EE236 : Electronic Devices Lab
Lab 1 [Tuesday Batch]

Prajwal Nayak (22B4246)

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1 Readings

1. **1N914 :-**

V_D(Volts)	I_D(mA)
0.4	0.00
0.5	0.10
0.55	0.31
0.6	0.78
0.65	2.20
0.7	5.70
0.75	15.14
0.44	0.01
0.77	19.01
0.72	7.5
0.725	10
0.741	12.5
0.76	17.5

2. **Blue LED :-**

V_D(Volts)	I_D(mA)
2.59	0.00
2.62	0.01
2.65	0.02
2.70	0.07
2.75	0.16
2.8	0.36
2.85	0.91
2.9	1.66
3	4.94
3.05	7.40

3. **White LED :-**

V_D(Volts)	I_D(mA)
2.35	0.00
2.36	0.01
2.4	0.03
2.45	0.12
2.5	0.22
2.55	0.51
2.60	1.01
2.65	2.06
2.70	3.45
2.75	4.85
2.80	6.69
2.84	8.55

4. **Green LED :-**

V_D(Volts)	I_D(mA)
2.11	0.00
2.12	0.01
2.15	0.03
2.20	0.11
2.25	0.30
2.30	0.54
2.35	0.80
2.40	1.18
2.45	1.72
2.50	2.24
2.55	2.86
2.60	3.50
2.65	4.46
2.70	5.37
2.75	6.41
2.80	7.06
2.85	8.46

5. **Red LED :-**

V_D(Volts)	I_D(mA)
1.63	0.00
1.64	0.01
1.65	0.02
1.7	0.08
1.75	0.30
1.8	1.15
1.85	2.71
1.9	4.82
1.95	8.13
2.00	12.79
1.91	6.00
1.927	7.50
1.962	10.04

2 Circuit

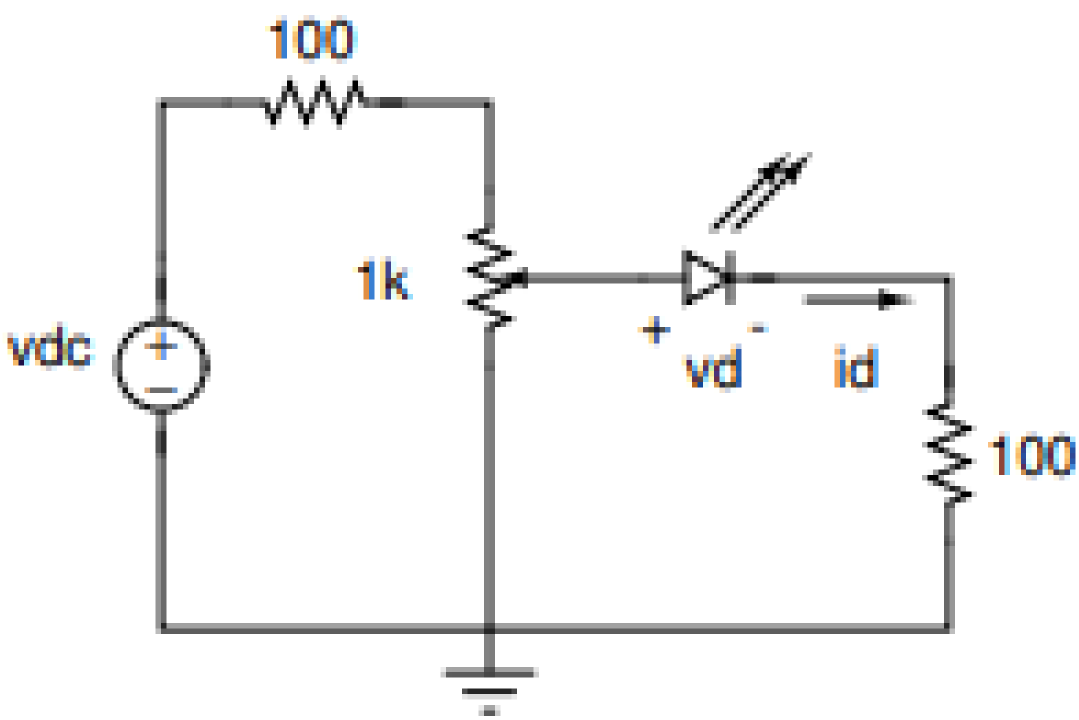
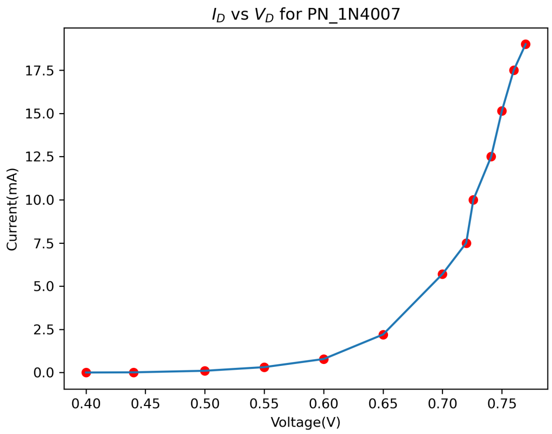
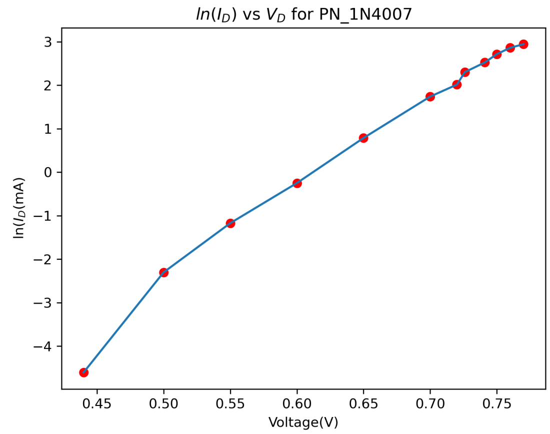


