Mitchell Larson
CE 3101
Lab 2
3/15/18

CE 3101 Lab Experiment 2

Abstract

Diodes are a unique electrical component that provide characteristics that make them especially useful in digital and power circuits. The discovery of the first diode marked a historical moment in the computing industry and has led to countless advancements and new technologies that have changed how the world works. In particular, one of its most useful characteristics is its switching behavior that occurs as it enters the range of 0.5 V – 0.7 V (depending on the semiconducting material used to construct the semiconductor). In a diode, this behavior is a result of placing p-type and n-type materials adjacent to each; because of the electo-chemical consequences of placing electron deficient materials next to materials with a surplus of free electrons, a natural insulating region forms, preventing current flow. The barrier is not insurmountable though, and with enough external voltage (forward bias), enough force can be applied to cause electrons to cross the insulating behavior, essentially “switching on” the diode.

In this experiment, the goal was to produce such a reaction, and observe the current-voltage relation for two different types of diodes (1N4148 switching diode and 1N4007 rectifier diode). To do this, a simple circuit was constructed using a signal generator, a resistor, a diode, and an oscilloscope. Essentially, the signal generator was used to create an increasing sweep of voltage, ranging from 0V to 1V. The voltage was then read across the resistor and using simple circuit theory laws such as Ohm’s law and Kirchoff’s voltage law, a current through the circuit was derived, along with the voltage across the diode. The derived voltage and currents were then plotted, revealing the I-V characteristics for the both diodes. Further, the signal generator was then used to create square waves rather than ramps, and the switching characteristics for both diodes were observed and analyzed. The findings in this experiment indicated that while both diodes had similar I-V characteristics, they differed greatly in their ability to switch at high frequencies.

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Experiments

Setup

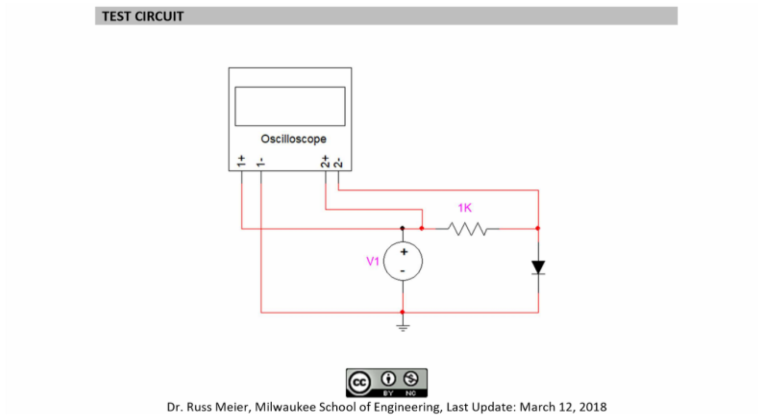

Figure 1 - Circuit used in the experiment

Figure 1 illustrates the circuit used in the experiment. The diode shown in the figure was simply switched with the actual diode under test. An analog discovery kit was used to generate the signal V1, as well as monitor voltage using its pins for scope 1 and scope 2.

Results – 1N4148 Switching Diode

The signal generator was configured to generate a 100 kHz ramp ranging from 0 to 1 V. Scope 1 of the oscilloscope was then used to measure the input voltage, and scope 2 was used to measure the voltage drop across the resistor in the circuit.

