The University Of Sheffield.

Department of Electronic and Electrical Engineering

First Year Laboratory: Light Emitting Diodes

BEFORE THE LAB: In order to prepare yourselves adequately, you must read this sheet up to the end of the section entitled, "The Initial Sample". This requires you to write some material on this lab sheet. The demonstrators will check that you have done this work before attending the lab. If you have not done so, you may not be permitted to carry out the lab.

This experiment takes place in the Electronic & Electrical Engineering Semiconductor Clean Room (D157) and NOT THE NORMAL FIRST YEAR LABORATORY. The clean room is located at the end of the corridor on D floor, past the 'St.Georges' coffee bar. Please gather at outside the entrance door to the clean room a few minutes before your allotted time. If you are late, you may not be allowed to enter the lab.

Laboratory Safety: The clean room contains many chemicals, a number of which can have detrimental effects on the human body. You will not be using hazardous chemicals in this experiment but it is still imperative that you work carefully and follow the instructions of the laboratory supervisors exactly to avoid being exposed to any hazard. The greatest hazard in this experiment is that you will be heating your sample on a hot plate. This is hot and will burn you if you touch it. This may seem obvious, but you should ensure that you understand this before carrying it out. You MUST ask the laboratory supervisor if you are unsure of this or any other aspect of safety in the clean room. Finally, because of the nature of the clean room environment, please wear clothing that covers your legs completely: shorts and skirts are not appropriate.

In case you have to miss the laboratory then you will need to have a very good reason. If that is the case please contact Prof. M. Hopkinson (f.bastiman@sheffield.ac.uk) to discuss the possibility of re-scheduling.

Light emitting diode (LED) lab

Objectives

The purpose of this laboratory is to give you some practical experience of handling and analysing semiconductor materials and devices within a clean room environment. You will gain some knowledge of practical device fabrication and characterisation that will underpin topics described in lectures, eg: EEE118. In addition, the diode characteristics that you observe here will help you in understanding the circuitry used in your first year project. In practice a full analysis of all the subtleties that you observe during this experiment will require further knowledge that you will not acquire until later years.

Introduction

In this class you will fabricate and test a light emitting diode. The fabrication has been simplified due to time constraints, but you will gain some experience in both handling the materials and in good clean room practice. In your second year you will carry out a more extended fabrication exercise that will introduce you to processes more typical of those used in industry. You are required to produce a short report for this experiment, details of which are provided at the end of the lab sheet. On this laboratory sheet you will find spaces for you to make notes about the various processes involved. This contradicts our normal practice of asking you to take all notes in your lab book. Unfortunately, the low quality paper used in your lab book can shed dust, which is damaging to the clean room environment.

Semiconductor theory

The theory of pn diodes is covered in greater detail in the lecture course EEE118. This section of the laboratory sheet contains a summary of that information.

