The p-n Junction Diode

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Abstract

In this experiment the properties of the semiconductor diode were investigated, particularly the asymmetrical and non-linear IV characteristics of the diode, as well as some applications of these characteristics. The diode was put to use as a half-wave and a full wave rectifier, creating a simple DC power supply.

Some of the main results for this experiment were:

$$e/KT = 18.1 \pm 1V^{-1}$$

$$\text{Temperature rise across diode} = 15 \pm 0.5K$$

$$\Delta V/V = 0.045$$

$$C_{\text{rect}} = 0.115x10^{-4}\mu F$$

$$C_{\text{resistor}} = 1.176x10^{-4}\mu F$$

$$V_{\text{reverse}} = 8mV$$

$$V_{\text{max}} = 508 \pm 4mV$$

Introduction and Theory

The aim of this experiment was to determine the I-V characteristics of a semiconductor diode and to examine its uses as a rectifier.

I-V Characteristic

The current through an abrupt semiconductor p-n junction is given by $I = I_0[exp(\frac{eV}{kT}) - 1]$. The quantity I_0 is dependant on the temperature of the junction and thus it is important in this experiment to take measures to ensure that readings are taken as close as possible to the (known) ambient room temperature. The graph of the relation between I and V is called the *characteristic* of the function.

Rectifiers

Because the current in a diode only flows one way, they can be used to convert AC current into DC current. While it is easy to convert a sinusoidal wave to a new wave given by the absolute value of the original wave using diodes, the true goal of a DC power supply is to provide a smooth steady waveform for a given voltage. This is achieved by adding a capacitor or capacitors into a rectifier circuit, so as to smooth the current. The smoothness of the output voltage can be quantitatively described by the ripple voltage, which is $\Delta V/V_0$ where V_0 is the peak voltage, while ΔV is the peak to peak variation of the voltage.

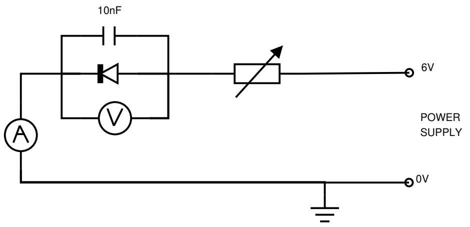

Figure 1: Measurement of I-V characteristic circuit

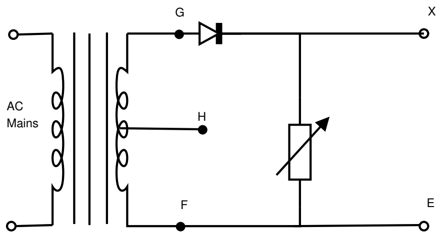

Figure 2: Half-wave rectifier circuit

Experimental Method

I-V Characteristic of p-n Junction Diode

The I-V characteristic of the diode was measured using the circuit in Fig. 1. The resistances used ranged from 68Ω to 111.1KΩ Readings of current and voltage for a range of resistances were taken quickly to ensure that the diode temperature deviated as little as possible from room temperature. These results are plotted in Figure TODO A reading was also taken with the diode reversed and the voltmeter disconnected, and no current was detected across the diode. A plot of ln(I) against V was made for the purposes of determining e/KT, the basis of which is the formula $Ln(I) = Ln(I_0) + (eV/kT)$

Half-wave rectifier

The circuit shown in Fig.2 was connected.

The resistance was set to $10k\Omega$ and the oscilloscope was connected to the terminals X and E. With this circuit we found the diode conducted for half of each cycle of the A.C. mains, with the waveform on the oscilloscope corresponding closely to the original sinusoidal wave. The peak voltage V_0 was measured using the oscilloscope, and compared to the R.M.S. voltage of the A.C. supply.

A $4\mu F$ capacitor was then attached across the resistance box R. This had the effect of smoothing the current across the resistor. The ripple voltage, i.e. the peak to peak variation of the smoothed voltage was measured for different values of R between $20k\Omega$ and $100k\Omega$ was measured, and plotted against 1/R. It was confirmed that the maximum value of the voltage across C remained constantly at V_0.

Finally the circuit was connected as in 3, i.e. a small resistor was connected between F and E. The voltage across it was measured in the oscilloscope. The

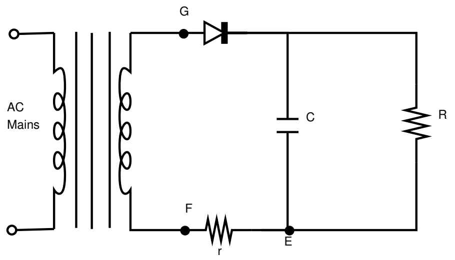

Figure 3: Circuit to measure half-wave current

peak current i_p across this was measured, as was the fraction of the cycle for which it flowed. The charge flowing through the rectifier was then compared to the charge flowing through R per cycle.

Full-wave rectifier

The circuit was set up as in 4. This is a full wave rectifier. The waveform for this circuit was measured and compared with that of the half-wave rectifier. Using the oscilloscope, the fractional ripple voltage $\Delta V/V$ with C connected was measured. The maximum reverse voltages across the rectifiers were measured too.

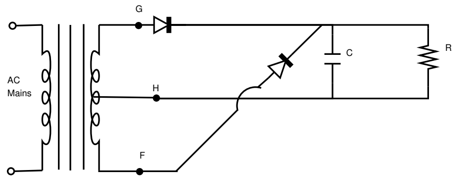

Figure 4: Full-wave rectifier circuit

Results and Analysis

Using dimensional analysis we can derive the units of e/kT, the argument proceeds thus:

$$\begin{aligned} k = \text{Boltzmann's constant} &= \frac{[J]}{[K]} \\ e = \text{Elementary charge} &= [C] \\ T = \text{Absolute temperature} &= [K] \\ \text{therefore,} & \\ \frac{e}{kT} = \frac{[C][K]}{[K][J]} &= \frac{[C]}{[J]} \end{aligned}$$

Or in words, k has units of energy per temperature, e has units of Coulombs, therefore e/kT has units of Coulombs per Joule, or V^{-1}.

