Forbidden energy gap in semiconductors

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1 Theory

The I-V characteristics of a semiconductor are given by:

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

Where,

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

Here e is electronic charge, V is voltage across the semiconductor, k is the Boltzmann constant, T is the temperature in kelvin and E_g is the bandgap energy.

If we assume that $e^{\frac{eV}{kT}} >> 1$ and $AT^{3+\frac{\gamma}{2}}$ is roughly constant $(= C)$ then we can write $I = Ce^{\frac{eV}{kT} - \frac{E_g}{kT}}$. Taking log on both sides,

$$kT \ln I = kT \ln C + eV - E_g$$
$$\ln(\frac{I}{C}) = \frac{eV - E_g}{kT}$$

So, T and V are linearly related if all the other quantities are assumed to be constant.

2 Procedure

The experiment is rather simple. We have a device that can control the current through an LED and detect the voltage drop across it as well as its temperature. The LED and the thermometer are immersed in a container containing silicon oil and the temperature is gradually raised.

1. The terminals of the LED are plugged in and a constant current of 70 μA was made to flow throughout the LED.

2. Meanwhile, the chamber was heated to a temperature of about 120^0C and the diode is introduced inside the beaker (close to the thermometer).

3. As the temperature falls, the potential difference across the LEDs is plotted against the temperature (the current must be kept constant).

3 Observations:

The experiment was performed for two semiconductors: a red LED and a green LED.

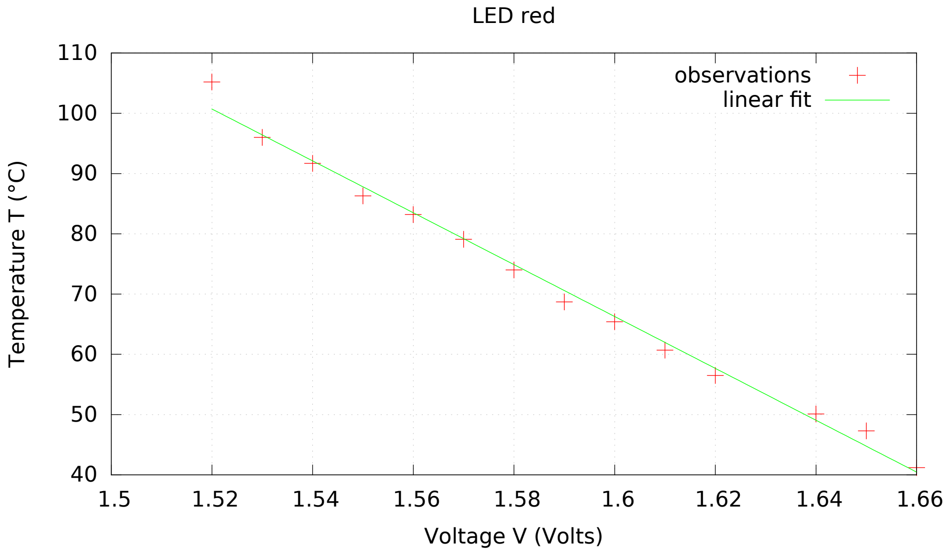
Red LED I=70 uA

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

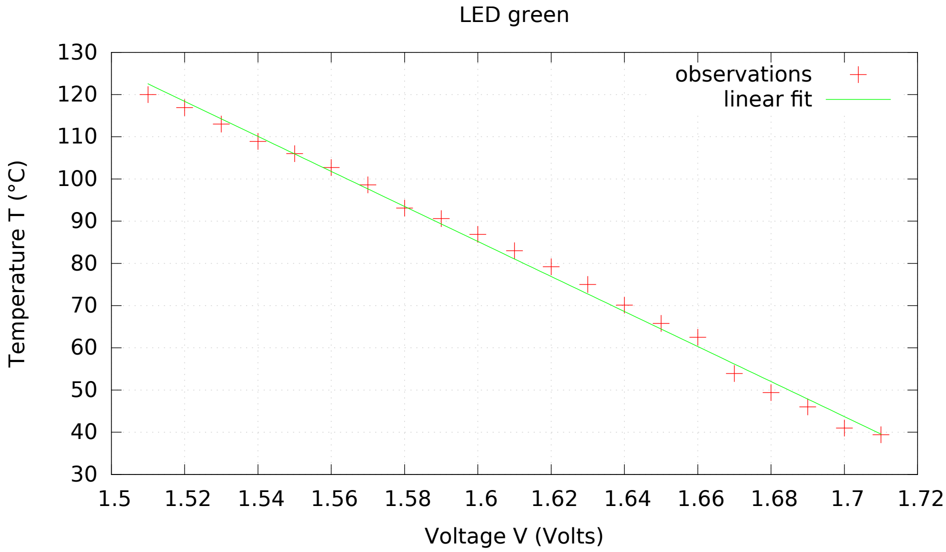
3.1 Red LED



Final set of parameters		Asymptotic Standard Error	
m	= −430.516	+/− 11.12	(2.583%)
c	= 755.105	+/− 17.66	(2.338%)

Thus, the value of $E_g = 2.3884 \pm 0.117 (4.921\%)\, eV$

3.2 Green LED



Final set of parameters   Asymptotic Standard Error

m	= −414.844	+/− 6.599	(1.591%)
c	= 748.947	+/− 10.63	(1.42%)

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

3.3 A short note on error analysis:

We have a graph of the form: $T = mV + d$

$$m \equiv e/k\ln(\tfrac{I}{C})$$
$$d \equiv -E_g/k\ln(\tfrac{I}{C})$$

Thus, measuring e in the units of electronic charge,

$$E_g = -d/m$$

Now, the relative error in E_g will simply be the sum of relative errors in the slope and the intercept.

4 Results

E_g was found to be $2.463 \pm 0.074\,eV$ for a green LED and $2.3884 \pm 0.117\,eV$ for a red LED.

5 Comments

The experiment can be done faster by putting some ice directly in the heating chamber while cooling. But care must be taken that it doesn't fall into the oil (otherwise it might short circuit the LEDs). In order to reach the temperature of about 120^0C, heater should be turned off at about 80^0C. The thermometer and the diode should be placed very close to each other (away from the wall), because the temperature is not constant throughout the system.