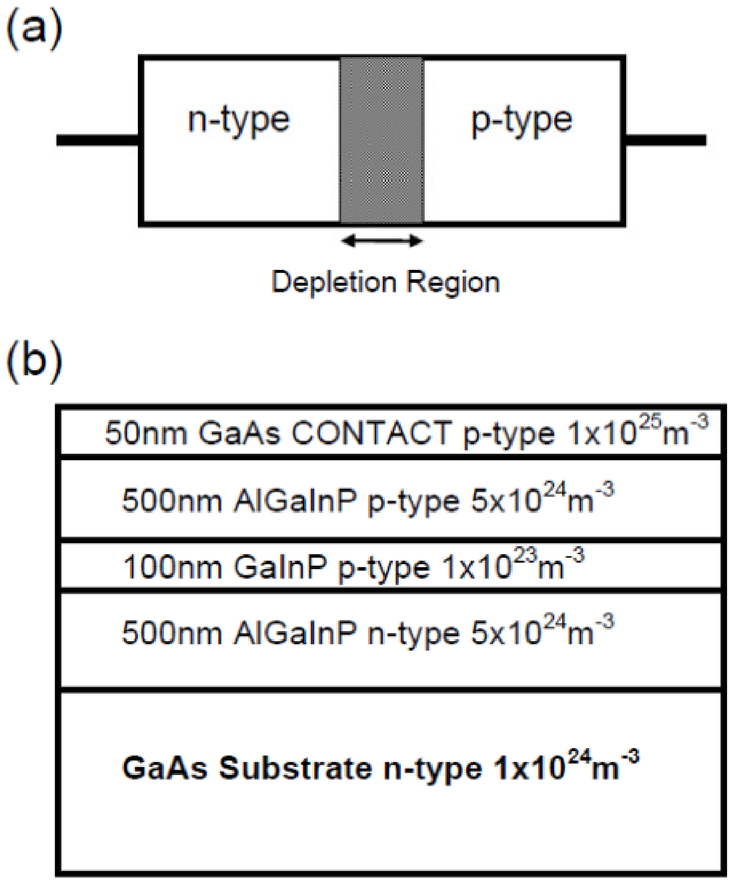
A simple semiconductor diode (see Fig. 1(a)) is a sandwich of two regions: an n-type region (with many free electrons) and a p-type region (which has a deficit of electrons, or alternatively can be referred to as containing holes). When electrons mix with the holes they recombine with each other and release energy. Normally (without an applied voltage) the electrons and the holes are separated in their own respective n- and p-regions by a ‘built-in’ voltage generated naturally at the junction. This provides a ‘barrier’ between the electrons and holes in the n- and p-regions respectively.

When an external voltage is applied in the ‘forward’ direction the ‘built-in’ voltage is opposed, the barrier collapses and the electrons and holes spill over towards each other at the junction between the two regions. This gives current flow and sometimes light output as the electrons recombine with the holes and release energy. The energy of each photon of the light produced is equal to the energy originally required to create an electron, which is recovered in the recombination process.

Figure.1.

