GROUP ASSIGNMENT-1

21AIE113

INTRODUCTION TO ELECTRONICS

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श्रद्धावान् लभते ज्ञानम्

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DEEMED TO BE UNIVERSITY

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QUESTION-1

Perform the experiment of Forward Bias and Reverse Bias of a PN junction silicon diode in Falstad circuit simulator.

a) Explain the theory behind the experiment.

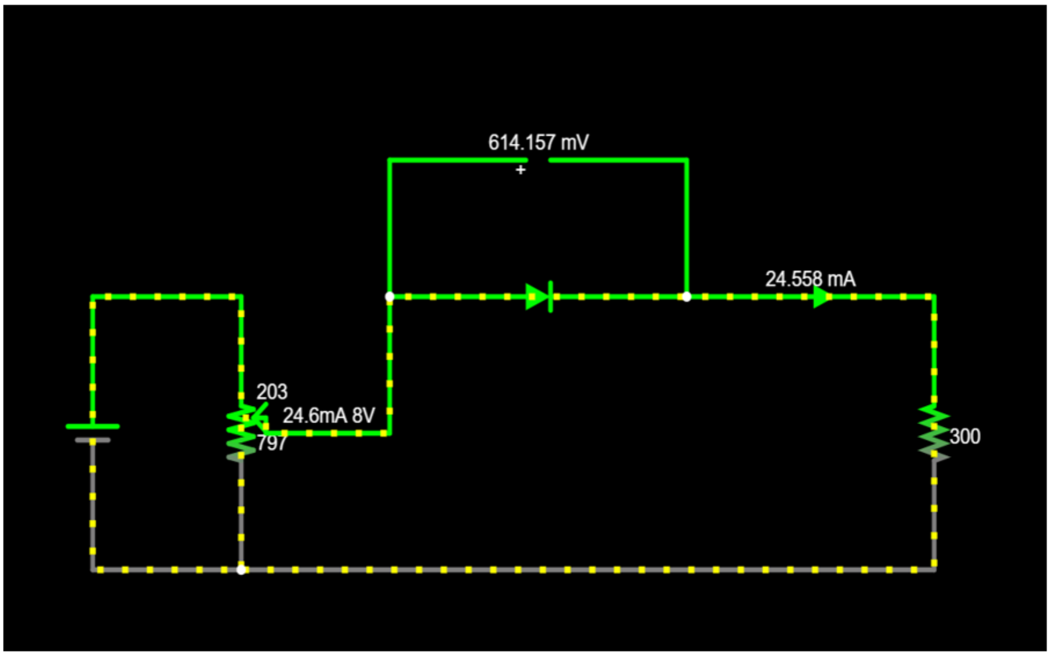
b) Draw the circuit diagrams, mention the components used, and state the procedure of the experiment.

c) Plot the V-I characteristics, mark the cut-in voltage, and calculate the static and dynamic resistance in the case of forward bias. Write down the inference from the VI characteristics.

- Forward bias or biasing is where the external voltage is delivered across the P-N junction diode. The P-side of the diode is connected to the positive terminal of the battery, while the N-side is connected to the negative terminal.
- The applied voltage is in this case the polarity of the junction barrier potential. As a result, the effective potential barrier and junction width both drop, resulting in a greater number of carriers flowing over the junction. Furthermore, the amount of voltage necessary to completely remove the barrier is lower. The majority of charge carriers are forced to move over a forward biased PN junction. The width of the depletion layer is shrinking as a result of this.

