Engineering Physics (2025)
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Module 2 Unit 2: Optoelectronics

Course Instructor:
Dr. Sreekar Guddeti
Assistant Professor in Physics
Department of Science and Humanities
Vignan's Foundation for Science, Technology and Research

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M2U2 Plan

1. p-n junction diode – forward and reverse conditions
2. Solar cell
3. Photo-diode

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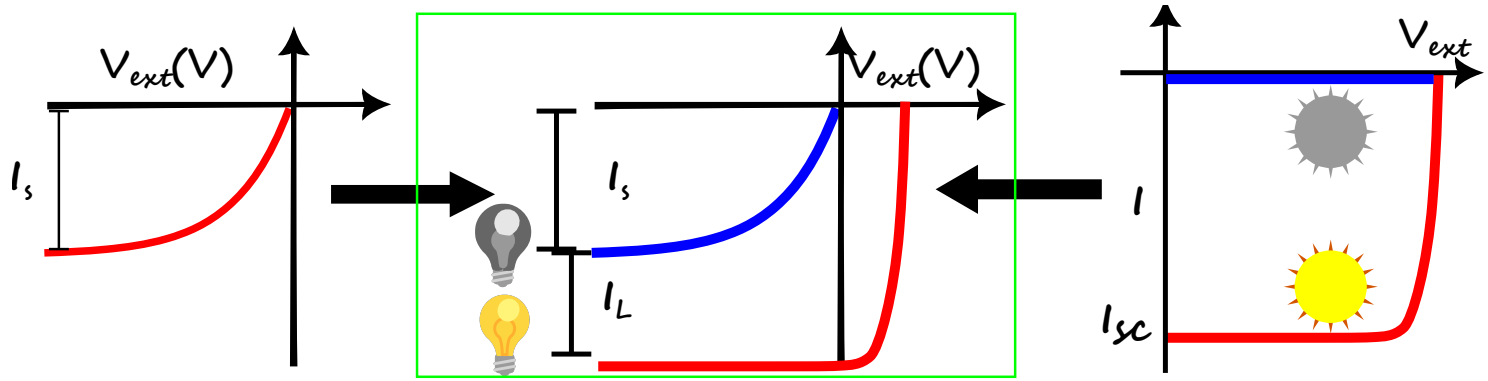
Photo-diode

Definition

A photo-diode is an opto-electronic device that is used to sense the presence of light.

- A photo-diode is a pn junction diode that operates under **reverse bias**.
- Due to the reverse bias, the depletion region width increase. This leads to decrease in junction capacitance.

