APPLICATION NOTE ON DIODE REVERSE RECOVERY MEASUREMENT

Introduction

A **diode** is a two-terminal electronic component that conducts current primarily in one direction (Forward bias) in the conduction path it has low (ideally zero) resistance and high (ideally infinite) resistance in the other.

A p–n junction diode is made of semiconductor material, usually silicon, but germanium and gallium arsenide are also used. Impurities are added to it to create a region on one side that contains negative charge carriers (electrons), called an n-type semiconductor, and a region on the other side that contains positive charge carriers (holes), called a p-type semiconductor.

When the n-type and p-type materials are attached together, a momentary flow of electrons occur from the n to the p side resulting in a third region between the two where no charge carriers are present. This region is called the depletion region because there are no charge carriers (neither electrons nor holes) in it. The diode's terminals are attached to the n-type and p-type regions. The boundary between these two regions, called a p–n junction, is where the action of the diode takes place. When a sufficiently higher electrical potential is applied to the P side (the anode) than to the N side (the cathode), it allows electrons to flow through the depletion region from the N-type side to the P-type side. The junction does not allow the flow of electrons in the opposite direction when the potential is applied in reverse, creating, in a sense, an electrical check valve.

A diode when functioning in its forward bias condition has its depletion region shrinked to almost nothing. That is, the external supply voltage applied will be used by the device to overcome the barrier potential which gets imposed on it due to the presence of immobile charge carriers in its depletion region. Now, imagine that one reverse biases this voltage by inverting the polarities connected to the terminals of the diode. Ideally, the act of doing so should bring the diode from its ON state to OFF state immediately. That is, the diode which is conducting current in its forward direction is expected to stop conducting instantly.
However, practically, this cannot be experienced as the flow of majority charge carriers through the diode does not cease right at the moment of reversing the bias. They will, in fact, take a finite amount of time before stopping and this time is known as **reverse recovery time of the diode**.

During this reverse recovery time of the diode, one can see that there will be fairly large amount of current flowing through the diode, but in the opposite direction (I_{rr} in Figure 1). However its magnitude reduces and gets saturated to a value of reverse saturation current, once the time-line crosses reverse recovery time (t_{rr}) of the diode. Graphically one can describe the **reverse recovery time of the diode** as the total time which starts from the instant at which the reverse current starts to flow through the diode to the time instant at which it reaches to zero (or any other pre-defined low level, say 25% of I_{rr} in the figure) while decaying (tt), on reaching its negative maxima.

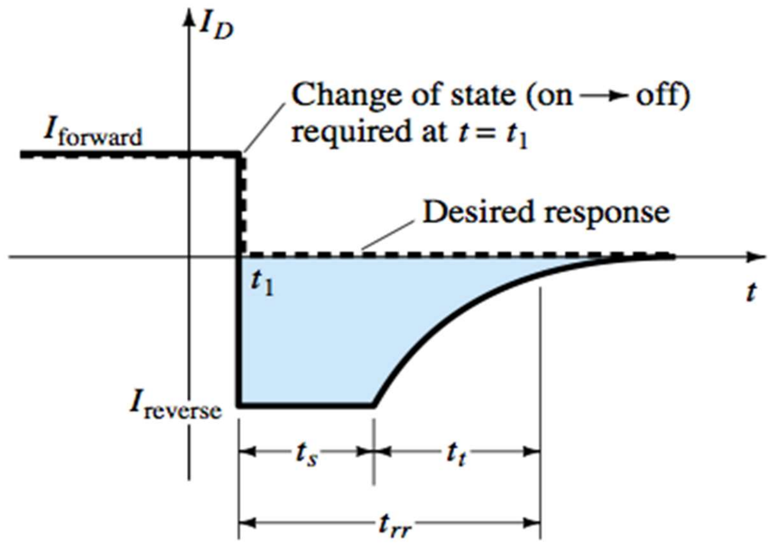

Figure 1: Reverse recovery of diode [4]

The formula for Reverse Recovery Time denoted by **trr**.

$$t_{rr} = t_s + t_t$$

Naturally, it is an important consideration in high-speed switching applications. Most commercially available switching diodes have a trr in the range of a few nanoseconds to 1 us. Units are available, however, with a trr of only a few hundred picoseconds.

