Photoelectric sensors

This task is focused on measuring light characteristics of photoelectric elements (components). For this measurement we use photo resistor, phototransistor and photodiode.

Task

1. Get familiar with given components used for detection of light and use catalog to determine their parameters.

2. Perform these measurements:

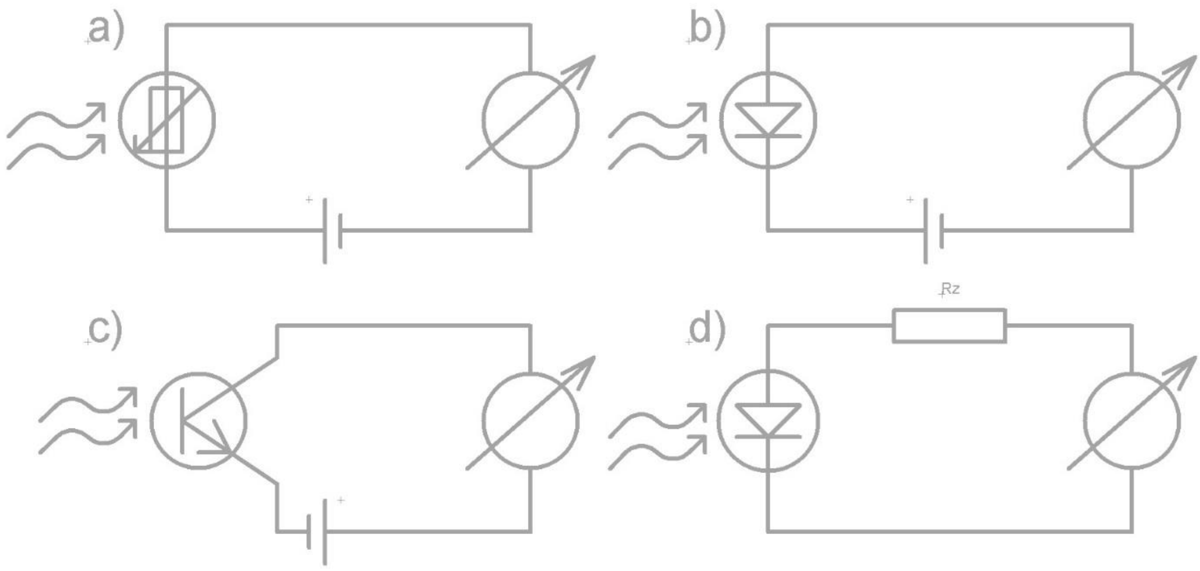
    - Light characteristics of photo resistor
    - Light characteristics of phototransistor
    - Light characteristics of photodiode in both gate and resistance connection

3. Determine the influence of color filters on light characteristics of listed photodetectors
4. Count equation of regression lines in linear parts of static characteristics; make the final evaluation and comparison of results.

Diagram of connection

On Pic. 1 is illustration of resistance connection with photo resistor, photodiode and phototransistor, where the source of DC current is serially connected to circuit with photodetector and measuring device.

On Pic. 1d is gate connection of photodiode, which is working as active photo component.



Pic. 1 Resistance connection a) photo resistor b) photodiode c) phototransistor d) gate connection of diode

Photo sensors can be connected in resistance or gate mode. Based on their application photo sensors can fulfill different functions:

a) incoming light is transformed into DC current (voltage), size of transformed current is directly proportional on light (photo sensor)
b) incoming light is transformed into electric signal, which amplitude is changed rapidly, if intensity of light is above defined level (photo relay)
c) incoming light is transformed into pulse voltage, its frequency is proportional to light

Theoretical analysis

If we say “detector” in optoelectronics we mean a component which transform light energy into another quantity which can be also measured, e. g electric current, voltage etc.

Photodetectors are separated into two groups. First group consist of heat detectors. Incoming light creates heat which change some parameters which are temperature dependable. Second group consist of quantum detectors, where incoming photons interact with electrons inside the material. Big part of quantum detectors is formed by photoelectric detectors – photo vacuum tube. Its function is based on inner and outer photoelectric effect, which is described by equation:

$$hv = \frac{1}{2} m_e v^2 + A_e \quad (1)$$

where:

h - Planck constant ($6{,}625 \times 10^{-34}$ Js)

m_e – electron weight ($9{,}109 \times 10^{-31}$ kg)

v – speed of electron leaving the photocathode surface

A_e – output work of electron

Outer photoelectric effect is manifested by passage of electric current created by smashed in electrons, in case that output work A_e of electron is smaller than energy of incoming quantum of light with energy hv. Outer photoelectric effect was used by vacuum and gas emission photo vacuum tube.

