KLINGER SCIENTIFIC
Bringing You Science Since 1955

PIN DIODE CHARACTERISTICS - KSCIPIN

1. Key Concepts

- Semiconductors
- Photodiodes

2. Introduction

PIN diodes are extensively used a photodiodes. The thickness of the intrinsic layer in the PIN diode can be customised to suite the application. PIN diodes can be designed so as to optimise the quantum efficiency and the frequency response. PIN diodes have replaced PN junction diodes in optical applications because, PN junction diodes have low switching frequency, low quantum efficiency, and low current handling capacity.

3. Objective

Study of PIN diode characteristics under the following conditions

• dependence of the photocurrent (IPH) on the applied voltage at constant light flux (Φ) in the reverse displacement mode of the PIN diode.
• current (I) depending on voltage (U) in the direct displacement mode of the PIN diode.

4. Theory

A PIN diode is a photodiode made up of three layers: a highly doped **P layer**, pure intrinsic high resistivity **I layer** and a highly doped **N layer**. When a PIN diode is irritated,a majority of the photons are absorbed in the intrinsic region leading to the generationof charge carriers that contribute to the photocurrent (I_{PH}).

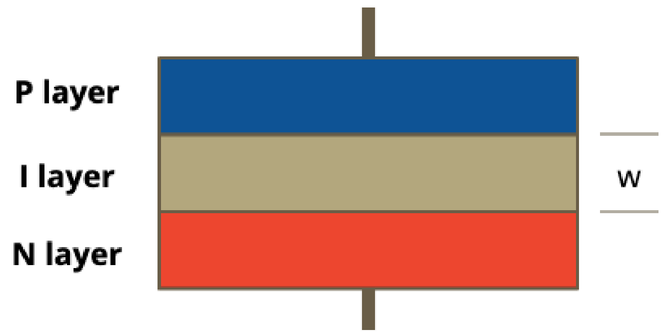


Figure 1: PIN diode structure.

PIN DIODE CHARACTERISTICS

PIN diode has high quantum efficiency, low voltage operation capability and high switching speed. All these properties make PIN diode suited for operations in RF and microwave range.

Forward bias operation:

The holes and the electrons from the P and the N layer respectively are injected into the intrinsic I layer. The average lifetime of the charge carriers (τ_a) is relatively large in the I layer, resulting in the increase injected carrier density in the I layer. PIN diode is normally operated in the

high injection charge density condition[A]. This results in the lowering of resistivity of the I layer.

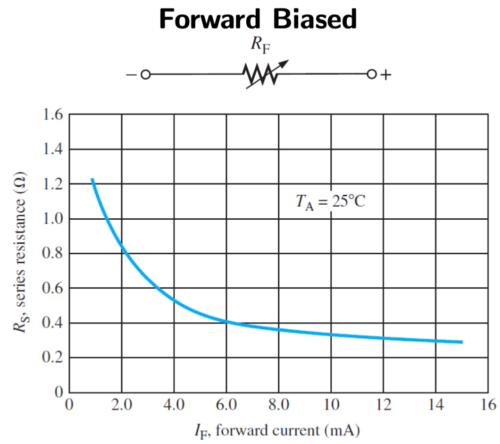


Figure 2: Forward bias mode in PIN diode

$$Q = \tau_\alpha I_F \qquad (1)$$

The quantity of charge stored (Q) depends onthe following:

- The lifetime of charge carriers (τ_a)
- Forward bias current (I_F)

The resistance of the I layer is inversely proportional to the charge stored Q and can be expressed as follows.

$$R_s = \frac{W^2}{Q(\mu_n + \mu_p)} \qquad (2)$$

Combining (1) & (2) we get

$$R_s = \frac{W^2}{\tau_\alpha I_F(\mu_n + \mu_p)} \qquad (3)$$

μ_n: mobility of the electrons and μ_p: mobility of the holes, and W: is the width of the intrinsic layer

At dc and very low frequencies, the PIN diode is similar to a PN diode; the diode resistance is described by the dynamic resistance of the I-V characteristics. In forward bias mode, thePIN diode acts like a current-controlled variable resistance.

A: ($n' \approx p' \gg n_i$, n : is the average electron density in the I layer, p : is the average hole density in the I layer and n_i : is the average density of charges in the original I layer)

Reverse bias operation:

On applying a reverse bias voltage across the PIN diode, The majority charges stored inthe I layer move to the p and n layers respectively. Further increase in the reverse biasvoltage leads to increase in the depletion of charge carries in the I layer. The PIN diode in the reverse bias condition can be modelled as a Capacitor.