- The number of holes and electrons are combined with each other once the junction is crossed.
- Each hole in P side combines with an electron that is from the N side. Due to this reason, a covalent bond will break and an electron generated from the covalent bond move towards the positive terminal.
- There is a formation of electron-hole pair.
- Holes carry current in the P region.
- Electrons carry current in the N region

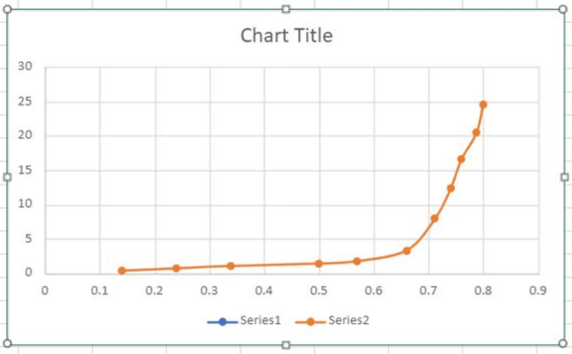
Forward Bias



- Components used :-
- Voltage source , Potentiometer, Diode, Voltmeter, Ammeter, Resistor, wire
- Procedure:- Draw a voltage source and potentiometer in parallel and connect both of them with wires. After that draw a diode and connect the diode with an ammeter followed by a resistor connect the end of resistor with a wire to previously connected voltage source and potentiometer . Draw a voltmeter parallel to diode and connect that to diode edges and starting point of diode connecting with voltmeter to potentiometer and run it.

VI characteristics

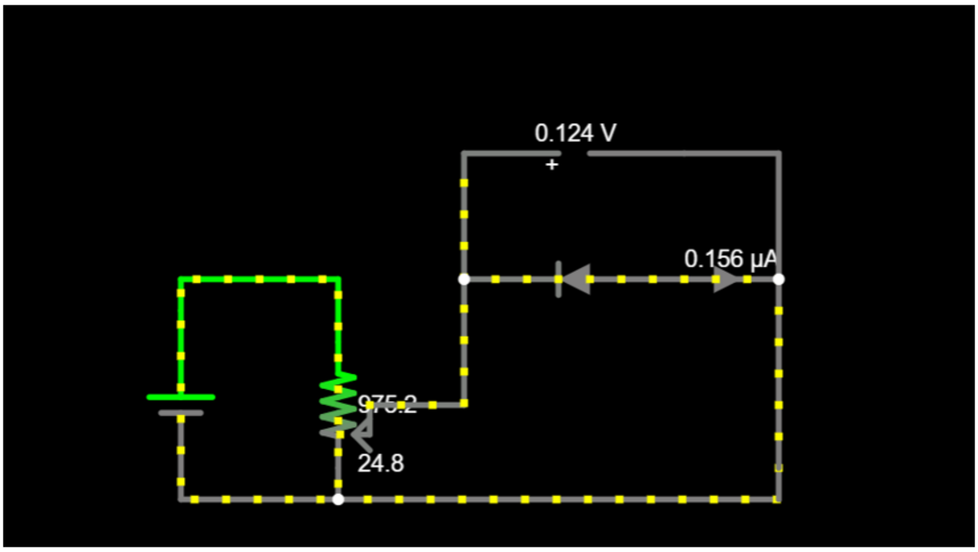
Vd	Id
0.14	0.36
0.241	0.69
0.34	1.043
0.501	1.389
0.57	1.729
0.66	3.297
0.712	7.9
0.741	12.34
0.76	16.53
0.788	20.43
0.8	24.56



Theory

- When we apply the external voltage across the semiconductor diode in such a way that the positive terminal of the battery is connected to its n-side and the negative terminal of the battery is connected to the p-side of the diode then it is said to be in the condition of reverse bias. When an external voltage is applied across the diode, as the direction of the external voltage is the same as that of the barrier potential, the total voltage barrier sums up to be (V_0+V). Also, the width of the depletion region increases. As a result of this, the motion of carriers from one side of the junction to another decreases significantly.

