Photodiode Characteristics and Applications

Electronic Devices Lab : Experiment 3

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Aim of the experiment

- To study the forward and reverse bias I/V characteristics of a Photodiode.
- To measure the response of the Photodiode for different lights and different intensities. (4 LEDs are provided, along with their current vs intensity data)
- To use the Photodiode as an optical signal sensor in combination with an Infra-red LED.

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Background Information

Photodiode:
A photodiode is a light-sensitive semiconductor diode i.e it produces current when it absorbs photons.

Under dark conditions, a photodiode behaves like a regular P-N junction diode. But when photons are incident on it, the I-V curve shifts downwards, increasing the reverse current. Hence, a photodiode is operated in reverse bias (because different types of incident light will give different reverse currents).

A photodiode can be used as an optical sensor.

Summary of the Process
Dark Condition: Under no light (dark), the photodiode behaves like a regular p-n junction diode, with a very small reverse leakage current.
Illuminated Condition: When light is incident on the photodiode:
Photons are absorbed, generating electron-hole pairs.
The electric field in the depletion region separates the charge carriers, leading to an increase in reverse current proportional to the light intensity.
Key Parameters
Responsivity: The sensitivity of the photodiode to light, defined as the ratio of photocurrent to incident optical power.

Quantum Efficiency: The efficiency of the photodiode in converting incident photons to electron-hole pairs.

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Background Information

Infra-red LED:
Infra-red LEDs are just regular LEDs with wavelength ranges between 800 *nm* and 980 *nm*. Hence it falls outside the visible light range.

Since the light emitted by IR LEDs are not visible to the human eye, they are used in applications such as remote control, motion sensing, security cameras, etc.

You may be familiar with the basic line following robot made using IR sensors. The IR sensors use IR LED and Photodiode pair (opto-coupler).

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Components required

- Photodiode
- LEDs (Infra-red, Red, Green, Blue)
- Resistors - 100Ω ($\times 2$), $1k\Omega$ ($\times 1$)
- Potentiometer - $1k\Omega$, 500Ω
- Black cone/box/cylinder/something
- Breadboard, connecting wires

Mechanism of Operation
Reverse Biasing:
Photodiodes are typically operated in reverse bias mode, meaning that a voltage is applied in such a way that the p-type side is connected to the negative terminal and the n-type side to the positive terminal of the power supply.
This expands the depletion region, allowing the photodiode to operate effectively as a light sensor.
Photon Absorption:
When light (photons) falls on the photodiode, it penetrates the semiconductor material. If the energy of the incoming photons is greater than the band gap energy of the semiconductor, they can be absorbed.
The absorption of photons generates electron-hole pairs within the depletion region or near it. The principle of the photoelectric effect governs this process.

Generation of Electron-Hole Pairs:
When a photon is absorbed, it excites an electron from the valence band to the conduction band, creating an electron-hole pair.
The electron (negative charge carrier) is free to move, while the hole (positive charge carrier) represents a missing electron in the valence band.
Separation of Charge Carriers:

The electric field present in the depletion region quickly sweeps the generated electron toward the n-type region and the hole toward the p-type region.
This movement of charge carriers generates a photocurrent, which is the output current of the photodiode.
Increased Reverse Current:

The increase in photocurrent due to the generated electron-hole pairs results in a measurable increase in the reverse current flowing through the photodiode when illuminated.
The amount of photocurrent is proportional to the intensity of the incident light.

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Experiment Setup

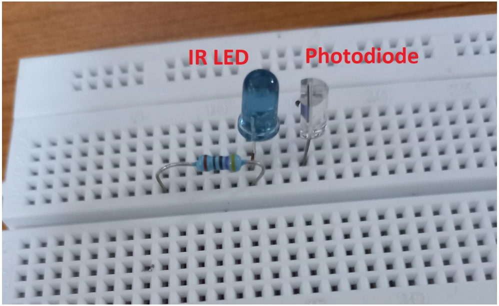

Figure: Relative positions of LED and photodiode

The LED and the photodiode should be very close to each other as shown in the above figure. The flat surface of the photodiode must face the LED.

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Experiment Setup

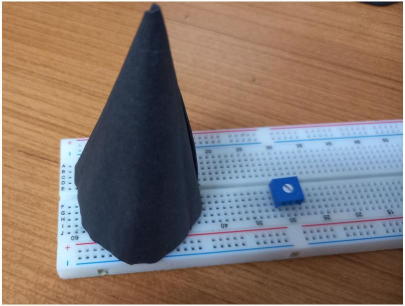

Figure: Black cap to cover photodiode

While measuring any characteristics, use the cap to cover the circuit to make sure light from outside does not fall on the photodiode.