Figure 1: Circuit

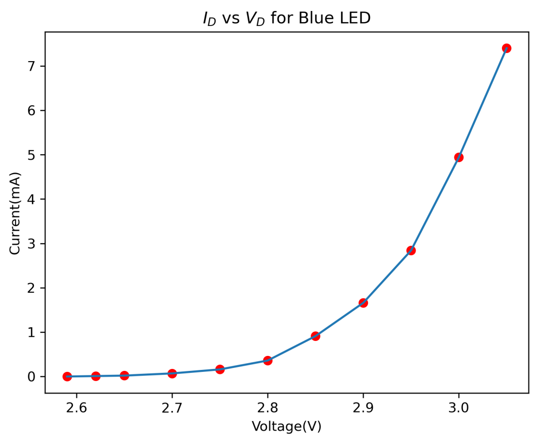
3 Plots

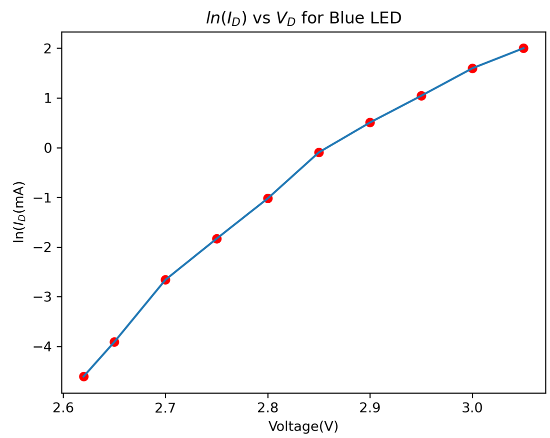
1. 1N914:



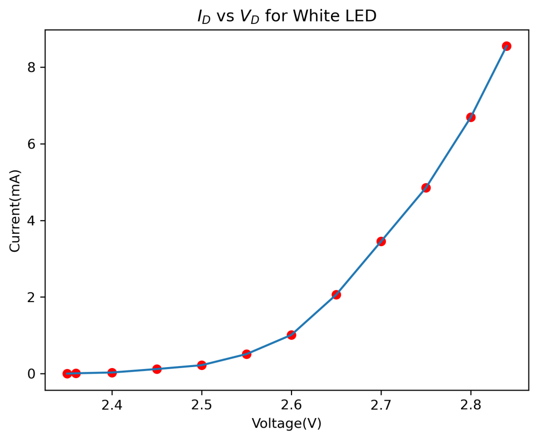


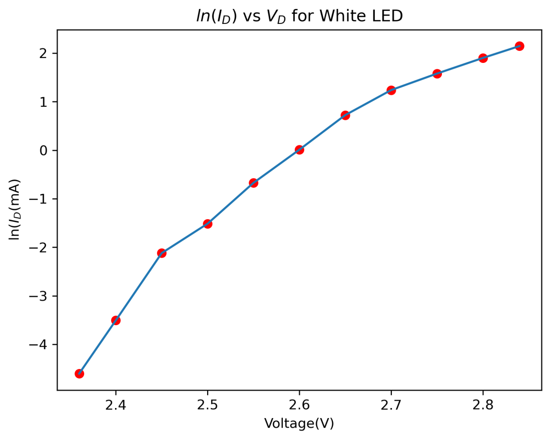
2. Blue LED:



