EXPERIMENT 6
CHARACTERISTICS OF LIGHT DETECTORS

PURPOSE

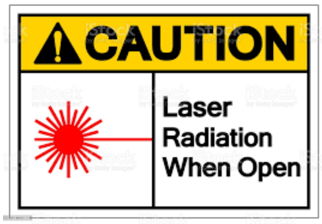
The aim of this expriment is to understand some characteristics of a light detector. As an example application, we will use LDR and photodiode.

EQUIPMENT

DC source, luxmeter, powermeter, spectro-photo-meter, laser diodes, multimeter, oscilloscope.

NOTE

Lasers can cause damage in biological tissues, both to the eye and to the skin. Unprotected Human Eye is extremely sensitive to laser radiation and can be permanently damaged from direct or reflected beams. High power lasers can also burn the skin. There are some government regulations that define classes of laser according to the risks associated with them.



THEORY

Photodetectors are sensors of light. There is a wide variety of photodetectors which may be classified by mechanism of detection, such as photoelectric or photochemical effects, or by various performance metrics, such as spectral response. Semiconductor-based photodetectors typically photo detector have a p–n junction that converts light photons into current. The absorbed photons make electron–hole pairs in the depletion region. Photodiodes and photo transistors are a few examples of photo detectors. Solar cells convert some of the light energy absorbed into electrical energy.

There are a number of performance metrics by which photodetectors are characterized and compared. Some of them are listed in Table 1.

Table 1: Performance metrics of photodetectors

Metric	**Description**
Spectral response	The response of a photodetector as a function of photon frequency
Quantum efficiency	The number of carriers (electrons or holes) generated per photon
Responsivity	The output current divided by total light power falling upon the photodetector
Noise-equivalent power	The amount of light power needed to generate a signal comparable in size to the noise of the device
Detectivity	The square root of the detector area divided by the noise equivalent power
Gain	The output current of a photodetector divided by the current directly produced by the photons incident on the detectors, i.e., the built-in current gain
Dark current	The current flowing through a photodetector even in the absence of light
Response time	The time needed for a photodetector to go from 10% to 90% of final output

Photodetectors are included in many devices, such as, Gaseous ionization detectors, Photomultiplier, Photodiodes, Phototransistors, Pinned photodiodes, Photoresistors or LEDs. It I,s interesting to note that that if LED is reverse-biased it acts as photodiode!

LDR

A photoresistor or Light Dependent Resistor (LDR) is a resistor whose resistance decreases with increasing incident light intensity. It can also be referred to as a photoconductor. A typical LDR and its circuit symbol are shown in Figure 1.

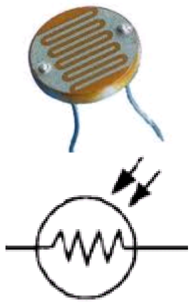


Figure 1.

LDR is made of a high resistance semiconductor. If light falling on the device is of high enough frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electron (and its hole partner) conduct electricity, thereby lowering resistance.

LDR come in many different types. Inexpensive cadmium sulfide (CdS) cells can be found in many consumer items such as camera light meters and street lights. Typical characteristics are shown in Table 2.

Table 2: A typical LDR characteristics

Parameter	Conditions	Min	Typ	Max	Unit
Cell resistance	1000 LUX 10 LUX	- -	400 9	- -	Ohm K Ohm
Dark Resistance	-	-	1	-	M Ohm
Dark Capacitance	-	-	3.5	-	pF
Rise Time	1000 LUX 10 LUX	- -	2.8 18	- -	ms ms
Fall Time	1000 LUX 10 LUX	- -	48 120	- -	ms ms

The sensitivity of a LDR is the relationship between the light falling on the device and the resulting output signal (resistance). An example sensitivity plot is shown in Figure 2. Like the human eye, the relative response of a LDR cell is dependent on the wavelength (color) of the incident light. Each photoconductor material type has its own unique spectral response curve. Typical spectral response is shown in Figure 3.