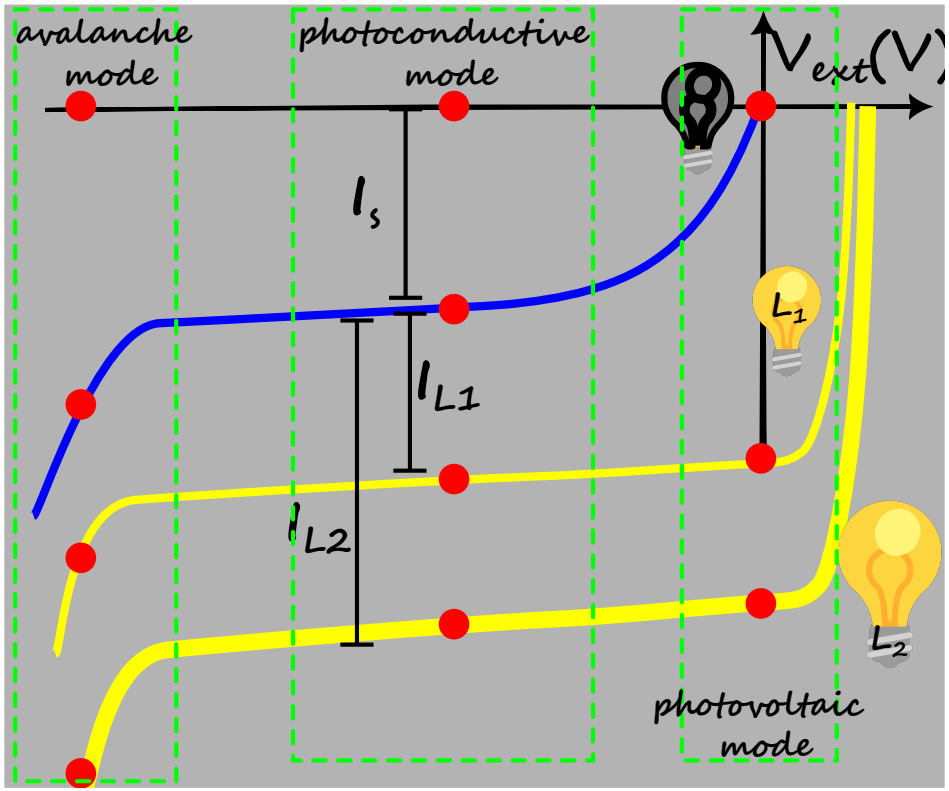
Photo-diode – $I - V$ characteristics



- The $I - V$ characteristics of photodiode can be considered as $I - V$ characteristics of solar cell under forward bias and $I - V$ characteristics of pn junction under reverse bias.
- The reverse bias generates reverse current that saturates to reverse saturation current I_s at high bias.
- In addition to the reverse current, if the photons are incident on the diode there is an additional photocurrent I_L.
- Thus the external bias is negative and the net current is negative and the $I - V$ characteristics is given by

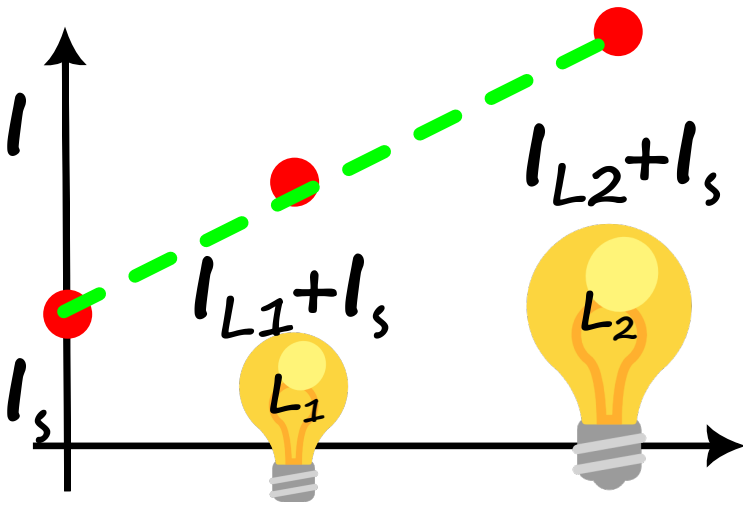
$$I = I_s \left[\exp\left(\frac{eV}{k_B T} \right) - 1 \right] - I_L$$

Photo-diode – Modes of operation



- The photo diode has three modes of operation
  1. photoconductive mode – reverse bias
  2. zero bias mode – reverse bias voltage is set to zero
  3. avalanche mode – **very** high reverse bias
- In every mode of operation, there are two states of operation
  1. Photons are not incident
  2. Photons are incident