Storage Time (ts) is the required period of time for the minority carriers to return to their majority-carrier state in the opposite material.

Transition Interval (tt) is the second period when the storage phase has passed and the current will reduce in level to that associated with the non-conduction state.

This phenomenon of reverse recovery is basically parasitic effect experienced in the case of diodes and is seen to be dependent on the doping level of silicon and its geometry. Also, even the junction temperature, the rate at which the forward current falls and the value of the forward current just before the reverse biased gets applied are also seen to affect its value. Greater is the reverse recovery time; slower will be the diode and vice-versa. Thus the diodes with lesser reverse recovery time are preferred, especially when the requirement is of high switching speed. Moreover, during this time interval, there will be a significant amount of current-flow back towards the supply which provides power to the diode. Hence the **reverse recovery time of the diode** is an important design factor which we should consider while designing the power supplies.[1]

Measurement method using B1500A semiconductor Device Analyzer and DC probe station

Fast BTI (DC stress Id-Vg): Reverse recovery Test, using WGFMU

Step1: Keep the DUT (Device Under Test) in the probe station and probe the device.

Figure 2: DUT probed on DC probe station 2

Step 2: Check IV characteristic of device by applying -1 V to +1V DC and make a note of maximum current at 1V (Refer Red file 3.0 Operating procedure). [2]

Note: In this application note WGFMU is used for pulsing which has a limitation of voltage (0-10V pulse and 0-10mA) make sure that you connect the DUT within the operating limits of WGFMU.

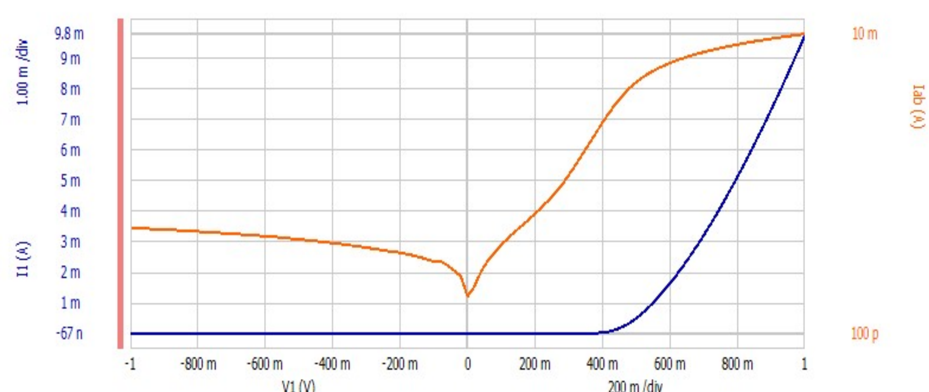

Figure 3: Diode IV characteristics

Step 3: Connect the 2 Pulse unit/RSU to the probe station manipulator cables using BNC male to Triax female connector.

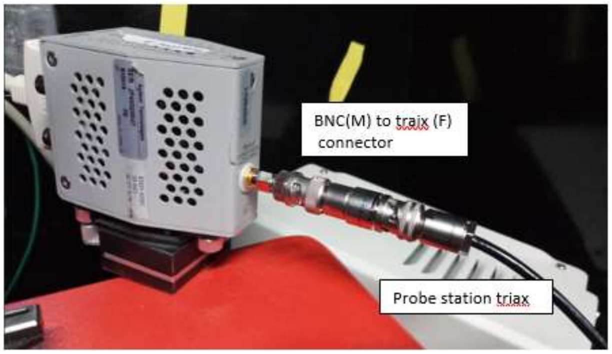

Figure 4: RSU to probe station connection

Step 4: Open Application test from the Easy expert software. From the category list select WGFMU using check box. From library select Fast BTI (DC stress Id-Vg).

