INDOSAW
COMMITTED TO EXCELLENCE

INSTRUCTION MANUAL

STUDY P-N JUNCTION

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OBJECTIVES: **To Study the Energy Band Gap & Diffusion Potential of P - N Junction.**

<u>PN JUNCTION SET-UP</u>

The set-up consists of following:

1. PN junction set up.
2. Oven with thermometer. (Display on Panel)
3. A Samples of junction transistor with connecting leads
4. Diode 1N5402 to measure junction capacitance.
5. Connecting lead to connect oscilloscope for measure junction capacitance.
6. Power Cord

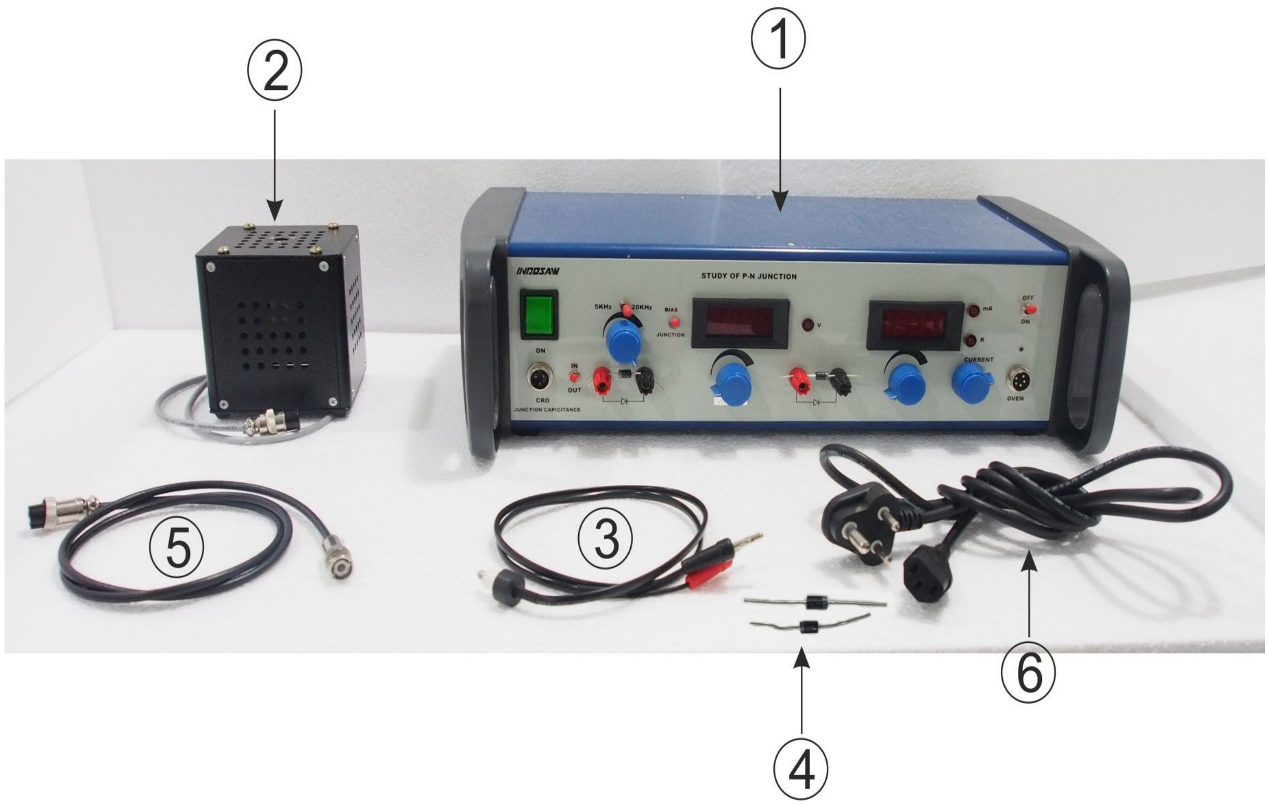

Fig. 1 : Different Components of P – N Junction Set-up

EXP-1: Determination of the reverse saturation current I_0 & material constant η.

The current I in the p-n junction is given by, $I = I_O(e^{\frac{qV}{\eta kT}} - 1)$ ....(1)

where, q = electronic charge = 1.602×10^{-19} Coulomb

η = material constant = 1 for Ge

= 2 for Si

k = Boltzman's constant = 1.38×10^{-23} J/K

T = Temperature in Kelvin

V = Junction voltage in Volt.

