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ASSESSEMENT OF THE EFFECT OF TEMPERATURE ON DRIFT AND DIFFUSION CURRENT ON PN-JUNCTION SILICON DIODE UNDER FORWARD BIAS CONDITION

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ABSTRACT

Assessment on how temperature effects diffusion and drift current of p-n junction under forward bias condition was carried out here using silicon diode as the base of study with consideration of the Einstein diffusion relation for both holes and electrons as the constituent of carriers in p-n junction. The temperature of the diode was set at various values starting with room temperature and ensuring that it is maintained during each set of experiment for every forward bias voltage when the drift current and diffusion current is being obtained. This was carried out for all the set temperature as set out in work and the trends were presented on tables and graphs as showcased here where it is seen that the drift and diffusion current for various temperatures behave uniquely in relation to given forward bias voltage and current.

1 INTRODUCTION

There are many factors like field width of the depletion layer that affect the operation of P-N junction of semiconductor because of how it influences carrier concentrations and other parameters in the p-n junction [1]. Over years, the effect of temperature on the operation of all the semiconductor devices has been of concern and more pronounced when compared to other factors because it has been established right from the era of the vacuum devices like diode, triode withstand high temperature while in operation up to the recent dispensation when many of the electronics components today are now built from intrinsic and novel /extrinsic semiconductor materials such as (GaAs), zinc oxide (ZnO), copper-antimony sulphide (Cu-Sb_2S_3) etc that temperature stands to be influential factors to all electronic components [2;3]; [4] vacuum tube devices that even now it has been replaced by semiconductor devices like p-n junction diodes,

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transistors etc. Accordingly, [5]. temperature highly influences the operation of semiconducting devices. Semiconductor material has a negative temperature co-efficient of resistance, which means that the resistance of a semiconductor material decreases with increase in temperature this is because the energy required to break their covalent bond is very small being 0.7 eV for Ge and 1.1 eV for Si [6] or that their band gap is small or may direct [7]. But contrary to metal conductor that has narrower bad gap compared to any of the semiconductors mentioned above, the resistivity increase with increase in temperature. [8]. This study is based on the general nom that all electronic devices are designed to operate at a given room temperature depending on its temperature operating capacity. Though theoretically, above a temperature of 0K, the atoms of semiconductor materials experience lattice vibrations that impedes on electrons' free movement in the material leading to the interaction between electrons and vibrating lattice atoms that invariably results from scattering phenomenon in a semiconductor culminates to phonon/lattice scattering. Generally semiconductor material has a negative temperature co-efficient of resistance, which means that the resistance of a semiconductor material decreases with increase in temperature this is because the energy required to break their covalent bond is very small being 0.7 eV for Ge and 1.1 eV for Si [10] or that their band gap is small or may direct [11] [12] but contrary to metal conductor that has narrower bad gap compared to any of the semiconductors mentioned above, the resistivity increase [13] with increase in temperature[14;15] and thus we study the effect of temperature on drift current under forward bias condition as it is known that temperature affects carrier concentration in semiconductor materials especially when they are in operation as we based and thus picked interest in examining the influence of temperature on diffusion current at various temperature range in order to ascertain at which temperature the effect is more vulnerable and pronounced.

2.00 THEORETICAL AND EXPERIMENTAL PROCEDURE

2.01 THEORETICAL HIGHLIGHT

Theoretically, the current –voltage relation of diode is given as according below

$$I = I_S\left(e^{\frac{qV}{kT}} - 1\right) \quad 1$$

Where Saturation Current is (I_s) is given by

$$I_S = AT^3 e^{-E_g/KT}$$

A is a constant depending on the diode.

E_g is the energy band gap of silicon.

On the other hands the diffusion current relating to the concentration of charges for both P-type and N-type region can written a

$$I_D = qD\frac{dn}{dx} \quad \text{and} \quad I_D = qD\frac{dp}{dx} \quad 3$$

D Einstein's diffusion the diffusion coefficient which is mathematically given by

$$D = \mu\frac{kT}{q} \quad 4$$

$\frac{dn}{dx}$ and $\frac{dp}{dx}$ are the gradient of electron and hole concentration respectively.

where μ is the mobility of charge carriers.

