EE236: Experiment 6
Minority carrier lifetime measurement

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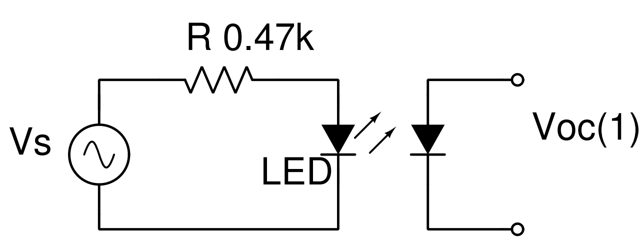
1 Aim of the experiment

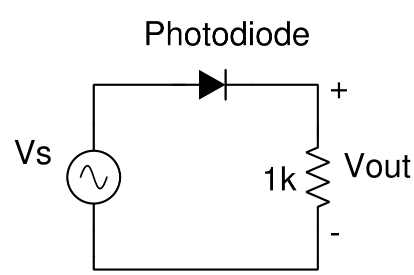
We make use of two distinct techniques to measure minority carrier lifetime in semiconductor photodiode.

- Observe voltage decay with time by shining and removing light on the sensor.
- Provide a waveform with different forward and reverse biases and plotting a graph between them

2 Methods



(a) Circuit for Part 1



(b) Circuit for Part2

Photodiode is connected through a resistor in series. The circuit is provided voltage from a function generator which is set to provide square-wave input of varying frequencies.

2.1 Part 1

LED is provide 5V continuous pulses from function generator emitting light pulses. The light pulses fall on the open circuited photodiode placed beside. We adjust the input wave frequency so that transient is properly revealed. The corresponding waveform is observes on the Digital Storage Oscilloscope and the life time is calculated by the formula given.

$$V_{oc}(t) = A - \frac{kT}{q}\frac{t}{\tau_0}$$

Hence, we then calculate the minority carrier lifetime τ_0 using slope of linear region in transient.

2.2 Part 2

We adjust the value of DC offset in function generator for different values of V_1 and V_2. The data is recorded for different DC offsets at 3 different frequencies which are 1 kHz, 40 kHz, and 100 kHz. The data consists of voltage across resistor and use it to find storage time τ_s. This data will be used to plot graph and estimate τ_0.

3 Observations

3.1 Part 1

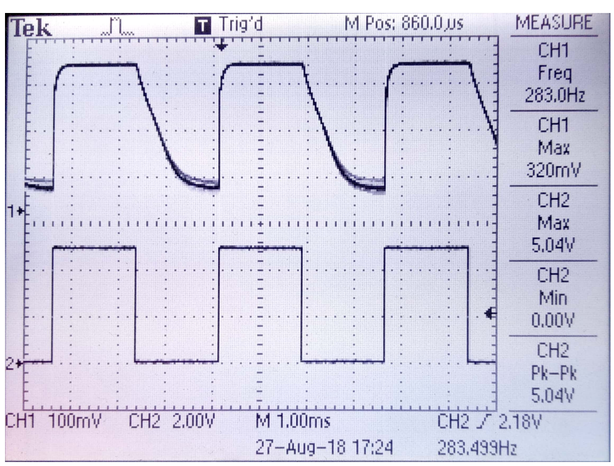
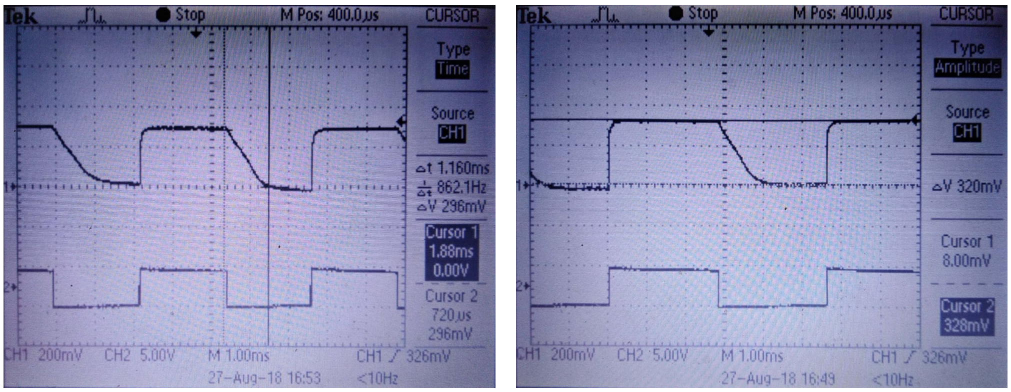


Figure 1: V_{oc} : Photodiode's response to 5V Pulses

We can clearly see the almost linear voltage decay as soon as the light turns off. We obtain the above waveform on providing 5V pulses to the LED and calculated slope of linear region.