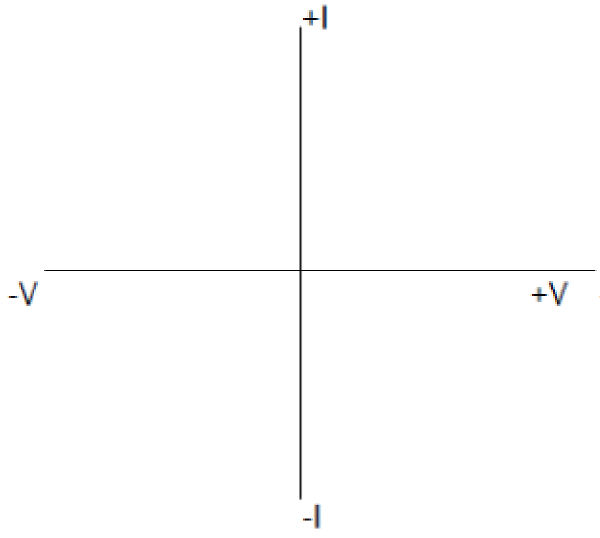
(a) Simplified diode structure,

(b) Actual material structure

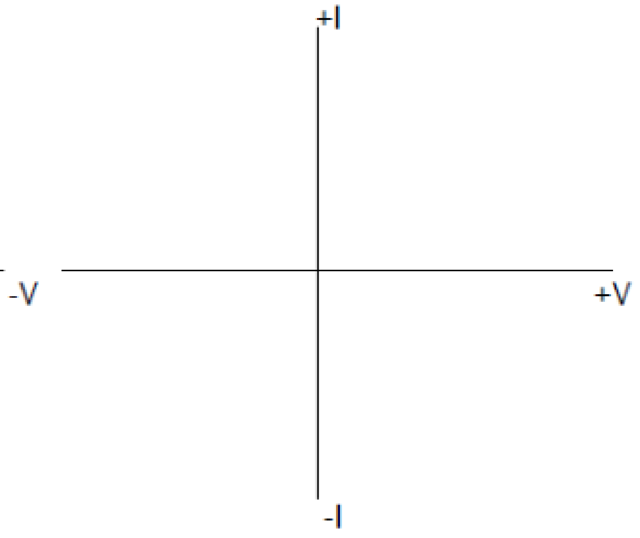


Diode Characteristics

The LED is just a special type of diode that happens to emit light. Before you arrive at the lab, we wish to ensure that you understand what a diode is, so in the space on the next page we ask you to sketch the characteristics of a diode. In practice, diodes are used for many purposes but for the purposes of this section; let us just consider them as rectifiers. First consider what it is we want from a rectifier. Then sketch the I-V characteristics of a perfect rectifier (the “Ideal Diode”). Of course, no such perfect device exists, but it is useful to consider what we would want if it was possible. Remember to include the positive and negative voltage directions (which give positive and negative currents respectively). Next sketch the I-V characteristics that you might expect from a real silicon diode (such as we might get from stores). Later we will compare this with the characteristics you will actually measure from the LEDs you have fabricated.



An Ideal Diode



A Real Diode

The initial sample

You will be provided with a semiconductor sample. This is based on a wafer of commercial n-type semiconductor cut from a long cylindrical crystal (as shown in Fig.2)

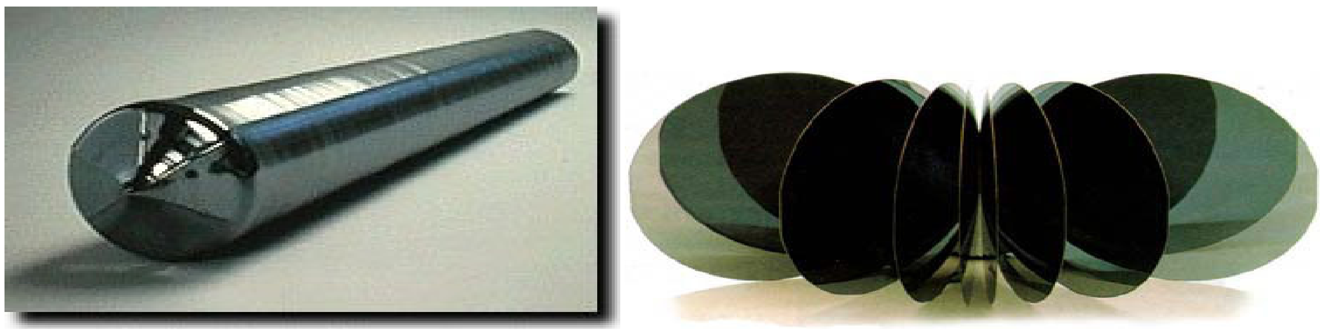


Fig.2. Cylindrical semiconductor crystal (‘boule’) and semiconductor wafers which are produced from it by cutting and polishing

Onto one face (which we will call the front) of this has been deposited a sequence of thin layers of different semiconductor materials with different optical and electrical properties. Details of the material structure are shown in Fig. 1(b). (You will find it very challenging to work out the function of each of these layers.) The top layers are p-type so that the whole structure forms a p-n junction. Prior to the experiment the clean room staff will have fabricated a contact onto the back face of the n-type semiconductor. (This is mainly gold, with some extra different metals added to improve its performance.)

Your job is to fabricate a similar contact on the front face of the sample. You will then have a complete p-n junction diode with two metal contacts between which you can apply a voltage and so investigate the diode behaviour.

