DREXEL UNIVERSITY
Electrical and Computer Engineering
College of Engineering

Drexel University
Electrical and Computer Engineering Dept.
Electronic Devices Laboratory, ECE-370

TITLE: **Light Emitting Diodes: Characteristics and Composition**

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SECTION: **061**

DATE PERFORMED: **5/13/2022**

DATE DUE: **5/20/2022**

Objective

In this lab, the characteristics of the PN junction were explored once again. This time, the focus was shifted to characteristics of switching bias and how various types of diode react to said switching.

Theory

In switching, a diode is switched between the 'on' state of forward bias and the 'off' state of reverse bias typically using a square wave generator. The square wave, as well as experimental setup is as follows:

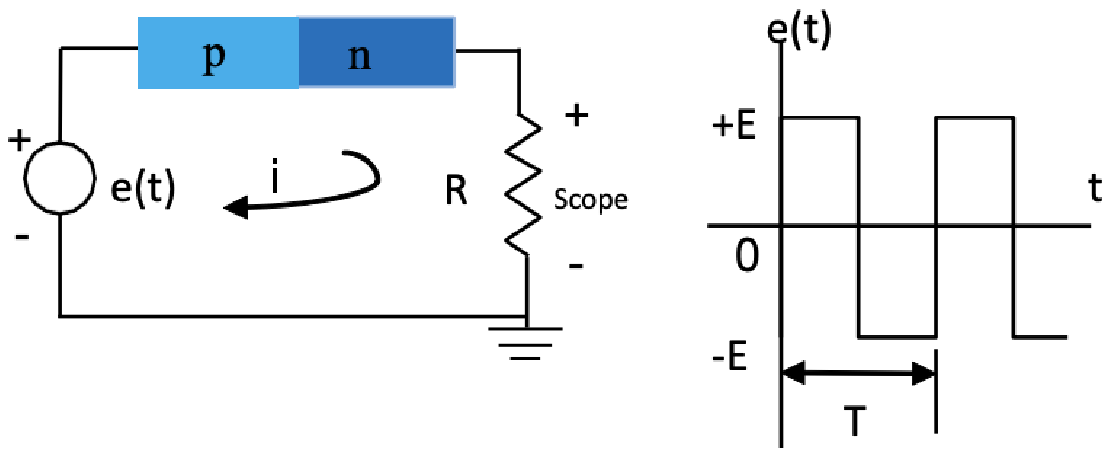


Fig. 1: Circuit used and Input waveform

As seen in Figure 1, the square wave generator switches the pulse from E to -E, according to e(t). When e(t) is positive, the diode is said to be forward biased, and when it is negative, the diode is said to be reverse biased. When E is much larger than the turn on voltage of the diode, or when the exponential behavior of the IV characteristic is exhibited, almost all of E will appear across the resistor. This is due to the diode acting as a short circuit, due to the low resistivity. Using the approximation that E >> Vo, the following equation can be approximated for steady state forward current:

$$i \approx E/R$$

Equation 1: Steady State Forward Current E >> Vo

When -E is the applied voltage, the diode will be reverse biased causing a very high impedance akin to that of a short circuit. There will be a very small reverse saturation current flowing due to the reverse bias. When the diode goes from the original 'on' state to the 'off' state the minority excess carriers are not instantaneously removed, thus there is a finite time for the diode to go from the on state to the off state, despite the instantaneous switching of the bias.

This phenomenon can also be thought of in terms of the diode's capacitance. The capacitance of the diode prevents the voltage across the diode from changing instantaneously. As soon as the bias switches there will be a -i current flowing. Gradually as the charge accumulates, the electric field in the depletion region will increase thus increasing the voltage across the diode, until it acts almost as that of a short circuit with all of e(t) appearing across the diode. The current will decrease to the reverse saturation current because the resistivity of the diode becomes so high. The current as a function of time is as follows:

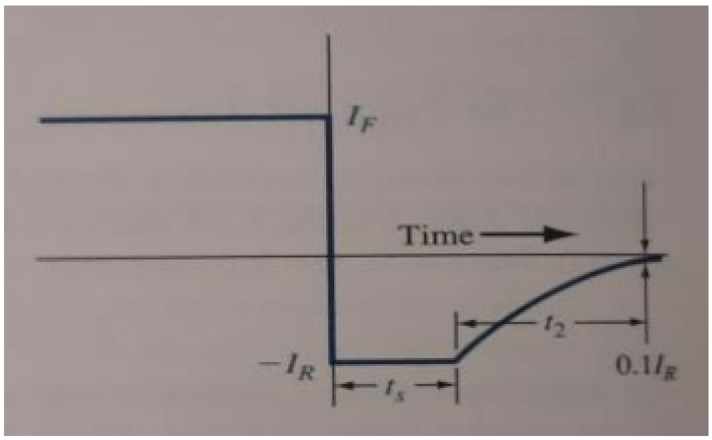


Fig. 2: Variation of current with time

The time it takes for the current to increase from -E/R is known as the storage delay and represents the time it takes for the excess charge carriers to reach their thermal equilibrium values. After the storage delay time, the voltage across the resistor will reduce as well the current in the system decaying to the reverse saturation value. The storage delay time is an important factor in switching diodes, and a diode with a small storage delay with respect to the switching time is optimal. The formula for storage delay is:

$$t_{sd} = \tau_p \left[\mathrm{erf}^{-1} \left(\frac{I_f}{I_f + I_r} \right) \right]^2$$

Equation 2: Storage Delay with Error Function

The lifetime on the right side of this equation is the lifetime of the minority holes on the n-side of the junction. This function is very complicated as it includes the inverse error function, but when the flowing times are much larger than the minority lifetime, a simpler equation for the storage delay can be written as:

$$t_{sd} = \tau_p \ln(1 + \frac{I_f}{I_r})$$

Equation 3: Storage Delay Simplified

Or:

$$t_{sd} = \tau_p \ln(1 + \frac{Q_p(0^+)}{\tau_p I_r})$$

Equation 4: Storage Delay Alternate Simplification

Fig 3: Oscilloscope trace 1

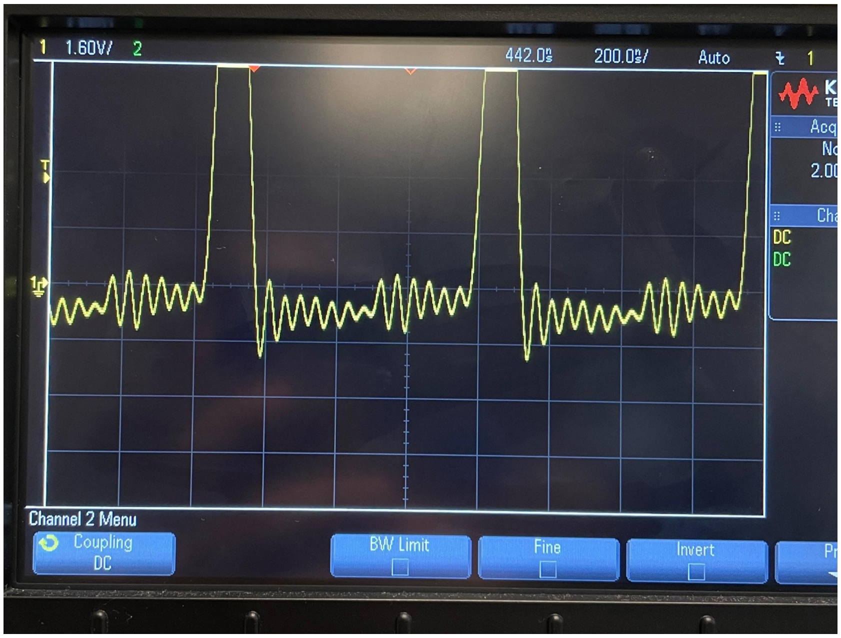
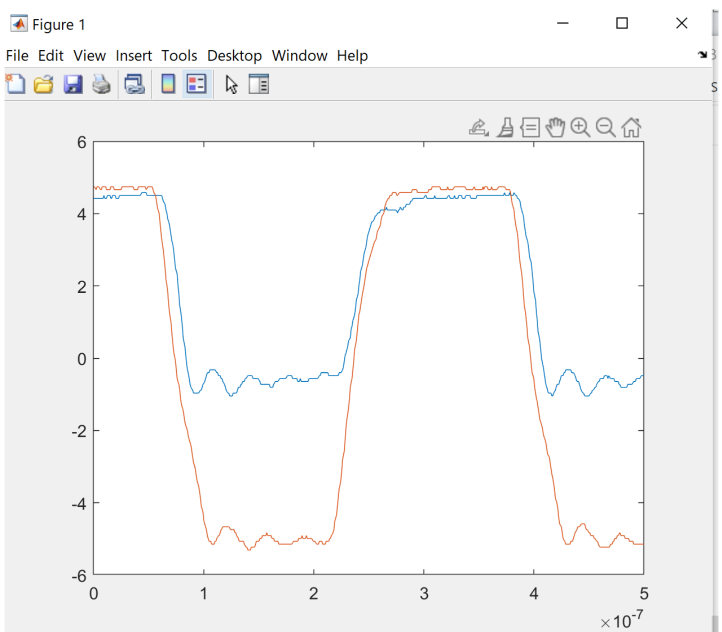