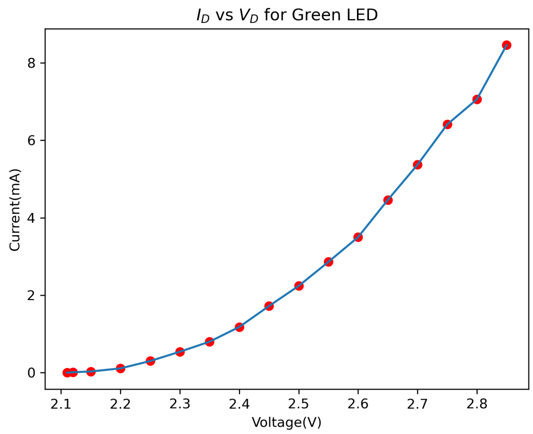


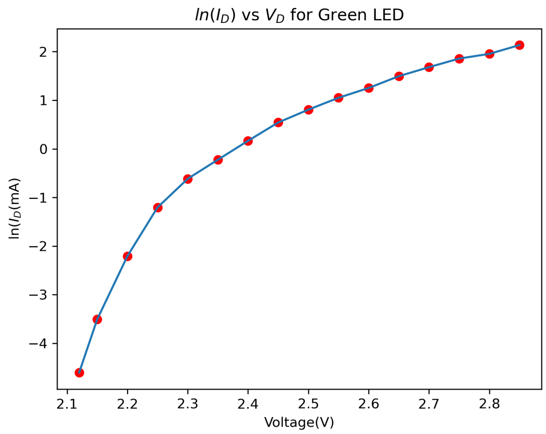
3. White LED:



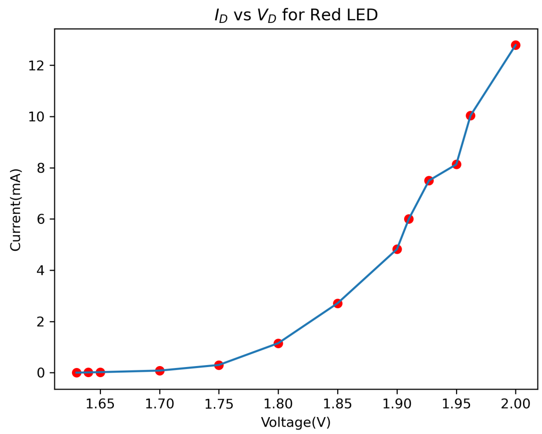


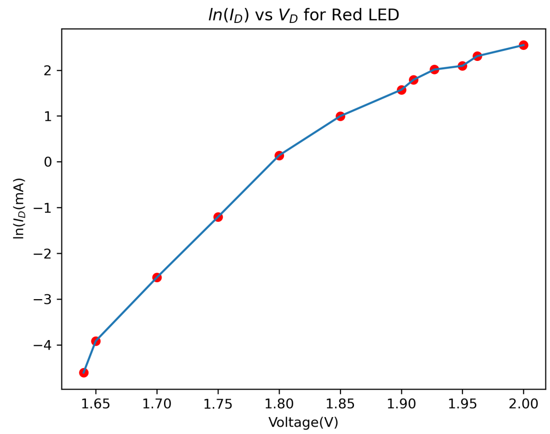
4. Green LED:





5. Red LED:





4 Ideality Factor and Saturation Current

The following are the steps to get ideality factor(η) and saturation current(I_S) from slope and intercept (which we obtain by linear regression) respectively:

1. Linear regression of the points ln(I_D) vs V_D gives us a line of the form:

$$ln(I_d) = cV_o + d \tag{1}$$

2. The I/V characteristic of a forward biased diode is given by:

$$I_D = I_{00}e^{-\frac{E_g}{kT}}(e^{\frac{qV_D}{\eta kT}} - 1) \tag{2}$$

This equation holds for all positive values of V_D

3. The saturation current is given by:

$$I_S = I_{00}e^{-\frac{E_g}{kT}} \tag{3}$$

4. Using equations (2) and (3):

$$I_D = I_S(e^{\frac{qV_D}{\eta kT}} - 1) \tag{4}$$

5. Assuming qVD >> ηkT and applying logarithm to the base e on both sides of equation (4), we get:

$$ln(I_D) = \frac{qV_D}{\eta kT} + ln(I_S) \tag{5}$$

Since this equation is an approximation, it holds for only high positive values of V_D

6. Comparing equation (1) with equation (5), we can relate the two:

$$c = \frac{q}{\eta kT} => \eta = \frac{q}{ckT} \tag{6}$$

$$d = ln(I_S) => I_S = e^d \tag{7}$$

7. The following is the table of values of ideality factor and saturation current of the given diodes and LEDs:

Diode	Slope	η	Intercept	I_S
1N914	21.5246	1.787	-13.38	1.54 x 10^{-9}
Blue LED	15.37	2.502	-16.36	5.428 x 10^{-10}
White LED	13.58	2.8322	-35.75	2.97 x 10^{-16}
Green LED	7.905	4.865	-19.538	3.27 x 10^{-9}
Red LED	19.82	1.9405	-36.3	1.72 x 10^{-16}

5 Band Gap

The way to calculate band gap includes the following steps:

1. From the data obtained from experimentation, compare with the graphs given below and check at what wavelength the peak occurs. The graphs for the different LEDs are as follows:

2. We can get the wavelength from the graphs and then calculate the band gaps using the following equation:

$$E_g = \frac{hc}{\lambda} = \frac{1240}{\lambda} \tag{8}$$

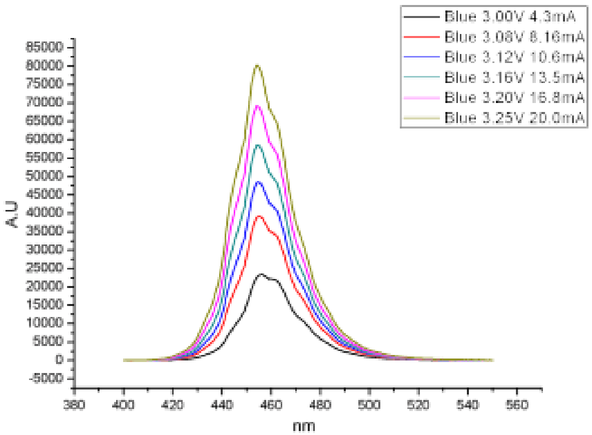
   Here λ is in nanometers and E_g is in eV.

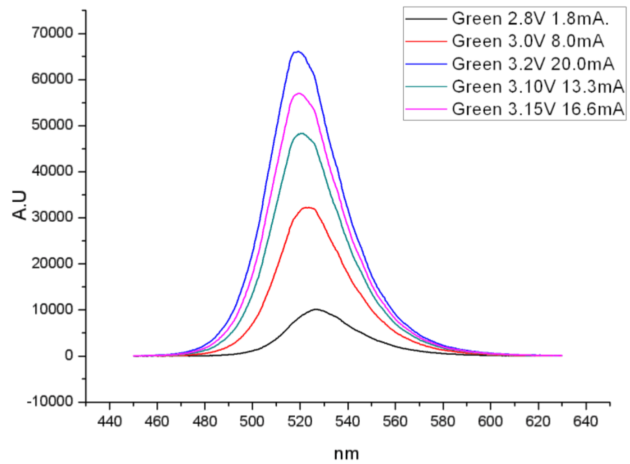
3. The following table shows the values of λ and E_g accordingly.