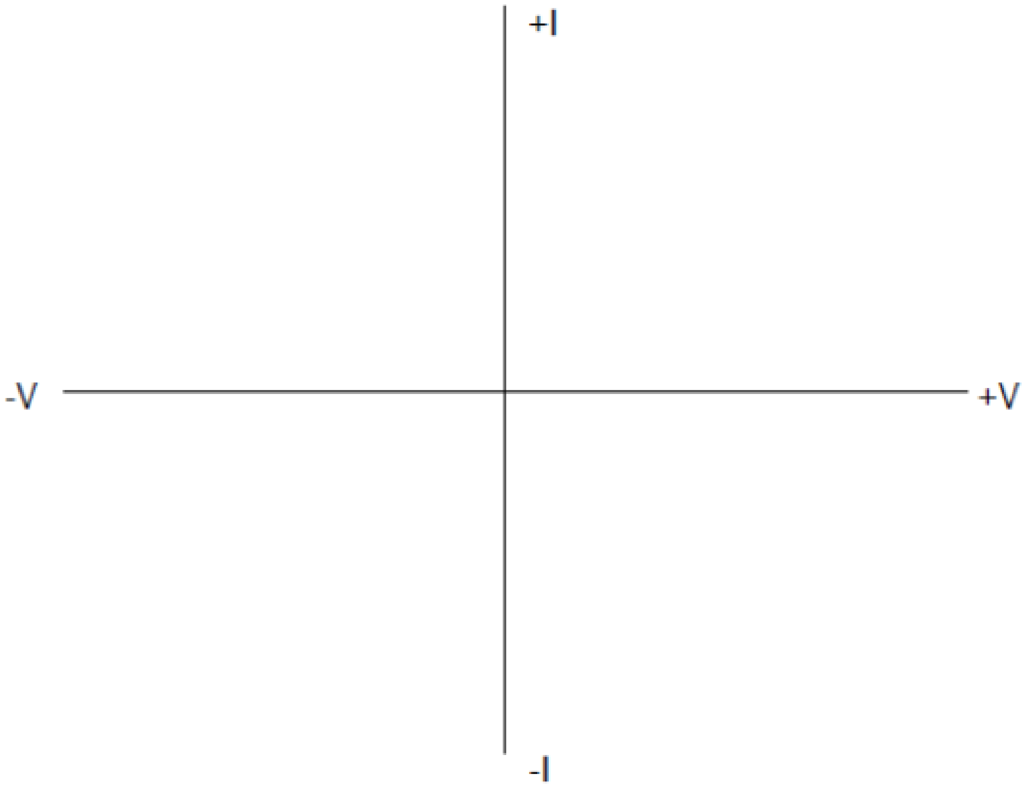
Fabricating the p-contact

The type of contact you will form is based on an indium dot. This type of contact is quick to make and is still widely used in research laboratories in the assessment of test samples. Basically, indium is a metal that is easy to connect to and it undergoes a reaction with the semiconductor that blurs the metal/semiconductor interface in a subtle way (which is probably still not fully understood). For you the first stage is to identify the front (p-type) face. This is the one that does not have the gold contact on it and is dark grey in colour. If you get this wrong it will destroy the sample, so if you are in doubt please ASK.

The supervisor will demonstrate how to place the indium dot onto the surface. Take any notes you need in the space below:

Testing and assessing the device

Using the equipment provided examine the electrical (current-voltage) characteristics of your device. You should ensure that you put a voltage across the device in both directions. Sketch the I-V curve of the device:



Is this the type of characteristic that you expect from a diode? Compare with your prediction.

Does the device give out light? Comment on the brightness.

Is the device uniformly illuminated? A small sketch to indicate the spatial location of the observed behaviour might be useful.

Can you identify (experimentally) which part of the I-V curve is associated with the light emission? Note this will mean using different test modes. Show the demonstrator your results and explain your deductions below.

Comment on the effect of changing the voltage levels on the optical brightness. Do you see any saturation of the intensity? If so, record the current at which this happens.

In the final part of the experiment the demonstrator will supply you with a number of commercial LEDs, labelled A, B, C and D. Attach these to the curve tracer and measure their current voltage characteristics. The results can be written in the following table:

LED	**V_{TO}**	**V_F at 200mA**	**Colour**	**Intensity**
A				
B				
C				
D				

What observations do you have about these characteristics compared to the ‘home made’ LED?

What device (A, B, C or D) seems brightest to the eye?

Which has the lowest turn on voltage?

Which has the lowest resistance in forward bias?

