Háskóli Íslands
Rafmagns- og tölvuverkfræði

Rafeindatækni fastra efna
December 2, 2005

HÁSKÓLI ÍSLANDS

Light and Laser Diodes

Students:
Sveinn Steinar Benediktsson
Sævar Öfjörð Magnússon

1 Introduction

LEDs (Light Emitting Diodes) and laser diodes have become increasingly more important in various applications, LEDs are used to build huge full color billboard displays, and laser diodes are used in the communications industry to transmit data and phone conversations via optical fibers. Recently, a development team managed to fabricate a LED using only silicon (Si), which means that the merger of conventional semiconductor electronics and optoelectronics is close. Already, scientists have managed to transmit data optically with a silicon laser at a rate of 10 Gb/s, competing with state of the art fiberoptics communications systems. This could also mean the introduction of optical connections between chips, removing the bandwidth bottleneck created by a circuit's copper wiring.
In this short study we review the basic properties of LEDs and laser diodes.

2 Light Emitting Diode (LED)

2.1 Light intensity measurement

A measurement of light intensity from a LED (Light Emitting Diode) measured with a Si-sensor that is connected to a picoampere-meter.
The LED and a resistance were connected in series with a function generator and a picoampere-meter, as can be seen in the figure below.

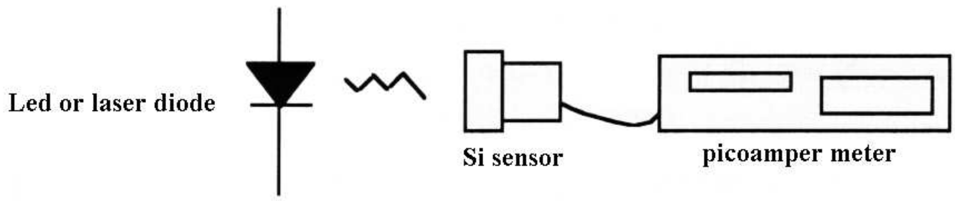

Figure 1: Equipment setup

We observe the relationship of the current through the diode with the intensity of the emitted light. By varying the resistance in the circuit and measuring the voltage across it the current can be found by Ohm's law. The resistance values we used ranged from 10Ω to 10000Ω. The results of our measurements are shown in the graph below
We see from the graph above that the light intensity increases linearly as the current increases. The equation for the line is:

$$ln(P_{LED}) = k \cdot ln(\frac{V}{R}) + b \quad (1)$$

Where k is the slope of the line and b is the intersection with the y-axis. We used linear regression to obtain the slope and intersection of the trendline, and found that $k = 0.7076$.

We also need to determine the efficiency of the LED. We can estimate that the power dissipated in the diode is approximately

$$P_L \approx I_L^k R_L,$$

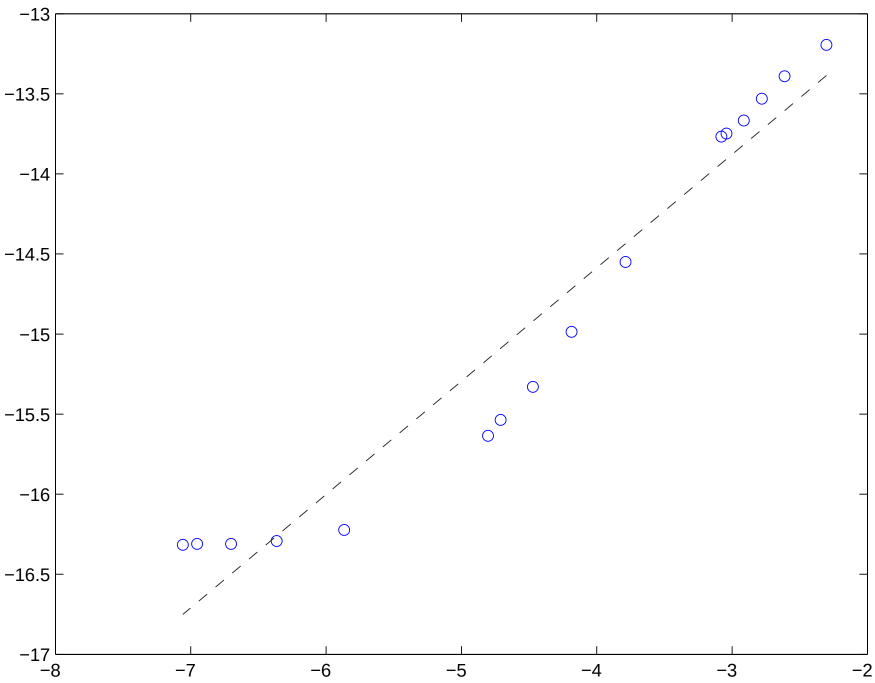

Figure 2: Light power vs. current (log-log)

where R_L is the resistance of the diode. We want to compare this to the power dissipated if R_L were a normal resistor:

$$P_R = I_L^2 R_L$$

Thus, the efficiency is

$$\eta = \frac{I_L^k R_L}{I_L^2 R_L} = \frac{e^k}{e^2}, \tag{2}$$

in our case (as the graph is log-log). We conclude that the efficiency is $\eta \approx 27.44\%$.