The reverse saturation current is usually too small to measure directly. An indirect graphical method may be obtained by taking logarithm of equation (1) for $e^{\frac{qV}{\eta kT}} \gg 1$ as,

$$\ln I = \ln I_0 + \frac{qV}{\eta kT} \qquad \text{....(2)}$$

If V & $\ln I$ are plotted on graph paper a straight line is obtained. This line intersects the current ($\ln I$) axis at $\ln I_0$ & its slope may be solved to compute η,

$$\eta = \frac{q \Delta V}{k T \Delta \ln I} \qquad \text{....(3)}$$

Note the junction voltage by varying the current source. The values of junction voltage & current are displayed on the panel display provided on the setup.

PROCEDURE:

- Connect the PN junction set up to the ac mains. Ensure that the oven switch is off.
- Connect the junction transistor lead to the 'Junction Terminals' provided on the setup as polarity indicated on it.
- Keep the Left Hand Side Digital Display in "Junction Mode."
- Keep the Right Hand Side Digital Display in "Current Mode"
- Switch on the PN junction set up.
- Vary the Junction Voltage Knob and obtain current as a function of junction voltage.
- Determine the material constant η.

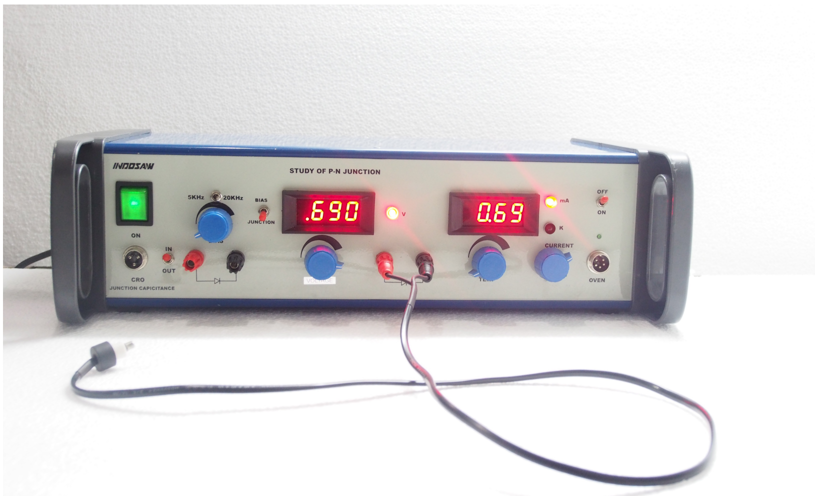

Fig. 2 : Study of *I-V* Characteristics of Sample BC 109 in Forward Bias

SAMPLE DATA: BC 109

S.No	Voltage, *V* (Volt)	Current, *I* (mA)	ln *I*
1	0.312	0.03	-3.507
2	0.500	0.10	-2.303
3	0.576	0.20	-1.609
4	0.624	0.30	-1.204
5	0.650	0.50	-0.693
6	0.664	0.69	-0.371
7	0.678	0.97	-0.030
8	0.687	1.20	0.182
9	0.694	1.44	0.365
10	0.703	1.81	0.593
11	0.711	2.24	0.806
12	0.727	3.50	1.253
13	0.736	4.54	1.513
14	0.752	7.09	1.959
15	0.764	9.78	2.280
16	0.772	12.40	2.518
17	0.775	13.61	2.611