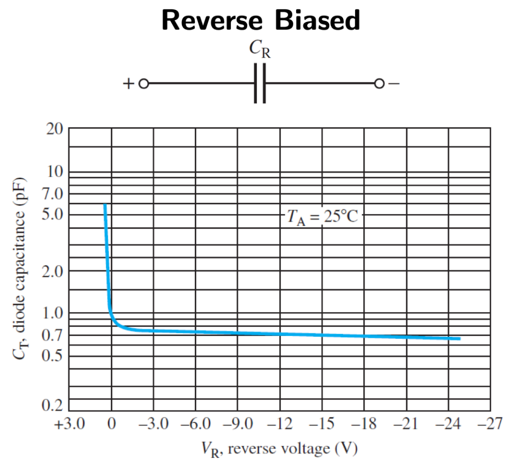


Figure 3: Total capacitance in reverse bias mode in PIN diode

PIN photodiode:

Owing to its high quantum efficiency, high response time and low operational voltage, PIN photodiodes extensively used as photodetectors. The width of the I layer can be tailored to achieve the desired quantum efficiency and frequency response of the device.

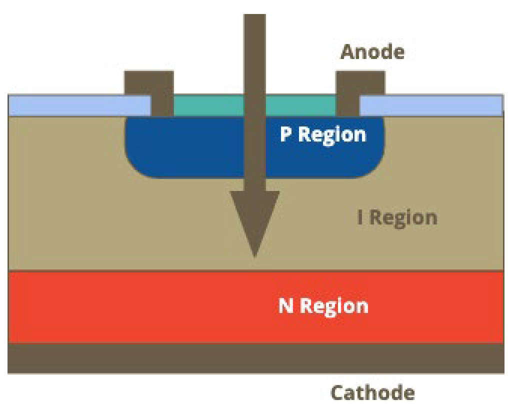


Figure 4: Structure of PIN photodiode

PIN DIODE CHARACTERISTICS

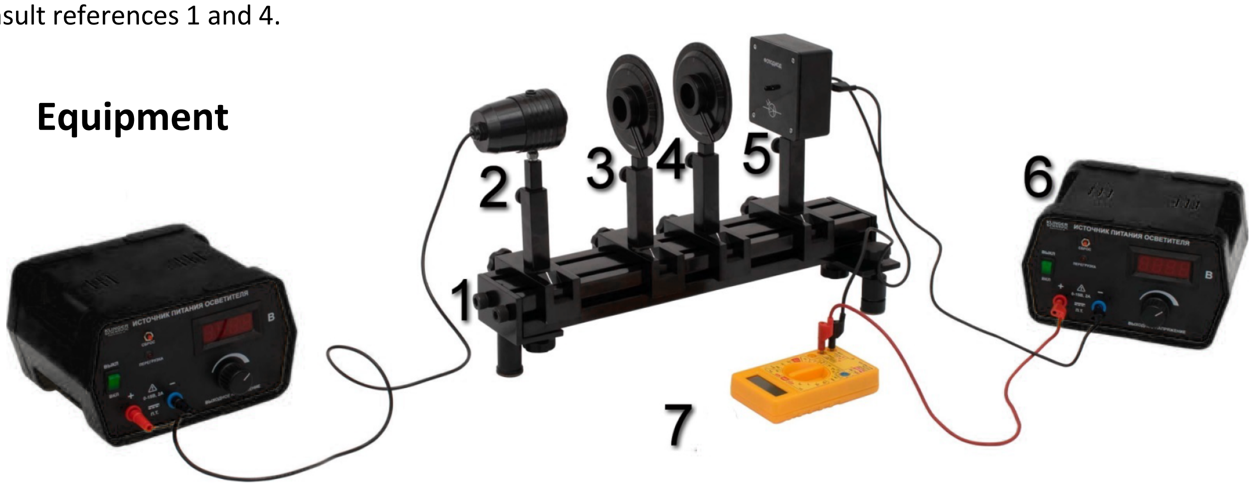
PIN diodes are operated in the reverse bias condition when used as photodiodes because, the photocurrent (IPH) is of a greater magnitude in a reverse biased condition than when the PIN diode is in forward bias condition. When PIN did is irradiated with light, the photos are absorbed by the semiconductor and electron-hole pairs are generated. These charge carriers produced in the I layer or within a diffusion length will be separated by the applied bias voltage, leading an increase in current density and resulting in current flow.

