Band-gap | Semiconductor

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February 2015

1 Theory

We state without justification that in a semiconductor, the I-V characteristics are given by

$$I = I_0 \left(e^{\frac{eV}{kT}} - 1 \right)$$

where I_0 is given by (again without justification)

$$I_0 = AT^{3+\frac{\gamma}{2}} e^{\frac{-E_g}{kT}}$$

and e is electronic charge, V is voltage, k is the Boltzmann constant, γ is also assumed to be constant, T is absolute temperature and E_g is the bandgap energy.

If we further assume that

- in the first equation, the factor of 1 can be neglected (assertion: which is typically the case)
- in the second equation, $AT^{3+\frac{\gamma}{2}}$ is roughly constant compared to the exponential term

then we can write $I = Be^{\frac{eV}{kT} - \frac{E_g}{kT}}$, where definition of B is implicit ($B = AT^{3+\frac{\gamma}{2}}$). This is the equation we'll work with. We have

$$kT \ln I = kT \ln B + eV - E_g$$
$$T = \frac{e}{k \ln(\frac{I}{B})} V - \frac{1}{k \ln(\frac{I}{B})} E_g$$

Now it is clear that we expect a linear relation between T and V.

1.1 E_g and its error analysis

We start with defining some quantities by comparing with $T = mV + c$ as

$$g \equiv k \ln \frac{I}{B}$$
$$m \equiv e/g$$
$$c \equiv -E_g/g$$

which implies (if $e = 1$ (electron volts unit)),

$$E_g = -c/m$$

If c has a relative error $\pm\frac{\Delta c}{c}$, and m has a relative error $\pm\frac{\Delta m}{m}$, then the relative error in E_g will be

$$\frac{\Delta E_g}{E_g} = \frac{\Delta c}{c} + \frac{\Delta \mathrm{m}}{m}$$

Note that the absolute temperature $T = T_{^0C} + 273.15$ and our theoretical result holds for T in kelvins only. Thus if we substitute for T in our linear relation to get $T_{^0C} = mV + c'$, we'll get $c' = c - 273.15$. From the graph, we'll get c' which can be related to E_g as

$$E_g = -\frac{c' + 273.15}{m}$$

where (repeating for clarity), m is the slope and c' is the intercept when we plot the temperature in ^0C.

2 Experimental Setup

The setup is rather simple to use. We are given a device that can control the current through a component (LED or diode in our case) and show the voltage drop across it. This device also has an attachable thermometer. The component and the thermometer both are immersed in a container containing oil and this container can be heated using a heater. One could also use ice to accelerate the cooling, if the system is at a high enough temperature already.

2.1 Procedure

The procedure then is obvious.

- We attach the component to the terminals of the given device (one with a display)
- We set the current to the desired value (say $10\,\mu A$)
- We plugin the thermometer also into the device

- We immerse both the thermometer and the component into the heating chamber and initiate the heating. Its made sure that
  - the component and thermometer's sensor are as close to each other as possible
  - both are roughly in the centre of the container (to avoid inhomogeneous heating)
- We wait till the temperature rises to say 120 ^0C and then let the temperature fall
  - while that happens, we record temperature (T) and voltage (V) everytime the value of V on the display changes.

3 Observations

3.1 Time-line

Feb 9	Monday	Started reading the theory
Feb 10	Tuesday	Completed the record of the previous experiment | started performing the next experiment | red LED observations taken (by Sagar)
Feb 13	Thursday	Performed the experiment with a green LED | wrote the code for data analysis and plotting | printed the record of the previous experiment
Feb 16	Monday	Completed the analysis and record | starting with the theory of the next experiment

3.2 Readings and analysis

We performed the experiment for two semiconductors, a red LED and a green LED.