ANALYSIS

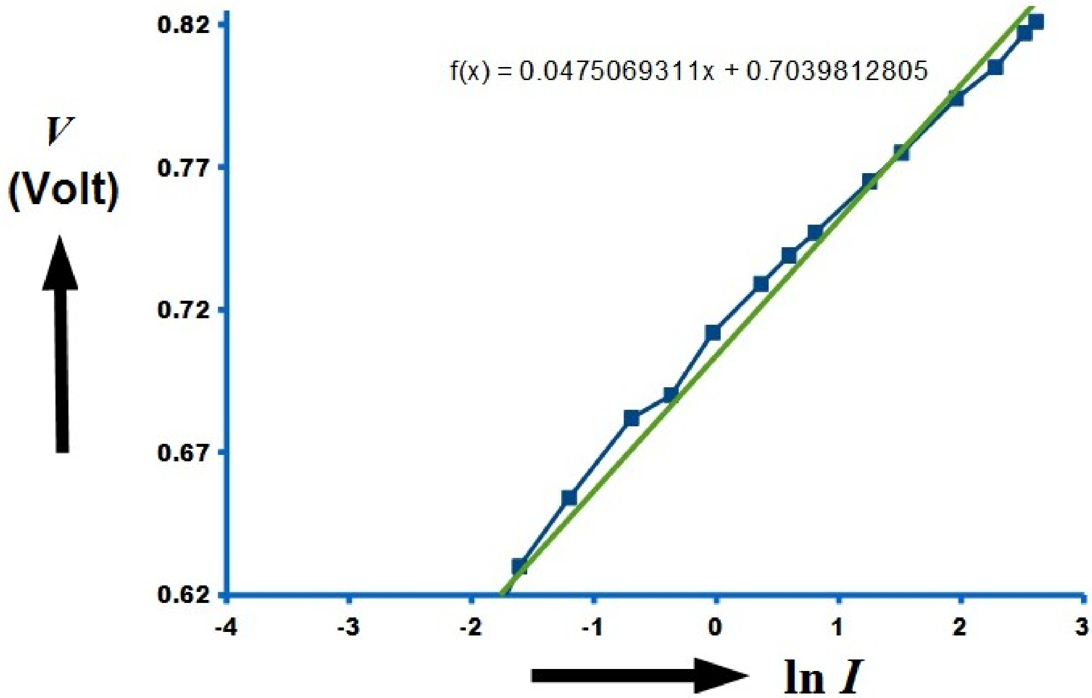

Fig. 3 : Graphical Representation of Variation of *V* as a Function of ln *I* of Sample BC 109

Slope = $\dfrac{\Delta V}{\Delta \ln I}$ = 0.0475

Therefore, η **=** $\dfrac{q\Delta V}{kT\Delta \ln I}$ = 1.81 at T = 303 K

EXP-2: Forward Bias Characteristics of Junction Diode (IN5402)

PROCEDURE:

- Connect the PN junction set up to the ac mains. Ensure that the oven switch is off.
- Connect the junction diode to the 'Junction Terminals' provided on the setup in forward bias as polarity indicated on it.
- Keep the Left Hand Side Digital Display in “Junction Mode.”
- Keep the Right Hand Side Digital Display in “Current Mode”
- Switch on the PN junction set up.
- Vary the Junction Voltage Knob and obtain diode current (I) as a function of junction voltage (V).
- Plot I as a function of V.

Fig. 4 : Study of Forward Bias Characteristics of Sample IN5402

SAMPLE DATA: IN5402

S. No.	Voltage, V (Volt)	Current, I (mA)
1	0.000	0.00
2	0.493	0.4
3	0.532	1.00
4	0.564	2.00
5	0.582	3.00
6	0.595	4.00
7	0.604	4.87
8	0.606	5.00
9	0.614	6.00
10	0.621	7.00
11	0.627	8.00
12	0.632	9.00
13	0.637	10.00
14	0.642	11.00
15	0.645	12.00
16	0.649	13.00
17	0.651	13.61

