ENG5055: Micro and Nano Technology: Manufacture of a Red LED from a GaAs Substrate

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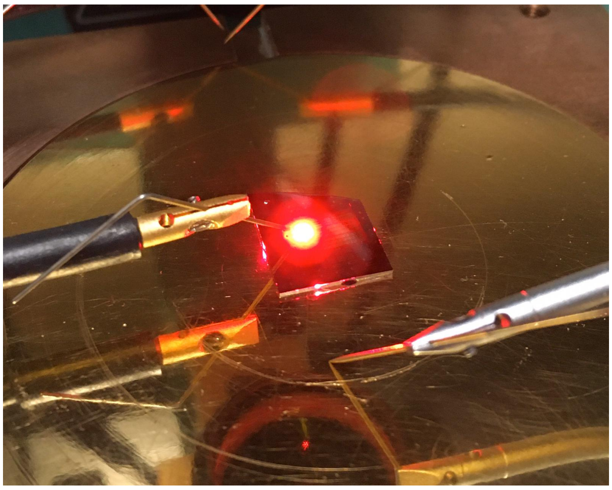

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List of Figures

1 Introduction

12.5%

Describe the motivation for making red LEDs [500 Words max + Figures]

LEDs are more energy efficient than traditional incandescent lighting

Narrow wavelengths.

LEDs can be very small for their optical power.

LEDs can be switched on and off very quickly, this is useful for PWM control for dimmable bulbs.

Televisions

LEDs are cost effective for use on a large scale

The basic function of a Light-Emitting Diode is that two semiconducting layers of types P and N

Longer Lifetime than incandescent

[1]

2 Fabrication

2.1 Cleanrooms

3.125%

Briefly describe why fabrication takes place within a cleanroom. [100 words max]

The clean rooms minimise contamination

there are different scales of cleanroom and so the results from fabrication can be more predictable, e.g. in terms of the likelihood of devices having errors. ¡– is this true?

A cleanroom is a controlled environment

Fabrication of electronic devices takes place in a cleanroom. Cleanrooms are controlled environments where atmospheric conditions are controlled. The class of a cleanroom specifies the number of particles of various sizes for a give volume of air. Guaranteeing the number and size of contamination particles in a fabrication process gives a reasonable approximation as to the feasibility and the probability of success. As devices become smaller, the need for better cleanrooms increases since smaller particles will have a greater effect on the performance and yield of the devices.

2.2 Cleans

3.125%

Briefly describe why we carry out steps 1 and 9. [100 words max]

Prior to spinning the photoresist for both the p-contact and the mesa etch, the substrates were cleaned to ensure that there was no contamination on the surface and to ensure that the photoresist was deposited correctly.

The cleaning process comprised of 3 minutes in an ultrasonic bath each for OptiClear, acetone and isopropanol (IPA) to remove any particles or organic compounds on the substrate surface. Special attention was given when transferring the substrate from the acetone to the IPA so that the acetone did not dry out and leave a residue. The substrate was then rinsed briefly in RO water before being dried thoroughly by the N2 gun. Lastly the substrate was ashed in an oxygen plasma for 3 minutes at 150W.

too many words.

2.3 Photolithography

9.375% Briefly describe the processes carried out in steps 2 and 10. Comment on the exposure parameters and choice of developer. [250 words max + Figures]

For the photolithography steps, the substrate was placed on a suitably sized vacuum chuck in a resist spinner. The vacuum was checked before spinning to ensure the substrate did not come off at high spin speeds. The resist used was Microposit S1818 which was spun at 4000rpm for 30 seconds. According to the S1800 series datasheet [2], this would result in the desired resist thickness of $1.8\mu m$. The S1818 was filtered as it was deposited and it was made sure the the majority of the substrate was covered prior to spinning

After spinning the back of the sample was cleaned with cotton bud soaked with acetone. This removed any unwanted photoresist and stopped the back of the sample contaminating or sticking to the hotplate.

After spinning the substrate was baked on a hotplate at 115°C for 120 seconds. This hardened the photoresist enough so that it would not stick to the photomask or that the resist structure would not collapse and distort after developing.

The SUSS MicroTec MJB4 mask aligner was used to align the masks on the substrate with a hard contact. The resist was exposed for XXXX seconds.

The resist was then developed in a 1:1 H_2O:Microposit developer concentrate for 75 seconds. After being rinsed in RO water and dried with the N2 gun, the substrate was again ashed in an oxygen plasma for 3 minutes at 150W to remove any residual resist.