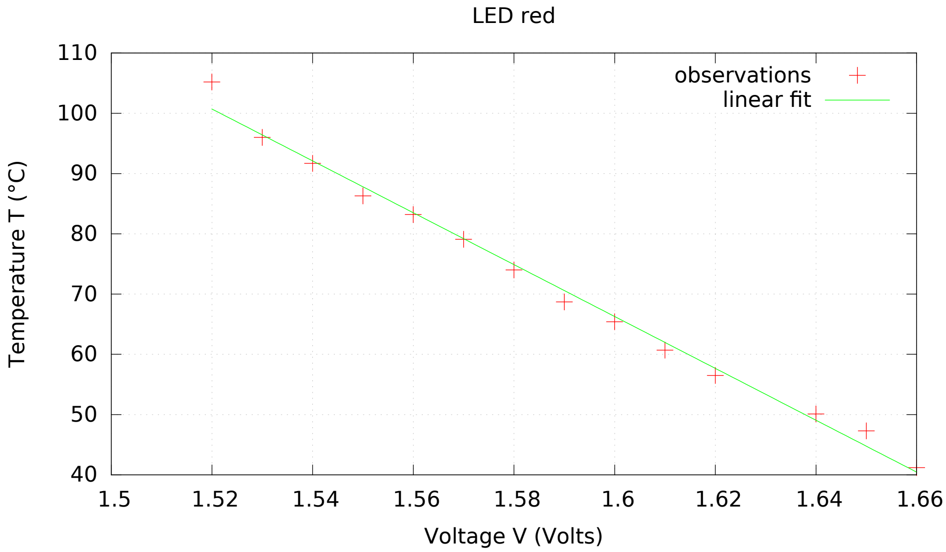
Red LED I=70 uA

Temperature (T) [C]	Voltage (V) [V]
105.2	1.52
96	1.53
91.7	1.54
86.3	1.55
83.2	1.56
79.1	1.57
74	1.58
68.7	1.59
65.4	1.6
60.7	1.61
56.5	1.62
50.1	1.64
47.3	1.65
41.2	1.66

Green LED I=70 uA

Temperature (T) [C]	Voltage (V) [V]
120	1.51
116.9	1.52
113	1.53
108.9	1.54
106	1.55
102.7	1.56
98.6	1.57
93.1	1.58
90.6	1.59
86.9	1.6
83	1.61
79.2	1.62
75	1.63
70.1	1.64
65.8	1.65
62.5	1.66
53.9	1.67
49.4	1.68
46	1.69
41	1.7
39.4	1.71

3.2.1 Red LED

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Final set of parameters            Asymptotic Standard Error
=======================            =========================

m               = -430.516         +/- 11.12        (2.583%)
c               = 755.105          +/- 17.66        (2.338%)
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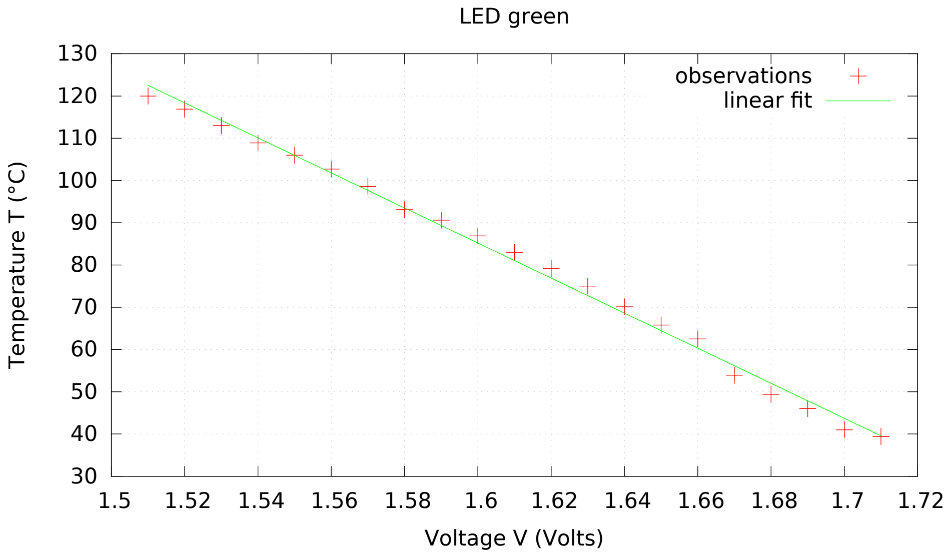
Thus, the value of $E_g = 2.3884 \pm 0.117(4.921\%)\, eV$

3.2.2 Green LED

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Final set of parameters            Asymptotic Standard Error
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m	= −414.844	+/− 6.599	(1.591%)
c	= 748.947	+/− 10.63	(1.42%)

Thus, the value of $E_g = 2.463 \pm 0.074\,(3.01\%)\,eV$

4 Results and Critique

The value of E_g was found to be $2.463 \pm 0.074\,eV$ for a green LED and $E_g = 2.3884 \pm 0.117\,eV$ for a red LED. The relation was found to be linear to about 2%. One could make the experiment performance faster by using ice to cool down the system. Other than this, the experiment seemed to be reasonably well setup.

5 Acknowledgements

I thank my teammates for their contribution in performance of the experiment and discussion of the theory. The lab manual was referred to for the theory (since I don't fully understand the derivations of the equations we started with).