PHY 351 / 651 – LABORATORY 11

PHOTODIODE DETECTOR CHARACTERIZATION

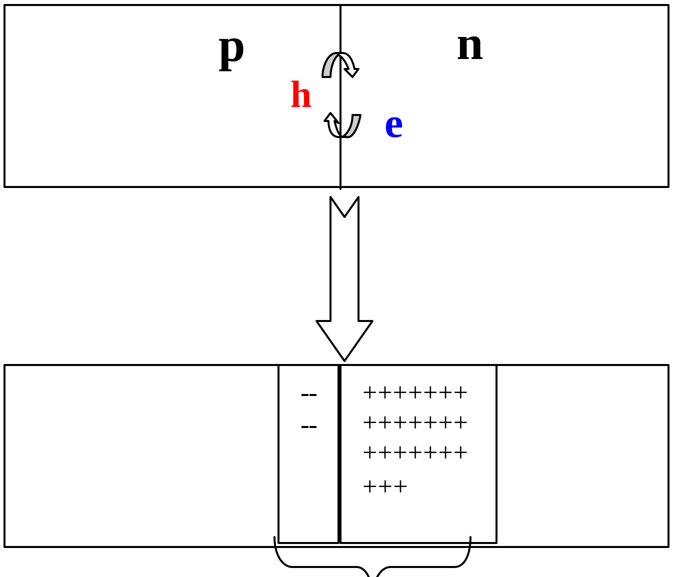
Introduction

Experimental physics, biology, chemistry, diagnostic medicine, and several other aspects of modern technology take advantage of the unique properties of solid-state detectors as fast, accurate and efficient position sensitive devices. In particular, silicon detectors are the foundation of precision tracking system, such as micro-strip or pixel devices used in particle physics. Photodiodes are widely used to convert light signals into electrical signals. We will use photodiodes to illustrate the main properties of silicon detectors.

In general, modern silicon detectors are based on the p-n junction that you may have encountered in previous electronics courses as a rectifying element, conducting almost perfectly current in one direction and being an almost open circuit for DC currents in the opposite direction.

Detector grade silicon is generally a high purity crystal. It has high resistivity, implying that most of the crystal electrons are in the valence band. Thermal motion may promote 1 e^- to the conduction band, leaving a "hole" [absence of an electron, behaving from the electrical point of view as a positive charge] in the valence band. Thus intrinsic Si is a device that carries current through 2 different carriers, electrons and holes. The key technology that allows the production of silicon detector is controlled doping of the intrinsic Si device. Si is a group 4 element. Fig 1 shows a schematic view of an n-type silicon, where a substitutional P atom has replaced a Si atom and a negative-charge electron is "donated" to the conduction band. This produces an excess of electrons in the conduction band: the electrons become the majority current carriers in this device.

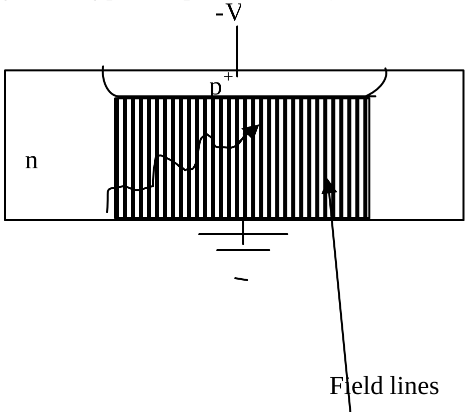
An interesting process happens when p-type and n-type silicon share a boundary surface (p-n junction). The majority carriers from the two regions flow across the boundary and "annihilate each other". Thus a "space charge region" is formed, deplete of charge carriers:



Space charge region: the total positive charge in the n-type silicon must balance the total negative space charge in the p-type

The space charge produces a potential difference that is called built-in potential that prevents further flow of majority carriers from one region to the area. An external potential modulates this intrinsic potential barrier: if the sign of the external voltage across the junction is opposite to the one of the built in potential, current is resumed [positively biased diode], if the sign of the external voltage is the same as the built-in potential, the potential barrier increases and the size of the space charge region is increased.

The reverse-biased diode is the key element of modern photon detectors such as photodiodes or silicon strip detectors. The space charge region is a region of non-zero electric field [remember the electric field inside a capacitor]. Now we have all the elements to build a silicon detector, whose behavior is illustrated in Fig. 3. For simplicity, the bulk of the detector is assumed fully depleted [the space-charge region touches the bottom electrode]. Generally, silicon detectors are built with a very asymmetric junction, so that the space charge region occupies mostly the n-type component of the junction.



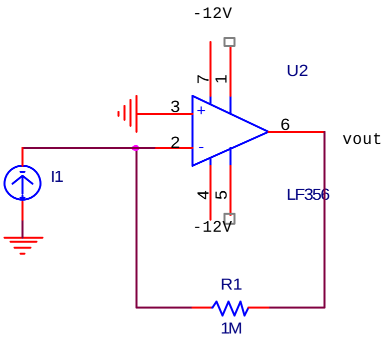
Introductory Note: The transimpedance amplifier

A very neat way to measure current exploits some properties of the ideal operational amplifier, namely the very high input impedance seen at the inverting and non inverting inputs and the very low output impedance at the output node.