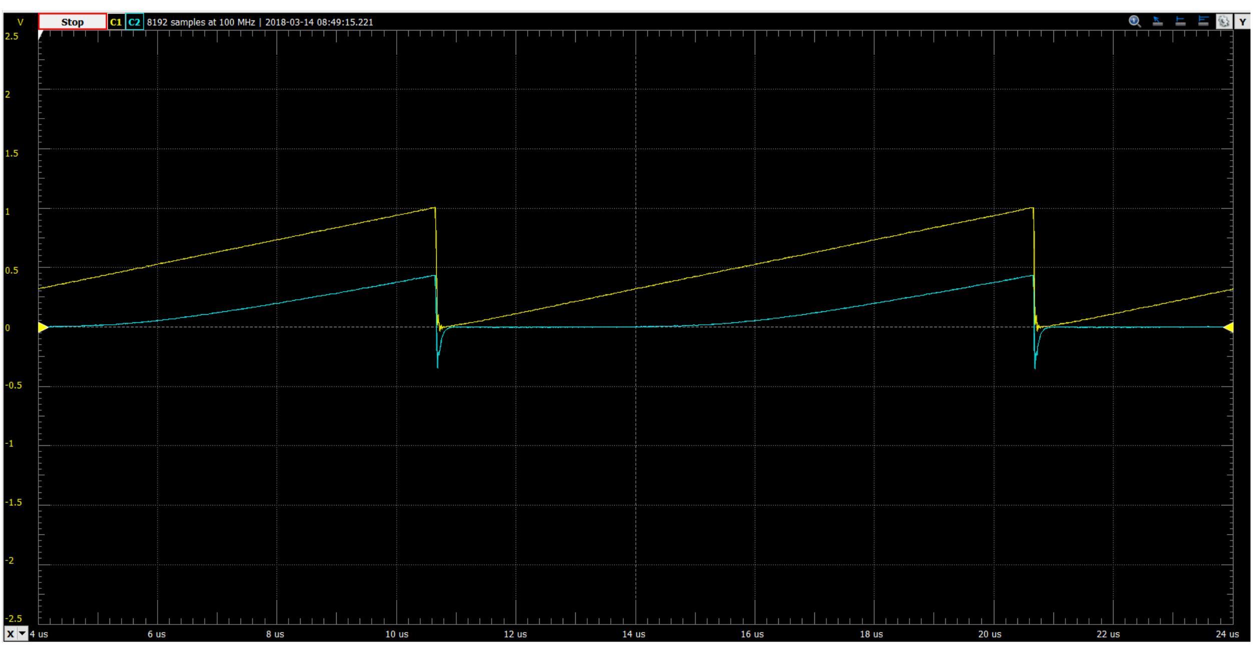

Figure 2 - Oscilloscope view of input voltage (yellow) and voltage drop across resistor (blue)

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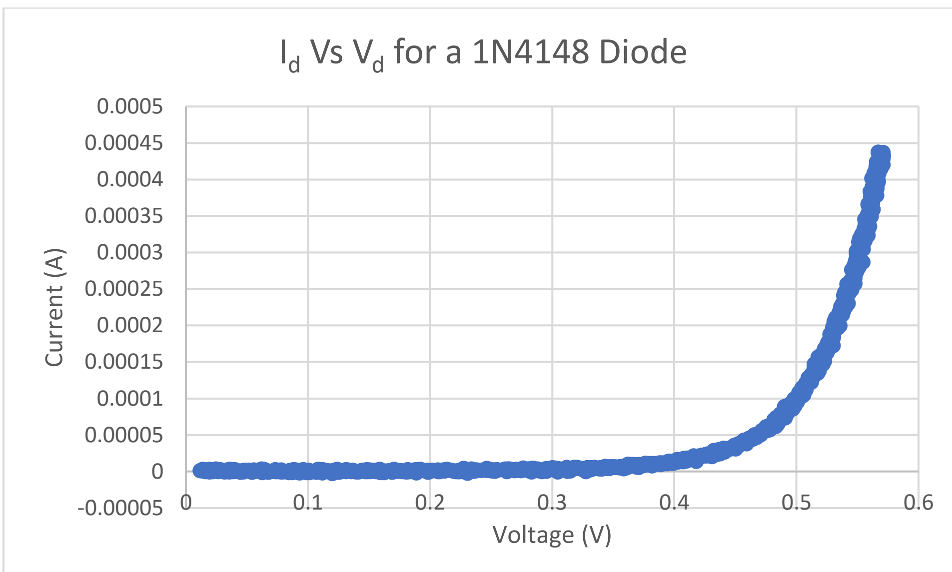
In figure 2, the generated voltage is very distinct, ramping up linearly from 0 to 1 volts. The voltage drop across the resistor is shown in blue and is notably not linear for the entirety of the voltage sweep. This indicated that a component in the circuit was exhibiting exponential behavior, which could be explained by the diode placed into the circuit. The voltage drop across the resistor notably stabilized into a linear trend as the sweeping input voltage reached a voltage near 0.6 V. This occurs due to the diode fully switching to its on state and essentially becoming a short circuit. From the plot, the turn on voltage was derived using Kirchoff's law and subtracting the voltage across the resistor from the input voltage in the "linear region" of the plot. This resulted in a turn on voltage for the 1N4148 diode of:

$$1.003149425 \text{ V} - 0.433573587 \text{ V} = 0.569575838 \text{ V}$$

The diode was expected to exhibit voltage drops across it that followed a logistic curve as the input voltage was increased, eventually saturating at its turn-on voltage. The data from the oscilloscope was exported to Excel and using the voltage readings for the source voltage and the voltage across the resistor, the voltage across the diode was derived. The current through the diode was then calculated for each point by dividing the voltage drop across the resistor by the resistance of the resistor (1000 Ohms). Plotting the derived diode current against the derived diode voltage yielded the following plot:



As expected, the voltage across the diode began to asymptote close to 0.57 volts, which confirms with the calculated turn-on voltage determined to be 0.570 volts.