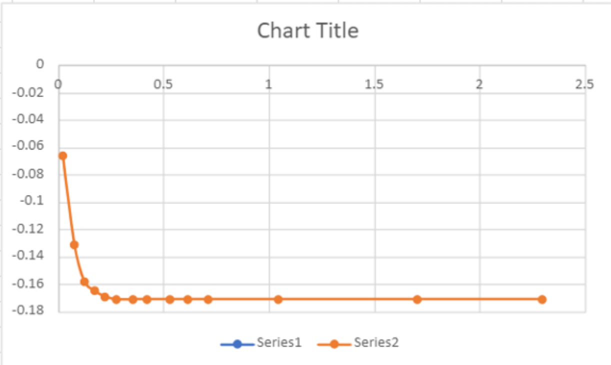
Reverse bias



- Components used:-Voltage source , Potentiometer, Diode, Voltmeter, Ammeter, wire
- Procedure:- Draw a voltage source and potentiometer in parallel and connect both of them with wires. After that draw a diode and connect the diode with an ammeter connect with a wire to previously connected voltage source and potentiometer . Draw a voltmeter parallel to diode and connect that to diode edges and starting point of diode connecting with voltmeter to potentiometer and run it.

Vi characteristics of reverse bias

Vd	Id
0.023	-0.066
0.078	-0.131
0.125	-0.158
0.173	-0.165
0.224	-0.169
0.275	-0.171
0.354	-0.171
0.421	-0.171
0.53	-0.171
0.617	-0.171
0.714	-0.171
1.043	-0.171
1.708	-0.171
2.3	-0.171



Cut in static and dynamic resistance in forward bias

- Cut in voltage:-The voltage at which the forward diode current starts increasing rapidly is known as the cut in voltage of a diode. Here in the above picture we can observe that cut in voltage is 12.34.
- Static Resistance:- It is Voltage divided by current

$$Rd=Vd/Id$$

Here to calculate Static resistance consider a point like 0.74 volts

The static resistance here calculated is Rd= 0.741/12.34 =60 ohm is the static resistance .

Dynamic Resistance:-It is defined as the ratio of differential change in voltage to a differential change in current.

$$Rd= \Delta Vd/\Delta Id.$$

Dynamic Resistance

Here also consider the point to be calculated for dynamic resistance for example 0.69 milli ampere so taking VI characteristics as reference

ΔId= 1.043-0.36=0.683

Do the same with ΔVd= 0.34-0.14=0.2

Now the formula to calculate is Rd= $\Delta Vd/\Delta Id$.

=0.2/0.683

= 292 ohm

Inference:- If the voltage increases then current also increases accordingly in forward bias and forward current is negligible upto knee voltage. In reverse bias the constant current of micro ampere flows through diode and it increases gradually to maximum at reverse voltage.

QUESTION-2

Write a Matlab program to calculate the current flowing through a diode during forward bias. (Hint: Shockley's equation and consider n as 1).

Shockley's Equation: - $I_d = I_s (e^{Vd / n*VT} – 1)$

Here we are required to find the current flowing through a diode during forward bias

So, by Using Shockley's Equation, we can calculate the current flowing through out a diode during forward bias experiment.

In Shockley's Equation:

I_d = Current flowing through the diode.

Is = Reverse saturation current.

V_d = Applied forward-bias voltage across the diode:

n = Ideality factor (given n = 1)

Vt= Thermal Voltage

Here,

Thermal Voltage, VT = $(k*T_k)/q$

Here, in the above Equation

- k = Boltzmann's constant (1.38×10^{-23} J/K)
- T_1 = Absolute temperature in Kelvins = 273 + temperature in "C
- q=Magnitude of electronic charge (1.6×10^{-19} C)

We can consider Tk as 27c, as 27 C as it is the common temperature for components in an enclosed in the operating system

Here, Tk= 273 +C=273+27= 300 K

MATLAB to calculate the current flowing through a diode during forward bias.

```
Vt =

    0.0259


Id =

    0.2784

fx >>
```