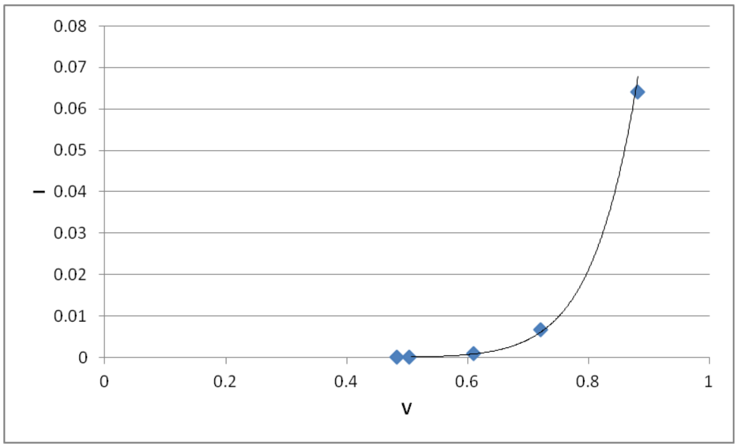

Figure 5: I-V Characteristic

The I-V characteristic of the semiconductor diode is shown below in Figure 5.

The graph of ln(I) against V is shown in Fig6

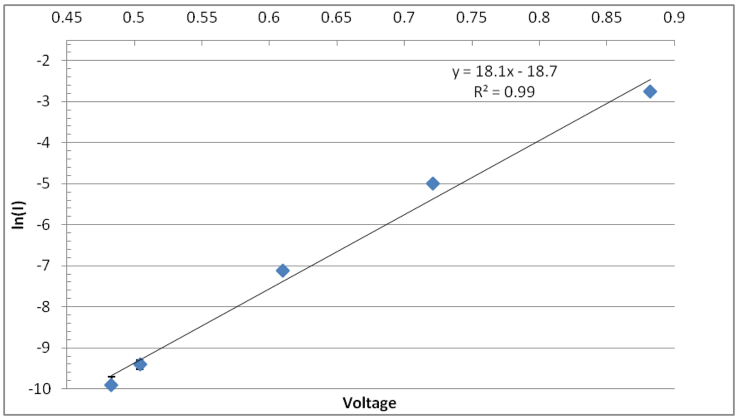

Figure 6: Plot of ln(I) against Voltage

The value for e/KT which was found from the graph was $18.1 \pm 1V^{-1}$. This differs from the accepted value by a factor of approximately 2, which makes sense since the equation for the current through a silicon diode should be given as

$$I = I_0(exp(eV/\eta kT) - 1)$$

where $\eta \approxeq 2$

The voltage for the diode at room temperature was

$$V_1 = 1.123 \pm 0.01V$$

The steady state voltage was

$$V_2 = 1.089 \pm 0.01V$$

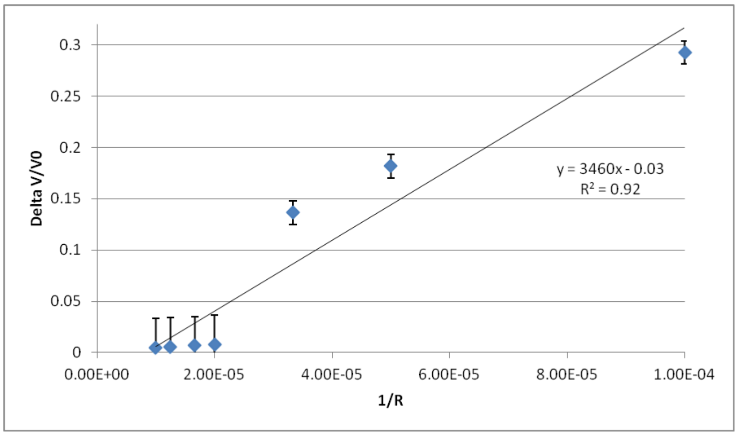

Figure 7: Plot of $\Delta V/V_0$ against Voltage

giving a difference of $34 \pm 1mV$ This corresponds to a temperature rise of $\Delta T = 15 \pm 0.5K$

Half wave rectifier

We found the peak voltage across the resistor, when set to be $10k\Omega$ to be $7.04 \pm 0.01V$. When divided by $\sqrt{2}$ this gives 4.97V which compares to the RMS voltage of 5V across the A.C. supply.

The plot of fractional ripple voltage $\Delta V/V_0$ against 1/R is shown below in Figure 7.

The peak current i_p was found to be $0.78 \pm 0.03mA$ and flowed for 0.175ms. The period of the cycle was found to be 20ms. The average current through the rectifier was found to be $5.74 \pm 0.05mA$ while the average current through the resistor was found to be $5.89 \pm 0.01mA$.

Full wave rectifier

We found the fractional ripple Voltage for a $10k\Omega$ resistance to be 0.045. The maximum reversed voltage was found to be 508 ± 4 mV.

Discussion and Conclusions

Our results showed the expected behaviour of the p-n semiconductor diode, that its behaviour depended on its orientation in the circuit and that it could be used effectively to convert AC current into a smooth DC current. We also found that the quality of the smoothed DC current, where quality is defined as a small $\Delta V/V_0$, is proportional to the resistance of the circuit, i.e. for a higher resistance, $\Delta V/V_0$ is lower, or that $\Delta V/V_0$ is inveresly proportional to R. Some results from our graphs had large error values that could have been improved with more data points.