2.4 Etching

9.375% In step 11, describe the choice of this etch process. What other process choices are there? Why do you think that this one was chosen? What advantages does this process have over other options? [250 words max]

Before etching, the depth of the resist was found to be 2022nm by the stylus profiler. The exposed areas of the substrate were wet etched for 60 seconds using a H_2SO_4:H_2O_2:H_2O 1:8:40 solution. The resist depth was measured again and found to be 2273nm giving an etch depth of 251nm. Since the thickness of the p+ GaAs contact layer is 150nm, the etch will have gone 101nm into the p-InGaAsP layer assuming the layer thicknesses are exact.

Another etching process is dry etching where the etchant is either a gas or plasma. Dry etching can have a slower etch rate and poor selectivity or etch ratio.

2.5 Metallisation

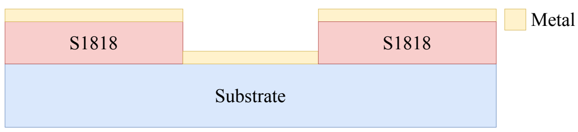
After developing the photoresist, the p-contact was metalised by evaporation deposition with Ti/Au 20/200nm. The back contact was then metalised by the same process with Ni/Au/Ge/Ni/Au 5/88/12/12/35nm.

After deposition, the metal was anneal by rapid thermal anneal at 400°C for 30 seconds. Annealing may be done for many reasons. It can reduce the resistance of the metal-semiconductor junction by reducing the trap density. The effect of this was not directly measure as the I-V response of contacts was not measured prior to annealing.

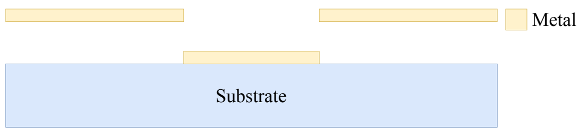
2.6 Lift-Off

9.375% Describe the concept of the lift-off process, using schematics as required. [150 words max + Figures]

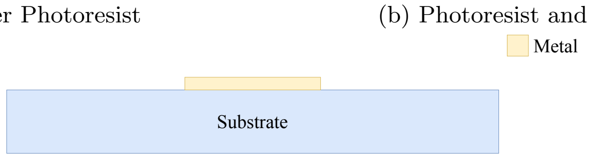
Once the resist has been exposed and developed and the metallisation steps have been completed, the remaining resist can be stripped leaving the desired metal patterns. The metal on the top of the resist will be removed alongside the resist, and the metal in contact with the substrate will remain. Figure 1 demonstrates this graphically.



(a) Single Layer Photoresist



(b) Photoresist and Lift-Off Resist Bilayer



(c) Single Layer Photoresist Developed with Flags

Figure 1: Comparison of Flagging from Single Layer and Bilayer Resist

For this process, the substrate was placed in a beaker of acetone in a 50°C bath for a few hours to dissolve the undeveloped resist. It was then cleaned in IPA to remove any acetone residue.

Suggest possible alternative process steps to achieve the same result as obtained in the lift-off process you have used. [50 words max]

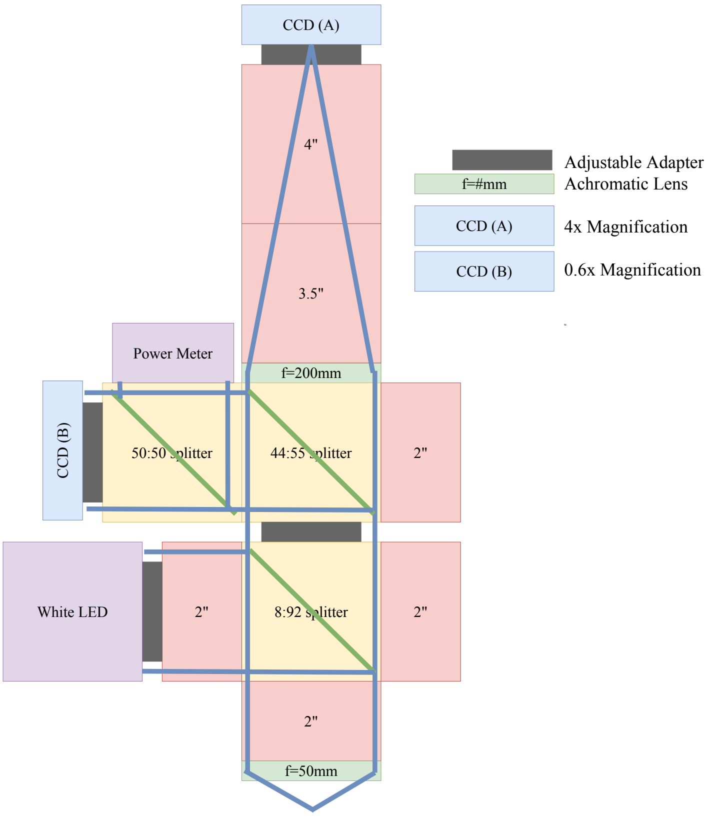


Figure 2: Schematic of the Test Apparatus. The device to be tested is placed at the focal point below the lens with a focal length of $50mm$

