rightarrow (kT) \ln(10^7) + E_i = E_f$$

$$0.026 \ln(10^7) + 0.55 = E_f = 0.97 \text{ eV}$$

$$p = N_A = n_i e^{(E_i - E_f)/kT} \Rightarrow (kT) \ln\left(\frac{N_A}{n_i}\right) = E_i - E_f \Rightarrow E_i - kT \ln\left(\frac{N_A}{n_i}\right) = E_f$$

$$V_{bi} = \frac{kT}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right) = 0.026 \ln\left(\frac{10^{16} 10^{17}}{(10^{10})^2}\right) = 0.026 \ln\left(\frac{10^{33}}{10^{20}}\right) = 0.778 \text{ eV}$$



Name: _____

PROBLEM 2 (10+10+5 Points)

Consider a p-n junction in GaAs with doping densities of $N_a = 8 \times 10^{15}/\text{cm}^3$ in the p-region and $N_d = 1 \times 10^{17}/\text{cm}^3$ in the n-region. Calculate the built-in potential V_{bi} , total depletion region width W , and the depletion region capacitance C_j , at a reverse bias of -5 V. Assume that the cross-sectional area of the pn-junction is $25 \mu\text{m}^2$.

$$25 \mu\text{m}^2 = 25 (\text{cm}^{-3})^2 = 25 \text{cm}^{-6} =$$

$$V_{bi} = \frac{kT}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right) = 0.026 \ln\left(\frac{8 \cdot 10^{15} \cdot 10^{17}}{(2.4 \times 10^6)^2}\right) = \boxed{1.21 \text{ eV} = V_{bi}}$$

$$W = \left[\frac{2 \epsilon_r \epsilon_0 (V_{bi} - V_A)}{q} \left(\frac{N_A + N_D}{N_A N_D} \right) \right]^{1/2} = \left[\frac{2 (8.85 \times 10^{-14} \cdot 13.1) (1.6 \times 10^{-19} (1.21 + 5)) \left(\frac{8 \times 10^{15} + 10^{17}}{8 \cdot 10^{15} \cdot 10^{17}} \right)}{1.6 \times 10^{-19}} \right]^{1/2}$$

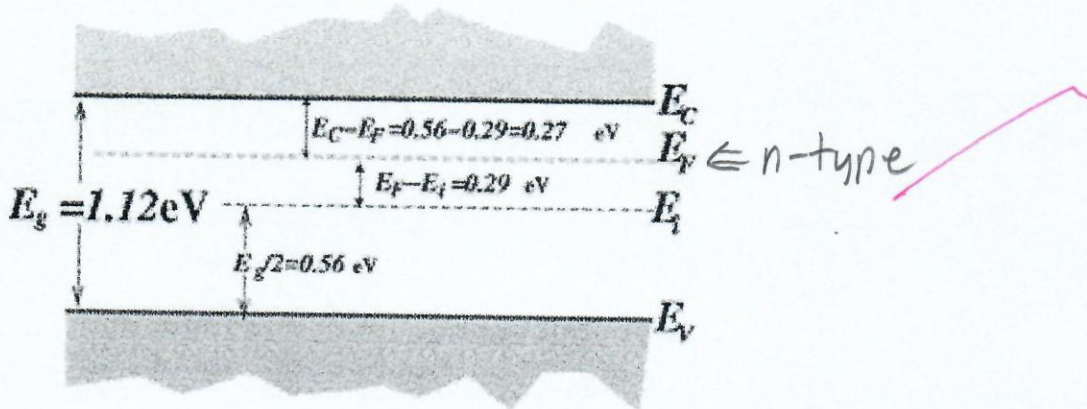
$$= 9.89 \times 10^{-5} \text{ cm}$$

$$C_j = \frac{\epsilon A}{W} = \frac{(8.85 \times 10^{-14} \cdot 13.1) (25 \times 10^{-6} \text{ cm}^2)}{9.89 \times 10^{-5} \text{ cm}} = 2.93 \times 10^{-13} \text{ F}$$

Name: _____

PROBLEM 3 (8 Points)

Consider the following energy level diagram for a doped Si crystal. What type of material is it – n-type or p-type? Compute the electron and hole concentrations from the information in the diagram.



$$n_0 = n_i e^{(E_f - E_i)/kT}$$

$$= 10^{10} e^{(0.29)/0.026} = 6.98 \times 10^{14} \text{ cm}^{-3}$$

$$n_i^2 = n_0 p_0 \Rightarrow p_0 = \frac{n_i^2}{n_0} = \frac{10^{20}}{6.98 \times 10^{14}} = 143201 \text{ cm}^{-3}$$

4

Name: _____

PROBLEM 4 (15 Points)

Calculate the drift current density in a semiconductor for a given electric field. Consider a germanium sample at $T = 300^\circ\text{K}$ with doping concentration of $N_D = 10^{17} \text{ cm}^{-3}$ and $N_A = 10^{16} \text{ cm}^{-3}$. The intrinsic carrier concentration is 10^{11} cm^{-3} . Assume complete ionization and electron and hole mobilities are $3900 \text{ cm}^2/\text{V}\cdot\text{sec}$ and $1900 \text{ cm}^2/\text{V}\cdot\text{sec}$. The applied electric field is $\mathcal{E} = 50 \text{ V/cm}$.

$$J_{\text{drift}} = q\mathcal{E}(n\mu_n + p\mu_p)$$

$$n = \left[N_D - N_A + \sqrt{(N_D - N_A)^2 + 4n_i^2} \right]^{1/2}$$

$$= 10^{17} - 10^{16} + \sqrt{(10^{17} - 10^{16})^2 + 4(2.4 \times 10^{13})^2} \quad N_D - N_A \gg 4n_i^2$$

$$\approx (9 \times 10^{16} + \sqrt{9 \times 10^{16}})^{1/2}$$

$$= 9 \times 10^{16} \quad \times$$

$$p = \frac{(2.4 \times 10^{13})^2}{9 \times 10^{16}} = 6.4 \times 10^9 \quad \times$$

10

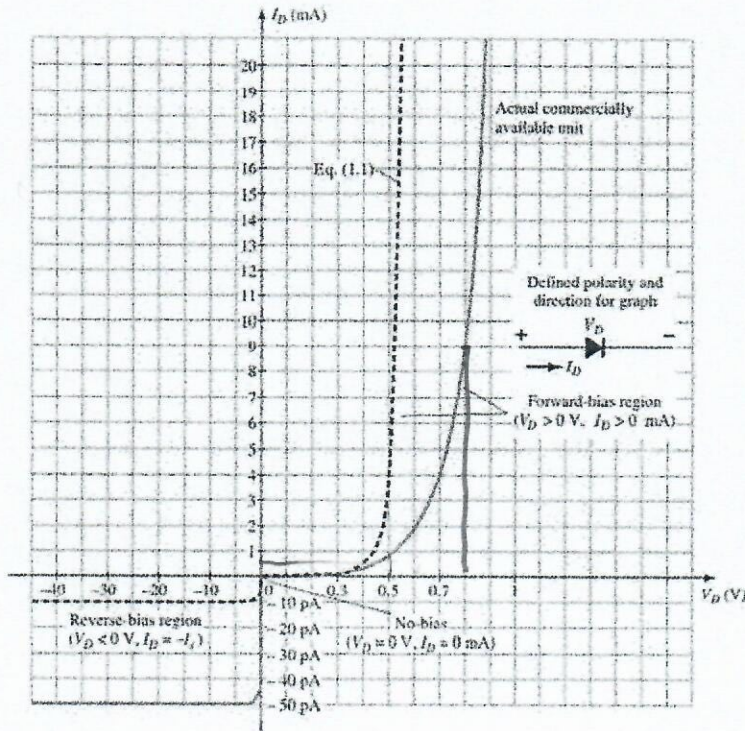
$$J_{\text{drift}} = 1.6 \times 10^{-19} (50) (9 \times 10^{16} (3900) + 6.4 \times 10^9 (1900))$$

$$= 2808 \text{ V/cm} \quad \times$$

Name: _____

PROBLEM 5 (12 Points)

Examine the current-voltage characteristic of a p-n diode below. Compute its forward resistance for $V_D = 0.5 \text{ V}$, 0.6 V , 0.7 V and 0.8 V .



$$R = \frac{V}{I}$$

$$R_1 = \frac{0.5 \text{ V}}{0.8 \text{ mA}} = 625 \Omega \quad \times$$

$$R_2 = \frac{0.6}{2 \text{ mA}} = 300 \Omega \quad \checkmark$$

$$R_3 = \frac{0.7}{4 \text{ mA}} = 175 \Omega \quad \checkmark$$

$$R_4 = \frac{0.8}{9 \text{ mA}} = 88.9 \Omega \quad \times$$

8

Name: _____

PROBLEM 6 (4+4+5 Points)

Consider a p-n diode made up of GaAs doped with $4 \times 10^{17} \text{ cm}^{-3}$ Si atoms, in which 70% of Ga atoms are replaced with Si atoms and 30% of As atoms replaced with Si atoms.

(a) What is the value of donor concentration, N_D ?

$$0.7(4 \times 10^{17}) = ? \quad 3$$

(b) What is the value of acceptor concentration, N_A ?

$$0.3(4 \times 10^{17}) = ? \quad 3$$

(c) What is the value of the built-in potential?

$$V_{BI} = 0.026 \ln \left(\frac{0.3 \cdot 0.7 \cdot (4 \times 10^{17})^2}{(2.4 \times 10^{16})^2} \right) \quad 2$$

Name: _____

PROBLEM 7 (12 POINTS)

Consider a uniformly doped GaAs p-n junction with doping concentrations $N_a = 5 \times 10^{17} \text{ cm}^{-3}$ and $N_d = 10^{17} \text{ cm}^{-3}$. Calculate V_{bi} at $T = 300 \text{ K}$ and $T = 400 \text{ K}$. Refer to the Appendix for intrinsic carrier concentrations. What is the fractional increase/decrease in the V_{bi} ?

$$V_{Bi} = \frac{kT}{q} \ln \left(\frac{N_a N_d}{n_i^2} \right)$$

$$V_{Bi, 300K} = 0.026 \ln \left(\frac{10^{17.5} \cdot 10^{17}}{(2.4 \times 10^6)^2} \right) = \boxed{1.3134 \text{ eV}} \quad \checkmark$$

$$V_{Bi, 400K} = (8.62 \times 10^{-5})(400) \left(\frac{10^{17.5} \cdot 10^{17}}{(5.98 \times 10^9)^2} \right) = \boxed{1.202 \text{ eV}} \quad \times$$

$$\text{Fraction} = \frac{1.3134 - 1.202}{1.3134} = \boxed{0.0845}$$

0

Name: _____

BONUS PROBLEM (10 points)

