Study of PN Junction

STUDY OF P-N JUNCTIONS

1. OBJECT To study various characteristics of p-n junctions.

2. INTRODUCTION This is an advanced level experiment, for studying commercially available p-n junctions, like germanium and silicon rectifiers, various types of light emitting diodes (LED's), zener diodes and transistor junctions. Besides obtaining the static characteristics of the device, the results also reveal the material characteristics of the semiconductors used.

Referring to the panel diagram shown in Fig. 1, the following subsystems and controls may be identified :

(a) Constant current source, adjustable from 0 to 12 mA.

(b) Temperature controlled oven with ON/OFF display, adjustable from room temperature to 360 K (approx.)

(c) Display-1, for directly reading CURRENT or oven TEMPERATURE through switch setting.

(d) Display-2, for showing JUNCTION voltage in experiments I and II or BIAS voltage in experiment III. Details of the experiments are given later.

(e) Switch selectable internal oscillator at 5 KHz/20 KHz.

(f) Sockets for OVEN, SENSOR, CRO and diode.

3. THEORY The three experiments which may be performed on the unit are described below in some detail.

Experiment - I

Determination of reverse saturation current I_o and material constant η

$T^{-1/2}$ $T^{3/2}$

The current I in a p-n junction is given by

$$I = I_o \left(e^{\frac{qV}{\eta kT}} - 1\right) \qquad \ldots\ldots (1)$$

293 K

re,

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

η, material constant = 1 for Ge

= 2 for Si

k, Boltzmann constant = 1.381×10^{-23} J/ K

T, Temperature in Kelvin

V, Junction voltage in volts

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

$$\ln I = \ln I_o + \frac{qV}{\eta kT}$$

If, V and lnI are plotted on a graph paper a staight line s obtained. This line intersects the current (lnI) axis at $\ln I_o$ nd its slope may be solved to compute η,

$$\eta = \frac{q}{kT} \frac{\Delta V}{\Delta \ln I}$$

The diode to be tested is connected to the terminals with the polarity as indicated. Readings are now recorded from the two displays set to JUNCTION and CURRENT respectively with the current source adjusted in steps from 100 µA to 10 mA.

Experiment - II

Determination of Temperature Coefficient of junction Voltage and Energy band-gap.

With the connections as in Experiment-I, the OVEN and SENSOR leads are inserted in the respective sockets. The diode is put in the oven and its forward current is set to a low value (say 1 mA) to avoid heating. The display-1 is now switched to TEMP, to read the oven temperature.

(ImA)

The Oven temperature can now be varied from room temperature to about 360 K in suitable steps and the junction voltage may be recorded. The temperature controlled oven requires about 5 minutes to stabilize at every new setting. Before noting any readings, one first ensure that a few ON/OFF cycles of the oven have been completed as shown by the indicator.

The reverse saturation current is given by

$I_o = k T^m e^{\frac{-V_{Go}}{\eta V_T}}$, and the diode forward current by

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

$I = k T^m e^{\frac{V - V_{Go}}{\eta V_T}}$, where for Si : m = 1.5, η = 2 and for Ge : m = 2.0, η = 1

Also $V_T = \frac{kT}{q}$.

aking logarithm ,

$$\ln I = \ln k + m \ln T + \frac{V - V_{Go}}{\eta V_T}$$

At I = Constant, differentiating w.r.t. T

$$0 = 0 + \frac{m}{T} + \frac{d}{dT}\left[\frac{(V - V_{Go})q}{\eta k T}\right]$$

$$0 = \frac{m}{T} + \frac{q}{\eta k T} \cdot \frac{dV}{dT} - \frac{(V - V_{Go})q}{\eta k} \cdot \frac{1}{T^2}$$

$$0 = \frac{m}{T} + \frac{q}{\eta k T} \cdot \frac{dV}{dT} - \frac{q}{\eta k T^2}(V - V_{Go})$$

$$0 = \frac{k T^2}{q} \cdot \frac{m}{T} + T\frac{dV}{dT} - (V - V_{Go})$$

$$\boxed{V_{Go} = V - T\frac{dV}{dT} - \frac{m \eta k T}{q}}$$

At 300 K for Si,

$$\frac{m \eta k T}{q} = (1.5 \times 2 \times 1.381 \times 10^{-23} \times 300) / 1.602 \times 10^{-19}$$

$$= 0.078 \text{ V}$$

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

Experiment - III

Study of depletion capacitance and its variation with reverse bias

The measurement is based on the circuit of Fig. 2 where C_D and G_D are the depletion capacitance and leakage resistance, espectively, of the diode under test.

The outputs V_1 and V_2 at two frequencies ω_1, ω_2 ay be written as, $(\omega_2 > \omega_1)$