Photoconductive mode

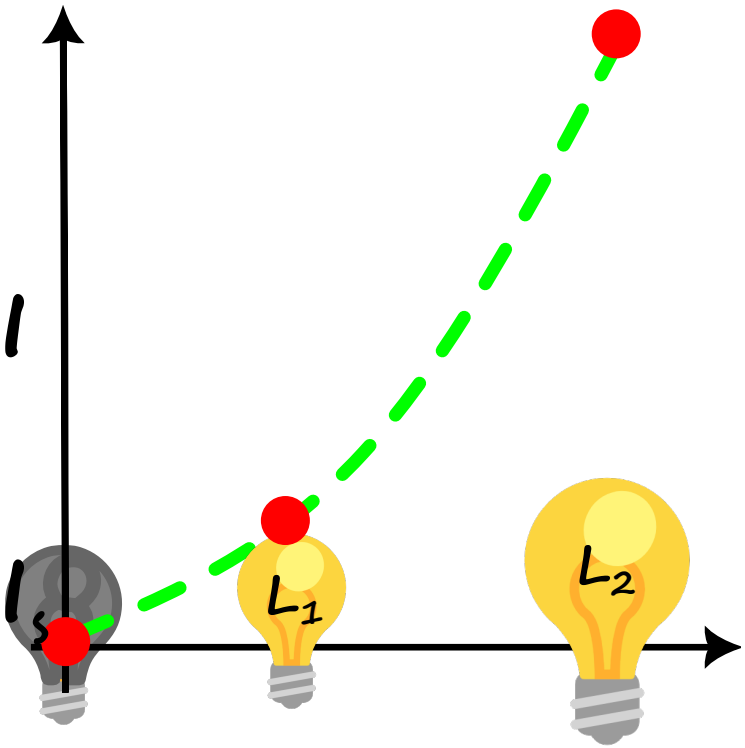


- Photo diode is under reverse bias.
- At zero light intensity, there is a non zero current due to the reverse saturation current. This is called **dark current**.
- Response of photodiode is linear. In this mode, photodiode is a linear sensor.
- Due to reverse bias, the depletion region width increases. Since the space charge region acts as a parallel plate capacitor, the junction capacitance C_{junction} is given by

$$C_{\text{junction}} = \frac{\epsilon A}{W}$$

where A is the cross sectional area of the depletion region and W is the depletion region width.
- Due to reduction in junction capacitance, photodiode is used for high frequency opto-electronic converters.

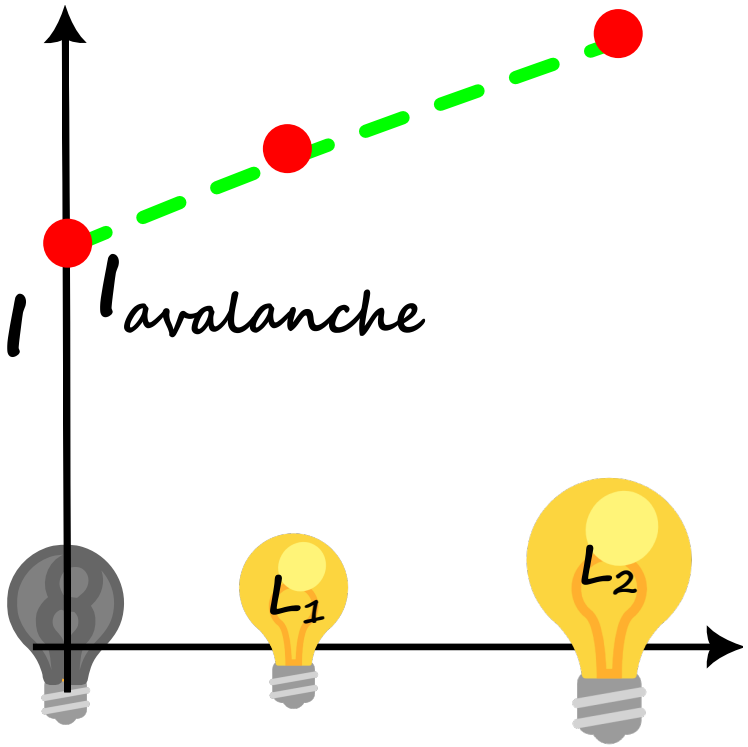
Photovoltaic mode



- Photo diode is under zero bias. This mode is the same as solar cell operation mode.
- At zero light intensity, there is zero current as there is no bias. Therefore, dark current is zero.
- Response of photodiode is non-linear. In this mode, photodiode is a non-linear sensor.

- Due to the zero bias, dark current is zero. So photo diode is used for detecting ultra low light.

Avalanche mode



- Photo diode is under very high reverse bias.
- The net electric field is so high that the generated charge carriers at the depletion region are accelerated to high kinetic energy. These energetic particle collide with silicon atoms and ionize them releasing secondary electrons. This is called **impact ionization**.
- The secondary electrons are also accelerated and ionize further atoms leading to a chain reaction also called avalanche.

- In this mode, photo diode is not used as sensor, but as an amplifier.
- Due to the avalanche effect, there is multiplication of the charge carriers. Therefore there is a net gain of current. In this mode, photo