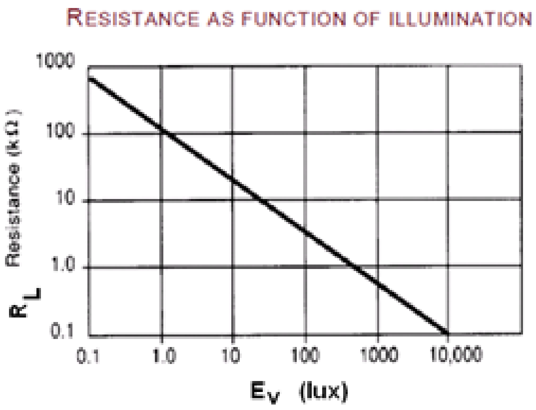


Figure 2: Typical sensitivity of LDR

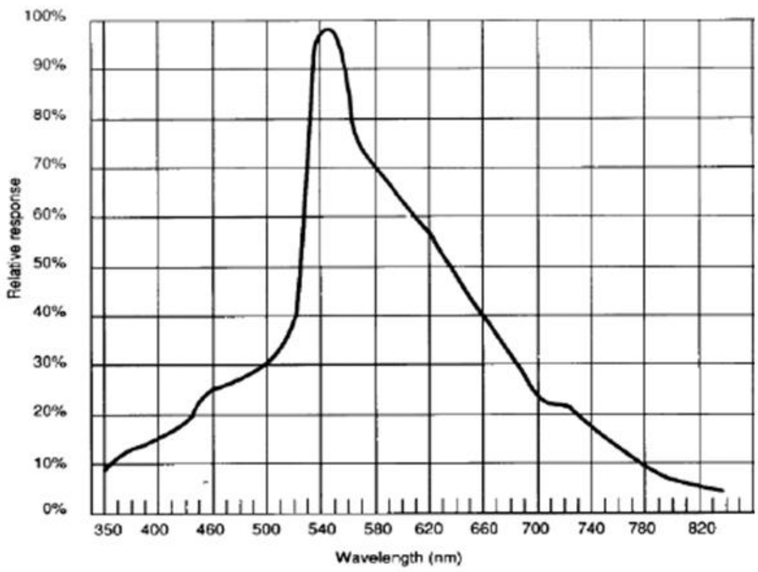


Figure 3: Typical spectral response of LDR

Photodiode

A photodiode is capable of converting light into either current or voltage, depending upon the mode of operation. A traditional *solar cell* is just a large area photodiode. Some photodiodes and circiut symbol of a photodiode is shown in Figure 4.

Figure 4.

When a photon of sufficient energy strikes the diode, it excites an electron, thereby creating a free electron and a (positively charged electron hole). Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced.

Materials commonly used to produce photodiodes are as follows:

- Silicon (Si)
- Germanium (Ge)
- Indium Gallium Arsenide (InGaAr)

When light falls on the photodiode, a reverse current flows which is proportional to the illuminance. An example one is shown in Figure 5. Responsivity of a a photodiode is measure of the electrical output per optical input. In SI units Ampere/Watt [A/W] is used a metric. An example responsivity plot for a Silicon photodiode is shown in Figure 5. Finally, as an example FDS10X10 photodiode charecteristics is shown in Table 2.

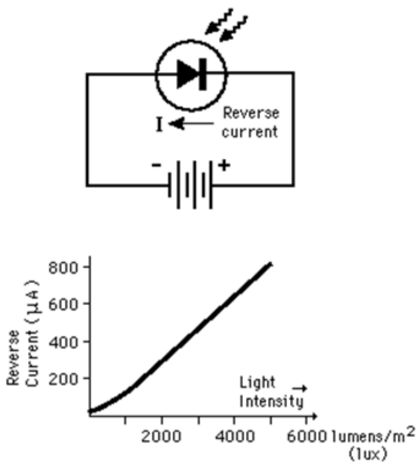


Figure 4: Typical reverse current vs light input

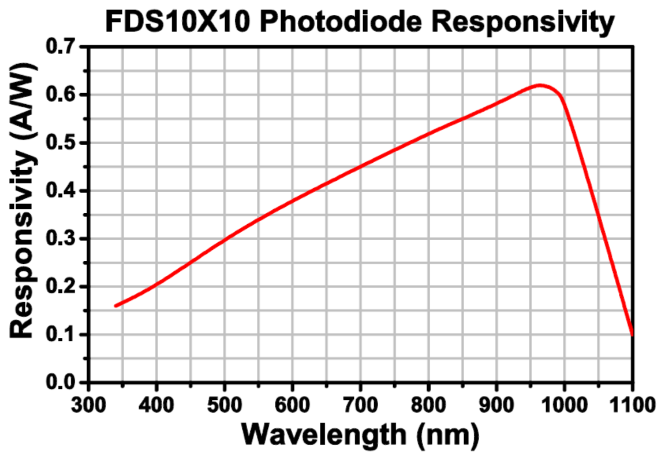


Figure 5: Typical spectral response of Si P.D.