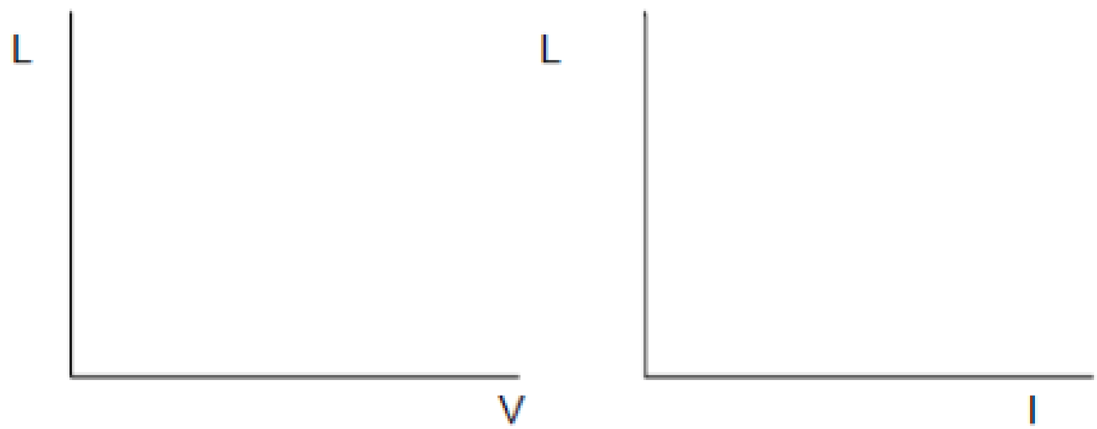
Why don’t you see light from one LED?

For each LED type, suggest one typical application.

Further questions (for discussion with demonstrators)

Some of these questions demand a grasp of concepts that you will not cover until later in the course. Most of them are not directly relevant to the report you will write, but we hope that you will find them interesting to think about. A demonstrator will discuss them with you as a small group once you've had a chance to think about the answers.

1. **Based on your measurements, speculate as to how curves of optical output power (symbol L for light) vs. voltage and vs. current might look.**



2. **Why does the device emit radiation (light)? What is the mechanism?**

3. **What governs or controls the perceived colour of light?**

4. **What would you need to do to change this colour?**

5. **Where in the device is the light generated? Which region of the diode?**

6. **Many photons which are created don't actually escape from the material. Any ideas why?**

7. **Where does the energy that the light carries away come from?**

8. **What's the power efficiency of the best LED you have measured?**

To finish: leave the room and remove the clean room clothing. Please WASH YOUR HANDS.

LED Lab Report

Part1: Please provide written answers to questions 1.-8, as listed above. This is to assess your understanding of the basic concepts introduced in this lab.

Part 2: Imagine you work for a company that produces LEDs and that it is your job to test incoming wafers for suitability for full production. As part of this job you will need to write a short "LED test report", which can then be looked at by your manager.

LED test report

The style of the report is up to each student. It should however address the following questions. The report need not be too long in order to address the most important questions- shorter can be better.

Procedure: Your manager will want to know the procedure used for making the test LEDs. Please describe the process as you have done in the lab. today

Tests: Describe a few basic parameters that you would wish to test, on the basis of what we have covered in the lab. Think about the most important parameters for the performance of the LED.

Number of wafers tested. We can get an awful lot of LEDs from one wafer. Also the manufacturers may buy in 100 wafers or more in each batch. As a result, we could make 10-100, 000 LED chips from a typical batch. Clearly we could not test every LED chip or every wafer. How many should we test and what method of selection should be used?

Recommendation (Reject or accept): Make a decision based on what you have seen in the lab as to whether to accept or reject wafers from the same batch as those used today. Please give as many reasons as possible why you made your decision. *(marks will be given for every good reason, but deducted for inaccurate or trivial reasons)*

Further tests: We have only done some very basic tests today. Can you recommend two further tests we should do? Why are these important? Describe briefly what equipment would be needed to perform these tests.

Parts 1 and 2 of the report should be posted in the black 'post box' in the corridor near to the department office with a cover sheet, following the usual procedure. The deadline is shown on the lab timetable.

This lab does not require Turnitin submission. However the usual rules on copying do still apply, so please make sure that your report is your own work