Generally, the total current in a diode is the sum of the drift current and the diffusion current

$$n_i = \sqrt{N_C . N_V . e^{-\frac{E_q}{2kT}}} \qquad 5$$

N_C and N_v are the effective density of states in the conduction and valence bands, respectively. The behavior of recombination and diffusion currents in a silicon PN junction diode under forward bias is governed by several key equations. These equations highlight the dependency on temperature, carrier concentrations, and material properties, providing a comprehensive highlight on the thermal influence on silicon diodes.

2.02 MATERIAL/METHOD

The materials that were procured for the experiment are (i) Silicon Diode: A standard silicon PN junction diode (1N4007) (ii). Power Supply: A DC and AC power supply capable of providing a variable voltage (0 to 20V), (iii) temperature controlled chamber (Oven). (iv) temperature sensor: (v). digital ammeter, (vi) voltmeter, (vii). heat sink and insulating materials that was used to prevent thermal runaway and ensure uniform temperature distribution. The temperature of the diode was set at room temperature of (25°C) and then connected to DC power supply which is already set to a low forward bias voltage range from 1v to 5v with the initial reading taken in the first instance at the room temperature with the voltage then being gradually increased in a step of 1.0volt respectively until the attainment of the maximum value set for voltage which is5voltage. The corresponding forward bias voltage and current were read simultaneously corresponding to every step increase in DC voltage supply during the readings. The same procedure was repeated for the diode temperature of 20^o, 40^o and up maximum of 150^o respectively.

Further, Shockley diode equation as stated in equation (1) was used with the obtained experimental data to assess the temperature effect on the diffusion and drift current and result were presented in the table and graph discussion section respectively.

RESULT AND DISCUSSION

The result of the effect of temperature on the diffusion, and drift current on PN-junction silicon diode under forward bias condition has been presented based on the analysis using Shockley diode equation as in equation 1 coupled with Einstein's diffusion equation as in equation 4 The entire diffusion current comprising current due to hole and electron as in equation 5 was also used in simulating the values of diffusion and drift current respectively. On the other hands, the experimental readings based on forward bias current and voltage were first obtained as mentioned above just as presented in tables and as plotted. In a similar manner, the corresponding a diffusion, and drift current base on forward voltage at different temperature and also at different applied voltage were presented in tables. First stating with total current versus forward voltages at various applied voltages at various temperature as in fig.1, followed by the graph of diffusion current versus forward voltage at various applied voltages at different temperature are presented at fig. 2 and for the drift current versus forward voltage at various temperature at different applied voltage also presented in graph of fig .3. While, behavior of graphs in each case were showcased on foot of each graph.

Table.1: Forward Voltage V_F and the Forward Current I_F at various applied voltages at 25, 40, 60, 80℃.

VOLTAGE(V)	V_F(V)	I_F(V)(mA)	V_F (V)	I_F (mA)	V_F (V)	I_F (mA)	V_F (V)	I_F (mA)
1.00	0.70	1.00	0.68	1.20	0.66	1.50	0.64	1.80
2.00	0.71	1.10	0.69	1.25	0.68	1.60	0.68	2.20

3.00	0.72	1.20	0.70	1.30	0.70	1.70	0.72	2.40
4.00	0.73	1.30	0.72	1.40	0.72	1.80	0.76	2.80
5.00	0.75	1.40	0.73	1.50	0.74	2.00	0.80	3.20
	25℃	***25℃***	***40℃***	***40℃***	***60℃***	***60℃***	***80℃***	***80℃***

Table.2: Forward Voltage V_F and the Forward Current I_F at various applied voltages at 100, 120, 140, 150℃.

VOLTAGE(V)	V_F (V)	I_F (mA)	V_F (V)	I_F (mA)	V_F (V)	I_F (mA)	V_F (V)	I_F (mA)
1.00	0.62	2.20	0.60	2.60	0.58	3.00	0.57	3.20
2.00	0.64	2.50	0.64	2.90	0.60	3.20	0.59	3.50
3.00	0.68	2.80	0.66	3.20	0.62	3.50	0.61	3.80
4.00	0.70	3.20	0.69	3.50	0.64	3.80	0.62	4.20
5.00	0.72	3.50	0.72	3.80	0.66	4.10	0.65	4.50
	100℃	***100℃***	***120℃***	***120℃***	***140℃***	***140℃***	***150℃***	***150℃***