Table 2: FDS10X10 Si photodiode characteristics

Specification		Value
Wavelength Range	λ	340 - 1100 nm
Peak Wavelength	λ_p	960 nm
Responsivity	$\Re(\lambda_p)$	0.62 A/W
Active Area		100 mm^2
Rise/Fall Time (R_L=50 Ω, 5 V)	t_r/t_f	150 ns / 150 ns
NEP, Typical (960 nm)	W/√Hz	1.50 x 10^{-14}
Dark Current (5 V)	I_d	200 pA
Capacitance (5 V)	C_j	380 pF
Package		Ceramic
Sensor Material		Silicon (Si)

Maximum Rating	
Max Bias (Reverse) Voltage	5 V
Operating Temperature	-40 to +75 °C
Storage Temperature	-55 to +125 °C

PROCEDURE

Part 1 ***Spectral Response of LDR and Photodiode***

Setup is shown in Figure 6. First determine peak wavelength and optical power of each laser diode (or any other light source) using spectrophotometer and powermeter. Then, measure curremt output of each photo sensor. Fill Table 3.

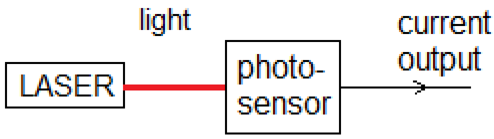


Figure 6: Exp. 1

Part 2 ***Rise-time and Fall-time Measurements***

Setup is shown in Figure 7. Laser is connected to a square-wave signal gererator to generate laser pulses. The laser output is taken by an LDR or a Photodiode. Then, input and output wave shapes are observed in oscilloscope to determine rise-time and fall-time of the sensor (LDR or Photodiode). Fill Table 4.

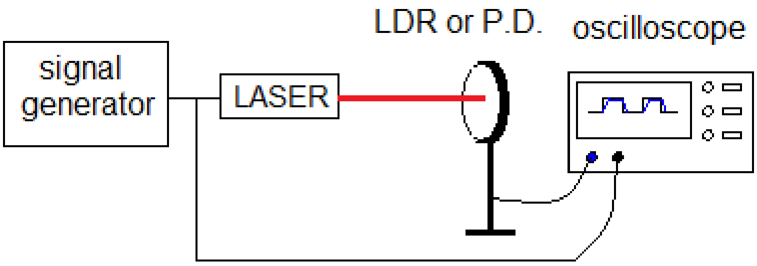


Figure 7: Exp. 2

Part 3 ***Resistance vs Light Intensity measurement of LDR***

Setup is shown in Figure 8. Connect LED to a variable DC source. First, measure light intensity via luxmeter. Then, replace light sensor with LDR and measure the output resistance. Repeat the experiment a few times by changing the light intensity. Fill Table 5.

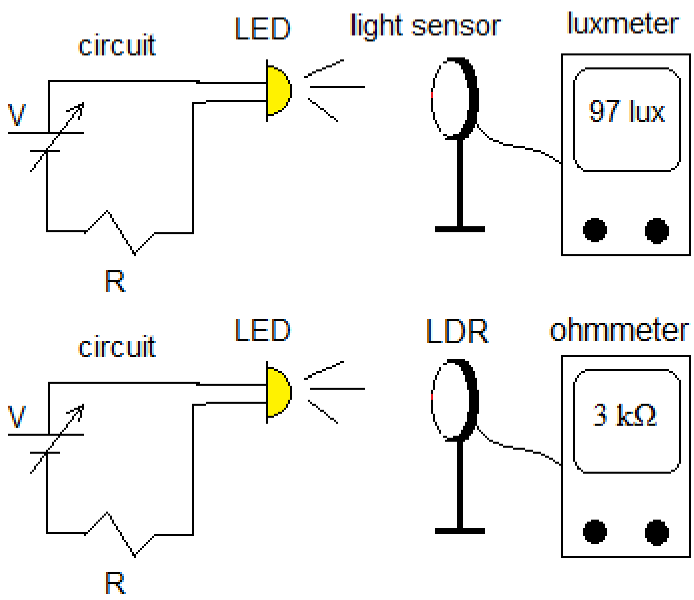


Figure 8: Exp. 3

QUESTIONS

For each question, write down your conculusion briefly.
Sensor stands for LDR and/or photodiode.

1. Plot the Responsivity of each sensor seperately (Figure 3 or 5).
2. Determine rise-time / fall-time of each sensor for the given pulse frequencies.
3. Plot LDR resisistance vs light intensity graph. Both axes are lograrithmic. Determine dark resistance of the LDR.
4. How can you measure Quantum Efiiciency of a photodiode via equipments in our lab? Sketch your design and explain your setup and procedure in details.

Table 3: Data for Exp 1

Laser diode (or othe light source)	Wavelength (nm)	Optical Power	Current Output

Table 4: Data for Exp 2

Frequency of signal generator	Rise-time of LDR	Fall-time of LDR	Rise-time of Photodiode	Fall-time of Photodiode

Table 5: Data for Exp 3

Light intensity	Resistance