The Semiconductor Diode

Pei Xian Yang and Arjun Behl
PCS 224-102 Liam Kischuck

Introduction:

The objective of this lab is to observe the changes in the flow of the current and the base voltage of a forward biased n-p-n diode as the temperature is varied. This lab's aim is to also measure the Boltzmann's constant and measure the reverse saturation current of the diode.

Theory:

A diode is a semiconductor device that allows current to flow in one direction and restricts the current from flowing in the opposite direction. If we connect the diode to a voltage source in a way so that a large current flows through the diode, the diode is forward biased whereas when we reverse the voltage, a small amount of current will flow in the opposite direction the diode is reverse biased. [1]**The value of reverse saturation current flowing through the circuit when the diode is reverse biased is very low so compared to forward bias current people usually neglect it when speaking about it.** The semiconductor diode is usually created by attaching a n-doped semiconductor to a p-doped semiconductor forming a pn junction. The relationship shown by current flowing through the diode vs voltage applied across the junction is shown below.

$I = I_o[e^{\frac{V}{Vt}} - 1] = I_o[e^{\frac{q}{kBT}V} - 1]$ …. 1, where I is the current, V is voltage, q is the absolute value of the charge on charge carriers, T is temperature in kelvins, Vt is the thermal voltage equal to, $Vt = \frac{kBT}{q}$,Io is the saturation current and K_b is Boltzmann's constant. If voltage is a lot greater than the value of thermal voltage, $I = I_o[e^{\frac{q}{kBT}V}]$ ….2, we will ignore negative I_o as its value will be a lot less than the value of the exponential term and can be neglected. If voltage is negative but its absolute value is greater than the value of thermal voltage, $I = -I_o$ …3, we will ignore negative $e^{\frac{q}{kBT}V}$ as its value will be a lot less than the value of the exponential term and can be neglected.

Taking natural logarithm of equation 2 we get, $\ln(I/I_o) = \ln(e^{\frac{q}{kBT}V})$

$$= \ln(I/I_o) = \frac{q}{kBT}V$$

$$= \ln(I) - \ln(I_o) = \frac{q}{kBT}V$$

$$= \ln(I) = \frac{q}{kBT}V + \ln(I_o)$$

Comparing it to equation of line(y= mx +c), we get y = ln(I), c = $\ln(I_o)$, x = V, m = $\frac{q}{kBT}$,

We will need to measure the voltage applied across the junction and the current flowing through the diode and plot these values on a coordinate grid. Using the best fit line, we can find the slope and the y intercept, which will give us the values of the saturation current and Boltzmann's constant. Uncertainties associated with Voltage and current also need to be measured.

Procedure:

In this lab the following equipment was used: an NPN transistor (TIP41A), a 200 mA current supplier, a thermometer, a multimeter, an insulated cup, ice cubes, and hot water.

Procedure:

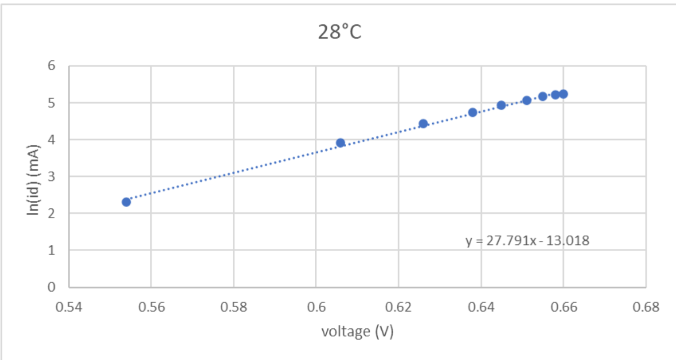
1. Connect the emitter and base of the transistor to the multimeter. Set the multimeter to the diode setting. For most diodes this will result in a forward bias.
2. Reverse the leads on the multimeter and check the reading.
3. Repeat steps 1-2 for the collector and base leads. The current should flow in one direction only.
4. Connect the negative and positive terminal of the current supply into the negative/GND and positive/V terminals on the multimeter. Connect the base of the transistor into the GND terminal, then connect the emitter and collector ends of the transistor to the V terminal. This will connect the transistor, multimeter, and current supply.
5. Record the value of the supply current and multimeter voltage, starting from a small current double the current for every successive measurement until 200 mA is reached.
6. Record the room temperature.
7. Repeat step 5 with the transistor submerged in ice water. Record the temperature of the ice water
8. Repeat step 5 with the transistor submerged in ice water. Record the temperature of the hot water.
9. Pour out the water and dismantle the circuit.