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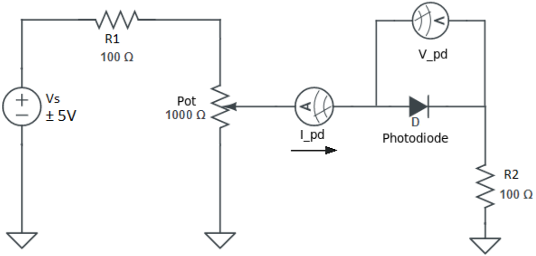
Part 1 : Dark I-V Characteristics of Photodiode

- Obtain the dark I-V characteristics of the given photodiode for forward as well as reverse bias. You can refer to the following circuit.



(Note that the voltage should be varied using the potentiometer)

- Plot the I_{pd} vs V_{pd} and the log(abs(I_{pd})) vs V_{pd} curves.
- Extract the ideality factor from the low forward bias $(0.2V - 0.6V)$ region of the I-V data.

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Part 2 : Photodiode response to lights of different intensities and wavelengths

- Choose any LED, say IR. Rig up the circuit shown below.

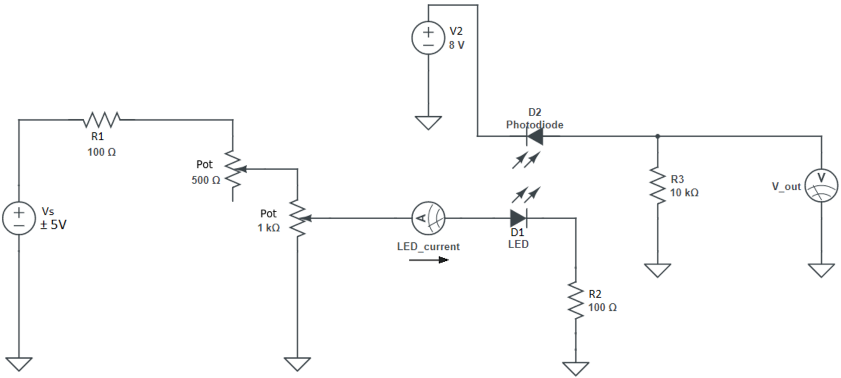

Figure: Circuit for Part 2

Part 2 : Photodiode response to lights of different intensities and wavelengths

ii Bias the IR LED to get the current corresponding to each intensity given in the IR LED table (refer end), and note down the output voltage V_{out} which is proportional to the photodiode current under LED illumination.

iii Repeat the same for other LEDs. You should have the responses of the photodiode for each LED at 3 given intensities (refer to tables in the end).

iv Once you have all the readings, plot the following-

a V_{out} vs wavelength for each intensity.

b V_{out} vs intensity for each LED.

iv Calculate efficiency of each LED using photodiode response at each intensity using the formula: $\eta = V_{out}/I_{led}$. Then plot efficiency vs wavelength for each intensity. Which LED is the most efficient?

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Make minor modifications for the existing circuit to obtain the circuit shown below. Use just the IR LED for this part.

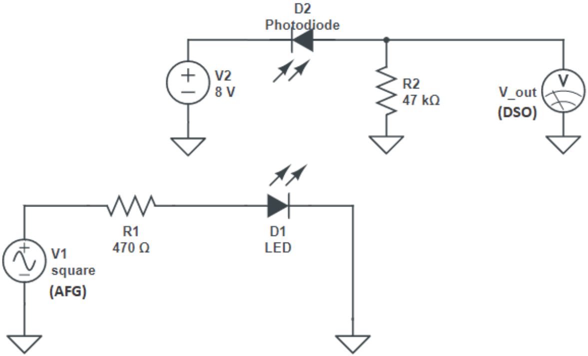

Figure: Circuit for Part 3

Part 3 : Application of photodiode as optical signal sensor

i Apply a pulse of amplitude $5V$ at $1kHz$ frequency and 50% duty cycle using the function generator. Observe photodiode output voltage on the DSO and measure its rise and fall times.

ii Increase the frequency (go in steps of 4-5kHz) and notice the change in the output. What is the maximum frequency of IR LED switching that the photodiode can follow the input pulse? Which device processes limit the photodiode response during the LED on and off cycles?

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Infra-RED Led: $(\lambda = 950nm)$

Current (mA)	**Intensity** (lux)
4.51	1000
5.17	1500
6.28	2000

RED Led: $(\lambda = 750nm)$

Current (mA)	**Intensity** (lux)
2	1000
3	1500
4	2000

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Current vs Intensity Data

GREEN Led: $(\lambda = 520nm)$

Current (mA)	**Intensity** (lux)
0.188	1000
0.294	1500
0.371	2000

BLUE Led: $(\lambda = 450nm)$

Current (mA)	**Intensity** (lux)
0.301	1000
0.416	1500
0.572	2000

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