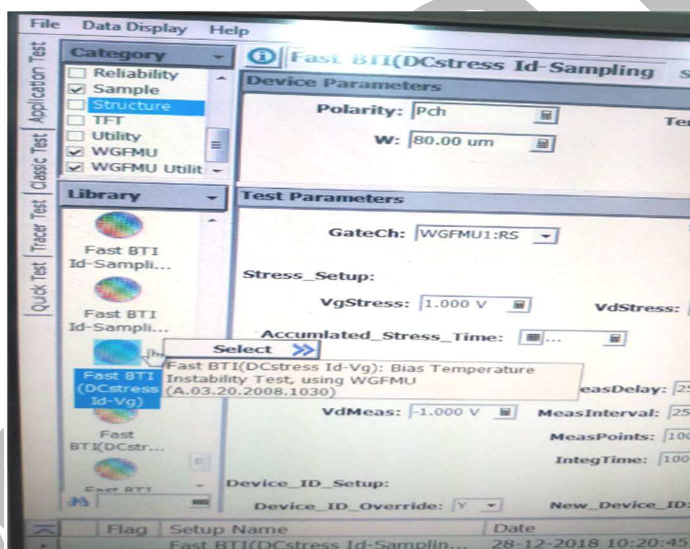

Figure 5: Selecting the fast BTI(DC stress Id-Vg) setup

Step 5: Enter the value for Vg Stress as 1V and Vd stress as 0V

Step 6: Enter the accumulated stress time values in the first column from up to down. Accumulated stress time as 1ms, 2ms, 3ms, 4ms and 5ms

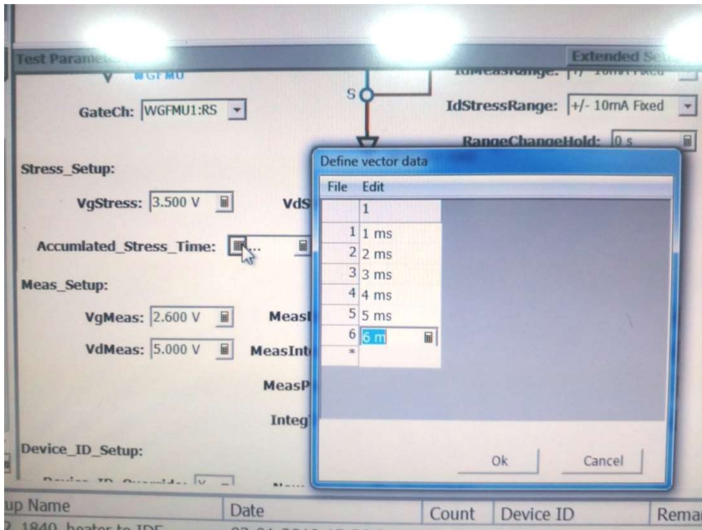

Figure 6: Vd Accumulated stress time

Step 7: Enter the values for measurement delay, measurement interval, measurement points and integration time and transient edge and point to plot. Refer below for the example.