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```
clc;
Vd=0.025;
%diode voltage
Is=0.171;
% reverese saturation current
n=1;
%ideality factor
k=1.38*10^(-23);
%boltzmann's constant
t=27;
%temperature
Tk=273+t;
% absolute tempurature
q=1.6*10^(-19);
% the magnitude of electronic charge
Vt=(k*Tk)/q
% thermal voltage
Id = Is*(exp(Vd/(n*Vt))-1)
% shockley's eqeation
```

QUESTION-3

The reverse saturation current of a diode at 25 deg. Celsius is 10pA. Plot the forward characteristic of the diode at the 0 degree Celsius and 100 degrees Celsius. Write down the inference from the plot.

Hint: The expression for the reverse saturation current is as a function of temperature is

$$I_S(T_2) = I_S(T_1)e^{[k_S(T_2-T_1)]}$$

where k_s = 0.072 / degree Celsius. T1 and T2 are two different temperatures.

The **saturation current** (or **scale current**), more accurately the **reverse saturation current**, is that part of the reverse current in a semiconductor diode caused by diffusion of minority carriers from the neutral regions to the depletion region. Increase in reverse bias does not allow the majority charge carriers to diffuse across the junction. However, this potential helps some minority charge carriers in crossing the junction. Since the minority charge carriers in the n-region and p-region are produced by thermally generated electron-hole pairs, these minority charge carriers are extremely temperature dependent and independent of the applied bias voltage. The applied bias voltage acts as a forward bias voltage for these minority charge carriers and a current of small magnitude flows in the external circuit in the direction opposite to that of the conventional current due to the moment of majority charge carriers. $\boldsymbol{I_S}$, the reverse bias saturation current for an ideal p–n diode.

Calculating reverse saturation using MATLAB

Formulae for calculating reverse saturation current at different temperature is given in question and using that formulae we calculate reverse saturation current at 0 and 100 degrees Celsius.

$$I_S(T_2) = I_S(T_1)e^{[k_S(T_2 - T_1)]}$$

```
t1 = 0;                   %Temp 1 = 0 degree Celsius
t2 = 25;                  %Temp 2 = 25 degree Celsius
t3 = 100;                 %Temp 3 = 100 degreee Celsius
Ist2 = 10*(10^-12);       %Saturation current at temp 2
ks = 0.072;               %Given in Question as info.
e = 2.718;                %Value of exponent

Ist1 = (Ist2)/(e^((ks)*(t2 - t1)));
                          %Saturation current at 0 degrees using formulae

Ist3 = (Ist2)*(e^((ks)*(t3 - t2)));
                          %Saturation current at 100 degrees using formulae
```

OUTPUT:

IEE_Assignment_1_Q3.m

```
t1 = 0;                 %Temp 1 = 0 degree Celsius
t2 = 25;                %Temp 2 = 25 degree Celsius
t3 = 100;               %Temp 3 = 100 degreee Celsius
Ist2 = 10*(10^-12);     %Saturation current at temp 2
ks = 0.072;             %Given in Question as info.
e = 2.718;              %Value of exponent

Ist1 = (Ist2)/(e^((ks)*(t2 - t1)))
                        %Saturation current at 0 degrees using formulae

Ist3 = (Ist2)*(e^((ks)*(t3 - t2)))
                        %Saturation current at 100 degrees using formulae
```

mmand Window

```
>> IEE_Assignment_1_Q3

Ist1 =

   1.6533e-12


Ist3 =

   2.2128e-09
```

Now, to plot the forward characteristic of diode at 0 degrees and 100 degrees Celsius we will need current flowing across the diode (I_D) at both the temperatures respectively and for calculating that we use **SHOCKLEY'S EQUATION.**

$$\boxed{I_D = I_s(e^{V_D/nV_T} - 1)}$$

I_s is the reverse saturation current
V_D is the applied forward-bias voltage across the diode
n is an ideality factor,

$$\boxed{V_T = \frac{kT_K}{q}}$$

k is Boltzmann's constant $= 1.38 \times 10^{-23}$ J/K
T_K is the absolute temperature in kelvins $= 273 +$ the temperature in °C
q is the magnitude of electronic charge $= 1.6 \times 10^{-19}$ C

V_D will be varying from 0V to 0.8V with step size of 0.01.

V_T here is thermal voltage, voltage produced within P-N junction due to action of temperature.

Calculating diode current (I_D)using MATLAB

Code:

Editor - C:\Users\HP\Desktop\IEE_Assignment_1_Q3.m

IEE_Assignment_1_Q3.m | untitled.m | +