As you are aware, the I_D - V_D curve for a diode is as follows:

$$I_D = I_s \left[e^{\frac{qV_D}{kT}} - 1 \right].$$

Rearrange this equation to derive the following equation for V_D :

$$V_D = \frac{k_B T}{q} \ln \frac{I_D + I_s}{I_s}.$$



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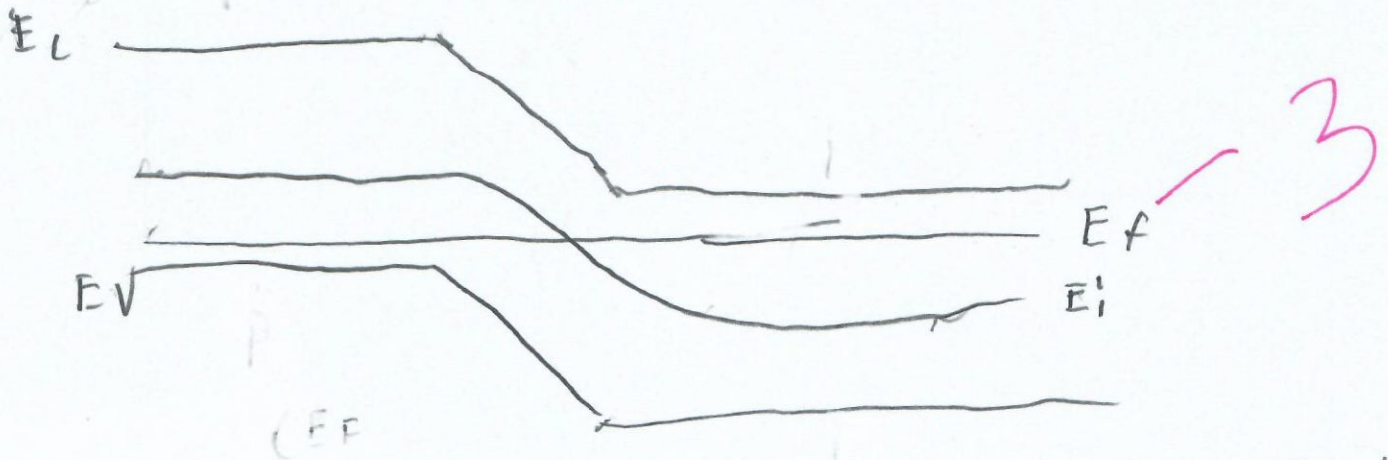
Name: Kymon Odumayo

Signature: Kymon

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$$= 0.778 \text{ eV}$$

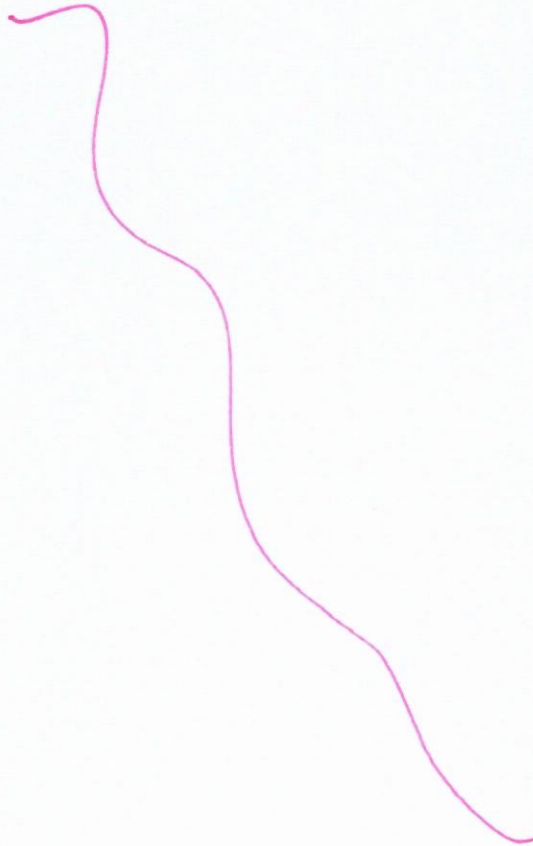
10

Name: _____

PROBLEM 2 (10+10+5 Points)

Consider a p-n junction in GaAs with doping densities of $N_a = 8 \times 10^{15}/\text{cm}^3$ in the p-region and $N_d = 1 \times 10^{17}/\text{cm}^3$ in the n-region. Calculate the built-in potential V_{bi} , total depletion region width W , and the depletion region capacitance C_J , at a reverse bias of -5 V. Assume that the cross-sectional area of the pn-junction is $25 \mu\text{m}^2$.

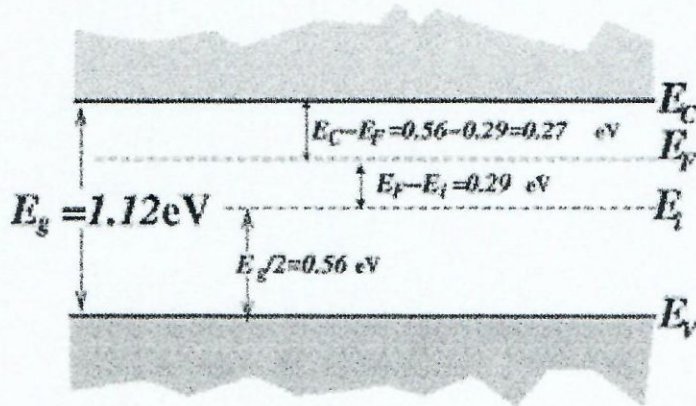
$$x_p = \frac{N_D}{N_A + N_D} W$$



Name: _____

PROBLEM 3 (8 Points)

Consider the following energy level diagram for a doped Si crystal. What type of material is it – n-type or p-type? Compute the electron and hole concentrations from the information in the diagram.



it is n type why?

$$n =$$

1

Name: _____

PROBLEM 4 (15 Points)

Calculate the drift current density in a semiconductor for a given electric field. Consider a germanium sample at $T = 300^\circ\text{K}$ with doping concentration of $N_d = 10^{17} \text{ cm}^{-3}$ and $N_a = 10^{16} \text{ cm}^{-3}$. The intrinsic carrier concentration is 10^{11} cm^{-3} . Assume complete ionization and electron and hole mobilities are $3900 \text{ cm}^2/\text{V}\cdot\text{sec}$ and $1900 \text{ cm}^2/\text{V}\cdot\text{sec}$. The applied electric field is $\mathcal{E} = 50 \text{ V/cm}$.

$$n = \frac{10^{17} - 10^{16}}{2} + \left[\left(\frac{10^{17} - 10^{16}}{2} \right)^2 + 10^{22} \right]^{\frac{1}{2}} = 1.602 \cdot 10^{16} \text{ cm}^{-3}$$

$$n \approx 9^{16} \quad p = \frac{n_i^2}{n} \quad p = \frac{10^{22}}{9^{16}} = 5396595.3$$

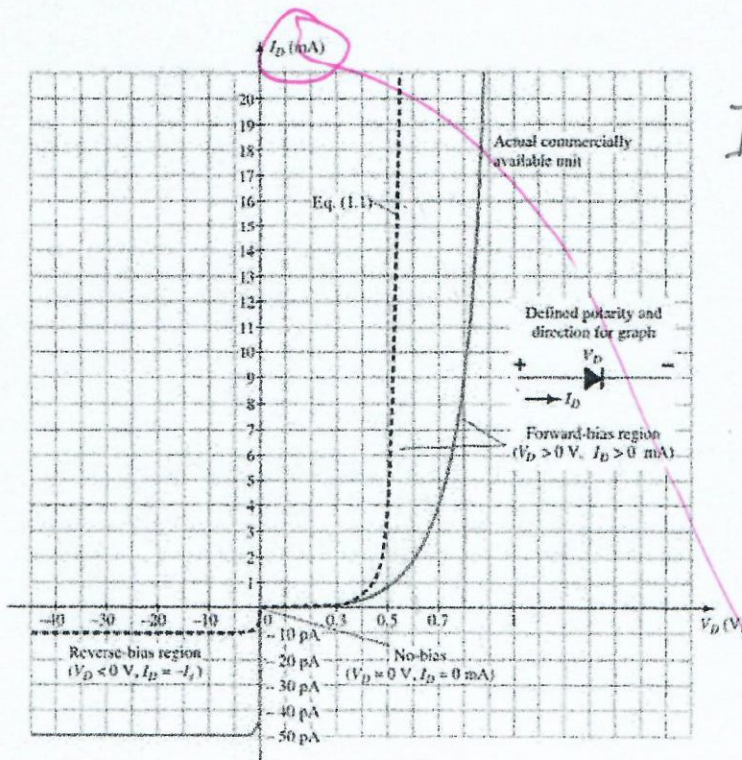
$$J = (1.602 \cdot 10^{-19} (9^{16} (3900) + 5396595.3 (1900))) 5$$

$$= 4.67 \cdot 10^{13} \text{ A cm}^{-2}$$

Name: _____

PROBLEM 5 (12 Points)

Examine the current-voltage characteristic of a p-n diode below. Compute its forward resistance for $V_D = 0.5 \text{ V}$, 0.6 V , 0.7 V and 0.8 V .



$\frac{V}{I} = R$

$$V_D = 0.5 \text{ V} = \frac{0.5}{1} = 0.5 \text{ } \Omega$$

$$V_D = 0.6 \text{ V} = \frac{0.6}{2} = 0.3 \text{ } \Omega$$

$$V_D = 0.7 \text{ V} = \frac{0.7}{4} = 0.175 \text{ } \Omega$$

$$V_D = 0.8 \text{ V} = \frac{0.8}{8} = 0.1 \text{ } \Omega$$

mA
4

Name: _____

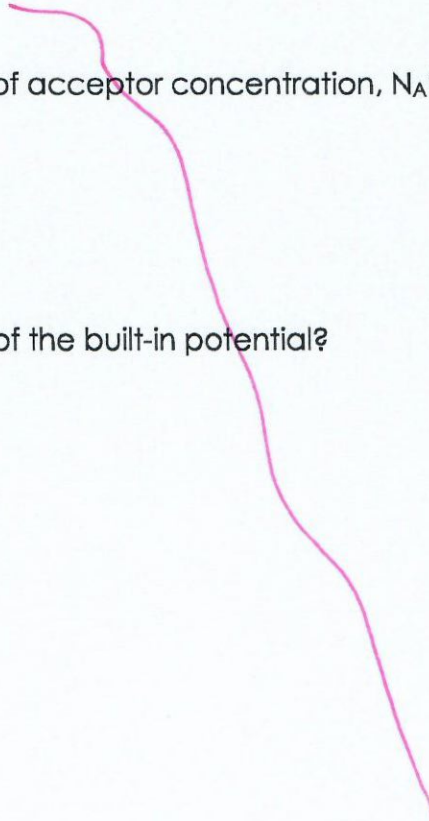
PROBLEM 6 (4+4+5 Points)

Consider a p-n diode made up of GaAs doped with $4 \times 10^{17} \text{ cm}^{-3}$ Si atoms, in which 70% of Ga atoms are replaced with Si atoms and 30% of As atoms replaced with Si atoms.

(a) What is the value of donor concentration, N_D ?

(b) What is the value of acceptor concentration, N_A ?

(c) What is the value of the built-in potential?