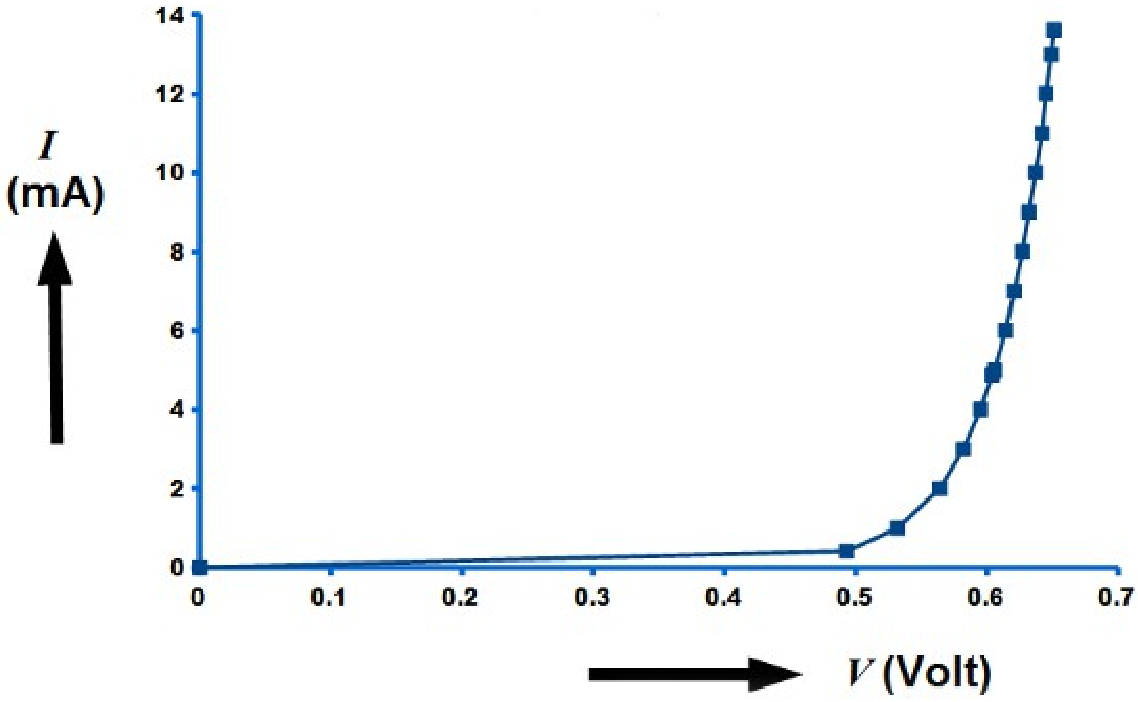

Fig. 5 : Forward Bias Characteristics of Sample IN5402

Knee Voltage = 0.58 Volt

EXP-3: Determination of Temperature Coefficient of Junction Voltage & Energy Band Gap.

With the connections as in experiment –1 the oven & the sensor leads are inserted in the respective sockets. The diode is put in the oven & its forward current is set to a low value to avoid heating. The right hand side display is now switched to TEMP, to read the oven temperature.

The oven temperature can now be varied room temperature to about 360 k in suitable steps and the junction voltage may be recorded. The temperature-controlled oven requires steps & 5 minutes to stabilized at every new setting. Before nothing any readings, one must ensure that a few ON/OFF cycles of the oven been completed as shown by the indicator.

The reverse saturation current is given by**,**

$$I_O = kT^m e \frac{V - V_{GO}}{\eta V_T}$$

& the diode forward current by

$$I = I_O(e^{\frac{V}{\eta V_T}} - 1) \approx I_O e^{\frac{V}{\eta V_T}}$$

$$= kT^m e^{\frac{V - V_{GO}}{\eta V_T}}$$

where for Si : m=1.5 η **=**2

for Ge: m=2.0 η =1

$$V_T = \frac{kT}{q},$$

Taking logarithm, $\ln I = \ln k + m \ln T + \dfrac{V - V_{G0}}{\eta kT}$

At I = constant, differentiating w.r.t T**,** $0 = 0 + \dfrac{m}{T} + \dfrac{d}{dT}\left[\dfrac{(V - V_{G0})q}{\eta kT}\right]$

or, $0 = \dfrac{m}{T} + \dfrac{q}{\eta kT}.\dfrac{dV}{dT} - \dfrac{(V - V_{G0})q}{\eta k}.\dfrac{1}{T^2}$

or, $0 = \dfrac{m}{T} + \dfrac{q}{\eta kT}.\dfrac{dV}{dT} - \dfrac{q}{\eta kT^2}(V - V_{G0})$

or, $V_{G0} = V - T.\dfrac{dV}{dT} - \dfrac{m\eta kT}{q}$

or, $0 = \frac{\eta k T^2}{q} . \frac{m}{T} + T\frac{dV}{dT} - \left(V - V_{G0}\right)$

Therefore, $V(T) - T\frac{dV}{dT} - \frac{m\eta kT}{q}$

At 300K for Si, $m\eta\frac{kT}{q} = \frac{(1.5 \times 1.81 \times 1.381 \times 10^{-23} \times 303)}{1602 \times 10^{-10}}$ = 0.071 V

Where slope of the V-T curve is the temperature coefficient of the junction voltage & V_{G0} is the energy band gap.