2.2 Spectrum measurements

The emitted light from the diode is passed through a spectrometer and the power of the light at each wavelength is measured with the Si-sensor and a frequency locked amplifier as shown in figure 3.
We used a minimum resistance value of 10Ω, giving us our maximum current through the LED. The spectrometer slit was set to 2000μ and measurements were taken every $3nm$, resulting in the graph in figure 4.
From this graph we were able to calculate the FWHM (Full Width at Half Maximum) for the diode:

$$\lambda_{\text{FWHM}} \approx 38.5\,nm$$

We also see from the graph that the light intensity peaks at

$$\lambda_p \approx 599\,nm$$

Now it is easy to calculate the energy gap of the semiconductor:

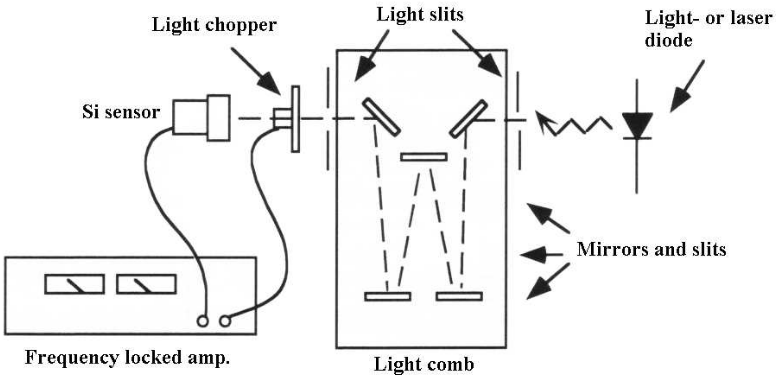

Figure 3: Equipment setup

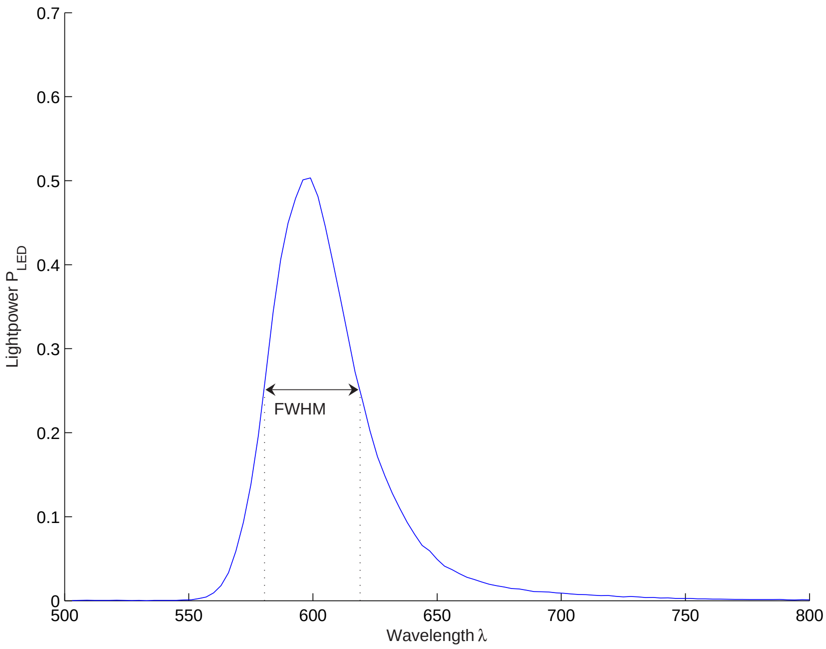

Figure 4: Lightpower as a function of wavelength for the LED.

$$E_g = \frac{h \cdot c}{\lambda_p} \tag{3}$$

Where h is Planck's constant and c is speed of light. We now know that the energy gap is

$$E_g \approx 2.06\, eV$$

The most common alloy composition used in LEDs is $GaAs_{1-x}P_x$, where x is a percentage read from figure 8.11 in Streetman & Banerjee. We estimate that the composition in the semiconductor we used is $GaAs_{0.6}P_{0.4}$.