Name: _____

PROBLEM 7 (12 POINTS)

Consider a uniformly doped GaAs p-n junction with doping concentrations $N_a = 5 \times 10^{17} \text{ cm}^{-3}$ and $N_d = 10^{17} \text{ cm}^{-3}$. Calculate V_{bi} at $T = 300 \text{ K}$ and $T = 400 \text{ K}$. Refer to the Appendix for intrinsic carrier concentrations. What is the fractional increase/decrease in the V_{bi} ?

$$V_{bi} = \frac{kT}{q} \ln \frac{N_A N_D}{n_i^2}$$

$T = 300$

$$\frac{(8.62 \cdot 10^{-3})(300)}{1.602 \cdot 10^{-19}} \ln \frac{(5 \cdot 10^{17} \cdot 10^{17})}{(2.4 \cdot 10^6)^2} = 1.0107408$$

$T = 400$

$$\frac{(1.38 \cdot 10^{-23})(400)}{1.602 \cdot 10^{-19}} \ln \frac{(5 \cdot 10^{17} \cdot 10^{17})}{(5.98 \cdot 10^6)^2} = 1.9777331$$

T

51.0

~~scribbles~~

Name: _____

BONUS PROBLEM (10 points)

As you are aware, the I_D - V_D curve for a diode is as follows:

$$I_D = I_s \left[e^{\frac{qV_D}{kT}} - 1 \right].$$

Rearrange this equation to derive the following equation for V_D :

$$V_D = \frac{k_B T}{q} \ln \frac{I_D + I_s}{I_s}.$$



ELECTRICAL ENGINEERING
DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY

ELEG 3302 -CRN 20134
Physical Principles of State Devices
Spring 2022

PROJECT
Semiconductor Design



Ivan Coronado

March 30, 2022

To:
Dr. A. Anil Kumar

Summary

A semiconductor is a physical substance designed to manage and control the flow of current in electronic devices and equipment. It either doesn't allow a freely flowing electric current or repels the current completely. A semiconductor sits between a conductor and an insulator and is commonly used in the development of electronic chips, computing components, and devices. It's generally created using silicon, germanium, or other pure elements.

Furthermore, Semiconductors are created by adding impurities to the element. The conductance or inductance of the element depends on the type and intensity of the added

impurities. There are two basic types of semiconductors. An N-type semiconductor is used when its conductance is higher, or there is a large number of free electrons. A P-type semiconductor is used when its inductance is higher, and there are less free electrons. Conventional devices and components built by using a semiconductor include computer memory, integrated circuits, diodes, and transistors.

Some of the elements that play an important role in semiconductors are Silicon and Germanium.

Silicon is the second most abundant element on earth, making up almost over 25% of the earth's crust by weight. there are many suppliers in the U.S. and around the world, primarily in California, Oregon, Florida, Asia-Pacific, China, and Europe.

Germanium is less useful than silicon due to its thermal sensitivity and cost, but it is still alloyed with silicon for use in some high-speed devices. IBM is a primary producer of these devices. The leader in germanium production in China, with the other major producers including the USA, Canada, Russia, and Belgium.

Requirements

Design a semiconductor with the following requirements:

1. It should be able to absorb radiation in the frequency range – 5×10^{14} Hz and 6×10^{14} Hz.
2. It Should be produce a current density of a least 100 KA/cm^2 .

□

Calculations

1. If frequency range of the radiation is 5×10^{14} to 6×10^{14}

The energy for radiation is $E = ER = hf$

$$\begin{aligned} \text{So, range of energy is} \\ &= 6.626 \times 10^{-34} \times 5 \times 10^{14} \text{ to } 6.626 \times 10^{-34} \times 6 \times 10^{14} \\ &= 33.13 \times 10^{-20} \text{ to } 39.756 \times 10^{-20} \\ &= (3.313 / 1.6) \text{ eV to } (3.9756 / 1.6) \text{ eV} \end{aligned}$$

$$(1 \text{ eV} = 1.6 \times 10^{-19})$$

Energy ranges from 2.07 eV to 2.48 eV

2. For current density of 100 km/cm^2 ,

Current density of intrinsic semiconductor is given by:

$$J = n_i (\mu_n + \mu_p) q E$$

Where :

- n_i = intrinsic carrier concentration
- μ_n, μ_p = mobilities of holes and electrons.
- E = Electric field.
- q = charge on electron.

Considering some standard values:

- $n_i = 1.5 \times 10^{10} \text{ cm}^{-3}$.
- $\mu_n = 1400 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$.
- $\mu_p = 450 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$.
- $q = 1.6 \times 10^{-19} \text{ C}$

Thus,

$$J = 1.5 \times 10^{10} (1400 + 450) (1.6 \times 10^{-19}) E$$

$$100 \text{ K} = (1.5 \times 1.85 \times 1.6) \times 10^{-6} E$$

$$100 \text{ k} = 4.44 \times 10^{-6} \times E$$

$$E = 22.5 \times 10^9 \text{ N/m}$$

So, the required electric field to produce a current density 100 k A/cm^2 is $22.5 \times 10^9 \text{ N/m}$.

Conclusion

Given the constant technological changes in the world, people look to innovate and make thing better and faster based in a necessity. Semiconductors makes some of the technological advances possible, people can find them from Satellites, cellphones, cars, computers to washer machines and rice cookers, to name just a few from the large variety of applications.

For the type of mindset in global corporations, some of the main requirements to make a successful product are to know if the product is financial sustainable, efficiency, and availability just to mentioned some of the requirements. In this particular case, every electronic and communication device have its own working conditions. To make certain devices work efficiently in the specific working conditions, we must choose a semiconductor that it matches those specifications.

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Project 1 – Semiconductor Design

Tyler Mannings – Computer Engineering

ELEG3303 – P01

Spring 2022



Project Overview

For this project we have been requested to design a semiconductor to suit the needs of our client. Given the specifications of a range of frequencies to be absorbed and a required current density to be generated in the semiconductor. Using these specifications, I have created a semiconductor solution that is both cost-effective and meets the standards set by the client.

The exact specifications given by the client are as follows:

- The semiconductor must be able to absorb radiation in the frequency range of 5×10^{14} and 6×10^{14}
- The semiconductor must produce a current density of at least 100 kA/cm^2

Using this information, silicon with a medium doping level of phosphorus atoms was chosen as a cost-effective semiconductor solution for the conditions. In the next pages I will demonstrate the decision-making process that led to this conclusion.



Project Details

Given the lack of other specifications such as the field that will flow through the conductor, there are a wide range of methods to create a semiconductor that will fit these needs.

Addressing the first specification, the semiconductor must have a band gap smaller than the energy the radiation provides so that the electrons in the valence band can absorb and use that energy. This means calculating the smallest required energy of radiation and using that energy of incidence will give us a maximum functional band gap.

The energy given by a frequency of light is the given by planks constant in the following equation: , where h is Planck's constant and f is the frequency of the light in Hz.

Using this equation, we arrive at a maximum band gap of: ?
Which gives a maximum available band gap of: ?

This band gap is satisfied by most commercially available semiconductors on the market today, and so there are many available options that can absorb the required frequency. The most commercially available of these are Silicon (Si) and Gallium Arsenide (GaAs). While GaAs has a band gap of 1.43, which is closer to the energy of the required frequency, it is far less commercially available and cost effective, and so Silicon (Si) is chosen as the semiconductor of choice with a band gap of 1.12 eV.

Property	Si	GaAs	6H-SiC	4H-SiC	GaN	Diamond
Bandgap, E_g (eV)	1.12	1.43	3.03	3.26	3.45	5.45
Dielectric constant, ϵ_r ¹	11.9	13.1	9.66	10.1	9	5.5
Electric Breakdown Field, E_c (kV/cm)	300	400	2500	2200	2000	10000
Electron Mobility, μ_n (cm ² /V·s)	1500	8500	500 80	1000	1250	2200
Hole Mobility, μ_p (cm ² /V·s)	600	400	101	115	850	850
Thermal Conductivity, λ (W/cm·K)	1.5	0.46	4.9	4.9	1.3	22
Saturated Electron Drift Velocity, v_{sat} ($\times 10^7$ cm/s)	1	1	2	2	2.2	2.7

$$^1 \epsilon = \epsilon_r \cdot \epsilon_0 \text{ where } \epsilon_0 = 8.85 \times 10^{-12} \text{ F/m}$$

Now that silicon is chosen, we will use the given information to form a silicon semiconductor that generates the desired drift current density.

Above we find a table of the relevant semiconductor properties of Si at 300K (~room temperature) that we will use to meet the second requirement:

For the second requirement, we are to make sure that the semiconductor produces a current density of at least 100kA/cm².

The equations for drift currents in an intrinsic semiconductor such as Silicon is known to be:

Where n_i is the intrinsic carrier concentration, and μ_n and μ_p are the electron and hole mobilities of a semiconductor respectively, q is the charge of an electron at 1.6×10^{-19}

Without information on the electric field through material, we are left to optimize for a likely context in which this semiconductor will be used. Given the high value of current density required, assume that this semiconductor is not in use in small voltage environments.

Using the values provided in the table above and the well-known intrinsic carrier concentration of silicon at 300K, allows us to form the equation

Solving for E in this equation gives us a value of necessary to produce the required current density. Even assuming non-small voltage conditions, this is a very powerful electric field to be induced for this context. To remedy this, we will use a doping agent of Phosphorus to create an n-type extrinsic silicon semiconductor, using the given value to find a suitable doping concentration.

The equation for the current density in an extrinsic semiconductor is where n and p are the concentrations of electrons and holes in the doped material.

In the case of using phosphorus as our doping material, we can assume that the number of holes is far less than the number of electrons so as to be insignificant, giving the revised equation of

Using the previously calculated value for the electric field gives a necessary n of 1.34×10^{10} .

To lower the electric field necessary in this material, we will consider a silicon sample with a medium doping level of 10^{16} phosphorus atoms/cm².

Solving for E with this newly provided semiconductor gives us a value of $E = 41,667 \text{ V/cm}^2$.

This is a value that is much easier to produce than the originally calculated value, using a material that is cost-effective and readily available for commercial use.

□

Conclusion

The primary goal of this decision-making process is to create maximum value and satisfaction for the client in their current use case. This heavily guided the decision process away from a variety of materials that could have satisfied the specifications much more closely.

Cursory searches for vendors find doped silicon wafers to be some of the most commercially available and cost-effective semiconductors on the market.

Amid a semiconductor shortage, availability and price will be extremely important to the clients supply chain, and therefore their satisfaction. Because of this, I recommend phosphorus doped silicon as the material of choice. It can be purchased from multiple vendors at a variety of specifications, allowing the client to easily edit the doping level of silicon if they find the level to be unsatisfactory for their conditions to ensure maximum satisfaction from the client.