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Results – 1N4007 Rectifier Diode

The same procedure was followed again, but the diode under test was switched with a 1N4007 rectifier diode, and the input frequency was reduced to 50 Hz. This resulted in the following oscilloscope reading:

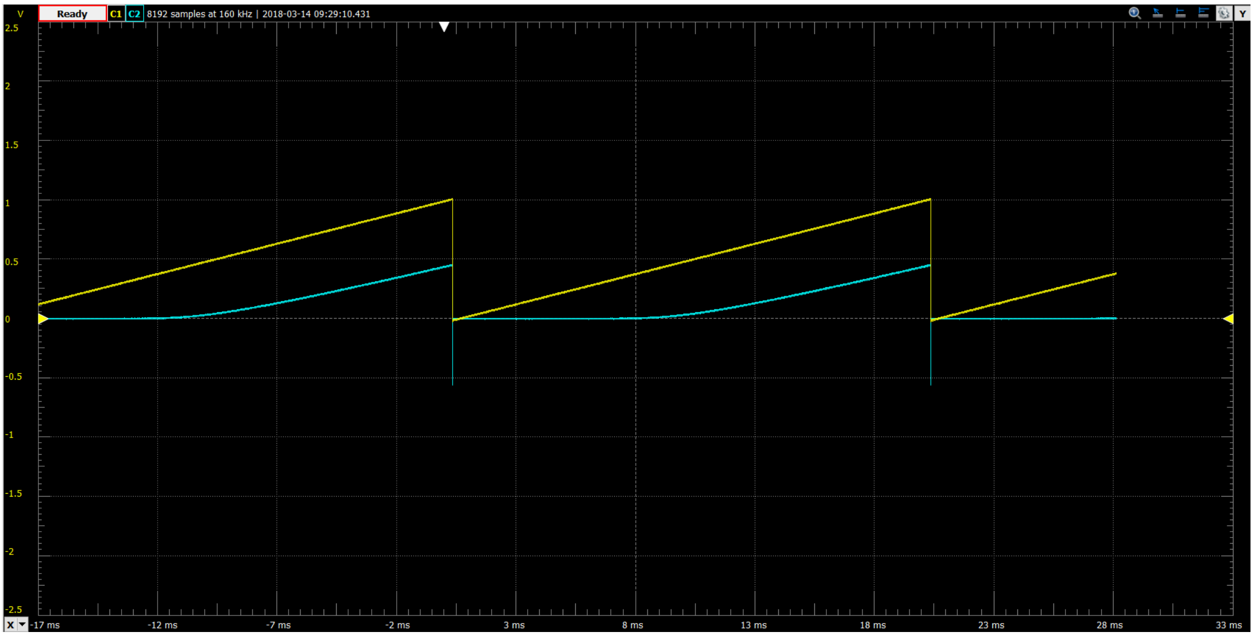

Figure 3 - Oscilliscope reading for a 1N4007 Rectifier Diode.

Upon first glance, the behavior of this diode appeared very similar to the switching diode - the voltage drop across the resistor exhibited exponential behavior, and then became linear with higher input voltage. To gain a deeper understanding of the differences between the two diodes, the turn on voltage was calculated using the same procedure as with the switching diode. This resulted in a turn on voltage of

$$1.011210256\text{ V} - 0.456435294\text{ V} = 0.554775\text{ V}$$

The turn on voltage of this diode was notably similar, but smaller than the switching diode. The voltage drop across the diode and the current flowing through it was then derived for the varying input voltages. This resulted in the following I-V characteristics