Go back to your notes on the op-amp and convince yourself that the circuit shown in Fig. A has the “transimpedance gain” given by:

$$V_{out} = -R1\ I1$$

Fig.A The transimpedance amplifier



If V_{out} is very small, you will have to subtract the offset voltage [Vout without any input current].

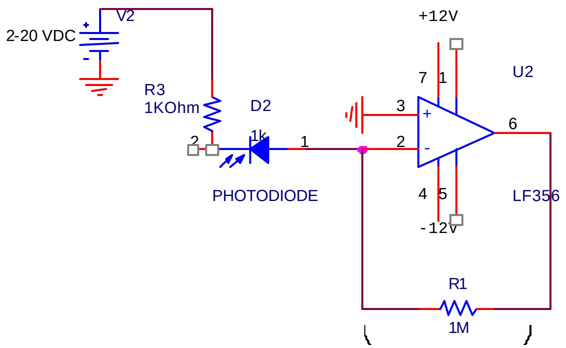
Experiment I:

Experimental set-up: Build the circuit shown in Fig.1. Proceeds in two steps: first build the transimpedance amplifier and measure the offset voltage [V_{out} in this configuration]. Then attach the photodiode and its biasing circuit. Make sure that V_2 has a positive polarity: if you bias the photodiode with a high forward voltage, too much current will flow and you may burn the device! To provide V_2, use the variable 2-20 V power supply.

Measurement: Measure the dark current as a function of the applied reverse bias. In order to make a precise measurement, start by building the transimpendance amplifier and measure the offset [vout without the photodiode attached to the transimpedance to the inverting input].

Analysis: Plot I_{dark} versus V2 [the reverse bias]. What can you say about the dependence of the dark current upon the reverse bias?

Fig.1



Transimpedance amplifier

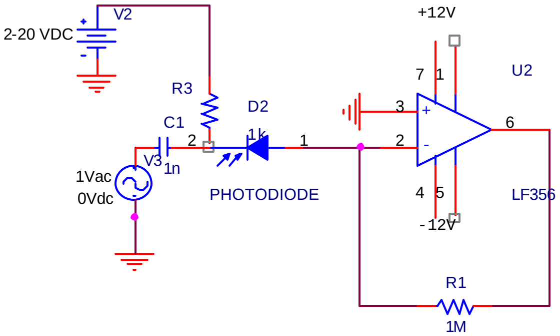
Activity II:

Experimental set-up: Build the circuit shown in Fig.2. Make sure that V_2 has a positive polarity: if you bias the photodiode with a high forward voltage, too much current will flow and you may burn the device! Note: the capacitor C1 should be as high as possible; it is a decoupling capacitor to prevent V2 from loading the BK sine wave generator.

Measurement: Measure the gain as a function of the applied reverse bias.

Analysis: You should be able to convince yourself that the gain of the system is given by the expression $|G|= 2\pi f C_D R_1$.From this equation and the measured gain, derive C_D. Plot C_D versus V2 [the reverse bias]. What can you say about the dependence of C_D upon the reverse bias?

Fig. 2



Activity III: The photodiode response to a light signal from an LED

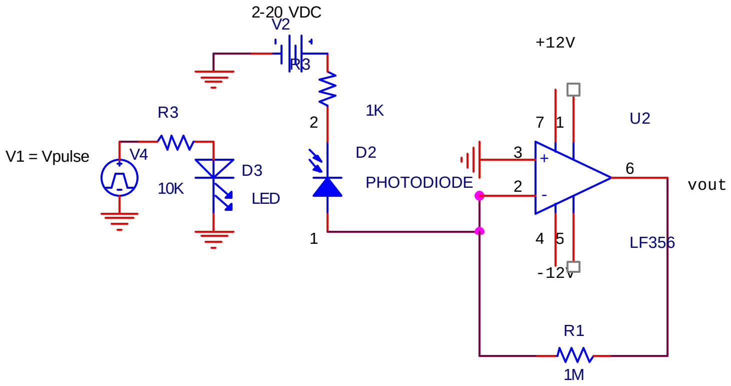


Fig.3

Experimental set-up: Position an LED to face the photodiode. You should bias it with the pulse generator configured to produce a positive square pulse of about 1.5 V. Use a big series resistance to provide some current limit. If you are not provided with the set-up in the black box you should try to shield the LED-photodiode pair from the light.

Measurement: Observe the output when the LED is pulsed. Increase the amplitude of the LED biasing pulse and observe its effects.

Analysis

Relate your observations to your expectations on the basis of the properties of this photon detector.
Describe the signal and any additional noise that you may observe.
Can you explain your observations? If you see noise, you may try to guess the source and how you would improve on this apparatus.