□

References

Material properties of silicon at 300K:

<https://www.tempoautomation.com/blog/choosing-the-right-semiconductor-materials-for-your-dev-board/>

General properties of silicon:

<https://www.pveducation.org/pvcdrom/materials/general-properties-of-silicon>

Information on price and availability of phosphorus-doped silicon:

<https://www.nanoshel.com/product/phosphorus-doped-silicon-wafer-2>

<https://www.msosupplies.com/products/100-mm-n-type-p-doped-prime-grade-silicon-wafer-100-ssp-1-10-ohm-cm?variant=23748366762042>

<https://www.sigmaaldrich.com/US/en/product/aldrich/647780>

<https://www.waferworld.com/post/gaas-wafer-vs-silicon>

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Project 2

Optimum Characteristics of a p-n Diode in a Half Wave Rectifier

Tyler Mannings – Computer Engineering

ELEG3303 – P01

Dr. Abburi Kumar

Spring 2022

- Excellent!
- well written, clear details
- Cost analysis ✓

Abstract:

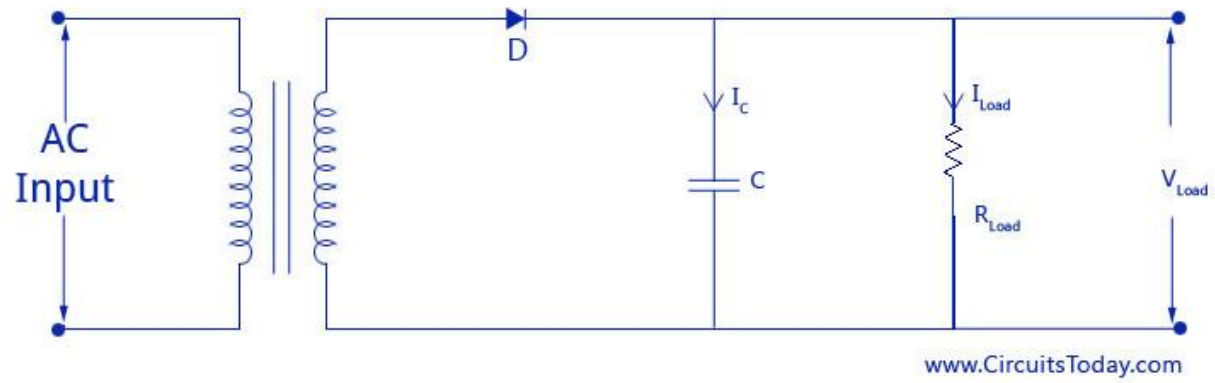
In this project, a client has come to us in need of a method to cheaply rectify a low frequency AC voltage signal to DC to supply power for an unknown device. For this project budgetary constraints are first and foremost on the client's list of priorities and so a simple, cost-effective setup that reasonably approximates a DC voltage is required in order to satisfy their needs. This has led to the selection of a half wave rectifier as the simplest and most cost-effective option available. Determining the components that will be used to make the most sufficient version of this design is a challenge that we will undertake and explore in the following report. Because of the open-ended nature of the request, a large amount of discretion will be necessary on our part to judge the possible solutions to their desires. To make sure that our discretion satisfies the client's needs, we will explore readily available solutions as well as generate possibly unique solutions to the problem at hand. In the end we will compare our generated options in order to determine the best recommendation for our client's needs going forward.

Introduction and Motivation:

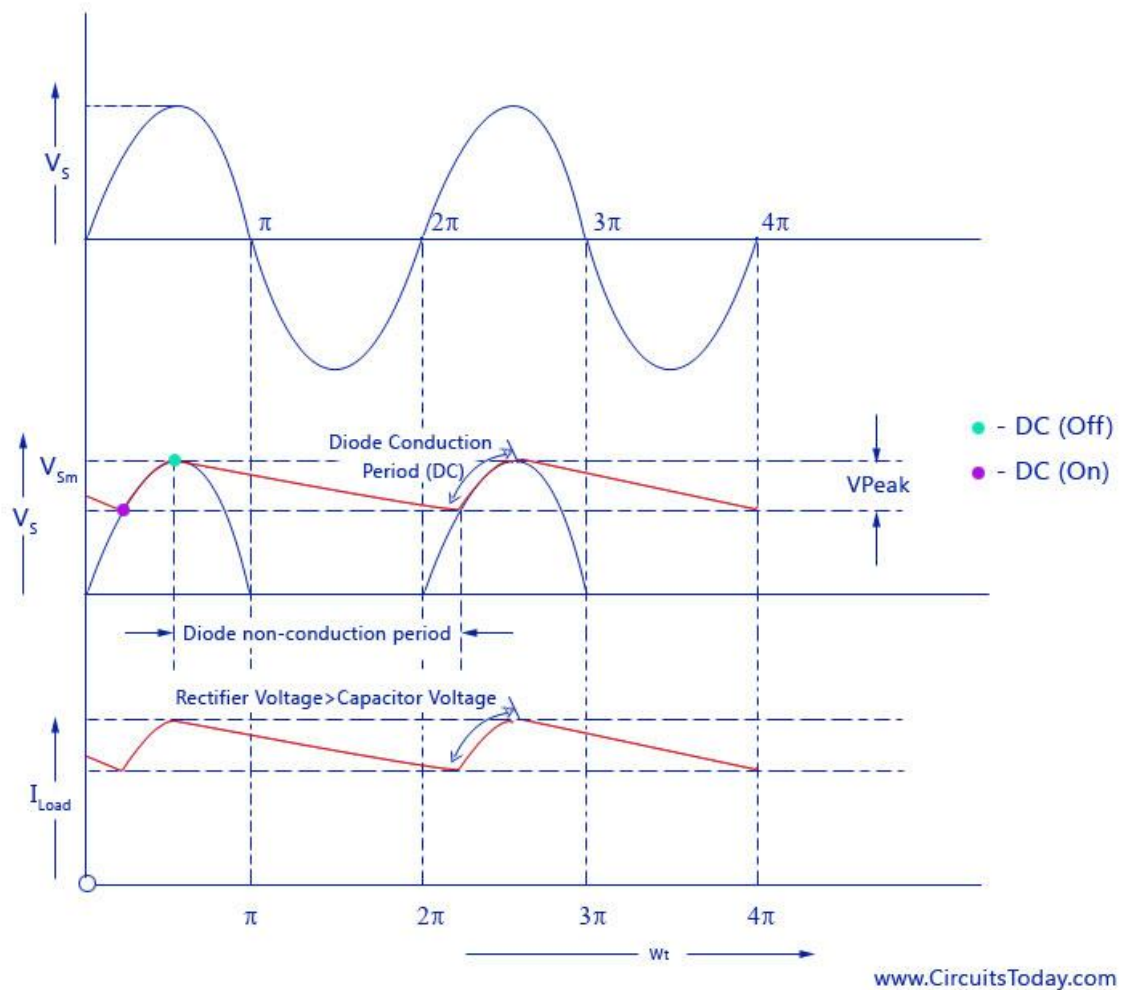
For this project we have been tasked with developing a system that will "reasonably" rectify an AC signal to a DC voltage. It has been made clear that the circuit must remain low cost, and we are given several criteria that our client wishes the circuit would satisfy. As cost is a severely prohibitive factor for the scope of this project, we are somewhat limited in our potential solutions to their problem. Based on the need for a low-cost circuit, we will use a half wave rectifier using a p-n junction diode in order to satisfy their requirements.

A half wave rectifier, as shown below, is a circuit that consists of running an AC voltage through a transformer, across which a diode feeds current to a parallel capacitor and resistance. The capacitor charges with each cycle before discharging in a time derived from the resistance and capacitance available. With a high enough $R \cdot C$ time constant, this has the effect of charging the capacitor before it can discharge significantly, approximating a DC voltage across the capacitor, and therefore across the resistance. A diagram of a half wave rectifier and its delivered voltage are shown below.

Half wave Rectifier with Capacitor Filter



Half wave Rectifier with Capacitor Filter - Waveform



As one might expect, the properties of the “DC” volage obtained rely heavily on the diode chosen for the circuit. To satisfy the client and meet their demands, we recognize the following conflicting criteria that must be optimized for:

- i) a diode with capacitance in a given range,
- ii) a low forward resistance to keep power consumption by the diode to a minimum
- iii) an output voltage less than the peak input value,
- iv) a reverse bias not exceeding the breakdown voltage
- v) a 50 Hz – 60 Hz input frequency.

Proposed Approach:

For the sake of most accurately meeting the needs of our client, we must gain an understanding of which priorities cannot be compromised on, and which can. The fact that a half-wave rectifier has been chosen for this project, as opposed to a full-wave or bridge rectifier, means cost is an overwhelmingly limiting factor for our client's application. With this in mind, there is an obvious preference that we choose a diode that is readily commercially available for a low bulk cost if at all possible.

To satisfy these conditions, we will first tabulate and examine the requirements that will likely be necessary for the scope of this project. Then we will use that information to create an imagined, producible diode that represent the satisfaction of the requirements. We will use that information to inform our examination of available commercial P-N diodes that may fit these requirements. Then we will choose among these options to determine the best diode to create a rectifier that fits our client's needs.

For an adequate approximation of DC current, the time constant RC of our circuit, will need to be significantly higher than the 20ms period represented in our minimum frequency of 50Hz. With a higher RC constant, the capacitor will be mostly charged for the duration of operation. This will minimize the change in voltage as a result of capacitor drainage (shown as V_{Peak} in the diagram above) and approximates a DC current.

One of our parameters is to keep the voltage loss by this circuit to a minimum. With the use of a half-wave rectifier, which intends to stop the voltage output for half of the rectified voltage, this minimization is difficult. In our case, balancing the RC time constant requirements with our desire for low power loss, leads us to desire a capacitance as high as possible in a cheaply available diode. As these options conflict so heavily with one another, especially in the market space available, multiple options and the rationale behind those options will be presented to our clients. With those options in mind, we can make recommendations based on the specific needs of our client for the circuits that they present.

We will explore our options by deriving and listing key parameters of each potential diode, and then comparing their benefits and disadvantages to determine our ultimate recommendations. To keep costs and space in the circuit to a minimum, we will attempt to generate the capacitance necessary in the circuit in the P-N junction of our diode.

Our first option will be to use doping to generate our own diode with a P-N junction that satisfies the requirements given by our client. This allows us to have a very fine control over the parameters that will create our rectifier. We can determine a useful capacitance value that minimizes the necessary resistance, and then explore the properties of this diode. We can find the voltage drop across our prospective diode as the voltage across the depletion width of its P-N junction. To balance forward voltage drop and reverse bias range, Silicon doped with Phosphorus and Aluminum will be used for this process.

We will also explore other commercially available diode options that can fulfill the needs of our client that we may have overlooked in our initial evaluation. Specifically we will take a look at one of the many Schottky diodes available on the market. Schottky diodes are diodes whose junctions are created by the barrier between an n-type semiconductor and a metal, which creates a junction similar to the p-n junction in practice. These junctions tend to have high capacitance overall, but lack a strong resistance to reverse bias. However, as many versions of these diodes exist that make up for this shortcoming via their construction, we will explore the option as a possible alternative.

Another possible option to attempt to balance cost-effectiveness against voltage loss, is the addition of an external capacitor to the circuit. This presents an alternative to relying on the capacitance of the semiconductor diode for the material, which results in an extremely large resistor being necessary for a satisfactory RC value.