3 Infrared Laser Diode (LD)

3.1 Light intensity measurement

Here, we wanted to measure the light intensity from a laser diode with a Si-sensor connected to a picoamper-meter. The setup is similar as displayed in figure 1.
We measured the current through the diode with the multimeter and the current from the Si-sensor. From the graph below we observe the relationship of the current through the diode with the intensity of the light emitted.

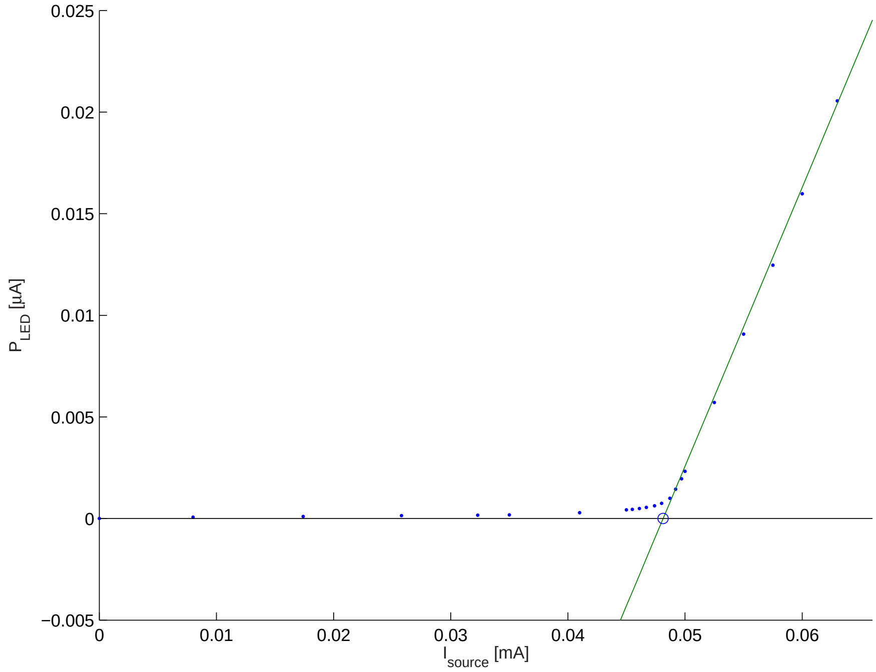

Figure 5: Light intensity of a laser diode as a function of current.

From the graph we can see that the light intensity of the diode increases very little until the threshold current I_{th} is reached. That is when

$$I_{th} \approx 48.1\,mA. \tag{4}$$

3.2 Spectrum measurements at different current levels

Finally, we measured light intensity of the laser diode at different wavelengths with three different current levels; below threshold current I_{th}, slightly above threshold current, and with maximum current. We start by displaying results from the maximum current measurement. Then we can estimate the wavelength where the light intensity peaks, and the FWHM for the laser diode.
The graph shows us that FWHM for the laser diode is

$$\lambda_{\text{FWHM}} = 0.25\,nm.$$

We now see that the bandwidth for the laser diode is much smaller than the bandwidth for the LED. This means that laser light is much more homogenous than light from ordinary

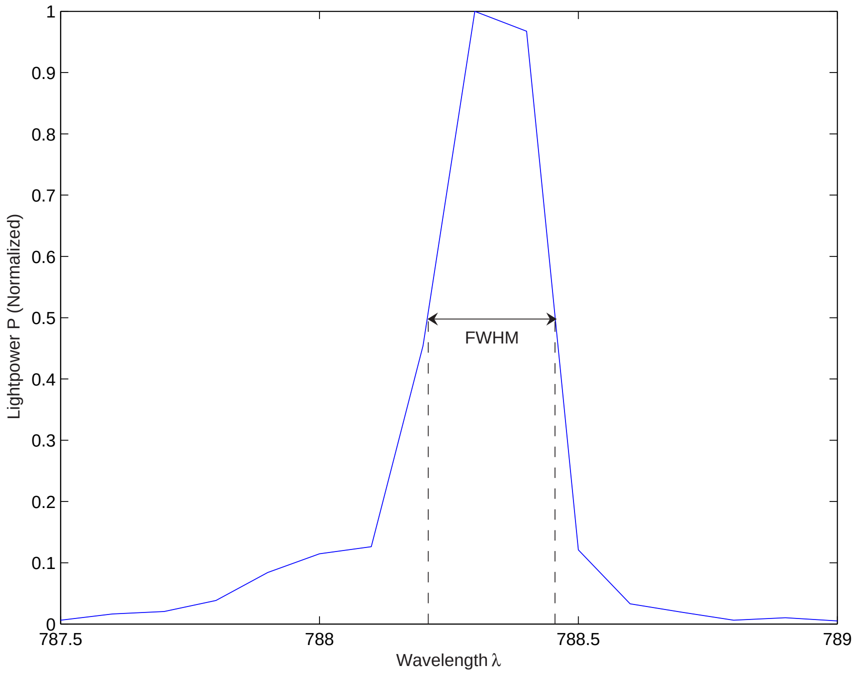

Figure 6: Light intensity of a laser diode as a function of wavelength.