```matlab
t1 = 0;                 %Temp 1 = 0 degree Celsius
t2 = 25;                %Temp 2 = 25 degree Celsius
t3 = 100;               %Temp 3 = 100 degreee Celsius
Ist2 = 10*(10^-12);     %Saturation current at temp 2
ks = 0.072;             %Given in Question as info.
e = 2.718;              %Value of exponent

Ist1 = (Ist2)/(e^((ks)*(t2 - t1)));
                        %Saturation current at 0 degrees using formulae

Ist3 = (Ist2)*(e^((ks)*(t3 - t2)));
                        %Saturation current at 100 degrees using formulae

Vd = 0:0.01:0.8;        %Applied voltage across diode from 0V to 0.8V
k = 1.38 * (10^(-23)); %Boltzmann Constant
Tk1 = 273;              %Temp 1 in Kelvins
Tk3 = 373;              %Temp 3 in Kelvins
q = 1.6 * (10^(-19));  %Magnitude of electronic charge
Vt1 = (k*Tk1)/(q);      %Thermal Voltage at temp 1
Vt3 = (k*Tk3)/(q);      %Thermal Voltage at temp 3

Id1 = (Ist1)*((e.^(Vd/Vt1))-1);
                        %Current through diode at temp 1 using
                        %Shockley's Equation

Id3 = (Ist3)*((e.^(Vd/Vt3))-1);
                        %Current through diode at temp 1 using
                        %Shockley's Equation
```

OUTPUT:

Command Window

```
>> IEE_Assignment_1_Q3

Id1 =

  Columns 1 through 14

         0    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000

  Columns 15 through 28

    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000

  Columns 29 through 42

    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0001

  Columns 43 through 56

    0.0001    0.0001    0.0002    0.0003    0.0005    0.0008    0.0012    0.0018    0.0028    0.0042    0.0064    0.0098    0.0150    0.0230

  Columns 57 through 70

    0.0352    0.0538    0.0822    0.1257    0.1922    0.2939    0.4494    0.6872    1.0507    1.6066    2.4566    3.7563    5.7436    8.7823

  Columns 71 through 81

   13.4287   20.5333   31.3965   48.0071   73.4057  112.2416  171.6240  262.4230  401.2601  613.5501  938.1539
```

Command Window

```
Id3 =

  Columns 1 through 14

         0    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000

  Columns 15 through 28

    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000

  Columns 29 through 42

    0.0000    0.0000    0.0000    0.0000    0.0000    0.0001    0.0001    0.0001    0.0002    0.0002    0.0003    0.0004    0.0006    0.0008

  Columns 43 through 56

    0.0010    0.0014    0.0019    0.0026    0.0036    0.0049    0.0067    0.0091    0.0124    0.0169    0.0231    0.0315    0.0430    0.0587

  Columns 57 through 70

    0.0801    0.1094    0.1492    0.2036    0.2778    0.3791    0.5173    0.7059    0.9632    1.3143    1.7934    2.4471    3.3391    4.5563