Relevant Computations:

Before we begin calculations of our diode, we must first determine the necessary RC time constant for a satisfactory DC approximation. For our calculations we want our ripple period τ , to be significantly larger than the period of our supplied voltage. In this case, our supplied period is given by $1/50Hz = 20ms$. If we take $R * C$ to be significantly higher than that we can create a baseline of $R * C \gg 0.02s \geq 1s$.

For the lowest possible resistance we take the capacitance of the diode to be its greatest reasonable value of 150pF. Using this value, we can calculate the rest of the parameters using the equation for junction capacitance as a function of the junction depletion width, assuming that under AC conditions the bias voltage is 0.

$$C_j = \epsilon A \left[\frac{q}{2\epsilon V_0} * \frac{N_a + N_d}{N_a N_d} \right]^{1/2}$$

$$(150 \times 10^{-12} F) / A = (11.7 * 8.85 \times 10^{-14}) \left[\frac{1.6 \times 10^{-19}}{2(11.7 * 8.85 \times 10^{-14})(V_0)} \frac{N_a + N_d}{N_a N_d} \right]^{1/2}$$

$$\text{Solving for the unknowns in this equation gives } \frac{2.72 \times 10^{11}}{A} = \frac{1}{V_0} \frac{N_a + N_d}{N_a N_d}$$

As V_0 represents the voltage across the depletion region and therefore the voltage drop scene across the diode, we optimize this value to be no greater than 0.7V. Assuming a base cross sectional area of $A = 0.01cm^2$ and assuming the temperature is $\sim 300K$ we can use the equation for the base voltage across a P-N junction to optimize a solution for our doping concentrations. Following the equation:

$$V_0 = \frac{kT}{q} \ln \left(\frac{N_a N_d}{n_i^2} \right) \rightarrow 0.7V = 0.026 \ln \left(\frac{N_a N_d}{1 \times 10^{20}} \right)$$

$$N_a N_d = 5.0 \times 10^{31} \text{ cm}^{-6}$$

Optimizing this equation in conjunction with the equation above for a silicon junction with higher concentration of donor ions than acceptor ions gives:

$$N_a + N_d = 2.7 \times 10^{16} \rightarrow N_a = 2 \times 10^{15} \text{ cm}^{-3} \text{ and } N_d = 2.5 \times 10^{16} \text{ cm}^{-3}$$

Given the relatively high reverse breakdown of silicon semiconductors and the high capacitance under no reverse bias, we can assume that under non-high voltage conditions, there will be minimal reverse current (on the order of nA) and a reverse breakdown voltage higher than will be seen in the circuit.

Using the capacitance of our circuit we can find the minimum resistance necessary to approximate DC Voltage:

$$RC = 1 \rightarrow R * 150 \times 10^{-12} = 1 \text{ s}$$

$$R \geq 6.67 \text{ G}\Omega$$

Researching online has led to a myriad of different variants of the Schottky diode that may fit our needs. Research has led us to examine the Micro Commercial Co. "SK310A-LTP" diode as a potential solution to the client's needs. This diode compensates quite a bit for the low reverse bias generally seen in Schottky diodes with a maximum reverse bias of 100V as noted on its datasheet. It retains a relatively low forward voltage of 850mV at 3A as well. Finally if the reverse capacitance of 240 pF holds under AC conditions, the necessary accompanying resistance is:

$$R * C = 1 \rightarrow R * 240 \times 10^{-12} \text{ s}$$

$$R = 4.17 \times 10^9 = 4.17 \text{ G}\Omega$$

Now we move to calculate an alternative option: adding an external capacitor to the circuit in line with the half wave rectifier diagram shown previously. For the sake of optimization, a capacitance that was readily commercially available value of capacitance, 0.1 μF . With this capacitor in place, the resistance necessary to achieve the desired minimum time constant is calculated below:

$$1 \times 10^{-7} \text{ s} * R = 1 \text{ s}$$

$$R = 1 \times 10^5 = 100 \text{ k}\Omega$$

Conclusions:

Recommending a diode configuration for our client will generally be a balancing act of desired outcomes and economic feasibility.

Here is a table of parameters of each alternative to better evaluate our options.

Parameters	Doped Silicon	Schottkey	P-N + Capacitor
Reverse Voltage	N/A (~70V-150V)	120V	250V
Capacitance	150pF	~240pF	1×10^6 pF
Price/unit	N/A (High)	\$0.105-\$0.12	$\$0.022 + 0.024 = \0.046
Operating Temp	~- 50°C ~ 125°C	- 50°C ~ 125°C	- 55°C ~ 125°C

Researching to find similar diodes to the ideal diode that was developed according to the calculations above resulted in very little similarities. This suggests that not we would most likely have to commission these diodes personally, which will likely be much more expensive than other prohibitively expensive rectifier configurations that were abandoned. The lack of similar alternatives suggests that there may be a technical barrier to creating these diodes as well that is well out of the purview of this project. As such, we move to commercially available solutions.

The Schottky diode presents an interesting possible solution to the problem at hand. The diode satisfies the requirements of the project certainly, and at 10-12 cents per unit, does not represent an exorbitant cost to our client, nor an extremely cheap alternative compared to many other diodes found online. However, the likelihood of the rated capacitance holding for the AC conditions necessitated by the project is unknown, and as data on this parameter was not available on the data sheet, testing would be required to confirm it's efficacy.

Further problems present themselves upon closer examination of the possible use cases of the device. The frequency range given for us to rectify is 50-60Hz. This lines up exactly with the standard AC voltage frequency of United States, Canada, and European standard main voltages. This suggests a possibility that the diodes could be used to convert the mainline voltage of any of these countries. In that context, we should prepare for the possibility of the circuit seeing the 120V AC of the US and Canada, or the 230V AC of most of the European world. With this in mind, the lone diode options become very liable to fail in the given conditions. This makes us turn our attention to other alternatives.

The resistor values chosen for both lone diode option result in an unsatisfactory level of energy dissipated by the circuit and a substantial amount of heat, which may damage the integrity of the rectifier, especially at high voltage. With the addition of a single 0.1 μ F capacitor to the circuit, more closely representing the half-wave rectifier diagram shown above, the RC constant increases 100000-fold. With a satisfactory RC time constant assured by the capacitor, a much smaller resistance can be used in the circuit, resulting in a much smaller power draw.

With this, we can justify the use of various, much more commercially available diodes. For a specific configuration with which to evaluate this option, we look to the Meritek "HC1206XR104K251" 0.1 μ F capacitor and the extremely widely available Rectron USA "1N4001-T" Diode.

At \$0.022 cents per unit, this diode presents a maximum reverse voltage of 1000V. At this voltage, it has a negligible leakage current of 200nA. As this is far above the voltage that will be present in the likely use cases for this material, the expected leakage current will be much smaller in our client's use case. The energy lost to its relatively high forward voltage of 1V can be mitigated by the power savings represented by the much lower resistance. ✓

The 1N4001-T presents a diode that exceeds the client's performance expectations while being significantly cheaper than all other presented options, even when combined with the cost of the capacitor. As such it is our strongly recommended option for any use case presented to the client.

References:

Equations and PN Junction information

Solid State Devices, 2nd Edition, by B.S. Nair and S.R. Deepa, PHI Mediamatics Publication, (2020)

Information on Schottky Diodes

https://en.wikipedia.org/wiki/Schottky_diode

<https://www.digikey.com/en/products/filter/diodes-rectifiers-single/280?s=N4lgjCBcoJwGxVAYygMwIYBsDOBTANCAPZQDaIALAAxUDMA7ABwgC6hADgC5QgDKnAJwCWAOWDmIAL6TCAVkh2UMByWRZVGSATQQQgCY8ATFXoQO3SCACqloZwDyqALK502AK4DclQpwCe7D5W%2BtgohACOATxSkkA>

Data on Schottky Diode SK310

<https://www.digikey.com/en/products/detail/micro-commercial-co/SK310A-LTP/2642015>

Datasheets and pricing for PN + Capacitor option

<https://www.digikey.com/en/products/detail/meritek/HC1206XR104K251/13586078>

<https://www.digikey.com/en/products/detail/rectron-usa/1N4001-T/12440240>



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ELEG3303P01

Optimum Characteristics of a p-n Diode in a Half Wave Rectifier

Author: Hunter Evans

Professor: A. Anil Kumar

— Check for typographical errors & grammar.

—

Summary:

Diodes come in many different varieties and can be hard to find what you are looking for if you do not have the knowledge to differentiate them. The main task that we are to solve is to find a diode that fits into five conflicting criteria's. This objective is meant for us to use what we learned in our Physical Principles of Solid-State Devices class to solve problems that we will do in the future. The main tools used in this project is the internet and knowledge obtained in class. When working on this project a major take away from it is that most of the work was already done when looking for specifics about the criteria's. Although these criteria's were not easy to overcome this project was a good steppingstone for future projects and will help with gaining a foothold in this field.

Introduction:

In this project we are assigned to find a diode that fits into five criteria's which are (1) a diode with capacitance in a given range ($10\mu\text{F}$ -- $100\mu\text{F}$), (2) a low forward resistance to keep power consumption by the diode to a minimum, (3) an output voltage less than the peak input value, (4) a reverse bias not exceeding the breakdown voltage and (5) an 50Hz-60Hz input frequency.

Theory:

When looking at what we had to do to find the diode that would fit these conditions is that there would be a list or graphs of varying diodes with a condition that would fit one of the criteria's we were looking for. Then from there we could use the knowledge we gained from class to filter through diodes that fit the rest of our conditions.

Data and Calculations:

While looking for the right diode to fit the first condition I found a website therepaircafe.wordpress.com that had list of diodes ranging from low to high forward resistance and separated by diodes. When looking at the graphs I chose to go with the silicon diode list because it had some of the lowest forward resistance out of all the graphs. Once on the list of Silicon diodes I choose BA159 to see if it could satisfy any more of the conditions I was looking for. So, I found a pdf file of its data sheet and started to compare.

1. BA159 Capacitance = $12\mu\text{F}$
2. Forwards Resistance: $R_D = \frac{V_D}{I_D} = \frac{520\text{mV}}{1\text{mv}} = 5.2\Omega$
3. Output Voltage $\geq$ Input Voltage: $V_F \geq V_{RMS} = 1.3\text{V} \geq 700\text{V}$
4. Reverse Bias not Exceeding Breakdown Voltage:
 - a. $V_{RMS} \geq V_{RRM} = 700\text{V} \geq 1000\text{V}$
5. Input Frequency = 60Hz

Analysis:

From my finding's I can saw that the BA159 Si-diode fits all of the conditions we were tasked to solve when finding the specific diode.

Conclusions:

This project is a great tool to learn from and how to manage future tasks that push us to use what we learned in class to solve problems. I found that when searching for the right diode it would have been harder if it were not for what I had learned in class. The way I used my knowledge from class has also given me a better of what I want to push my career towards. In conclusion, this project was a eye-opener for what this degree will offer me in the future.