LEDs.
We can also see at which wavelength the diode emits the most light intensity, that is at

$$\lambda_0 \approx 788.36\,nm$$

Next figure clearly shows the difference between the three current levels. The widest curve is when the current is slightly below threshold. The narrow peak is same as from figure (4), for the maximum current. The dashed line is when the current is slightly above threshold.
When the current has reached slightly above the threshold, stimulated emissions occur at frequencies corresponding to the cavity modes. The modes correspond to the integral of half-wavelengths, m, fitted within the cavity. The relationship of m, the length of the semiconductor L, refractive index n and the dominating wavelength λ_0 is:

$$m = \frac{2Ln}{\lambda_0} \tag{5}$$

Differentiating the equation in terms of λ_0 yields

$$-\Delta\lambda_0 = \frac{\lambda_0^2}{2Ln}\left(1 - \frac{\lambda_0}{n} \cdot \frac{\delta n}{\delta\lambda_0}\right)^{-1} \Delta m \tag{6}$$

Where $\Delta\lambda_0$ is the wavelength between modes m. We assume n=3.6, $\frac{\delta n}{\delta\lambda_0} = 0$ and $m = -1$ to obtain the equation for the length of the semiconductor, that is:

$$L = \frac{\lambda_0^2}{7.2\Delta\lambda_0} \tag{7}$$

From figure (7) we observe that

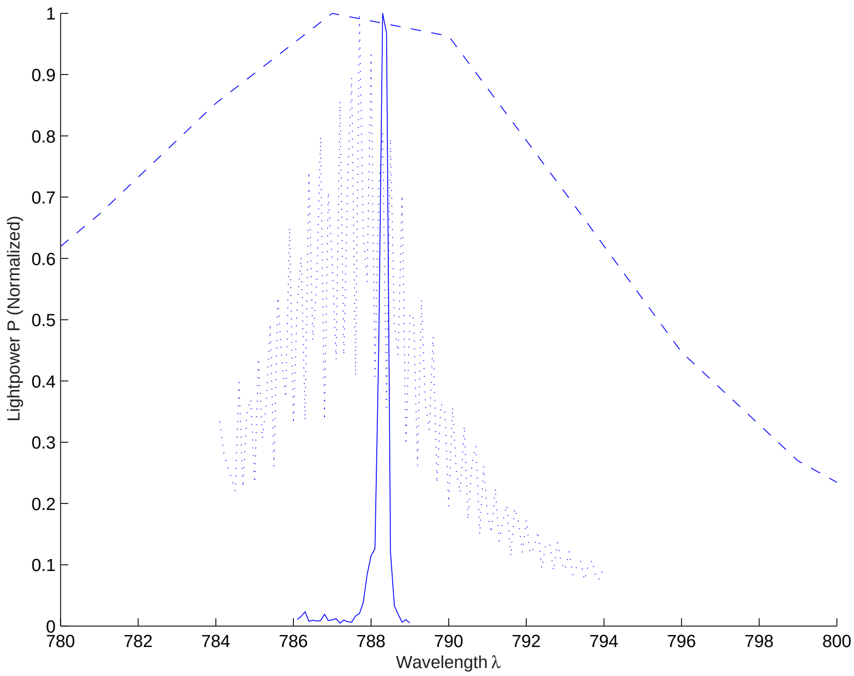

Figure 7: Light intensity of a laser diode as a function of wavelength.

$$\Delta\lambda_0 = 0.3nm.$$

Thus, the length of the semiconductor is

$$L = 288\mu m.$$

4 Conclusion

We have observed some of the basic properties of LEDs and laser diodes and established a basic understanding of how light is emitted from semiconductors. We have seen that light intensity increases proportional to the current through the LED and we have found the efficiency coefficient. Then we measured the light intensity as a function of wavelength to determine the bandwidth of the LED and the wavelength at peak intensity. From there we were able to determine the energy gap of the semiconductor, and, eventually, the length. For the laser diode we measured the light intensity as a function of wavelength
In section 1.2 we measured the light intensity as a function of the wavelength to obtain the Full Width at Half Maximum and determined what type of semiconductor the diode was made of.

In section 2.1 we determined the current threshold at which stimulated emissions begin and in 2.2 we observed the difference of wave-spectrum at maximum current and then slightly above and below current threshold. We also calculated the length of the semiconductor.