(a) Δt measurement

(b) ΔV measurement

Figure 2: Cursor Measurement

Δt in ms	ΔV in mV
1	277
1.02	280
1.04	284
1.08	296
1.12	310
1.15	318

Table 1: Recorded Values of Linear Regions

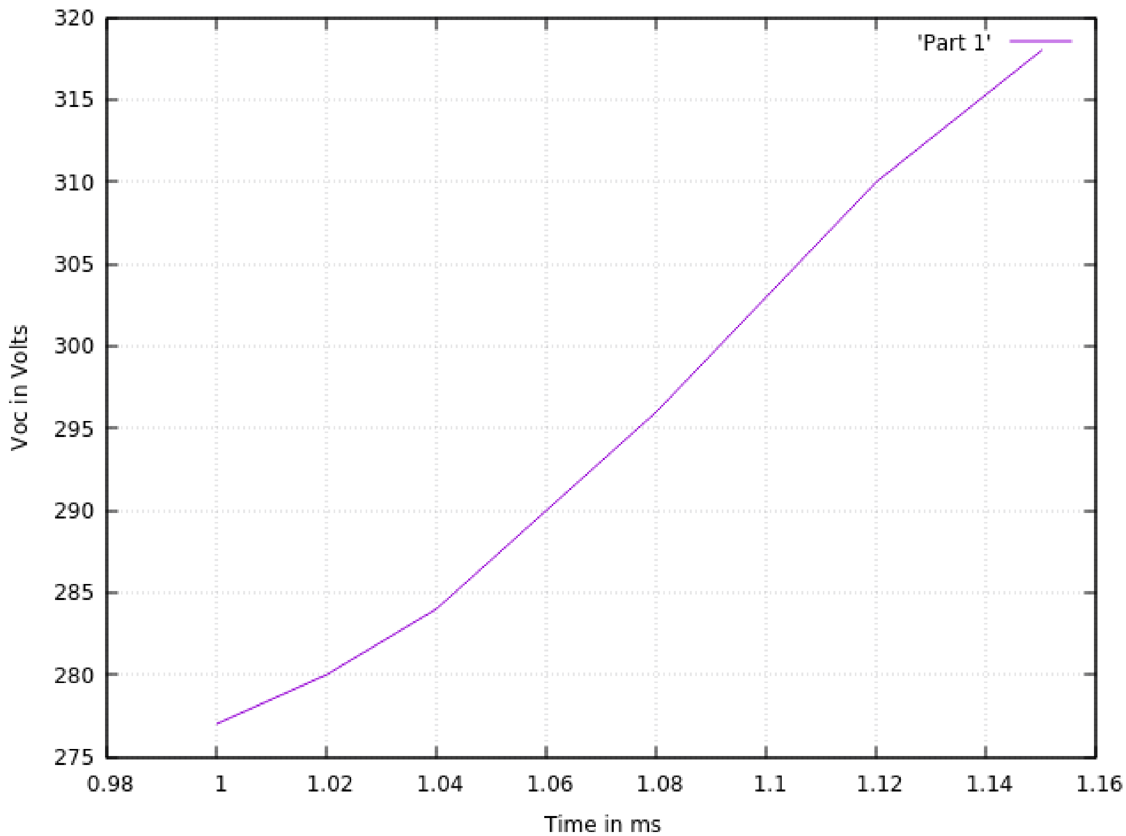
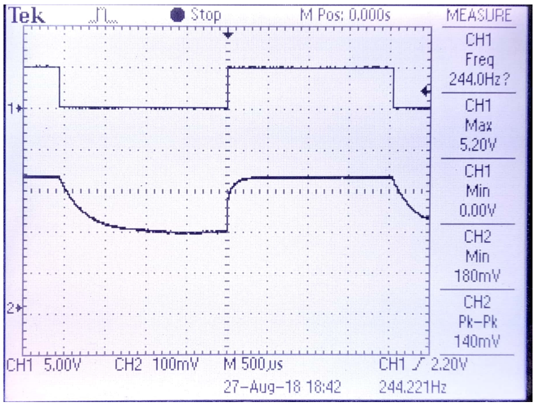


Figure 3: Voltage drop in decay vs time taken in linear region of decay

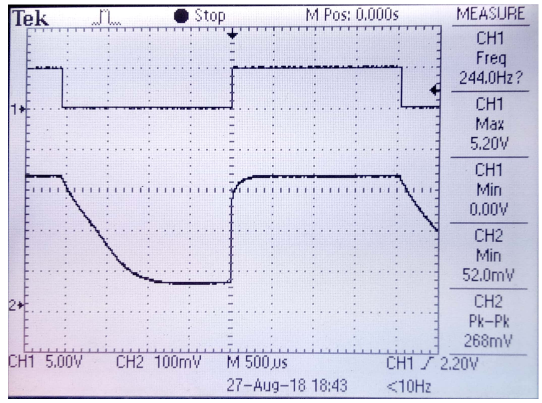
From the above plot, we can find minority carrier life time by finding the slope of best fit line.

$$\tau_0 = \frac{0.0256}{Slope} = \frac{0.0256}{285.342} = 89.7\mu s$$

Now, the next subpart asks what happens when LED and Photodiode are uncovered i.e. tape is removed.