Fig 4: Oscilloscope trace 2

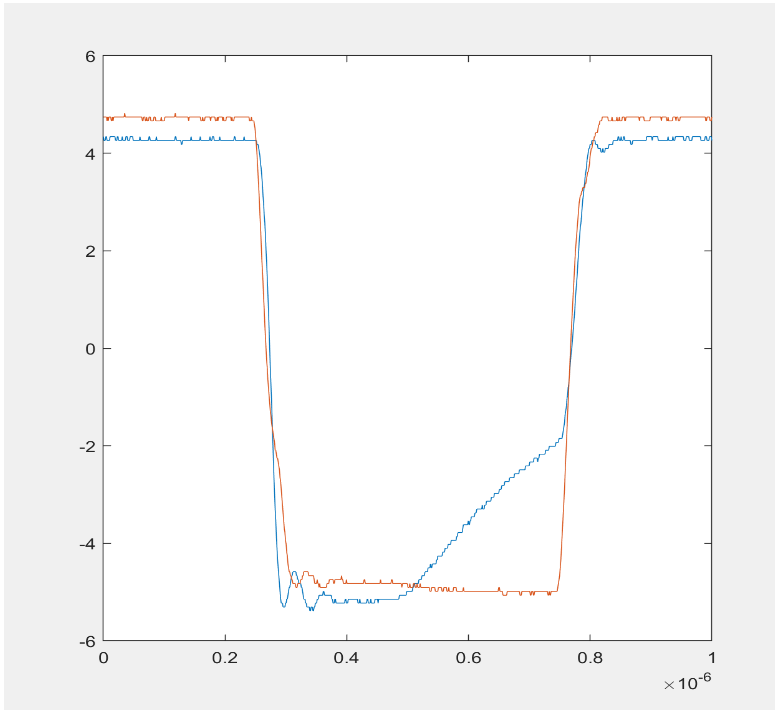
The following three graphs are captures of the voltage output of their respective diode when the storage delay when switching from reverse to forward bias became constant as a function of