Either electron-beam lithography or a negative photoresist could also have been used to achieve the same metal pattern. E-beam would likely be unsuitable since the minimum feature size doesn't warrant it and if a negative photoresist process were to be used the photomask would need to be inverted.

3 Test

3.1 Apparatus

Figure 2 shows a schematic of the apparatus used to test the LED. The measured power on the power meter will not be absolute but rather as an indication relative to other measurements on the same apparatus. This is true for two reasons. The light goes through beam splitters before being measured. Also, the light from the LED emits light in all directions so only a fraction of the light pass through the apparatus in the first place.

3.2 I-V Characteristics

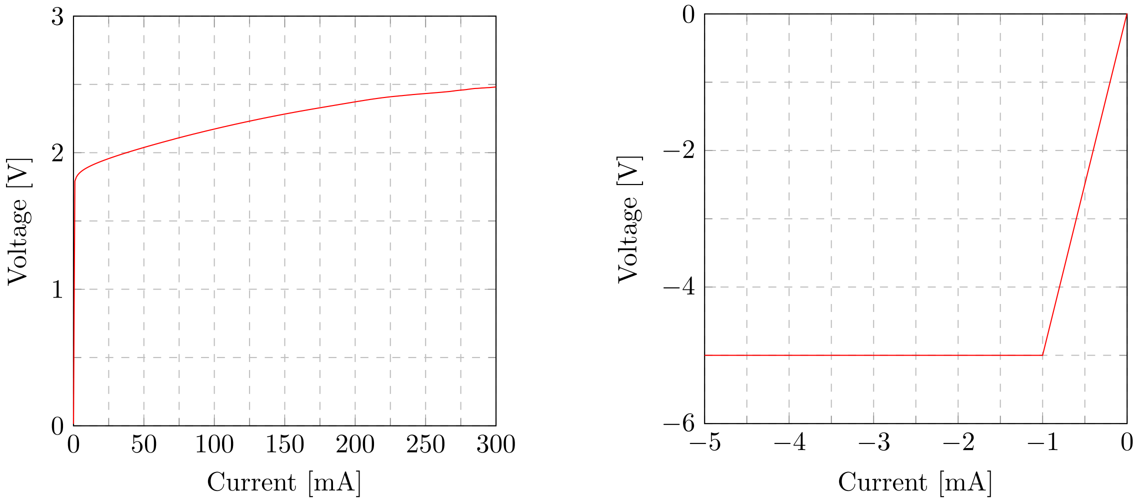
6.25%

Plot the forward and reverse bias VI characteristics of one of your diodes. Describe the salient features of the graphs [150 words max + Figures]

Figure 3 shows the forward and reverse current plots for this LED. The forward voltage turns on at $1.8V$ and increases to $2.5V$ at $300mA$. The reverse voltage doe not show a great deal. The voltage was limited to a range of $-5V$ to $5V$ and the first data point at $-1mA$ required more than $-5V$. As such, it shows a $-5V$ for all measured currents.

3.3 LI Characteristics

6.25%



(a) Forward Current

(b) Reverse Current

Figure 3: IV

Plot the output light power as a function of forward bias for one of your LEDs (or the standard). Describe the salient features of the graph. [150 words max + Figures].