References:

<https://therepaircafe.wordpress.com/2019/10/24/forward-voltage-of-various-diodes/ba157.pdf> (vishay.com)

[BA159 datasheet - Specifications: Diode Type: Standard Recovery ; Repetitive \(digchip.com\)](#)

Department of Electrical and Computer Engineering

Prairie View A&M University



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Project 1: Semiconductor Design

Solid State Devices: ELEG 3303

Spring 2022

Professor:

A. Anil Kumar

By:

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Project Summary:

The objective of this project is to simulate students working for Intel as a Physical Design Engineer Lead. In this position students are to design a semiconductor that follows the requirements given by the professor. These requirements are the semiconductor being able to absorb radiation in the frequency range of 5×10^{14} Hz and 6×10^{14} Hz while also being able to produce a current density of at least 100 kA/cm^2 . From there students are to calculate the band gap range required and pick a semiconductor material within the set range. Next is to identify all relevant values for the material such as: N_c, N_v and n_i . After the parameters are found acceptor and doping concentrations must be chosen and used to compute the current density to compare with the required value.

Formulas Used:

$$1) \quad eV = \frac{hf}{1.6 \times 10^{-19}}$$

$$2) \quad n = \frac{(ND - NA) \pm \sqrt{(ND - NA)^2 - 4ni^2}}{2}$$

$$3) \quad p = \frac{ni^2}{n}$$

$$4) \quad J_{drift} = (n\mu_n + p\mu_p)qE = n\mu_n qE$$

$$5) \quad I_{drift} = J_{drift} \times A = (n\mu_n + p\mu_p)qE \times A = n\mu_n qEA$$

Step-One:

Using equation 1) I was able to calculate the range of the band gap needed with the frequency range of 5×10^{14} Hz and 6×10^{14} Hz, which gives a band gap range of 2.067 eV and 2.4814 eV.

Step-Two:

After getting the needed band-gap range I went to look up semiconductor whose band gap was within said range. I was able to find the semiconductor HgI_2 which had a band gap of 2.13 eV.

Step-Three:

This step is where I ran into a problem as when I went to look up the properties of this semiconductor was unable to find anything on it, so I decided to try others withing the band gap range and was able to find Fe_2O_3 , Cu_2O and V_2O_5 and I unfortunately ran into the same problems. Thus, I decided to investigate those with the properties already listed and none of those had the band gap required leaving me at a roadblock.

*You should have done
a more extensive search.
Did you try AlAs, GaP, CdS, CdTe?*

Conclusion:

In conclusion I was unable to complete the project due to not finding any information on the semiconductors I found that fit the band gap range I calculated. It seems that more information was out there on more common semiconductors like silicon, germanium and GaAs. This problem could be due to little information or me using the wrong formula or calculating the needed band gap wrong. Either way I was personally unable to finish.

ELECTRICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY



- Good approach
- Check for
typos &
grammar

4/4

ELEG 3302 PHYSICAL PRINCIPAL OF STATE
DEVICES

PROJECT:
OPTIMUM CHARACTERISTICS OF A P-N DIODE
IN A HALF WAIVER RECTIFIER

PREPARED BY:

IVAN CORONADO

TO:
DR. A. ANIL KUMAR

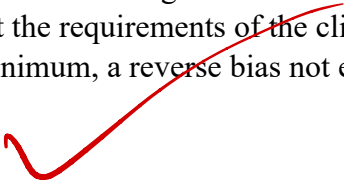
APRIL 24 ,2022

Purpose

The purpose of this project is to prove by a practical problem in this course that students can enhance learning and acquire the necessary skills to solve problems. Following and understanding the guidelines for a project plays an important role in the success of any project. Furthermore, developing multiple problem-solving scenarios and collecting the data are fundamental components to support the project.

Abstract

The project consists of developing a half-wave rectifier and investigate the characteristics of different diodes and a circuit configuration that will fit the requirements of the client such as low forward resistance to keep power consumption to a minimum, a reverse bias not exceeding the breakdown voltage, and fully functional at 50-60 Hz.



Problem / Statement

The problem statement is describing that as a solid ^{State} expert device working for a company, a customer is approaching to seek advice on a low-cost rectifier that provides for a “reasonable” price a rectification of an AC signal. Based in our experience, the customer might need a half wave rectifier (low cost) that operates under the following conflicting criteria:

- I. A diode with capacitance in a given range
- II. A low forward resistance to keep power consumption by the diode to the minimum
- III. An output voltage less than the peak input value
- IV. A reverse bias not exceeding the breakdown voltage
- V. A 50 Hz – 60 Hz input frequency

Given the specification, the client highlighted the importance of a low-cost solution to his needs. For this reason, the satisfaction of the client is very important as the quality of the product and service that he will receive.

Introduction

A rectifier is an electrical device that converts AC to DC ~~current~~. Rectifiers can be presented in a wide variety of physical from different types of diodes, resistors, and capacitors, to the most advanced diode in the industry. Furthermore, rectifiers are the most used these days because many electronics operate in DC sources making it a challenge because our homes and the way that we operate is on AC current. For this reason, the rectifier plays an important role in the lifestyle of many people, even our cellphones used rectifiers to convert that AC from the power outlet to DC current. It exists many configurations and different applications for rectifiers. In this case, a half-wave rectifier is used in transformers, AM radio, voltage multipliers, and many more.

Before the project starts, it will be proactive to have in essence some educational foundation about half wave rectifiers and how it works. A rectifier is an electronic device that converts AC to DC voltage, it converts AC (alternating current) into DC (current).

It starts with a sine wave because of the AC voltage passing through the circuit where the diode will let the current flow in one direction while the negative current is covered up (see figure 1.0) the graph is provided as an illustration for this particular case. During the negative cycle, the diode is in reverse biased as the anode is negative with respect to the cathode, therefore, no current through the diode or circuit. (see figure 1.1)

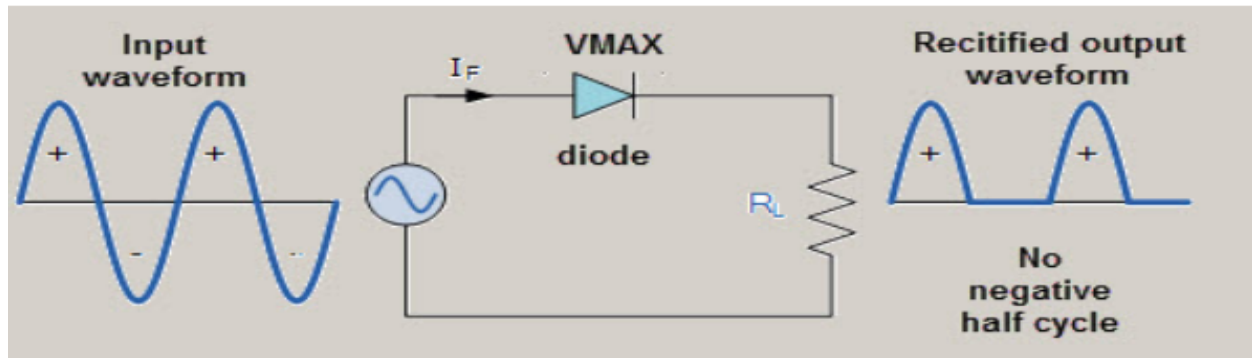


Figure 1.0

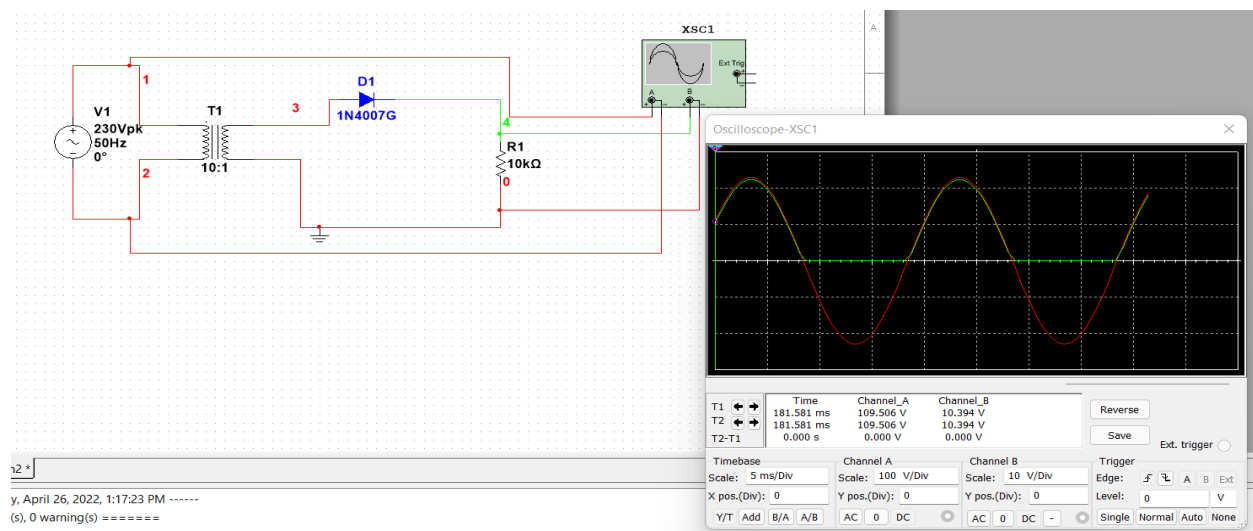


Figure 1.1

The figure 1.1 is a real simulation in Multisim, the upper half-wave is indicating the positive current (yellow) and the other half-wave is indicating the negative current (red), since this is coming from a DC source.

Furthermore, a half-wave diode rectifier with a capacitor will smooth the process by charging the capacitor and discharging it through the resistor load as is represented by the fig. 1.2

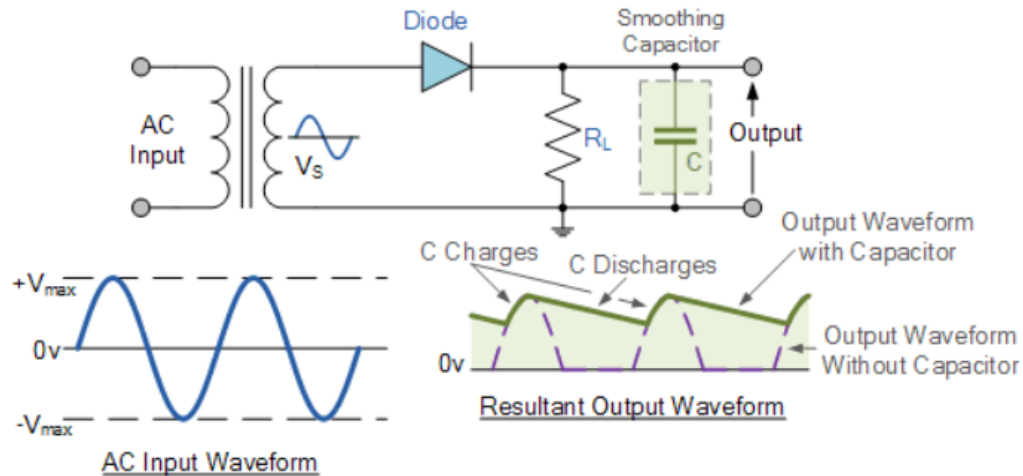


Figure. 1.2

The capacitor discharges until the input supply voltage is less than the capacitor voltage. When the input supply voltage is greater than the capacitor voltage, the capacitor again starts charging. When the positive half cycle is reached again, the diode is forward biased and allows electric current. This makes the capacitor charge again. The capacitor filters with a large discharge time constant will produce a very smooth DC voltage. Thus, a smooth and steady DC voltage is obtained by using the filter. (See figure 1.3 and 1.3.1)