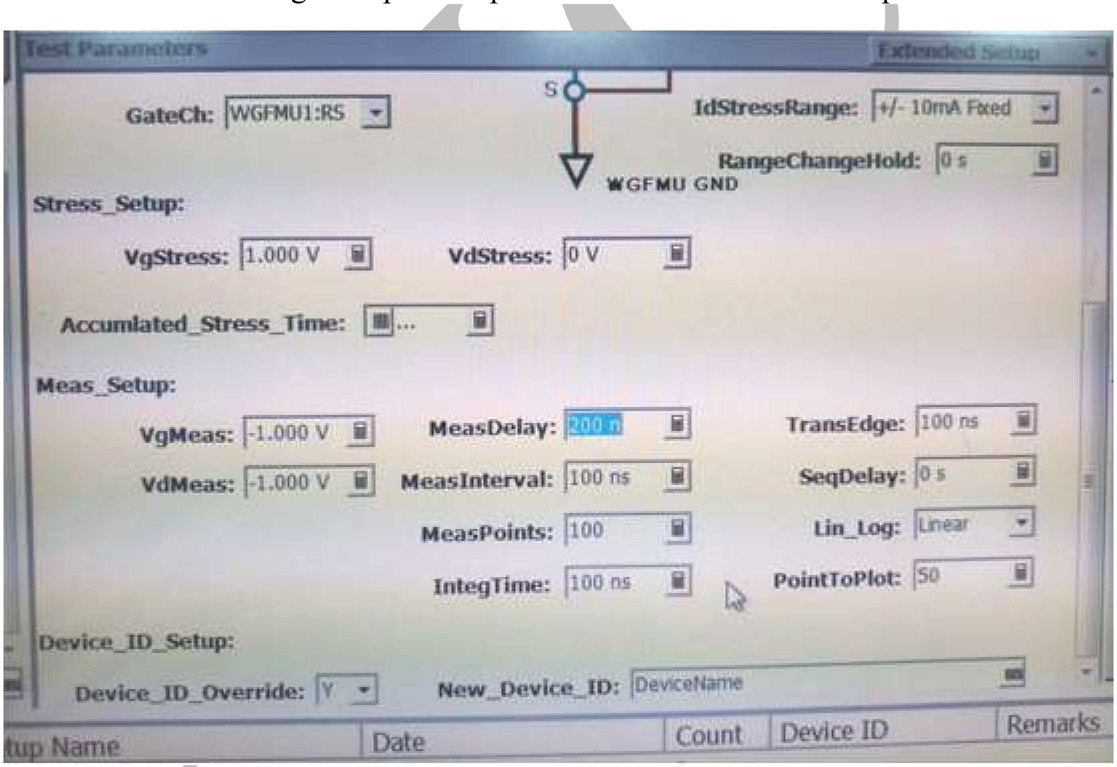

Figure 7: Measurement parameters

Step 8. Turn ON the multi-display ON

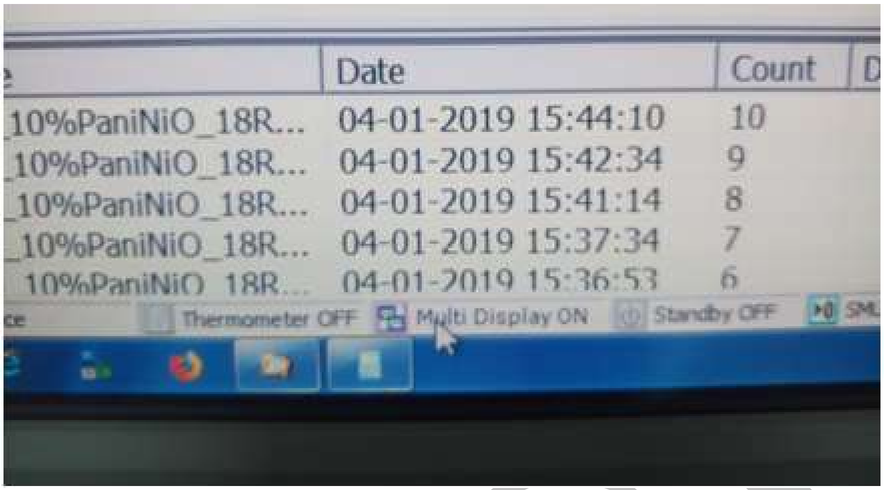

Figure 8: Turning ON the multi display ON

Step 9: Enter the setup Name and Run the setup.