  Columns 71 through 81

    6.2171    8.4834   11.5758   15.7954   21.5532   29.4098   40.1303   54.7587   74.7194  101.9563  139.1217
fx
```

(Note : To zoom the images, keep pressing CTRL + MOUSE SCROLL UP)

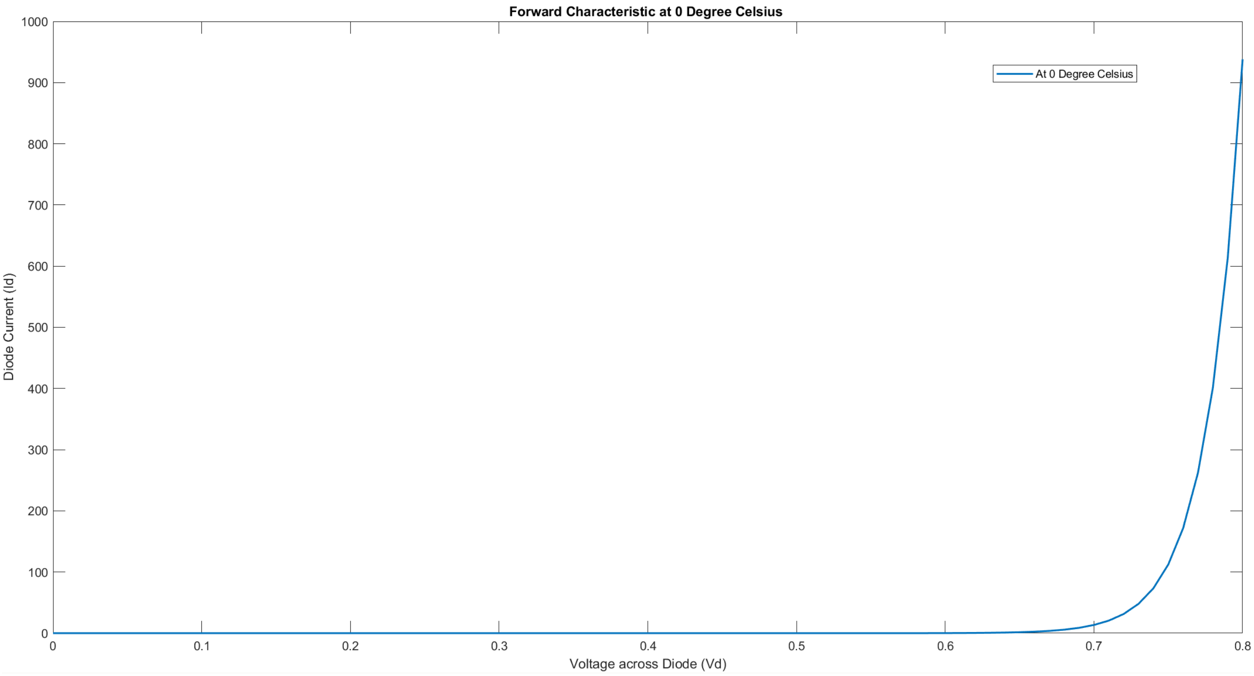
Plot of forward characteristic at 0 degree Celsius

```
t1 = 0;                   %Temp 1 = 0 degree Celsius
t2 = 25;                  %Temp 2 = 25 degree Celsius
t3 = 100;                 %Temp 3 = 100 degreee Celsius
Ist2 = 10*(10^-12);       %Saturation current at temp 2
ks = 0.072;               %Given in Question as info.
e = 2.718;                %Value of exponent

Ist1 = (Ist2)/(e^((ks)*(t2 - t1)));
                          %Saturation current at 0 degrees using formulae

Ist3 = (Ist2)*(e^((ks)*(t3 - t2)));
                          %Saturation current at 100 degrees using formulae

Vd = 0:0.01:0.8;          %Applied voltage across diode from 0V to 0.8V
k = 1.38 * (10^(-23));    %Boltzmann Constant
Tk1 = 273;                %Temp 1 in Kelvins
Tk3 = 373;                %Temp 3 in Kelvins
q = 1.6 * (10^(-19));     %Magnitude of electronic charge
Vt1 = (k*Tk1)/(q);        %Thermal Voltage at temp 1
Vt3 = (k*Tk3)/(q);        %Thermal Voltage at temp 3

Id1 = (Ist1)*((e.^(Vd/Vt1))-1)
                          %Current through diode at temp 1 using
                          %Shockley's Equation