PROCEDURE:

- Connect the PN junction set up to the ac mains.
- Insert the oven knob to the oven socket provided on set up. Ensure that the oven switch is in off mode.
- Connect the junction transistor lead to the terminals provided on the setup as polarity indicated on it.
- Insert the junction transistor provided at other end of lead in the oven.
- Keep the Left Hand Side Digital Display in “Junction Mode.”
- Keep the Right Hand Side Digital Display in “Current Mode”
- Switch on the PN junction set up.
- Vary the Junction Voltage Knob so that a forward diode current (I) of around 2 mA is obtained. This forward current of 2 mA will remain constant throughout the experiment.
- Now set the Right Hand Side Digital Display in “Temperature Mode.”
- Switch on the oven.
- Rotate the Temperature knob and note down the voltage as a function of temperature.
- When the data collection is over, switch off the oven and remove the transistor from the oven.

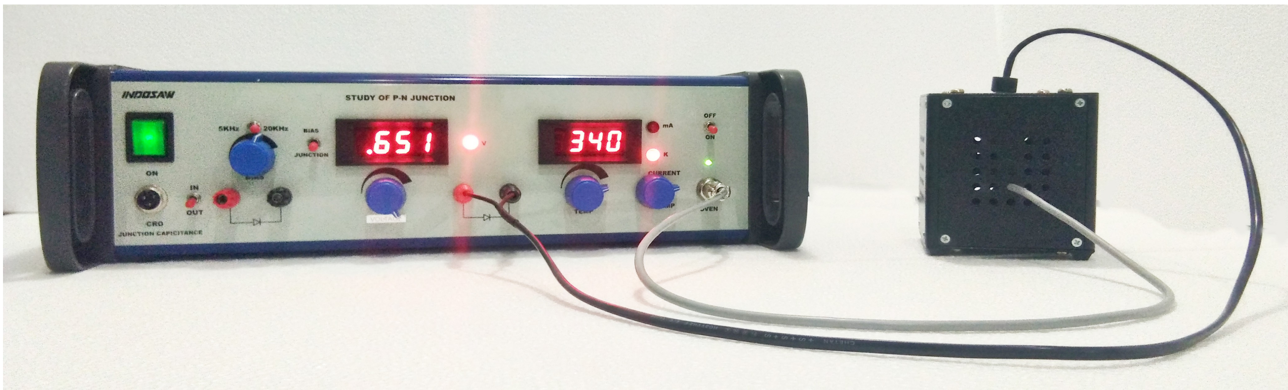

Fig. 6 : Experimental Arrangement to Determine Temperature Coefficient of Junction Voltage & Energy Band Gap. of Sample BC109

SAMPLE DATA: BC 109 (I_f = 2 mA)

Sr.no	t	T	VOLTAGE (V)
1	29	302	0.708
2	31	304	0.702
3	33	306	0.696
4	34	307	0.694
5	35	308	0.692
6	36	309	0.69
7	37	310	0.688
8	38	311	0.686
9	39	312	0.684
10	40	313	0.682
11	42	315	0.678
12	44	317	0.674
13	46	319	0.67
14	48	321	0.666
15	50	323	0.664
16	52	325	0.66
17	54	327	0.656
18	56	329	0.652
19	58	331	0.65
20	60	333	0.646