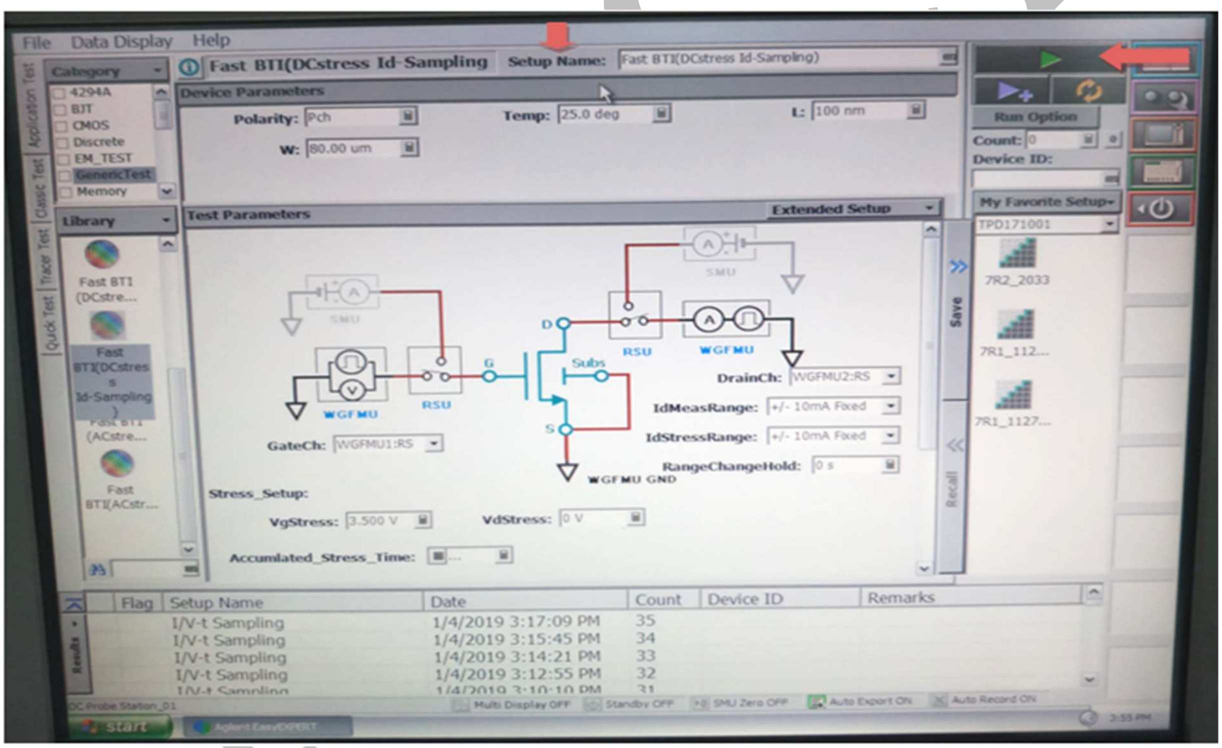

Figure 9: Running the measurement setup

Step 10: Measurement graph.