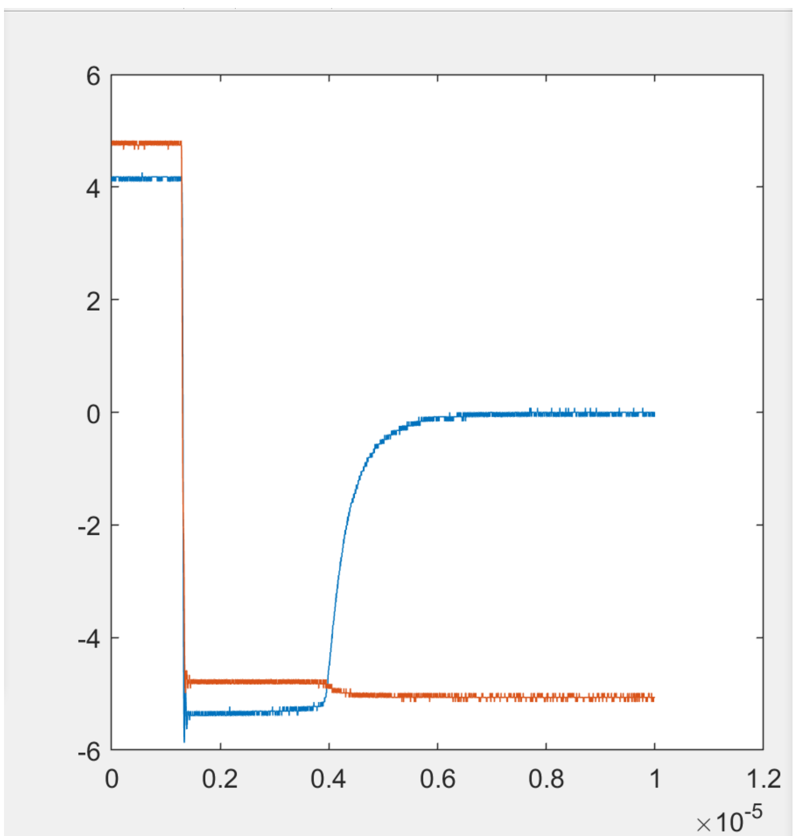
1N5817 - 3100000HZ



1N5817 - 3100000HZ

1N5401 - 1.3MHz





31k Hz - 1N4001

1. For each I-V curve, calculate the load line and find the diode operating point

With this curve, it is possible to find the load line by realizing that due to Kirchoff's voltage law V-IR-Vd = 0. From here, the next step is to see what the current through the circuit will be when the diode is acting as a short circuit. It is also necessary to find what the voltage across the diode is when the diode acts as an open circuit. These assumptions will yield V/R for the current and V for the voltage. Now with two points it is possible to draw a line going through points (0,V/R) & (V,0). In each scenario, there is a maximum applied voltage of 5 V with a resistor of resistance 1 kOhm. Starting with diode 1N4001 this graph is as follows:

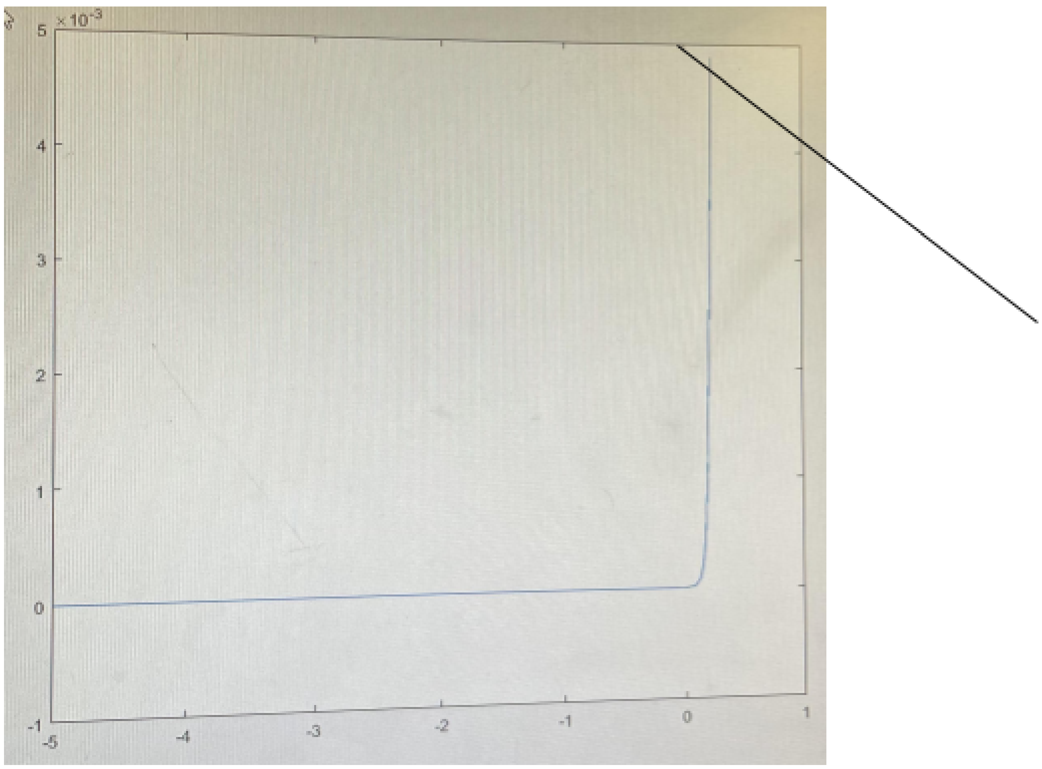


Fig 3: IV characteristic of 1N4001 diode w/ Load Line

Using the slope equation $m = (0 - (5/1000))/5 = \ - 0.001$, which yields an equation of 0.005-0.001x=y. The line edited on top of the graph in fig 3 represents the load line. The operational voltage and current is where the load line intersects the IV curve. It looks like it intersects at around 4.8 mA, and at a voltage of 0.2 V. This is the operating voltage for the 1N4001 diode.

The next diode is the 1N4817 diode, which has the same equation for its load line, as the circuit setup was the same.

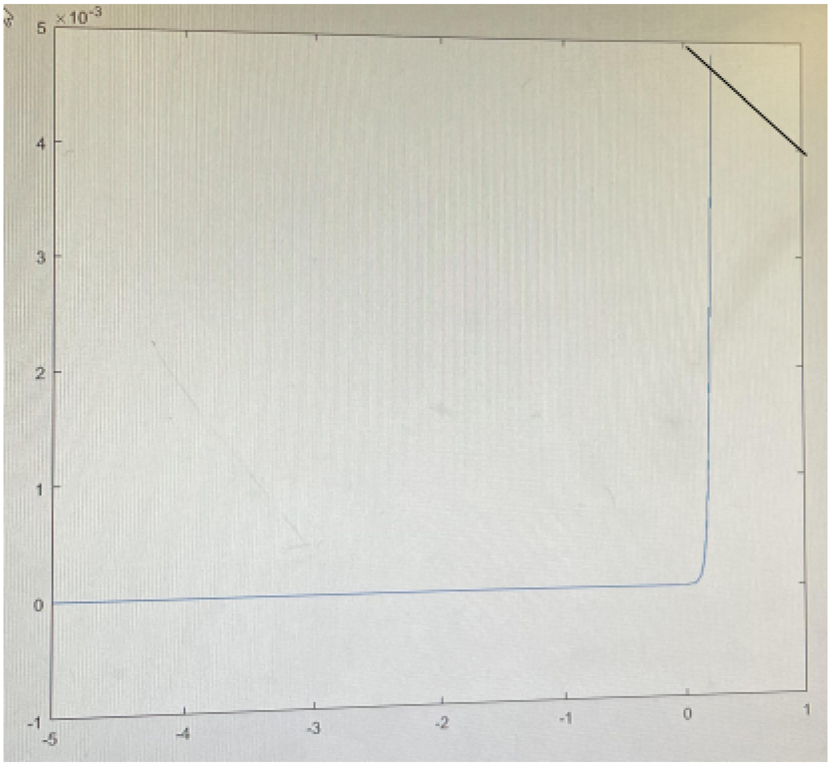


Fig 4: IV characteristic of 1N5817 diode w/ Load Line

Here, the line is on the upper right corner of the graph in fig 4. It seems to have operational characteristics very similar to the last diode. The intersection seems to occur at 4.75 mA and 0.25 V.