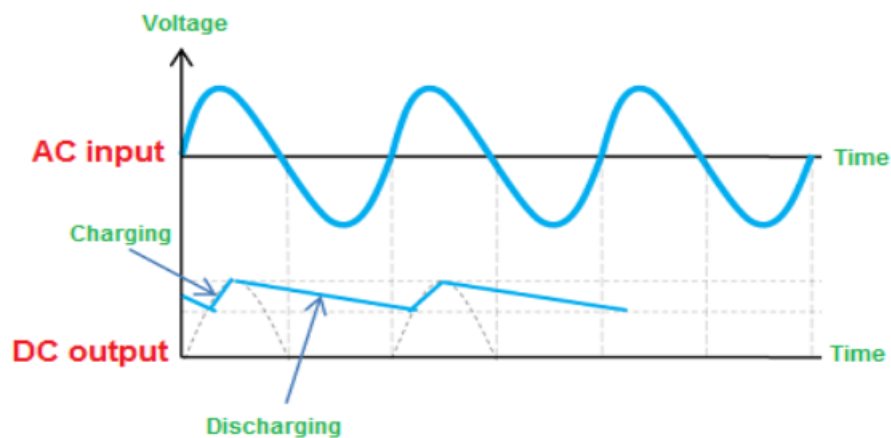


Figure 1.3

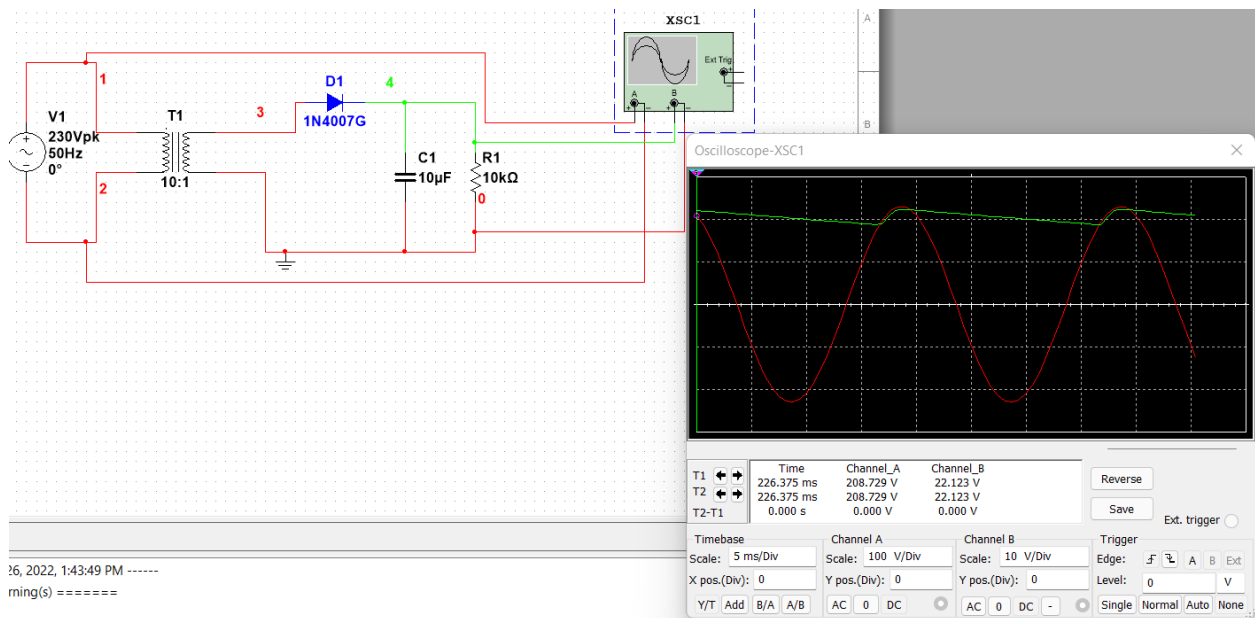
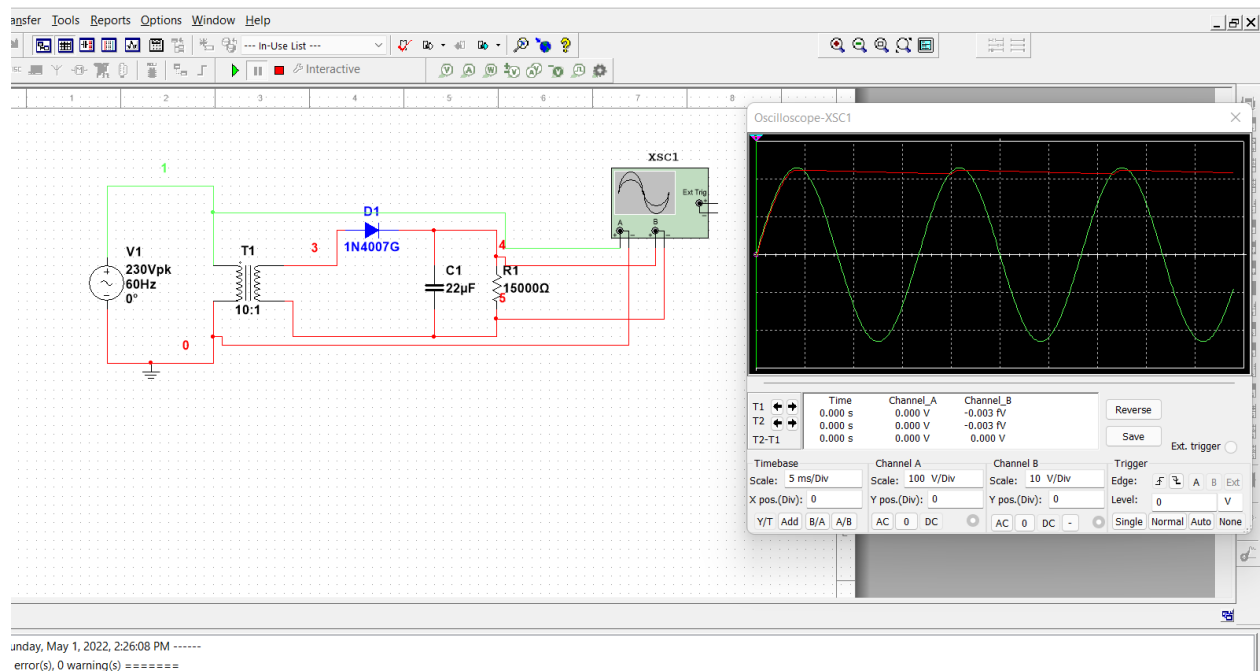


Fig. 1.3.1 – The image is a real simulation for a diode rectifier with a capacitor, the graph is indicating that the capacitor is charging and after that, it will discharge through the resistor (green path).



Regardless of the diode, let say a PN silicon and having a high capacitance (22 microFarat) and a small resistance load (1.5K ohms) makes the DC line more smoother, i.e reduce the ripple factor, the only drawback in having a big capacitor, it takes a longer time to charge in the first place, and after removing the power source the capacitor will discharge so slowly again, making inefficient for those longer gaps at the beginning and at the end.

APPROACHING SOLUTION

The approaching solution was designed for this particular project. It exists different application for rectifiers and diodes have different characteristics that make them unique from other diodes, for this reason, a critical analysis of the requirements and expectations are very important to have a successful product.

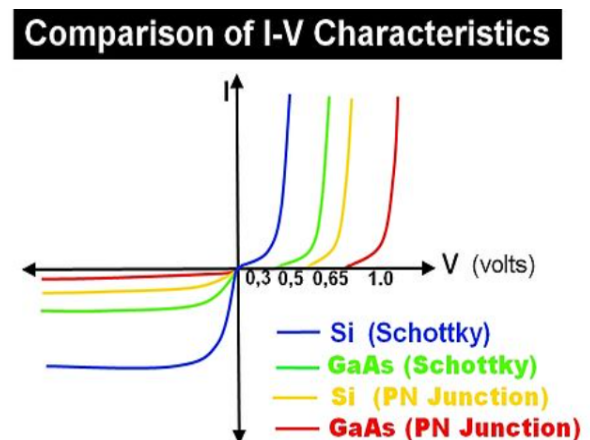
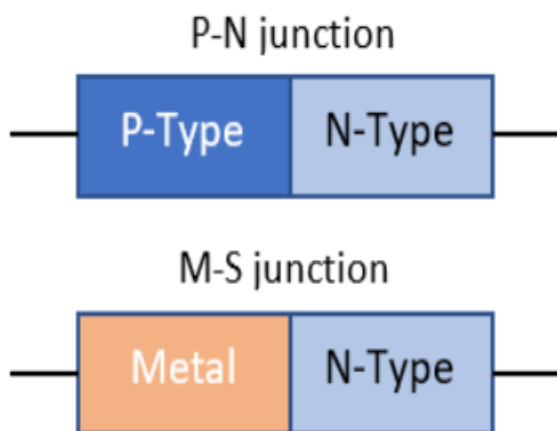
Based on the requirements of the client, it is very important to develop some research about diodes and considered some characteristics such as:

- Forward current
- Forward voltage
- Reverse resistance
- Capacitance
- Temperature stability

Furthermore, it is imperative to have a low-cost solution for a half-wave rectifier without affecting the quality of the product and its performance. As it was mentioned the way a rectifier works, I will be focusing as much as possible to meet the requirement of the client.

In general, a diode and a resistor are used for rectification, the main purpose is to convert AC to DC signal, and hence a capacitor is used as well. The purpose of the capacitor is to reduce the ripple voltage.

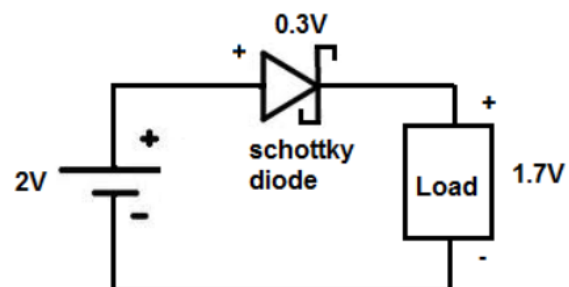
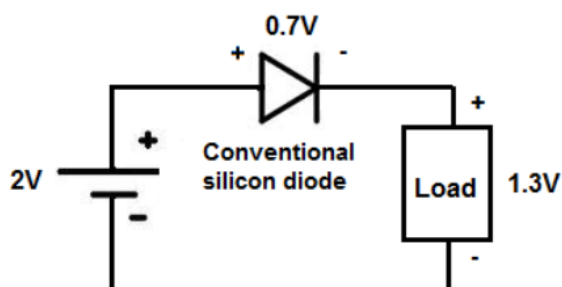
By considered a variety of options that it will fit the needs of the client, **the proposal** consists in an AC voltage source with a step-down transformer, a Schottky diode, a capacitor, and a resistor as the configuration for the half wave rectifier. Schottky diodes are used for their low turn-on voltage, fast recovery time and low-loss energy at higher frequencies. These characteristics make Schottky diodes capable of rectifying a current by facilitating a quick transition from conducting to blocking state.