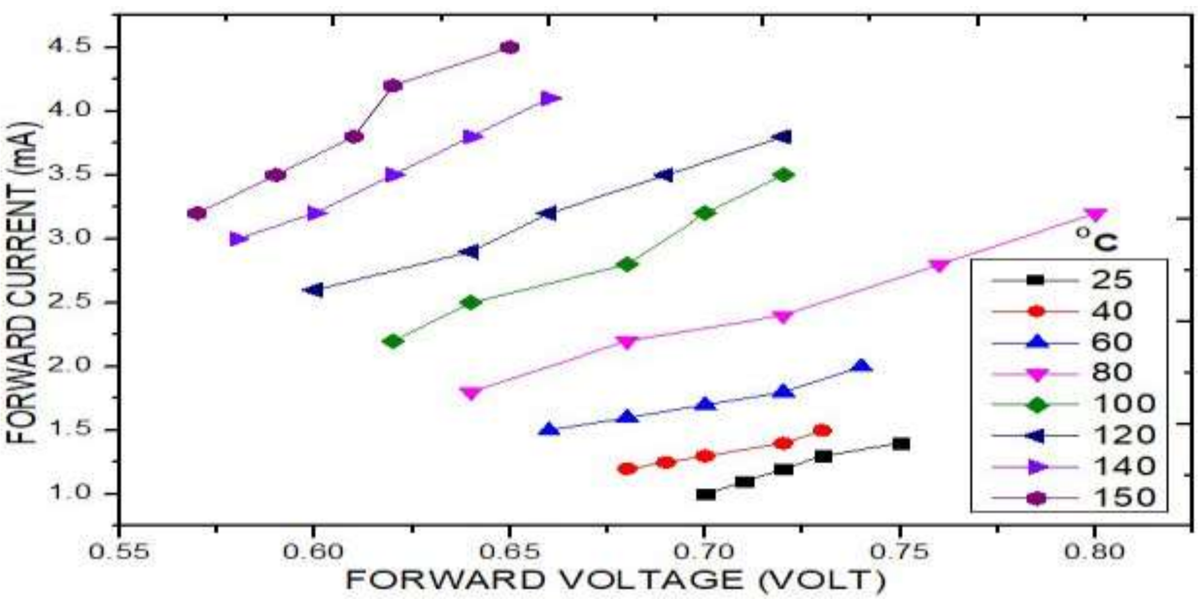


Fig.1: Graph of Total Current versus Forward Voltage at Various Temperatures

From the table as presented here, it appears that as the temperature increases there is a variation in the total current with temperature increase while at the other hand the forward voltage decreases with increase in the temperature.

Table.3: Forward Voltage V_F and Diffusion Current (mA) at various applied voltages at 25, 40, 60, 80℃.

VOLTAGE(V)	V_F(V)	Diffusion mA	V_F (V)	Diffusion mA	V_F (V)	Diffusion mA	V_F (V)	Diffusion mA
1.00	0.70	0.95	0.68	1.14	0.66	1.43	0.64	1.72
2.00	0.71	1.11	0.69	1.18	0.68	1.50	0.68	1.80
3.00	0.72	1.15	0.70	1.22	0.70	1.58	0.72	1.95

4.00	0.73	1.18	0.72	1.30	0.72	1.65	0.76	2.05
5.00	0.75	1.20	0.73	1.50	0.74	1.70	0.80	2.10
	25℃	***25℃***	***40℃***	***40℃***	***60℃***	***60℃***	***80℃***	***80℃***

Table.4: Forward Voltage V_F and Diffusion Current (mA) at various applied voltages at 100, 120, 140, 150℃.

VOLTAGE(V)	V_F (V)	Diffusion mA	V_F (V)	Diffusion mA	V_F (V)	Diffusion mA	V_F (V)	Diffusion mA
1.00	0.62	2.11	0.60	2.50	0.58	2.89	0.57	3.08
2.00	0.64	2.20	0.64	2.70	0.60	3.00	0.59	3.20
3.00	0.68	2.30	0.66	2.80	0.62	3.20	0.61	3.40
4.00	0.70	2.45	0.69	3.00	0.64	3.40	0.62	3.60
5.00	0.72	2.50	0.72	3.20	0.66	3.55	0.65	4.00
	100 ℃	***100℃***	***120 ℃***	***120℃***	***140 ℃***	***140℃***	***150 ℃***	***150℃***