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

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

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

squaring and subtracting after taking magnitudes,

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

$$C_D = \frac{\sqrt{V_2^2 - V_1^2}}{VR\sqrt{\omega_2^2 - \omega_1^2}}$$

In the present unit

$V = 200$ mV p-p

$R = 100\ K\Omega$

$\omega_1 = 2\pi 5 .\ 10^3$

$\omega_2 = 2\pi 20 .\ 10^3$

Which gives

$$C_D = 0.41\sqrt{V_2^2 - V_1^2}\ \text{pF}$$

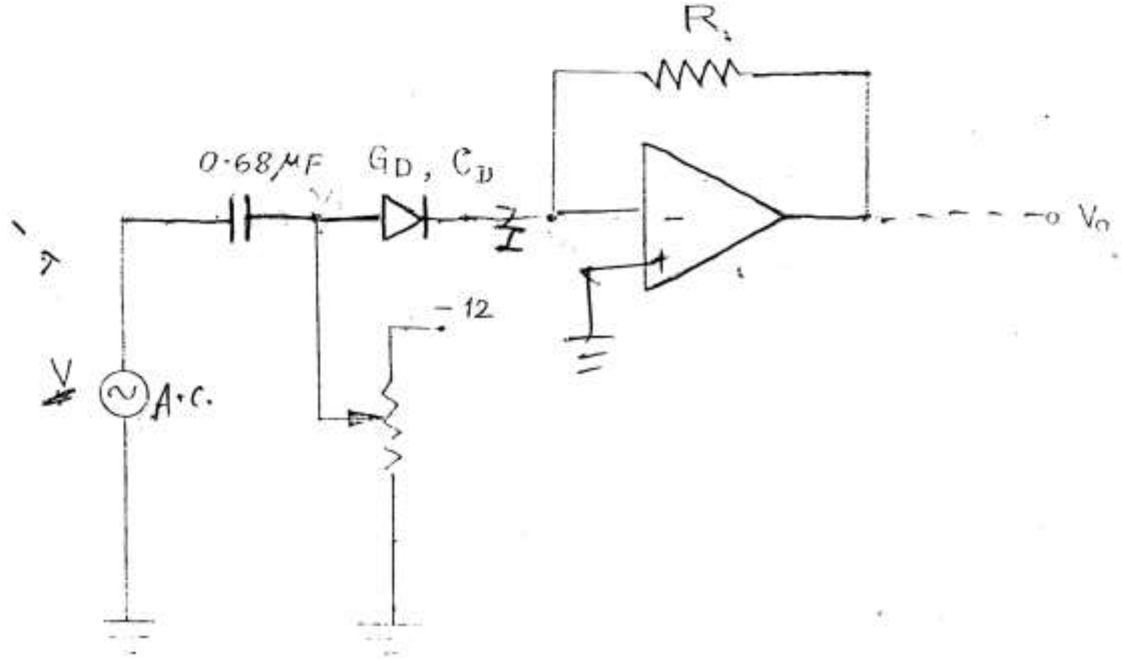

Fig. 2

where, V_1 is the p-p output voltage in mV at 5 KHz

and, V_2 is the p-p output voltage in mV at 20 KHz

For this experiment the p-n junction is connected to the left side socket. Note that no extra wire should be present with the diode. The display 2 is set to BIAS and a CRO is connected to measure the input and output voltages for the particular bias and frequency settings.

4. TYPICAL RESULTS

Experiment - I

(Reverse saturation Current I_0)

Sample : BC 109 (Base - Emitter Junction)

S.No.	Forward Current I in µA	ln I	Junction Voltage V in volt
1.	100	4.61	0.609
2.	200	5.30	0.634
3.	400	5.99	0.661
4.	700	6.55	0.683
5.	1000	6.91	0.697
6.	2000	7.60	0.724
7.	4000	8.29	0.751
8.	7000	8.85	0.775
9.	10000	9.21	0.788

From graph no. 1, we get

$\ln I_o = -10.9$

Slop of the curve $\frac{\Delta V}{\Delta \ln I} = \frac{0.23}{5.8}$

Therefore,

$I_o = 0.2 \times 10^{-10}$ Amp.

nd,

$$\eta = \frac{q}{kT} \frac{\Delta V}{\Delta \ln I}$$

$$= \frac{1.602 \times 10^{-19} \times 0.23}{1.381 \times 10^{-23} \times 303 \times 5.8}$$

$$\eta = 1.52$$

Experiment - II

Sample : BC 109 (Base - Emitter Junction)

I_f = 1.00 mA (constant for the set)

S.No.	Temperature	Junction Voltage
1.	303	0.697
2.	315	0.678
3.	322	0.664
4.	329	0.653
5.	337	0.639
6.	344	0.624
7.	351	0.611
8.	359	0.597

We know,

Energy Band gap $V_{GO} = V(T) - T\frac{dV}{dT} - \frac{m\eta k T}{q}$

From graph no. 2

At T = 300 K, V(T) = 0.705 V, $\frac{dV}{dT}$ = 1.80×10^{-3} V/K

& for Si at 300 K, $\frac{m\eta k T}{q}$ = 0.078 V

$V_{GO} = 0.705 + 300 \times 1.80 \times 10^{-3} - 0.078$

= 1.17 eV

Experiment - III

Sample : Si diode IN 4002

S.No.	Bias Voltage volt	V_1 (ω_1) mV p-p, 5 KHz	V_2 (ω_2) mV p-p 20 KHz	C_D pf
1.	0.00	16	62	24.6
2.	- 0.50	12	44	17.4
3.	- 1.00	10	38	15.0
4.	- 2.00	8	32	12.7
5.	- 3.00	8	28	11.0
6.	- 4.00	7	26	10.3
7.	- 5.00	7	24	9.41
8.	- 7.00	6	22	8.68
9.	-10.00	6	20	7.82

5. CONCLUSION

With this set-up some of the very important characteristics of a P-N Junction and its material properties may be determined as a simple laboratory experiment. The basic technique follows from the reference given below. The unit however has been carefully designed for the student environment, with built-in and protected current and bias sources, signal sources, digital displays and temperature controlled oven.

6. CAUTION

(i) In experiment 1 and 2, ordinary diodes used in power supplies should not be used due to their poor material quality.

(ii) In the experiment III : Junction capacitance of the diode/transistor junction, the devices should be directly connected with the terminals, connections through leads would result in additional capacitance and pick ups.

7. REFERENCE

Charles W. Fisher, "Elementary technique to measure the energy band-gap and diffusion potential of p-n junction", Am. J. Phys. 50 (12), Dec. 1982.