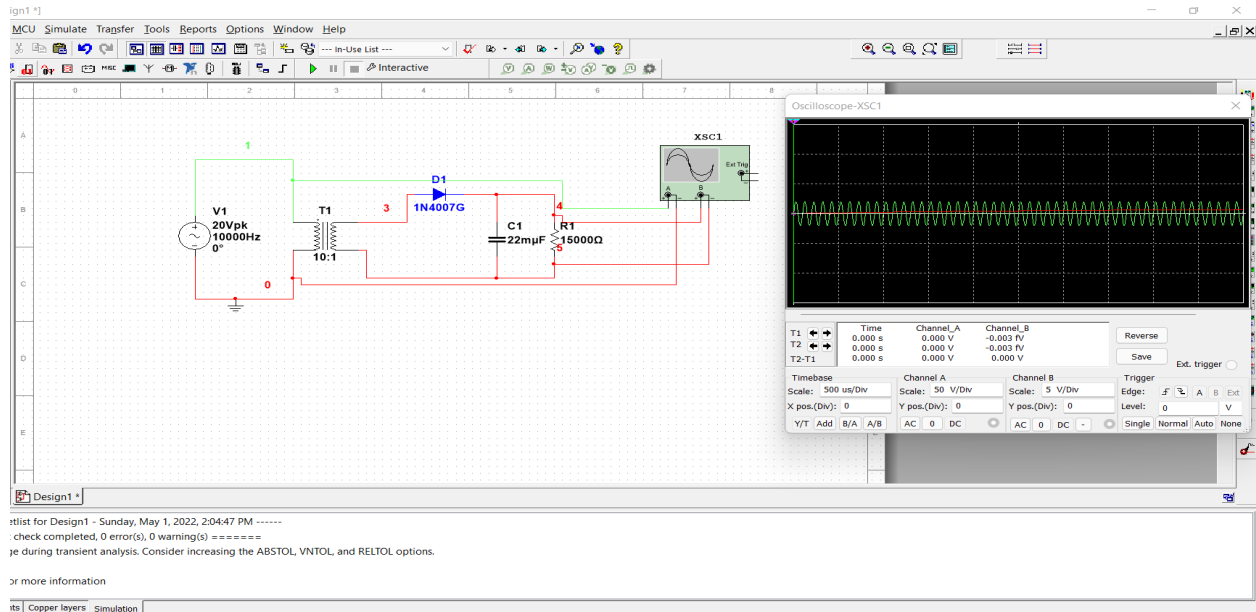
DIODE	FORWARD VOLTAGE DROP [V]	FORWARD RESISTANCE
Silicon	0.6 – 0.7	Low
Germanium	0.2-0.3	High
Schottky diode	0.3 -0.4	Low



- Germanium diode has low forward voltage drop but it has considerably high forward resistance. Germanium diode has the same forward voltage as a Schottky but Germanium diode has a very low switching speed.
- Silicon diode has low forward resistance, but it has considerably high forward voltage drop.
- Schottky diode has low forward voltage drop and low forward resistance respectively.
- Schottky diode is very beneficial for applications where saving power is an absolute must.
- A Schottky diode is used in numerous applications where other types of diodes will not perform very well.
- High efficiency and lower power consumption (Schottky diode).
- Low switching time (Schottky diode).
- Fast recovery time so it can be mostly used in the application of high-speed switching
- Schottky diode produces less unwanted noise than P-N junction diode



The Schottky diode can comply without issues with the client requirements and go beyond, the Schottky diode perfectly works where a silicon diode can't do it, the Schottky diode can work in very high frequencies without any problems (see fig 1.6 and fig 1.7).



The PN diode struggle to keep up with the high frequency, in this case, I set it up to 10000 Hz. (Fig 1.6)

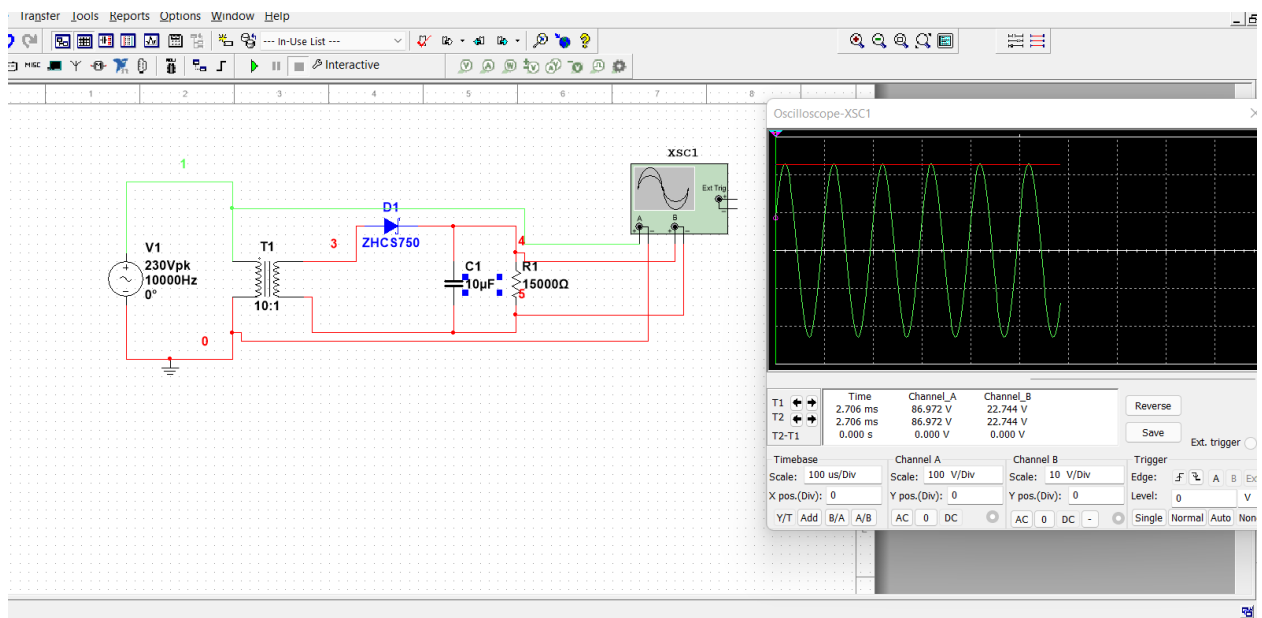
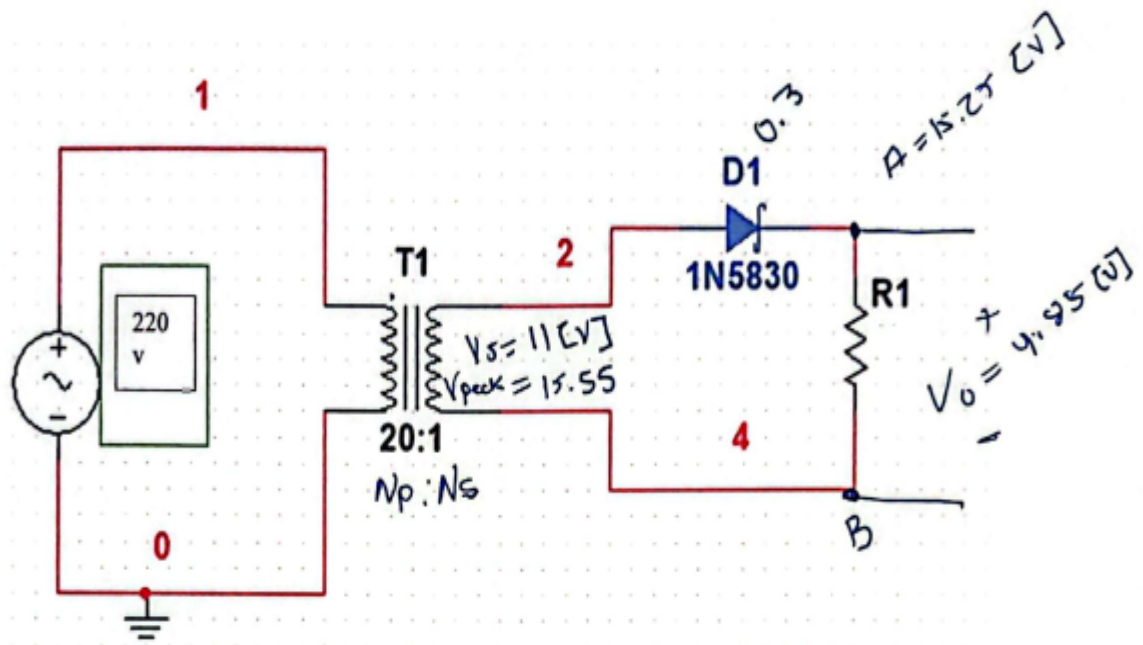


Fig 1.7 - On the other hand, the Schottky diode performed very well at 10000 Hz.

Calculation



In this FBD a 220 AC voltage source has been placed along with a step down 20:1 transformer, since there are not specific values, the FBD contains any numbers to prove that the Schottky diode complies with the requirements of the client.

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$\frac{V_s}{220[V]} = \frac{1}{20}$$

$$\frac{220}{20} = 11[V]$$

$$\begin{aligned} V_{peak} &= V_s \cdot \sqrt{2} \\ &= 11 \cdot \sqrt{2} \\ &= 15.55[V] \end{aligned}$$

$$A = V_{peak} - V_{drop} \text{ (Schottky diode)}$$

$$A = 15.55 - 0.3$$

$$A = 15.25$$

$$V_{avg} = \frac{15.25}{\pi} = 4.85[V]$$

Conclusion

In essence, a half-wave rectifier converts AC to DC current, the type of the configuration in the circuit will lead to its performance. It exists various configurations for maximum results such as a full-wave bridge rectifier and a full-wave rectifier with 2 parallel diodes. In this project, a half-wave rectifier was required, and the proposal complied with every aspect of the project, a diode with low forward resistance, a Schottky diode with a forward voltage of 0.3 V and a forward resistance very low; a circuit that satisfies the needs of the client, the proposal complied in that area by implementing an AC source, a step-down transformer, Schottky diode, a capacitor, and a resistor; A reverse bias not exceeding its breakdown voltage, even if the Schottky diode has a high breakdown voltage approx. 50V, for this type of rectification, will work as well as a PN diode for this particular area. Also, according to the calculations mentioned in the project, the output voltage is less than the peak voltage. The project encountered some challenges at the beginning because it exists many paths that can be applicable for this particular project, the bottom line is to highlight the requirements of the client. Lastly, it exists many diodes on the market, all of them have pros and cons, and every diode has a uniqueness that makes it suitable for certain applications. The project went over many hours of work, research, and dedication, and it highlighted the importance that rectification has these days, a lot of the electronic devices operate on DC current, so it is imperative to dominate this topic for the future success of the students.

References!