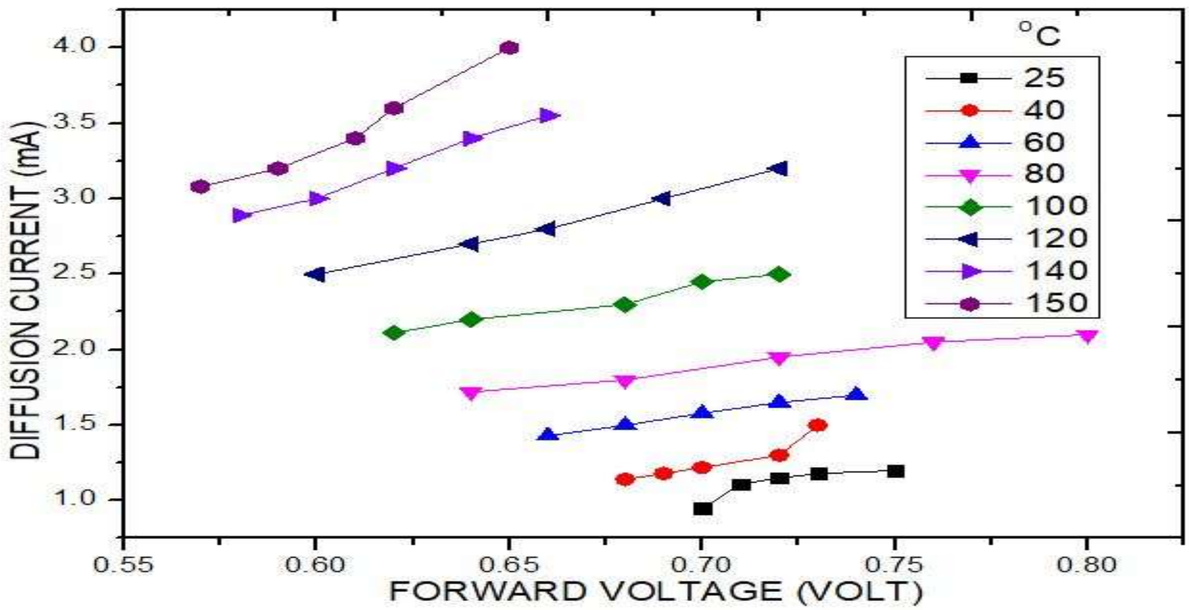


Fig.2: Graph of Diffusion Current (mA) Versus Forward Voltage at Various Temperatures

Generally, the observed difference in current for every increase in the temperature becomes pronounced as temperatures became higher as it can be seen that at 25℃ and 40℃ the difference in current is 0.2mA while at 140℃ and 150℃ is 1.0mA which is normal since increase in the temperature affects the thermal agitation which invariably will have effect on the flow of current in the diode.

Table.5: Forward Voltage V_F and the Drift Current (μA) at various applied voltages at 25, 40, 60, 80℃.