(a) Waveform with diode uncovered



(b) Waveform with diode covered

Figure 4: Side by side comparison of waveforms with diode uncovered and covered

3.2 Part 2

The following waveforms were observed.

V1	V2	Time
2.4V	-4V	23 μs
3V	-3.6V	36 μs
4.5V	-2V	64 μs
6V	-0.6V	140 μs

(a) 1kHz

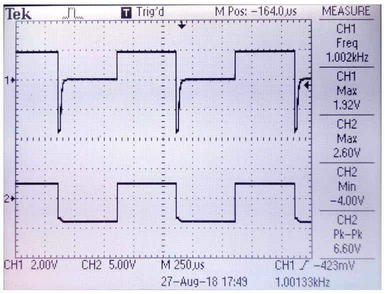
V1	V2	Time
2.2V	-4V	2.2 μs
4.5V	-2V	12.3 μs
3.6V	-3V	5.5 μs

(b) 40kHz

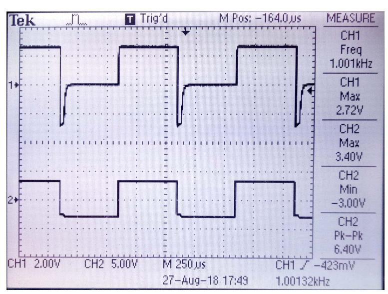
V1	V2	Time
2.5V	-3V	1.4 μs
4V	-4V	1.7 μs
5V	-3V	4.9 μs

(c) 100kHz

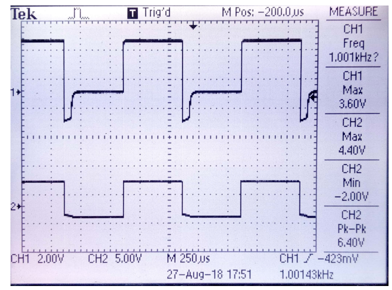
Figure 5: Data for storage time for different V_1 and V_2