In steady state conditions the current density through the reverse biased depletion regionis given by equation 4.

$$J_{tot} = J_{drift} + J_{diff} \qquad (4)$$

For the theoretical understanding of the Current density, resistance, voltage and currentina PIN diode consult references 1 and 4.

5. Equipment



S.No	Equipment	Item Code	Quantity
1	Optical Bench Set 0.4m	KSCIOB2	1
2	Light Source Holder	KSCIHA001	1
3	Polarizer Holder	KSCIHA004	1
4	Analyzer Holder	KSCIHA006	1
5	Photo Diode Module	KSCIHA021	1
6	Power Supply 0-15V,2A	KSCI - PSLS	2
7	Multimeter	KSCI-DMM	1

6. Safety Instructions

Components like horizontal bench and power supply are heavy. Take adequate safety measures while handling them.

7. Experimental Setup

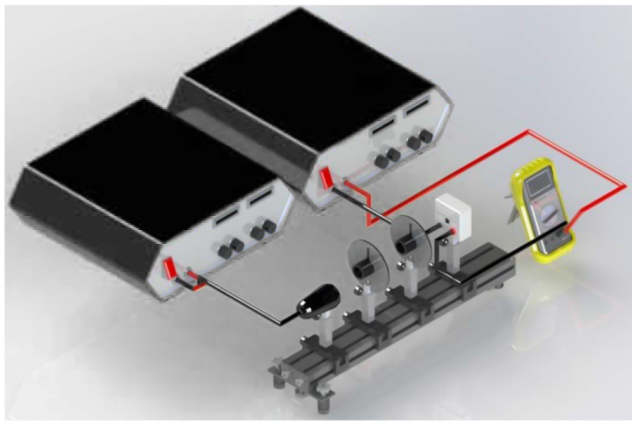


Figure 5: Diagram showing set up for measuring PIN diode characteristics.

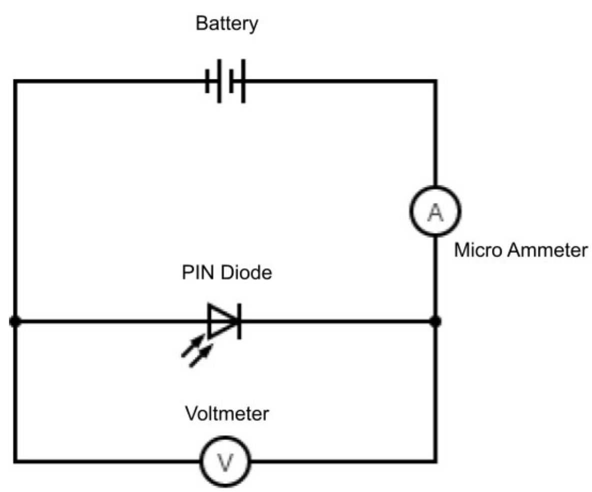


Figure 6: Circuit diagram for the PIN diode experiment.

- Place the optical bench on a stable horizontal surface such as a sturdy table top and make sure the bench is parallel to the horizontal surface using the adjustable mounts.
- Mount the light source securely on the upright, place the upright on the optical bench and lock the slide screw on the slider.
- Mount the polarizer stage on the upright, place it adjacent to the light source (along the optical path) and lock the slide screw on the slider.

- Mount the analyzer on the upright, place it adjacent to the polarizer and lock the slide screw on the slider.
- Mount the PIN photodiode on the upright and place it adjacent to the analyzer. Connect it to the power supply through an ammeter (multimeter).
- Ensure that the light source, polarizer, analyzer and the LDR are all aligned in the same optical axis.