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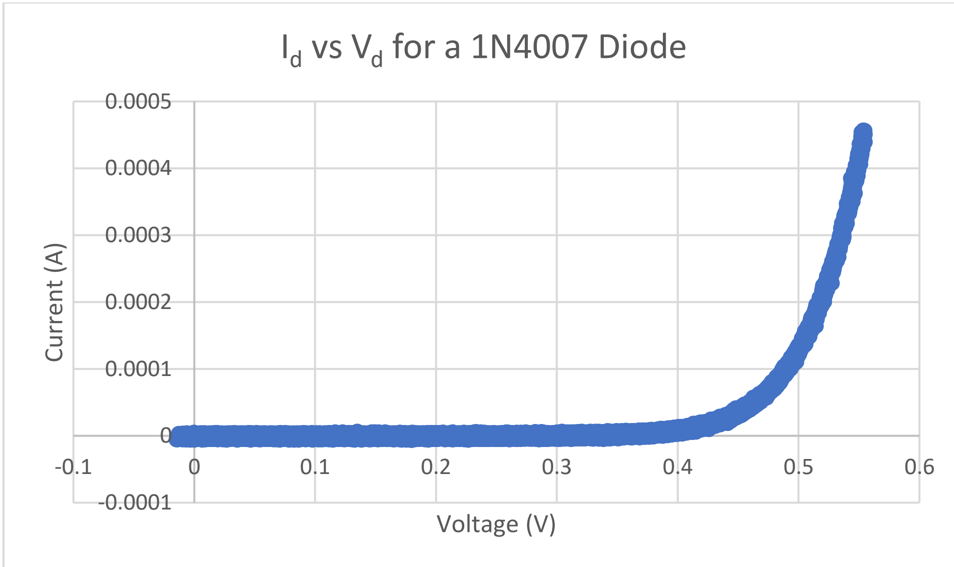

The I-V curve verified the calculated turn-on voltage for the rectifier diode, but it was still difficult to make a comparison between the characteristics of the diodes; the turn on voltages were different, but still similar in magnitude. To gain further understanding of their differences, a direct comparison needed to be made which would make it possible to compare the turn on voltages for both diodes and the shape of their curves.

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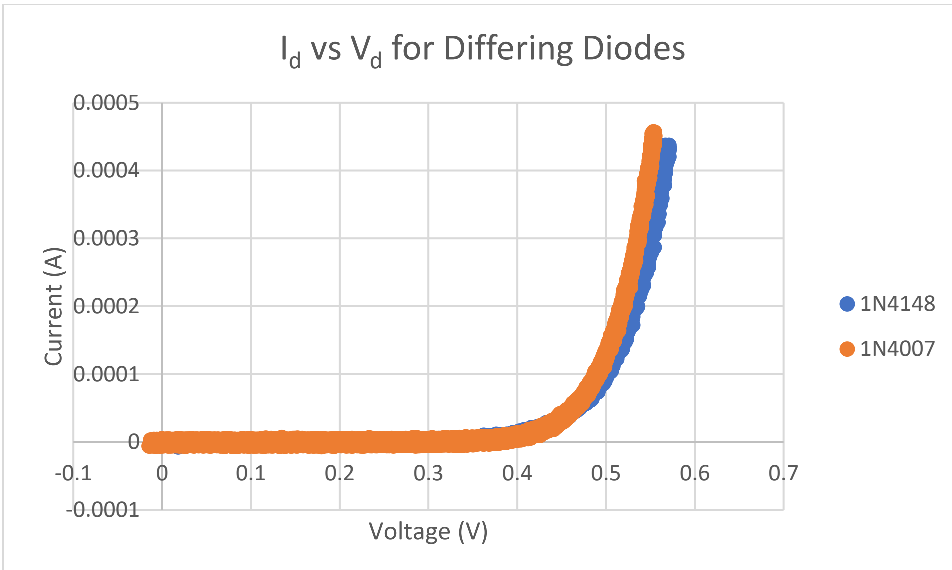
Comparison of Switching Diode vs Rectifier Diode

I-V Curve

The I-V curve for both the switching diode and the rectifier diode were overlaid onto the same graph to make direct visual comparisons. The resulting plot is shown below.



When the I-V characteristics of both diodes were overlaid, the differences became very clear. Both curves seemed to follow the same shape, but the switching diode had a greater turn-on voltage than the rectifier diode. The differences between turn-on voltages were relatively small however, and it raised questions on what made the diodes different. They seemed to be exhibiting similar behavior.