Id3 = (Ist3)*((e.^(Vd/Vt3))-1)
                          %Current through diode at temp 1 using
                          %Shockley's Equation

g1 = plot(Vd,Id1);        %Forward characterstic of diode at temp 1
```

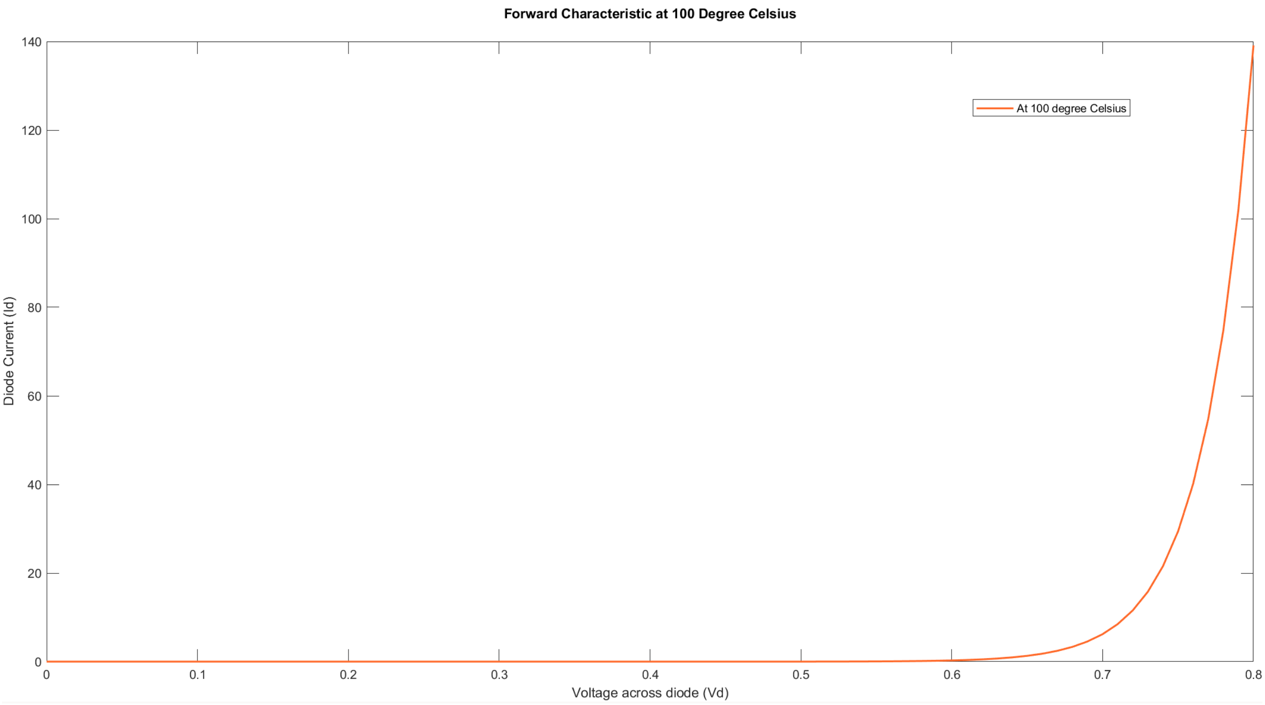
Plot of forward characteristic at 100 degree Celsius

```
t1 = 0;                  %Temp 1 = 0 degree Celsius
t2 = 25;                 %Temp 2 = 25 degree Celsius
t3 = 100;                %Temp 3 = 100 degreee Celsius
Ist2 = 10*(10^-12);      %Saturation current at temp 2
ks = 0.072;              %Given in Question as info.
e = 2.718;               %Value of exponent

Ist1 = (Ist2)/(e^((ks)*(t2 - t1)));
                         %Saturation current at 0 degrees using formula

Ist3 = (Ist2)*(e^((ks)*(t3 - t2)));
                         %Saturation current at 100 degrees using formu