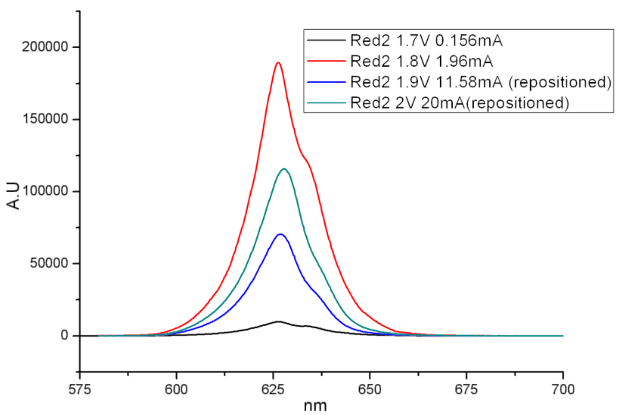
Diode	λ(nm)	E_g(eV)
1N914		1.1
Blue LED	450	2.755
White LED	550	2.254
Green LED	520	2.385
Red LED	620	2

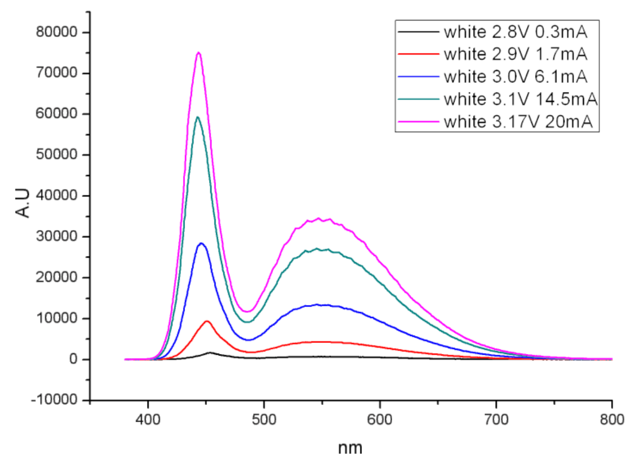
6 Cut-in voltage and its relation with band gap

The following is the table showing cutting voltage with cut-in voltage:









Diode	V_γ(Volts)	E_g(eV)
1N914	0.61	1.1
Blue LED	2.86	2.755
White LED	2.6	2.254
Green LED	2.36	2.385
Red LED	1.79	2

The following is the plot when linear regession is performed on points of V_γ v/s E_g. The R^2 value turns out to be 0.95398 which implies linear model fits the data pretty well.

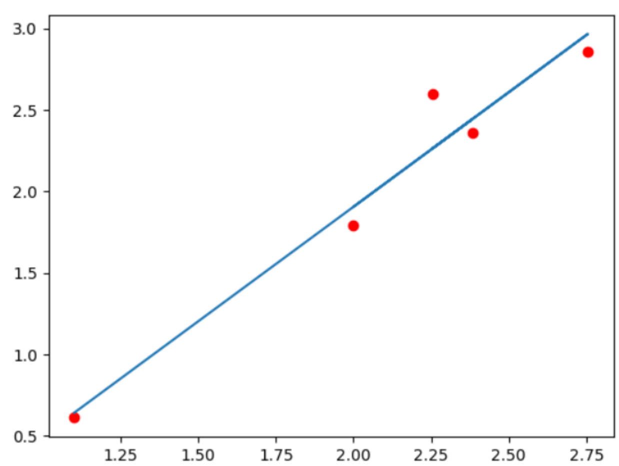


Figure 2: V_γ v/s E_g

Let us check if this is in accordance with our mathematical expectation :

$$I_D = I_S e^{\frac{V_D}{\eta V_T}} \tag{9}$$

Since I_D is much larger than I_S for practical purposes, we can simplify. The following is the equation of saturation current:

$$I_s = I_{00} e^{-\frac{E_g}{kT}} \tag{10}$$

For a diode to start conducting appreciably, we need to find the voltage at which the diode current I_D reaches a specific value, typically chosen as 1 mA for the cut-in voltage V_γ. So, let's set I_D to 1 mA and solve for V_D:

$$1mA = I_S e^{-\frac{V_\gamma}{\eta V_T}} => V_\gamma = \eta V_T ln(\frac{1mA}{I_S}) \tag{11}$$

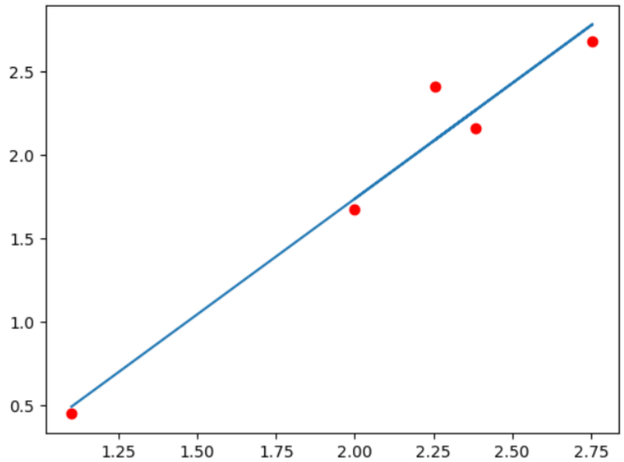
Substituting I_S into the expression for V_γ