Switching Characteristics

Through observation of the I-V characteristics, a small difference in turn on voltage was notable. Those findings did not provide a full picture of the differences between the diodes however. An important aspect of diode performance is how they react to different frequencies of voltage signals. To explore such characteristics, a square wave was generated for both diodes, and the voltage drop across the resistor was noted. The resulting oscilloscope views are shown below for a 1 V square wave with a frequency of 100 kHz.

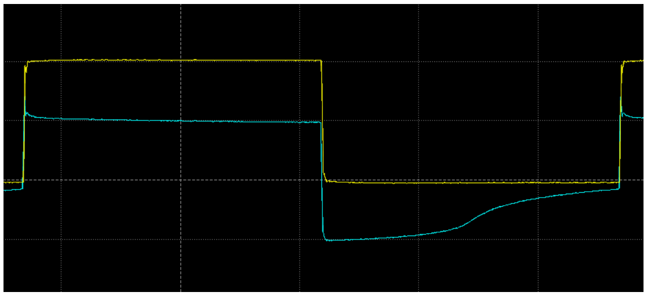


Figure 4 - Rectifier Diode

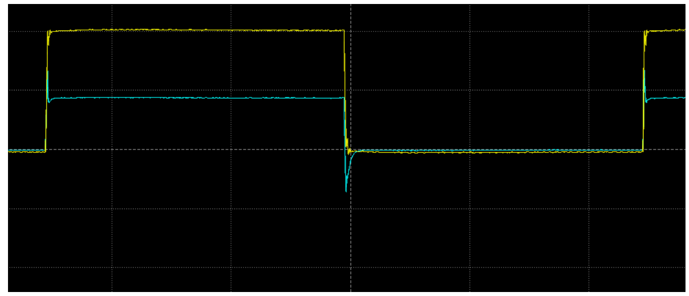
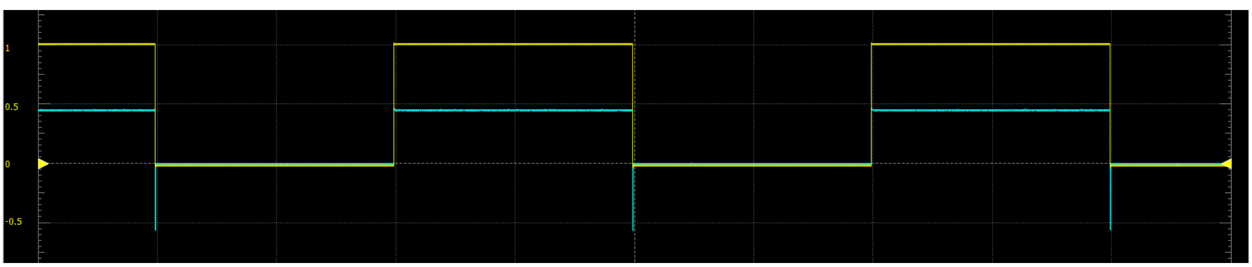


Figure 5 - Switching Diode

The figures shown above illustrate a key performance difference at high frequencies: that is, the switching diode was able to switch current flow off and on much more effectively. For the switching diode, the change in voltage across the resistor happened at almost the same exact moment that the input voltage changed. The rectifier diode behaved in a much different manner, exhibiting a very notable delay between input voltage changes and changes seen in the current flowing through the circuit. This behavior was very important to capture, because it means that a rectifier diode would not work properly in a circuit meant to be run at very high frequencies, such as a digital electronic circuit. It was possible that the rectifier diode being tested was designed for higher power systems with lower frequencies, so the rectifier's switching behavior was tested again at a lower frequency of 50 Hz. This resulted in the following behavior:



From this plot, it appeared that the rectifier diode was able to switch in a much more appropriate manner at lower frequencies. Rather than taking a quarter of a period to switch, it took a negligible amount of time when compared to the entirety of the period.

Conclusion

The performed laboratory experiment did a great job in highlighting important characteristics and differences in diode types. In pervious semiconductor courses, a large amount of focus was placed on the turn-on voltages of differencing diodes. This lab helped demonstrate that there were other important specifications that need to be noted when selecting a particular diode for a circuit being designed. When choosing a diode to use in a circuit, it is not only important to note its turn-on voltage, but also its performance under different frequencies. Switching diodes perform well in circuits with high frequencies and low power, while rectified diodes perform well in circuits with lower frequencies but can withstand higher power. This experiment not only reinforced understanding of previously taught subject matter, but it also introduced new material that was not provided in previous classes.