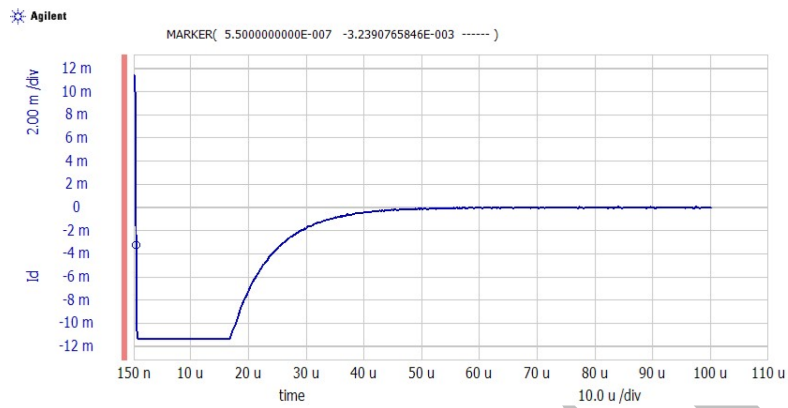

Figure 10: Measurement graph

Sample Details

Sample: p- phosphorous doped Solar cell

Sample size:2mm * 2mm

Measurement parameters

Vf=+1V, Vr=-1V, Accumulated stress time=1-6ms, transient edge =100ns

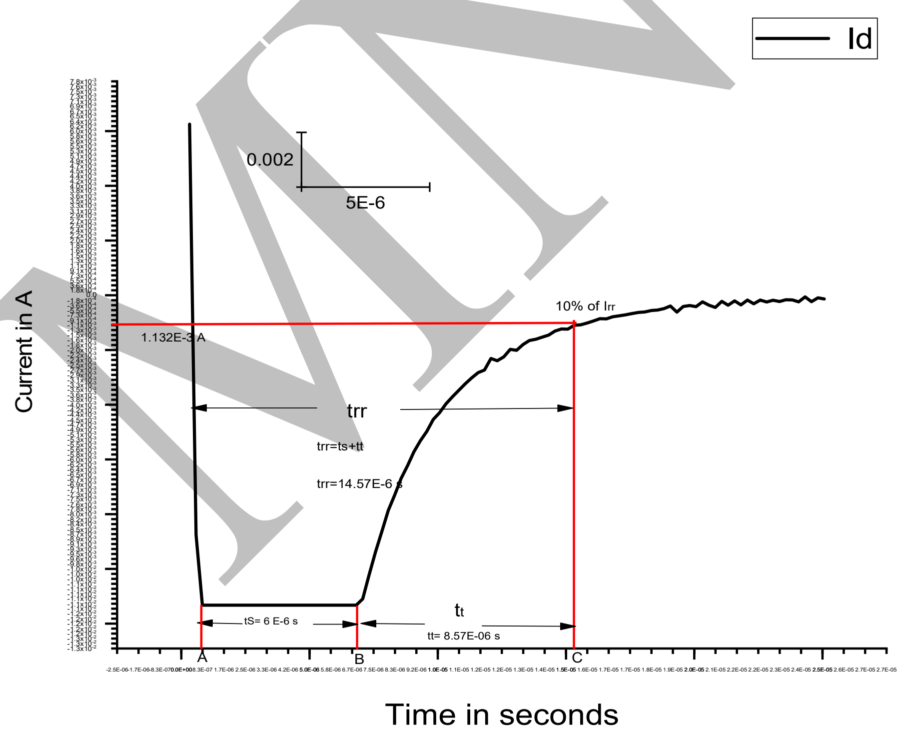

Figure 11: Plotted curve without load resistor

From the above graph we see reverse recovery time (trr), measured as the time between the initial zero crossing of the diode current to the time when this current reaches 10% of the peak reverse current.

From the graph

trr=ts+tt

trr= 16.17E-6 + 15.5E-06

trr =31.67E-6 s

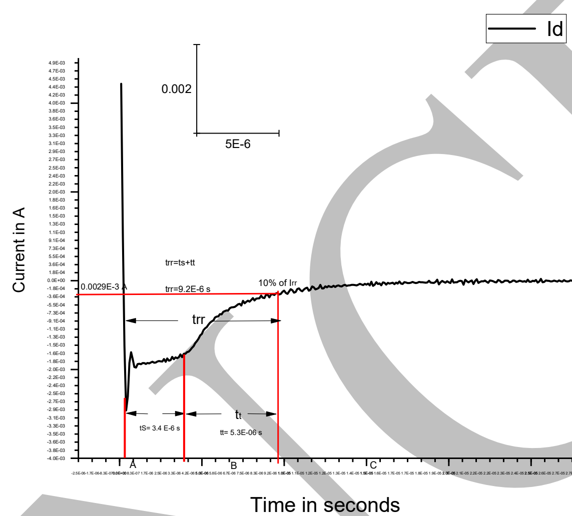

Figure 12: Plotted curve with 225ohm load resistor

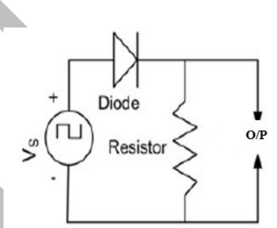

Figure 13. Circuit diagram for RR experiment

The above plot (Figure 12) was measured along with the 220 ohm load resistor for limiting the current The reverse recovery time (trr), measured as the time between the initial zero crossing of the diode current to the time when this current reaches 10% of the peak reverse current.