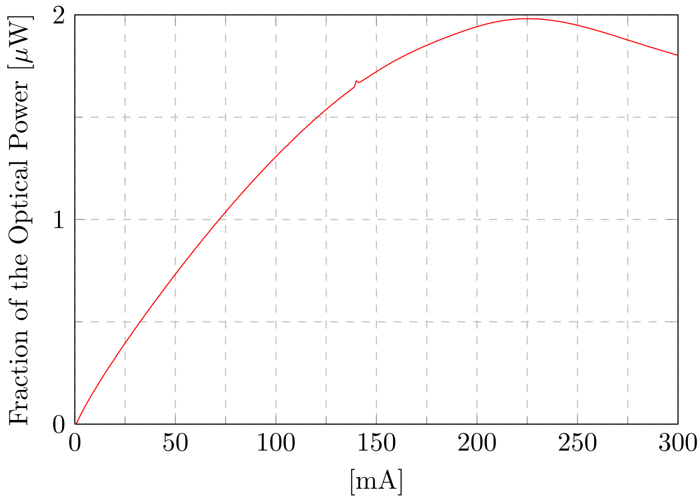


Figure 4: LI Characteristics

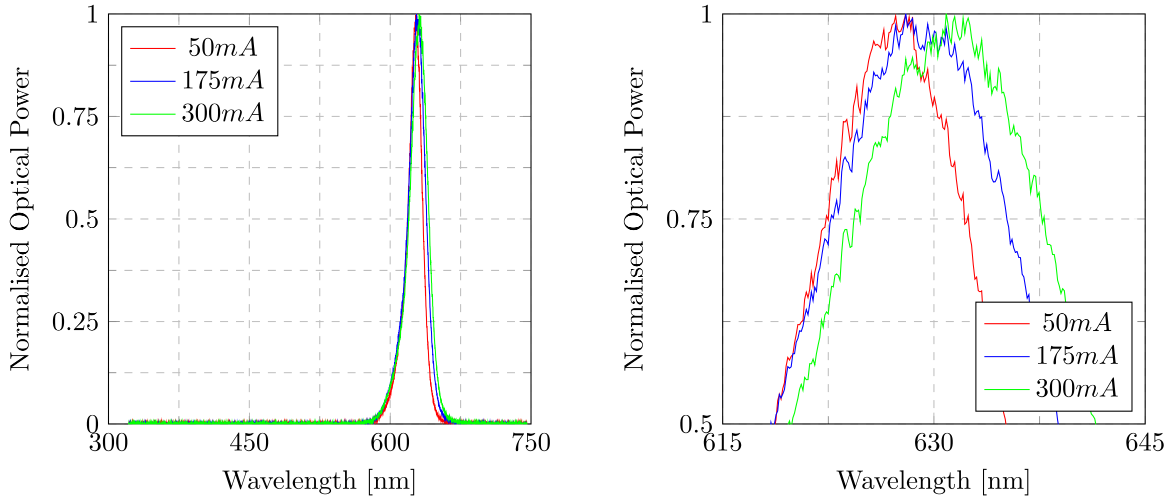
The optical power was measured against current from $0mA$ to $300mA$. As described in section 3.1, the power measured is not the total output power but a fraction. The results measurements are plotted in 4. This figure shows the optical power increase from $0mA$ to $220mA$ before decreasing again as the current increases to $300mA$. The peak power is not of any particular interest since it is not absolute but the current at which it occurs, $200mA$, is.

3.4 Spectral Characteristics

6.25%

Plot the emission spectra of your device as a function of current. Describe the salient features of the graph, and comment on any relationship to previous plots. Comment upon the collected power, system collection efficiency, and emitted power from the LED. [100 words max + Figures]

The emission spectra of the LED are plotted in figure 5. The spectrum was measured at $50mA$, $175mA$ and $300mA$. All plots are normalised to better understand the differences in spectrum. The peak optical power is around a wavelength of $630nm$. The exact peak is difficult to determine due to the



(a) Spectral Characteristics (b) Spectral Characteristics

Figure 5: Spectrum

noise on the measured signal, see figure 5b, but can be estimated to be approximately 627nm, 629nm, and 632nm for 50mA, 175mA and 300mA respectively. Even without a precise value, it is clear that there is a trend that the peak wavelength increases with the current.