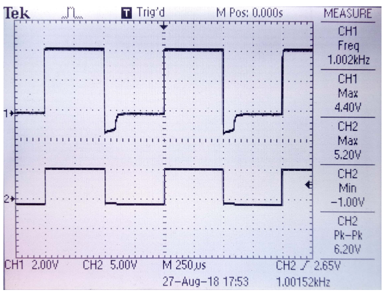
(a) 2.6V, -4V, 1kHZ



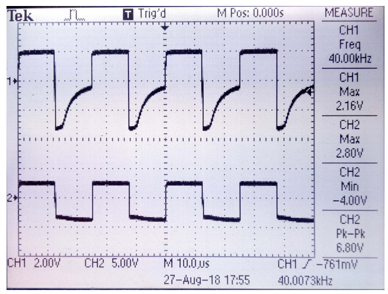
(b) 3.4V, -3V, 1kHZ



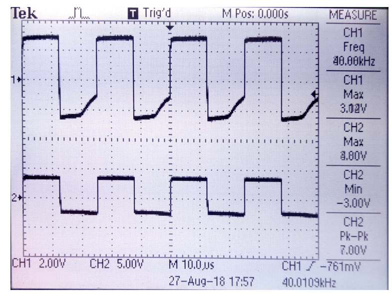
(c) 4.4V, -2V, 1kHZ



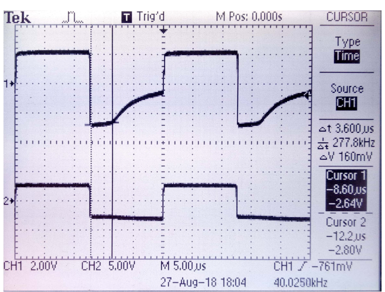
(d) 5.2V, -1V, 1kHz



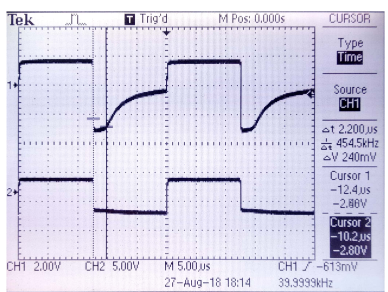
(e) 2.8V, -4V, 40kHz



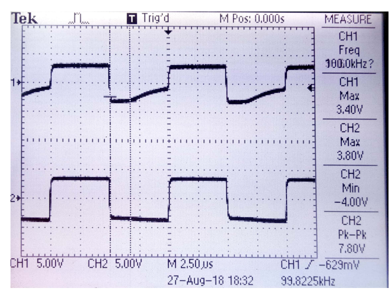
(f) 3.8V, -3V, 40kHz



(g) 40kHZ, Measurement

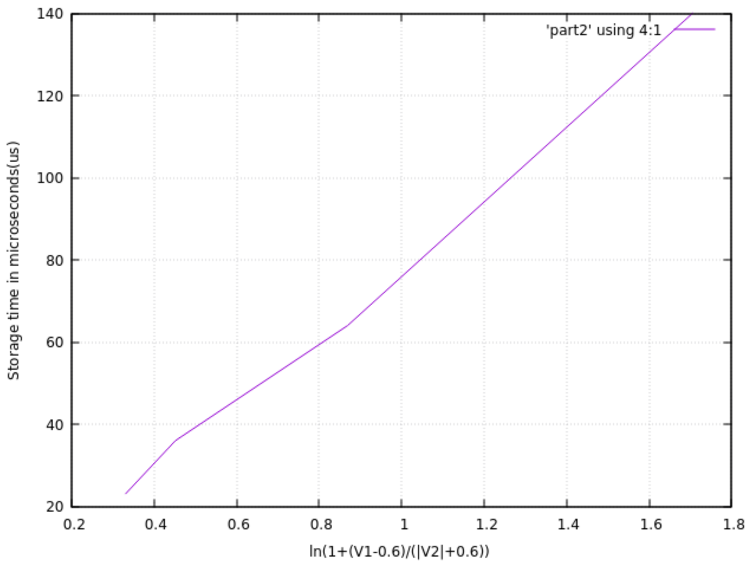


(h) 100kHz, Measurement

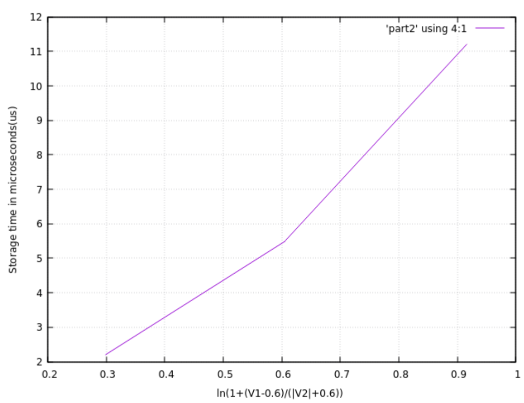


(i) 100kHz, Measurement

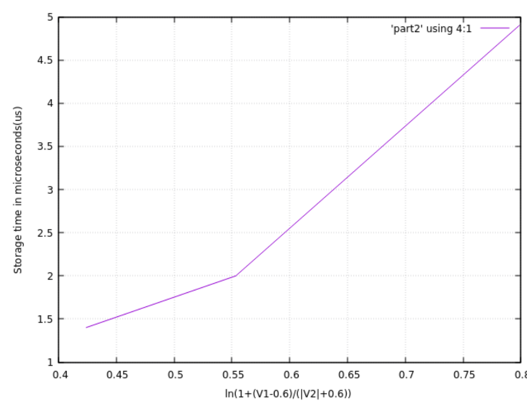
Figure 6: DSO Screenshots of waveform and τ_s measurements



(a) 1kHz



(b) 40kHz



(c) 100kHz

Figure 7: τ_s vs. $ln(1 + \frac{V_1 - 0.6}{V_2 + 0.6})$

τ_s is calculated from the slope of best fit line in these graphs.

Frequency	Minority Carrier Lifetime τ_s
1kHz	84.1 μs
40kHz	14.6 μs
100kHz	9.7 μs

We infer from observations that as frequency is increased, the storage time decreases.

4 Inference

When a reverse bias is applied right after forward bias, the current can not go to zero instantaneously. When reverse bias is applied, minority carriers start diffusing into depletion region. The current is much higher than reverse saturation current. The time taken to reach reverse saturation current is sum of minority carrier life time and recombination time.

4.1 Part 1

As soon as LED goes off, excess carriers start decaying and generation rate becomes zero. This decay is exponential in nature. The approximate Voltage decay can be given by

$$V_{oc}(t) = A - \frac{kT}{q}\frac{t}{\tau_0}$$

The slope in this linear relation is inversely proportional to τ_s which is used to calculate it. The time increases as initial voltage increases, as expected from the equation.

When the LED and diode were uncovered, the waveform's minima increased while maintaing it's shape. This is similar to applying a DC offset to waveform. This can be attributed to the excess light falling on diode from the environment(noise). This would not happen in a dark room.

4.2 Part 2

The higher the forward bias, the more number of carriers cross depletion region and take more time to decay when reverse bias is applied. On increasing the frequency, carriers have less time to get removed while input again gets high before recombination could finish. So, on increase in frequncy, naturally, τ_s should decrease.