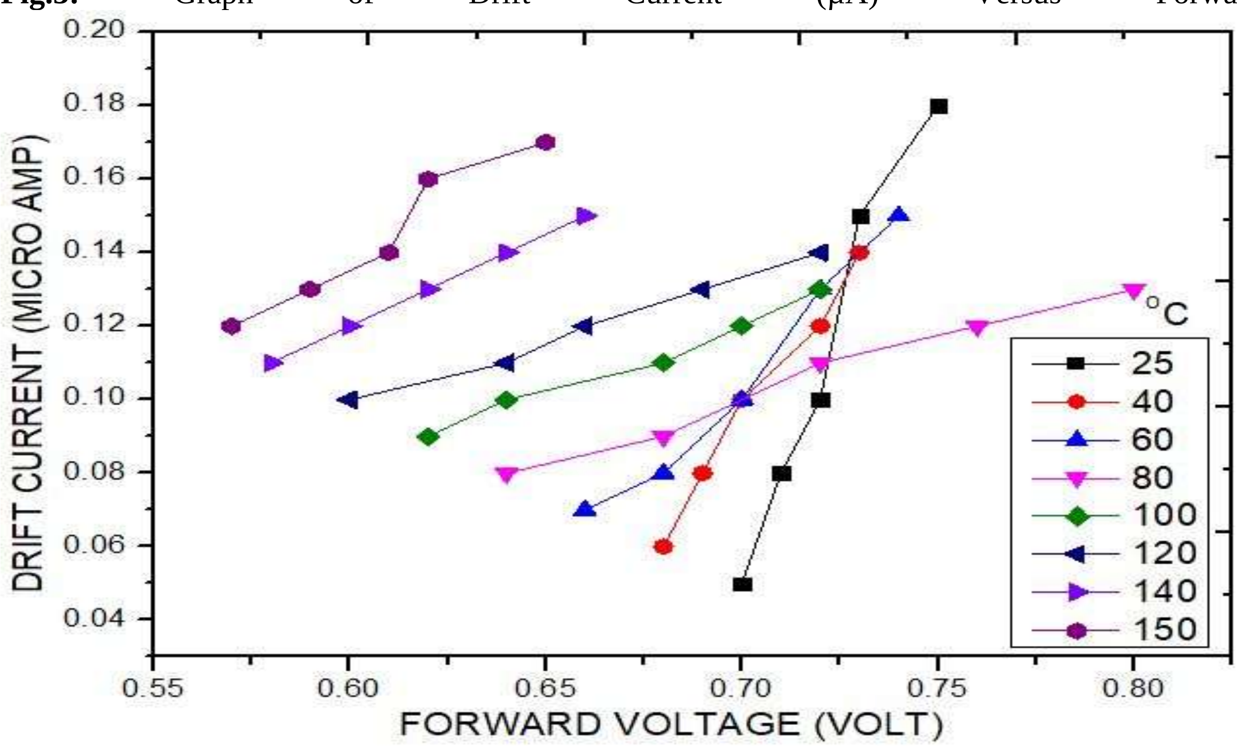
VOLTAGE(V)	V_F(V)	Drift(μA)	V_F (V)	Drift(μA)	V_F (V)	Drift(μA)	V_F (V)	Drift(μA)
1.00	0.70	0.05	0.68	0.06	0.66	0.07	0.64	0.08
2.00	0.71	0.08	0.69	0.08	0.68	0.08	0.68	0.09

3.00	0.72	0.10	0.70	0.10	0.70	0.10	0.72	0.11
4.00	0.73	0.15	0.72	0.12	0.72	0.13	0.76	0.12
5.00	0.75	0.18	0.73	0.14	0.74	0.15	0.80	0.13
	25℃	***25℃***	***40℃***	***40℃***	***60℃***	***60℃***	***80℃***	***80℃***

Table:6: Forward Voltage V_F and the Drift Current (μA) at various applied voltages at 100, 120, 140, 150°C.

VOLTAGE(V)	V_F **(V)**	**Drift(μA)**	V_F **(V)**	**Drift(μA)**	V_F **(V)**	**Drift(μA)**	V_F **(V)**	**Drift(μA)**
1.00	0.62	0.09	0.60	0.10	0.58	0.11	0.57	0.12
2.00	0.64	0.10	0.64	0.11	0.60	0.12	0.59	0.13
3.00	0.68	0.11	0.66	0.12	0.62	0.13	0.61	0.14
4.00	0.70	0.12	0.69	0.13	0.64	0.14	0.62	0.16
5.00	0.72	0.13	0.72	0.14	0.66	0.15	0.65	0.17
	100 °C	100°C	120 °C	120°C	140 °C	140°C	150 °C	150°C

Fig.3: Graph of Drift Current (μA) Versus Forwar



d Voltage at Various Temperatures.

In the case of drift current there is a little increase in drift current at all above temperature with decreases in forward voltage with rising temperature. It’s also observed from the graph trends that there is increase in drift current with a shift the value which is minor as compared to that of diffusion current as can be seen at 25℃ and on 1v where the current was measured to be 0.06μA while at 150℃ it was found to be 0.12μA being the fact that drift becomes higher because of increase in temperature.

Therefore, the increase in drift current with rising temperature is significant at lower applied voltages and at low temperatures, but shows a significant increase at higher voltages and higher temperatures because of decrease in the band gap of the diode due to forward biasing.

SUMMARY

From this assessment, it has been found that there is generally a pronounced effect of temperature on the drift and diffusion current on silicon p-n junction found from this study accept for some few values of temperature where there is an erratic deviation. The unexpected changes in the drift current shift with forward voltages at 25℃ and 40℃ as observed in result may be due to internal resistance from applied voltage source or due to the internal resistance from the PN-junction diode.

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