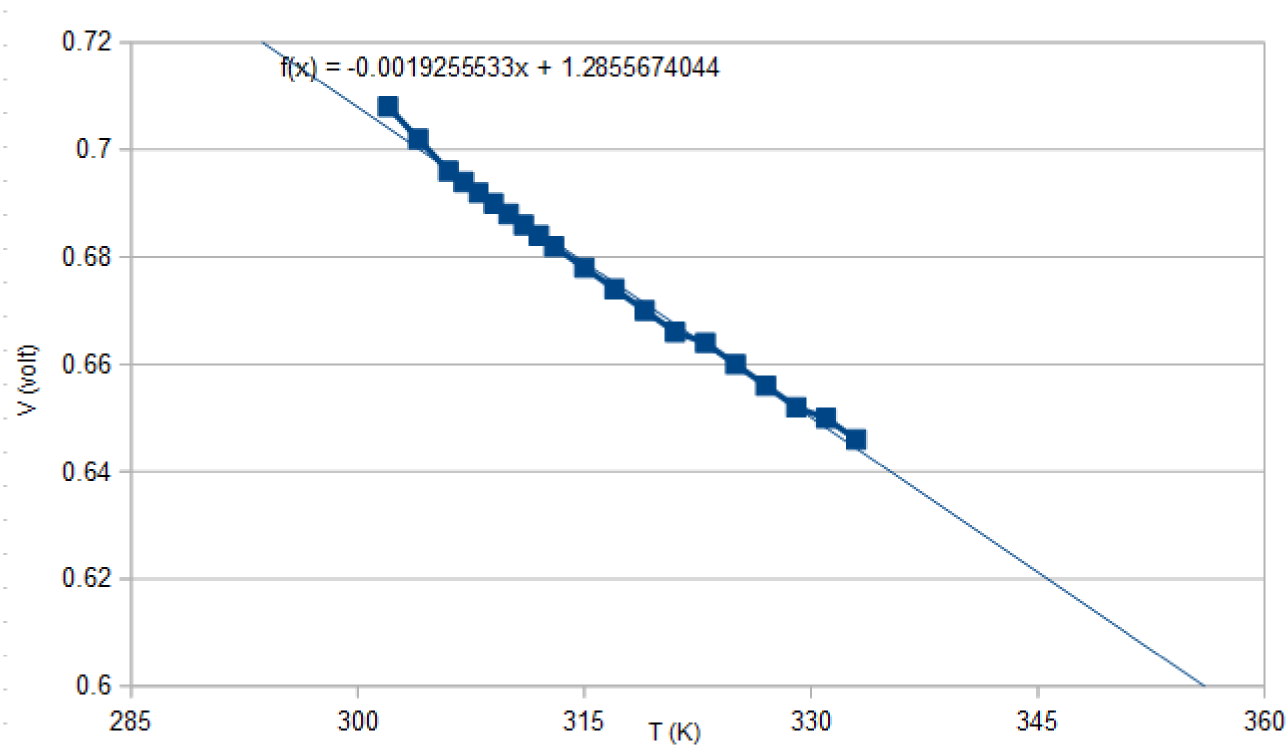

Fig. 7 : Graphical Representation of Variation of *V* as a Function of *T* of Sample IN5402

ANALYSIS:

We know, Energy Band gap, $V_{Go} = V(T) - T\dfrac{dV}{dT} - \dfrac{m\eta kT}{q}$

From graph, At T=303 K, V(T) =0.70, dV/dT= 0.0019 V/K $T\dfrac{dV}{dT}$ = 0.56

& for Silicon at 303K, $\dfrac{m\eta kT}{q} =$ 0.071 Volt.

V_{G0} = 1.18 Volt.

EXP-4: Study of the depletion capacitance & its variation with reverse bias

The measurement is based on C_D(depletion capacitance) & G_D (leakage resistance) of the diode under test.

The output voltages V1 & V2 at the two frequencies ω_1, ω_2 ($\omega_2 > \omega_1$) may be written as,

$$V_1 = -V(G_D + j\omega_1 C_D)R$$
$$V_2 = -V(G_D + j\omega_2 C_D)R$$

V is the input signal of same magnitude both for ω_1 **,** ω_2 .

Squaring & subtracting after taking magnitudes,

$$V_2^{\,2} - V_1^{\,2} = V^2 R^2 (\omega_2^{\,2} - \omega_1^{\,2}) C_D^{\,2}$$

or, $C_D = \dfrac{\sqrt{V_2^{\,2} - V_1^{\,2}}}{VR\sqrt{\omega_2^{\,2} - \omega_1^{\,2}}}$

V_1 is the p-p output voltage in V at 5KHz & V_2 is the p-p output voltage in V at 20KHz

or, $C_D = \dfrac{\sqrt{V_2^2 - V_1^2}}{VR\sqrt{\omega_2^2 - \omega_1^2}} = C_{DO}\dfrac{\sqrt{V_2^2 - V_1^2}}{V}$ where, $C_{DO} = \dfrac{1}{R\sqrt{\omega_2^2 - \omega_1^2}}$

Here, R = Feedback Resistance at The Amplifier End = 100 kΩ = 10^5 Ω;

$\omega_1 = 2\pi\nu_1 = 2\pi(5\times 10^3)$ rad/s; and

$\omega_2 = 2\pi\nu_2 = 2\pi(20\times10^3)$ rad/s.

Substituting these values, we can obtain, C_{DO} = 82.29 pF.

Therefore, $C_D = 82.29\dfrac{\sqrt{V_2^2 - V_1^2}}{V}$ pF

The measurement is based on C_D (depletion capacitance) & G_d (leakage resistance) of the diode under test.