The final diode explored was the 1N5401 diode. Once again, the setup didn't change so the load line will be the same.

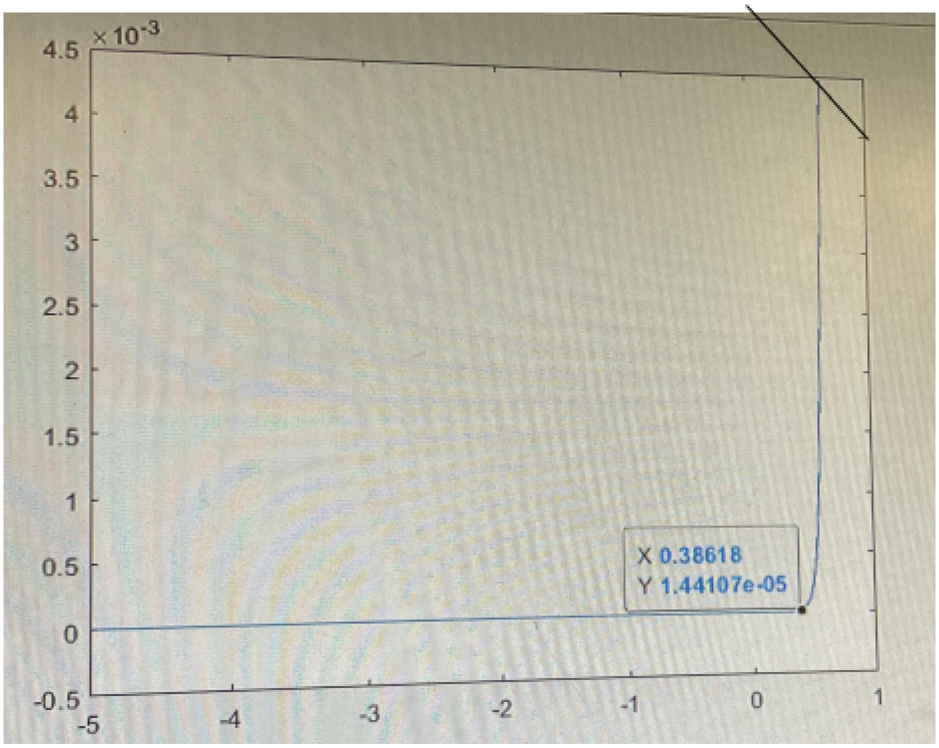


Fig 5: IV characteristic of 1N5401 w/ Load Line

This diode differs from the previous two as its current is slower to increase. The load line in the upper right hand corner of fig 5 intersects the IV curve at 4.5 mA or 0.5V which is also the operating voltage for diode 1N5401.

2. At each frequency, calculate the carrier lifetime of t_{sd} taken, using Equation 2.

$$t_{sd} = \tau_p \ln(1 + \frac{I_f}{I_r})$$

The team extrapolated the following variables for a frequency of 3100000HZ with diode 1N5817 using the oscilloscope output.

Tsd = 1.0, tf = 4.4, - Ir = 4.6

$$\tau_p = \frac{(1.0)}{ln(1+\frac{4.4}{4.6})} = 1.49\ seconds$$

Using the 1N5401 diode, captured at 1.3MHz, the team extrapolated the following points

$$\tau_p = \frac{(0.45)}{ln(1+\frac{4.6}{6.0})} = 0.79\ seconds$$

Using the 1N4001 diode, captured at 31MHz, the team extrapolated the following points

$$\tau_p = \frac{(0.2)}{ln(1+\frac{5.5}{6.0})} = 0.31\ seconds$$

3. Plot frequency against lifetime for each diode and discuss the results. Which diode is fastest? Which is slowest? What makes one diode faster than another for the switching application?