Vd = 0:0.01:0.8;         %Applied voltage across diode from 0V to 0.8V
k = 1.38 * (10^(-23));   %Boltzmann Constant
Tk1 = 273;               %Temp 1 in Kelvins
Tk3 = 373;               %Temp 3 in Kelvins
q = 1.6 * (10^(-19));    %Magnitude of electronic charge
Vt1 = (k*Tk1)/(q);       %Thermal Voltage at temp 1
Vt3 = (k*Tk3)/(q);       %Thermal Voltage at temp 3

Id1 = (Ist1)*((e.^(Vd/Vt1))-1)
                         %Current through diode at temp 1 using
                         %Shockley's Equation

Id3 = (Ist3)*((e.^(Vd/Vt3))-1)
                         %Current through diode at temp 1 using
                         %Shockley's Equation

g2 = plot(Vd,Id3);       %Forward characterstic of diode at temp 3
```

Graph:

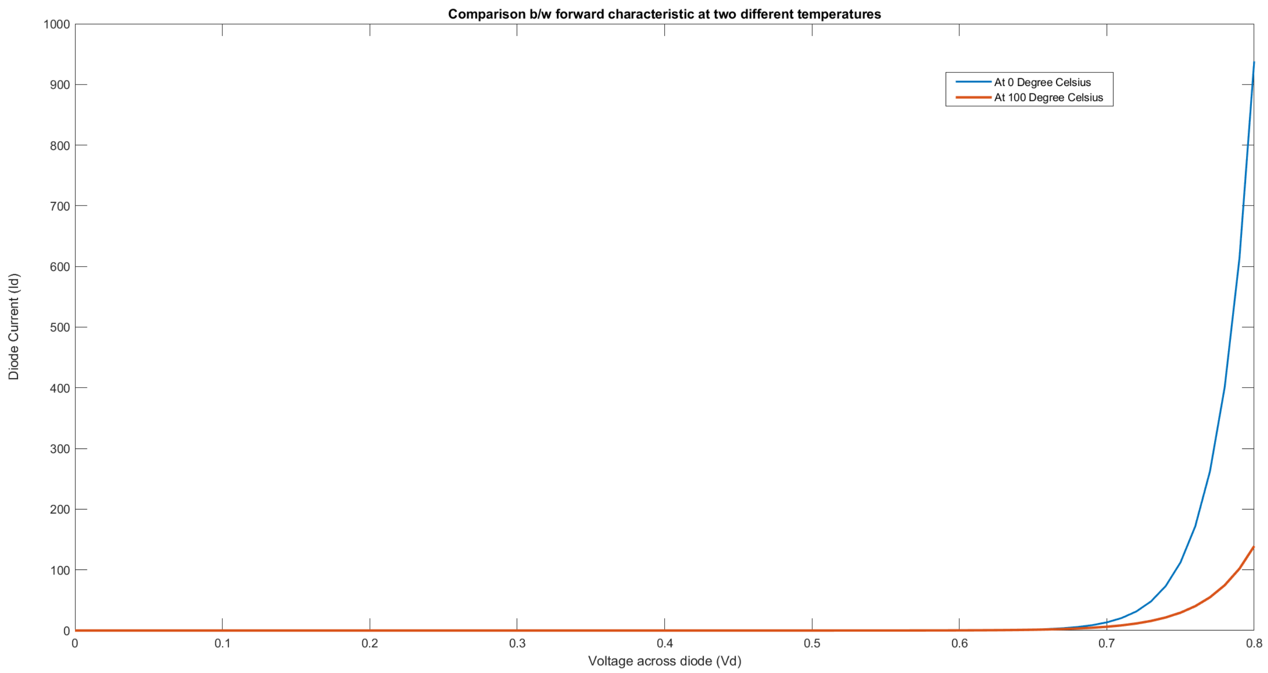


(Note : To zoom the images, keep pressing CTRL + MOUSE SCROLL UP)



(Note : To zoom the images, keep pressing CTRL + MOUSE SCROLL UP)

Comparison b/w diode current at both temperature



Inference:

For forward characteristic of diode, as voltage increases the diode current increases. The amount of increase in diode current depends on temperature.

THANK YOU