$$\begin{aligned} V_\gamma &= \eta \frac{kT}{q} ln(\frac{1mA}{I_{00} e^{-\frac{E_g}{kT}}}) \\ &= \eta \frac{kT}{q} (ln(\frac{1mA}{I_{00}}) + \frac{E_g}{kT}) \\ &= \eta \frac{kT}{q} ln(\frac{1mA}{I_{00}}) + \eta \frac{kT}{q} \frac{E_g}{kT} \\ &= \frac{\eta E_g}{q} + constant \end{aligned} \tag{12}$$

So we the mathematics we got with lives upto our experimental data. Now let us check the values for V_γ v/s E_g for $I_D = 50\mu$A and 5 mA

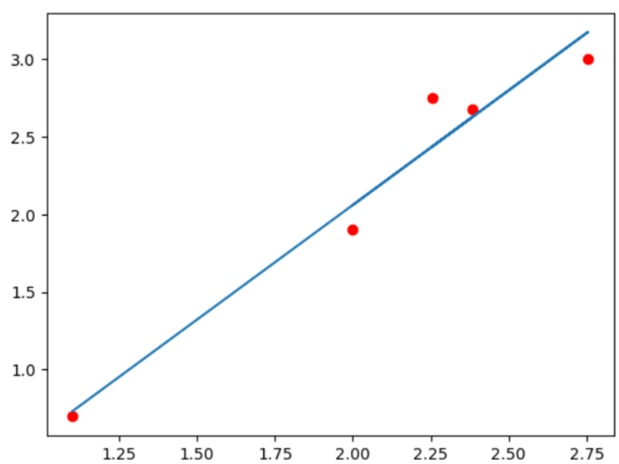
For $I_D = 50\mu$A

Diode	V_γ(Volts)	E_g(eV)
1N914	0.45	1.1
Blue LED	2.68	2.755
White LED	2.411	2.254
Green LED	2.1625	2.385
Red LED	1.675	2



The R^2 value turns out to be 0.957446 which implies linear model fits the data pretty well.
For I_D = 5mA

Diode	V_γ(Volts)	E_g(eV)
1N914	0.697	1.1
Blue LED	3.001	2.755
White LED	2.754	2.254
Green LED	2.679	2.385
Red LED	1.9001	2



The R^2 value turns out to be 0.95428 which implies linear model fits the data pretty well.

7 Finding other semiconductor parameters

Calculate the intrinsic doping densities of all the LEDs. Assuming density of states are approximately same for all the semiconductor materials, we have:

$$n_i \propto e^{-(\frac{E_g}{2KT})} \tag{13}$$

where E_g is the bandgap energy, k is the Boltzmann constant, and T is the temperature (typically 300 K). I calculate n_i relative to a known reference value using this formula. Next, I compute the doping density N_A using the built-in potential (V_{bi}) with the formula

$$V_{bi} = kTln(\frac{N_A^2}{n_i^2}) => N_A = n_i \times e^{V_{bi}\frac{q}{2kT}} \tag{14}$$

where q is the elementary charge. Since N_A is approximately equal to N_D, this approach allows me to determine the doping concentration by solving the equation derived from the built-in potential and intrinsic carrier concentration. This process helps me understand the electronic properties and optimize the performance of the semiconductor devices.

8 Final Table

Table 1: Parameters of Diodes

Diode	E_g (eV)	I_s (A)	V_{TH} (V)	n_i (cm^{-3})	N_A (cm^{-3})
1N914	1.1	1.54×10^{-9}	0.4	1.5×10^{10}	1.06×10^{17}
Blue LED	2.755	5.428×10^{-10}	2.59	1.6×10^{23}	1.77×10^{43}
White LED	2.254	2.97×10^{-16}	2.35	1.6×10^{23}	1.0111×10^{-5}
Green LED	2.385	3.27×10^{-9}	2.11	2.8×10^{20}	6.62×10^{38}
Red LED	2	1.72×10^{-16}	1.63	3.3×10^{17}	5.2×10^{31}

9 Experiment completion status

The experiment with all the measurements was performed in the lab.