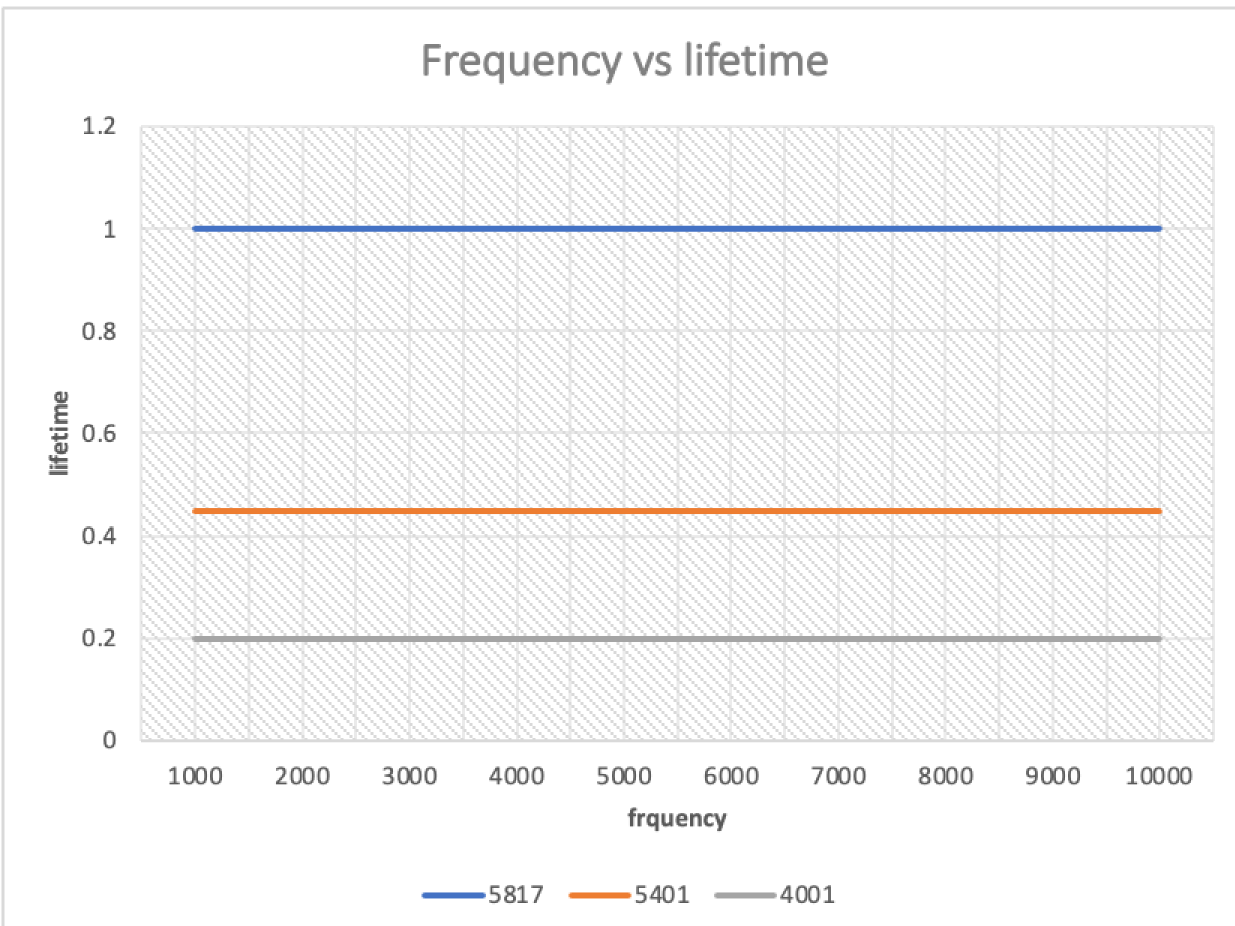


Fig 6: frequency vs lifetime plot

From the above plot, we can see that lifetime is independent of frequency as no change occurs to the lifetime of the diodes as frequency increases. The fastest diode is the 5817 and the slowest diode is 4001. The reverse recovery time of a diode is what makes it faster for switching applications. The smaller this value, the more suitable the diode is.

4.