The test sample of the diode is connected Iin reverse bias to the terminals provided at the left side of the set up. The left hand side display is set to bias & CRO is connected to measure the input & output voltage off the particular bias & frequency settings.

Fig. 8 : Experimental Arrangement to Determine Depletion Capacitance of Sample IN5402

SAMPLE DATA: SI DIODE IN5402

$V = V_{in}$ **(p-p)=3.0 V**

Biasing Voltage , V_B (Volt)	Output at 5 kHz (p-p), V_1 (Volt)	Output at 20 kHz (p-p), V_2 (Volt)	C_D (pF)
0.51	1.12	2.4	58.22
1.01	0.91	2.28	57.34
1.5	0.8	2.16	55.03
3.0	0.66	1.98	51.20
5.0	0.6	1.82	47.13
7.0	0.56	1.70	44.02
10.0	0.5	1.62	42.26

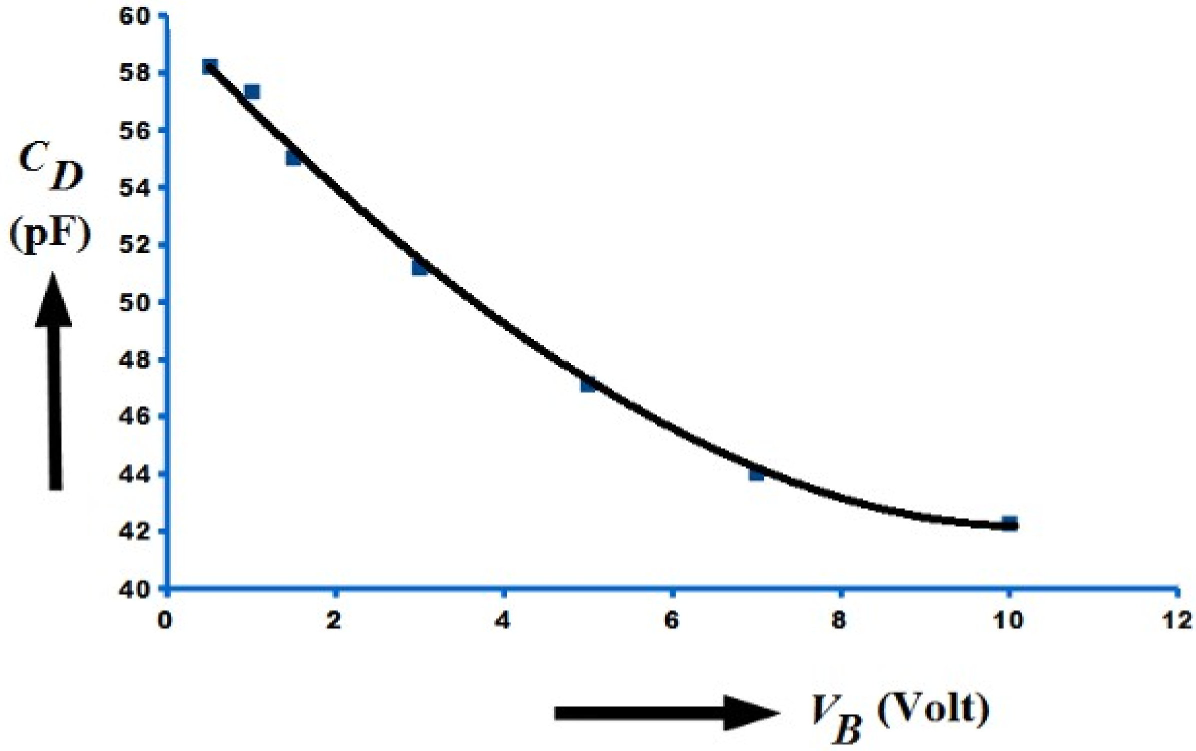

Fig. 9 : Graphical Representation of Variation of C_D (Depletion Capacitance) as a Function of V_B (Reverse Biasing Voltage) of Sample IN5402

CHECK POINTS:

1. In experiment 1&2, ordinary diodes used in power supplied should not be used due to poor material quality
2. In T-I mode, make sure that the oven switch is 'OFF' and SET temp knob is at minimum position before connecting the oven.
3. On each setting of temperature, please allow sufficient time for the temperature to stabilized, between 5-6 minutes
4. In experiment 3, junction capacitance of diode/ transistor junction, the devices should be directly connected with terminals, connections through leads would result in additional capacitance and pick ups.