Results and Calculations:

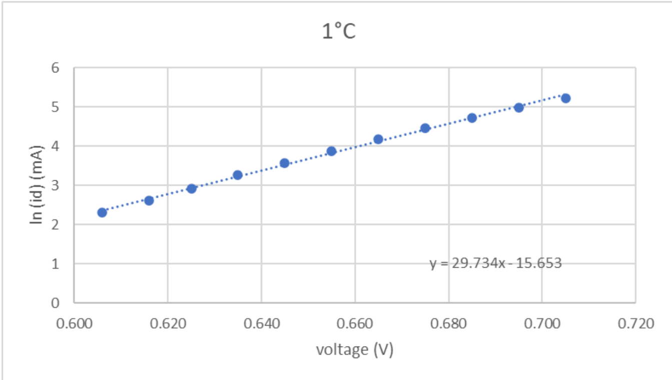
28°C		1°C		78°C	
I (ma):	**v(V):**	**I (ma):**	**v(V):**	**I (ma):**	**v(V):**
10.0	0.554	10.0	0.606	18.2	0.463
50.0	0.606	13.6	0.616	22.5	0.473
85.0	0.626	18.6	0.625	28.6	0.483
115.0	0.638	26.0	0.635	35.7	0.493
140.0	0.645	35.8	0.645	45.0	0.503
160.0	0.651	48.4	0.655	55.4	0.513

175.0	0.655	65.6	0.665	67.6	0.523
185.0	0.658	86.8	0.675	80.6	0.533
190.0	0.660	113.3	0.685	97.0	0.543
-	-	144.8	0.695	115.1	0.553
-	-	183.7	0.705	135.5	0.563

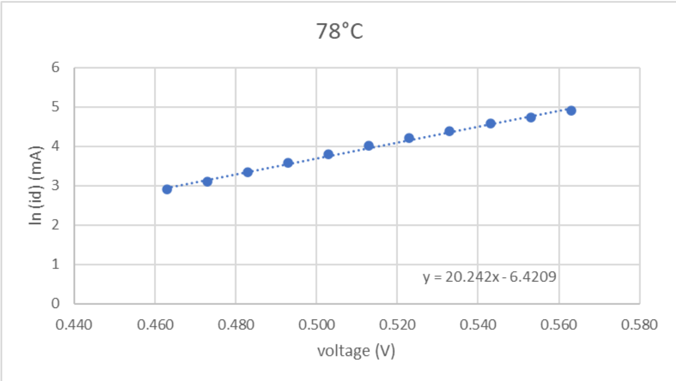
To determine the reverse current and Boltzmann constant, V >> Vt was assumed in the current diode equation, generating the equation $i_D \approx i_0 e$^(|q|V/k_BT). After taking the ln of both sides and rearranging, an equation where k_B resides in the slope and reverse current in the y-intercept. The final equation in the y=mx+b format is $\ln(i_D) = \frac{q}{kBT}V + \ln(i_0)$.



The k_B of 28°C is 7.558 x 10^{-5} +- 6.0724 x 10^{-7} eV/K
The i_o value is 2.22 x 10^{-6} eV/K



The k_B of 1°C is 8.034 x 10^{-5} +- 6.0724 x 10^{-7}
The i_o value is 1.59 x 10^{-7} eV/K



The k_B of 78°C is 7.217 x 10^{-5} +- 6.0724 x 10^{-7}
The i_o value is 1.69 x 10^{-3} eV/K

Discussion and Conclusions:

The final k_B value is 7.603 x 10^{-5} eV/K, with a standard deviation 4.10355 x 10^{-6}. The accepted value of k_B is 8.61733 x 10^{-5} eV/K. The error percentage is 11.78%. This error was likely due to the data collected with the hot water. At the start of data recording, the temperature was around 78°C, however by the time the last few voltages were recorded, the temperature dropped to around 65°C.

Calculating the thermal voltages for each temperature we have taken measurements at, we get;

At T = 28C, $V_T = \frac{kBT}{q}$= 0.0260

At T = 1C, $V_T = \frac{kBT}{q}$= 0.0236

At T = 78C, $V_T = \frac{kBT}{q}$= 0.0303

[2]**These values are comparatively very small to the voltages in our data set, hence the assumption that $V \gg V_t$ is true**

[3]**If the applied forward bias voltage is kept constant, but the temperature is raised, then the current will also increase with the temperature as affirmed by the data set.** As we raise the temperature of the diode, it generates more electro-hole pair, thus conductivity increases, hence the increase in current.

References:

Physics for Scientists and Engineers with Modern Physics”, by Raymond A. Serway and Jewett, Jr., 10th edition, Thomson, Inc.