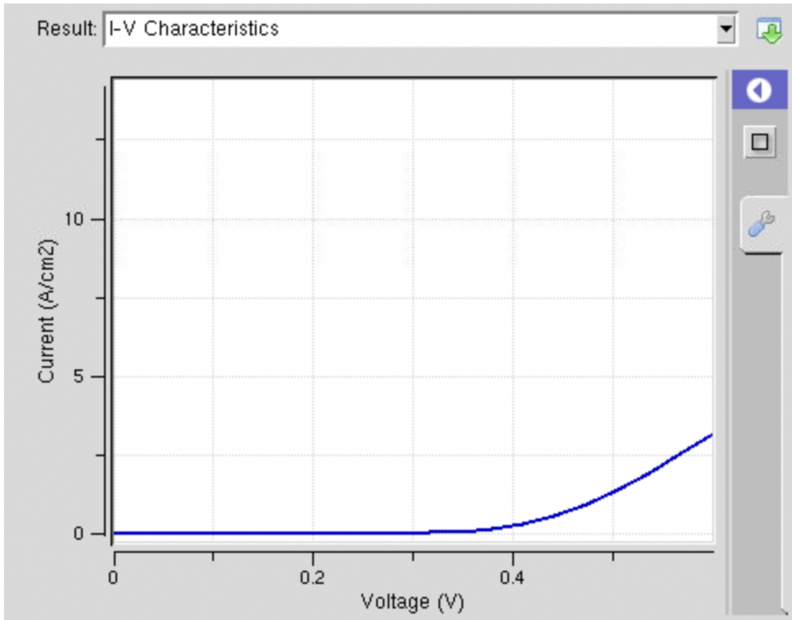


Figure 7: IV characteristic for Long base

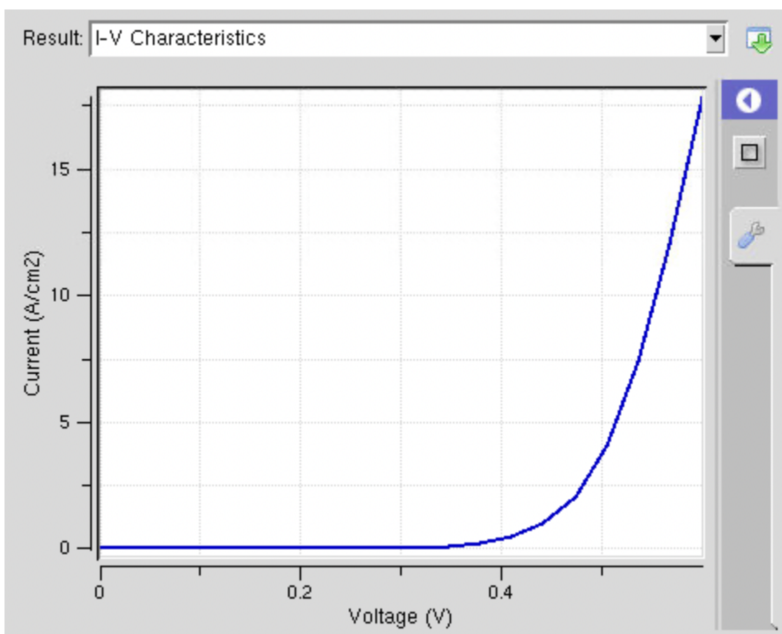


Figure 8: IV Characteristic for Short base

For the short base diode, the current is changing much faster. For example, looking at 0.5V for both plots, the long base is approx. at 1.25 A/cm2. Whereas, the short base is at approx. 3.75 A/cm2. The short base diode would be faster because the length of the lightly doped side of a p+-n diode is close to/less than the minority-carrier diffusion. Thus less charge is stored.

Bonus 2:

The oscilloscope probe impedance is advertised as 1MOhm parallel to 11pF. At what frequency does monitoring the AFG output directly on the scope begin to have a significant influence on the measurement?

When frequency drops from MHz to KHz the impedance is so high that the circuit is essentially short circuited. The capacitance in the probe then outputs a sinusoidal waveform instead of a square waveform with two definitive states as graphed below.