From the graph

trr=ts+tt

trr= 3.9E-6 + 5.3E-06

trr =9.2E-6

Extraction of storage time (ts) for different If(Forward current) using 225 ohm resistor in series with the diode to limit the current

Applied voltage	Storage time in sec	IF (Forward current in A)	IR (Reverse current in A)	1+If/Ir	Ln(1+If/Ir)
Values at +0.5V and -1V	2.0E-7	0.0033	0.00215	2.534	0.924
Values at +1V and -1V	3.40E-06	0.004437	0.00292	2.519	0.930
Values at +1.2V and -1V	6.20E-06	0.004927	0.00307	2.604	0.951
Values at +1.4V and -1V	7.70E-06	0.00542	0.00322	2.683	0.987
Values at +1.6V and -1V	9.11E-06	0.00597	0.00336	2.776	1.02
Values at +1.8V and -1V	1.03E-05	6.50E-03	0.003496	2.860	1.05
Values at +2V and -1V	1.20E-05	6.98E-03	0.003639	2.920	1.07

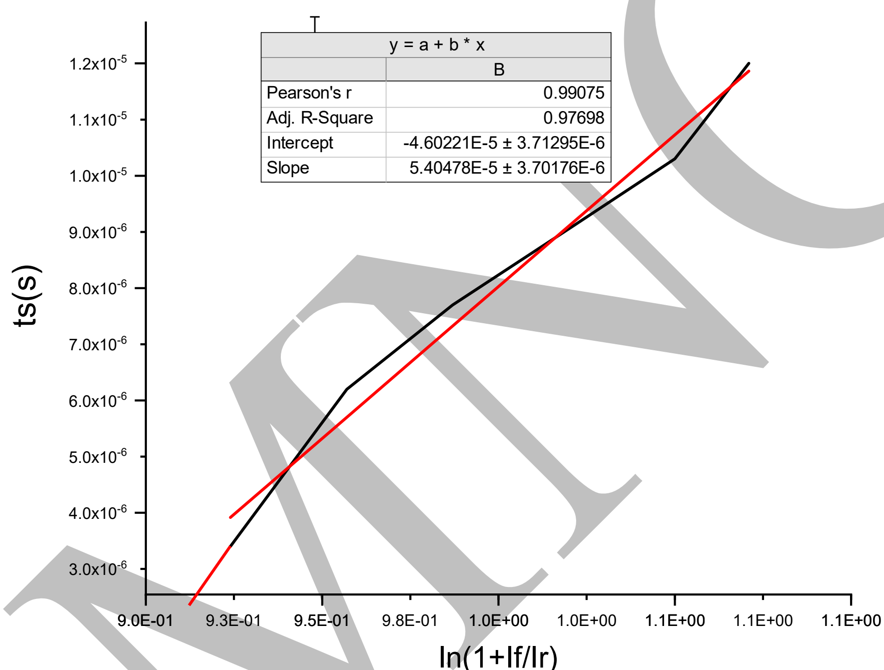

Figure 13: Plot of ts versus ln(1+If/Ir)

The lifetime is found from the slope and the intercept is (1+Qs/Ir*τr) which is obtained by extrapolating the line to the x-axis.

Extracted charge calculation:

from the plot, slope(lifetime)= 5.40E-5(slope)

Vf=+1V, Vr=-1V

If=0.004437, Ir= -0.00292

(1+Qs/Ir*τr)= 0.915

Qs =(0.915-1) * (Ir*τr)

Qs=1.34E-8 coulomb's

References

1. https://www.electrical4u.com/reverse-recovery-time-of-diode/
2. Red file Dc probe station 2
3. http://www.eng.uwi.tt/depts/elec/staff/rdefour/ee33d/s2_rrchar.html
4. https://www.eeweb.com/quizzes/reverse-recovery-time