8. Experiment

- Make the electrical connection to the PIN diode such that it is in reverse bias condition
- Power up (12 V DC) the light source and also switch on the power supply connected to the PIN photo diode.
- Rotate the analyzer such that the angle between the polarizer and analyzer is 0^o

9. Applied voltage vs photocurrent at constant luminous flux in reverse bias condition of PIN diode.

- The luminous flux on the PIN photo diode is controlled by using polarizera analyser combination.
- From Malu's law, we know that the ratio of light intensity obtained by the polarizer and analyzer combination is given by $cos^2(\vartheta)$. Therefore, we can get the relative light intensity (luminous flux) by measuring the and calculating $cos^2(\vartheta)$.
- Keeping the luminous flux constant, measure the photo current for different reverse bias voltages applied across the PIN photo diode. Plot the graph of photocurrent vs applied voltage for a different luminous flux.

in deg	in radian	$\cos^2(\vartheta)$	Current in (μA)			
			V = - 1.0 V	V = - 0.5 V	V = - 0.2 V	V = 0.2 V
0	0.000	1.000				
10	0.175	0.970				
20	0.349	0.883				
30	0.524	0.750				
40	0.698	0.587				
50	0.873	0.413				
60	1.047	0.250				
70	1.222	0.117				
80	1.396	0.030				
90	1.571	0.000				

Table 1: Photocurrent as a function of Applied Voltage at constant luminous flux.

9. Sample Readings

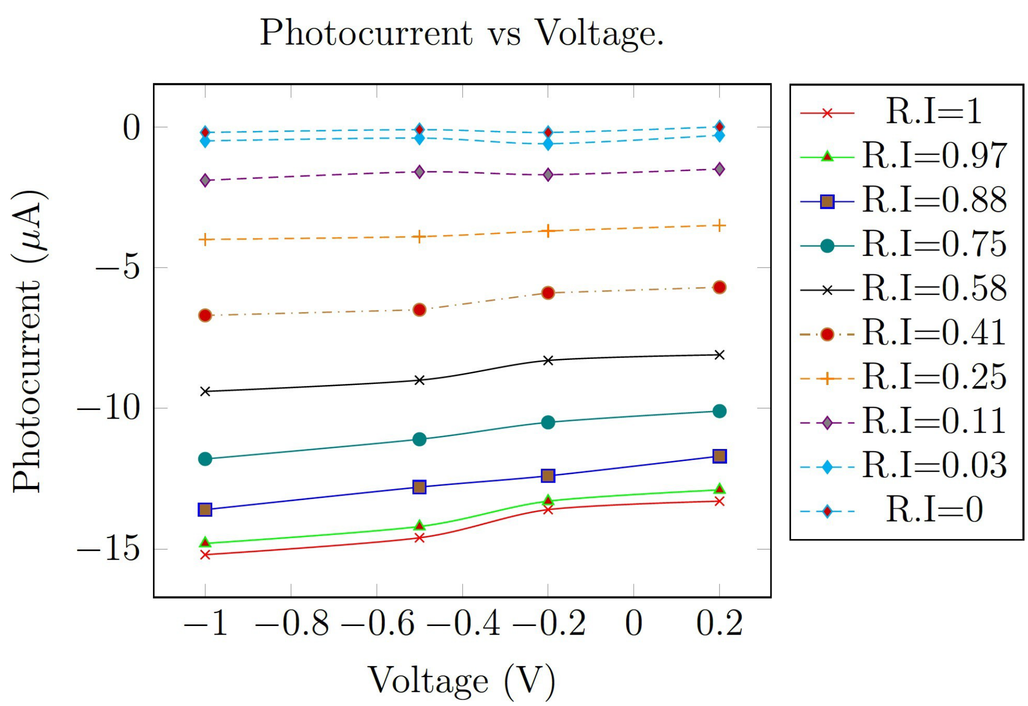


Figure 4: Photocurrent vs voltage at constant luminous flux.

9. Applications

1. **High voltage rectifier:** The PIN diode can be used as a high voltage rectifier. Theintrinsic region provides a greater separation between the P and N regions, allowinghigher reverse voltages to be tolerated. These rectifiers can be used in theapplications like CRT, power supply for laser, negative ion generators, copy machines, X-ray machines, microwave ovens etc.

2. **RF switch:** Due to the intrinsic layer between the p-n junction, the level ofcapacitance decreases. As a result, the level of isolation is increased when the diode is reversed bias. This makes it an ideal RF switch, because the switching rates arevery high. RF switches are used in microwave circuits etc.

3. **Photodetector:** In a PIN diode, the depletion region is increased by adding anintrinsic layer between the p-n junctions. Because of the increase in the depletion region, the volume of conversion is increased and the efficiency of the photodiode too.

11. References

Physics of semiconductor devices, S.M Sze, Wiley publication

Microelectronics: An Integrated Approach, Roger T. Howe and Charles G. Sodini,Prentice Hall

PIN photodiode detailed theory (https://www.ieee.li/pdf/essay/pin_diode_handbook.pdf)