3.5 Contact Resistance

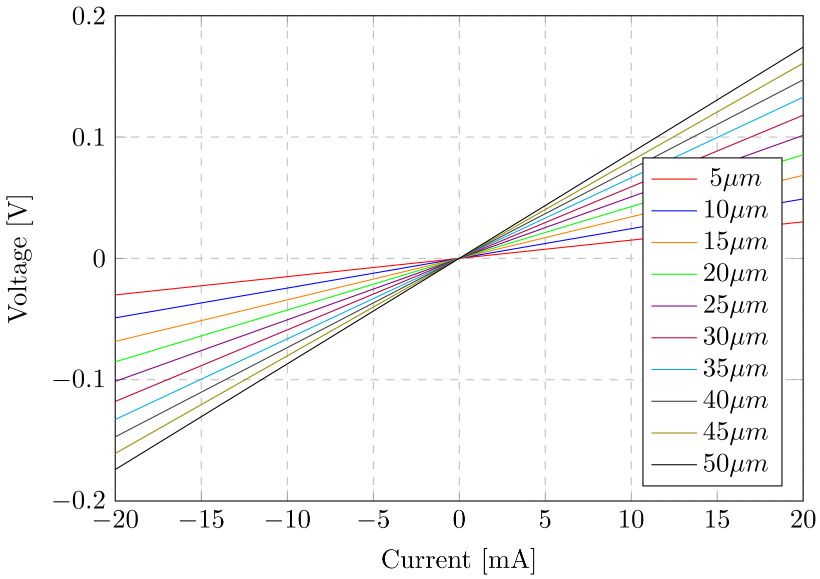


Figure 6: I-V Plot for CTLM Gaps from 5 to 50μm

6.25%

Plot CTLM results for one device from your group. Why do we use CTLMs over TLMs? Describe the salient features of the graph, and comment on any relationship to previous plots. Comment on why only the p-contact is analysed. [150 words max + Figures]

Figures 6 shows the I-V plot for all gap sizes measurements from the circular transfer length method (CTLM). The CTLMs had a radius of 200μm and gap sizes from 5 to 50μm in steps of 5μm. The plots for all gap sizes are close to linear implying that the contacts have an ohmic response.

The average resistance for each gap was found and plotted against the gap sizes, see figure 7. The

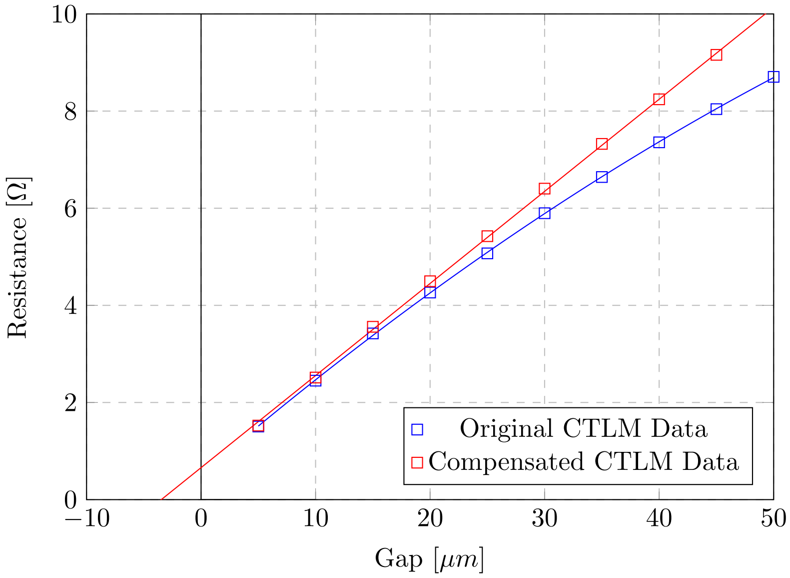


Figure 7: Plot of resistance against CTLM gap size with the as measured data in blue and the data with the correction factor shown in 1 applied shown in red. From the graph $2L_T = 3.473\mu m$, $2R_c = 0.659\Omega$, and $\rho_0 =$.......

gaps were not measured and are assumed to be exactly as designed. Due to the nature of CTLMs, the radii of the two contacts cannot be equal. It is therefore necessary to include a correction factor which is found using equation 1

$$C = \frac{1}{R_1} ln(\frac{R_1 + S}{R_1}) \tag{1}$$

When the line of best fit for the corrected resistance values, shown in red, on figure 7 are extrapolated it is found that the resistance values when the gap size is $0\mu m$ the resistance is 0.659Ω. This is equivalent to $2R_c$.

4 Commentary

15.625%

Highlight any process steps that you think may need more attention should you repeat the fabrication process. How would you redesign the process sequence if the scribe and break at process number 8 could be moved to the end? Comment upon how the LED operation varies with mesa diameter. Suggest how you may make the LED operate more efficiently. [300 words max + Figures].

References

[1] A. Einstein, "Zur Elektrodynamik bewegter Körper. (German) [On the electrodynamics of moving bodies]," *Annalen der Physik*, vol. 322, no. 10, pp. 891–921, 1905.

[2] Shipley microposit s1800 series photo resists. [Online]. Available: https://amolf.nl/wp-content/uploads/2016/09/datasheets_S1800.pdf