Inner photoelectric effect is manifested by change of electric conduction of sensitive layer in photodetector caused by incoming light. Photo vacuum tube based on change of electric conduction is called photoelectric resistors. Another manifestation of inner photoelectric effect is creation of electric current on interface of two areas, exposed to light, with different types of conduction. This effect is called photo voltage effect and photodetectors based upon it are photodiodes. Connected photodiode with voltage preload in closed direction, in which incoming light cause change of current flow is called resistance connection.

Gate connection of photodiode is characterized by creating electric voltage based upon amount of incoming light.

This result in fact photodiode is active type of detector, which means it can be itself source of electric current, which is created by incoming light.

Photodetector which consist of two PN structures and amplify electric current created in area of PN transition is called phototransistor.

Properties of photodetectors are characterized by several important quantities:

Spectral sensitivity V_λ of photodetector is defined by equation:

$$V_\lambda = \frac{i_f}{\Phi_\lambda} = \frac{u_f}{\Phi_\lambda} \tag{2}$$

where:

Φ_λ – Monochromatic shiny flow

i_f – Photoelectric output current

u_f – Photoelectric output voltage

Graphic representation of relative spectral sensibility on incoming light wave length is called spectral characteristics of detector.

Quantum efficiency η of photodetector is defined by equation:

$$\eta = \frac{i_f * h * v}{p * e} = \frac{\mathrm{u_f * h * v}}{\mathrm{P * R * e}} \tag{3}$$

where:

i_f – photoelectric output current [A]

u_f – photoelectric output voltage [V]

R - resistance [Ω]

P – performance of incoming light [W]

N – frequency of incoming electrons

e – electron charge (1,602 x 10^{-19} C)

Detectors based on outer photoelectric effect can reach quantum efficiency up to 30%, detectors based on inner photoelectric effect have quantum efficiency reaching nearly 100%, however certain wave length have the ability to make quantum efficiency reach 0%.

There is another equation for photodetectors:

$$\frac{V_\lambda}{R} = \frac{A * \eta * e}{h * v} \tag{4}$$

where:

A - amplifying current factor

Photodetectors volt-ampere characteristics is dependence of photocurrent on attached voltage during constant light flow Φ.

Photodetectors light characteristics can be obtained from group of curves, corresponding to rank of values Φ as dependence of photocurrent i_f on light flow Φ.

Frequency characteristics characterize detector sensibility for certain wave lengths. Detectors sensibility is roughly constant for lower wave lengths, but it drops to zero for higher wave lengths.

Photodetectors time constant τ represents time, during which photocurrent rises (during raping lighting change) to 63, 2% of stable value.

Threshold of sensibility is the smallest value of light flow, which can be indicated by detector. Its value is based upon murmur inside detector and its electric circuit, the size of light sensibility area inside detector and by width of transmitting band

Current during dark is photocurrent on output of detector, which has no light incoming to his sensitive measuring area. If we cool down photodetector current during dark is decreasing as well as murmur.

Types of photodetectors

a) Photo vacuum tube and photo accelerators are using outer photoelectric effect, in which photocathode, if its exposed to light source, emits electrons from its surface and these electrons can be accelerated in photo accelerators. Photocathode also emits secondary emissions which can be multiplied in auxiliary anodes. Photo vacuum tube are simple, have good linearity of light characteristics and very good frequency properties (τ=0,1s). Photo accelerators are used for measuring small light performances, they need source of high voltage, time constant is roughly 10ns and are hard to construct.

b) Photo resistor consist of semiconductor binary compound (e. g CdS, PbS, InSb, etc.) formed into very thin layer applied onto suitable base covered in housing. It shows very high sensibility V_λ = 1mA/Lumen, it can have performance load up to 100 mΩ and resistance in dark can reach several MΩ. Disadvantage is relatively high momentum (τ > 1ms) and temperature dependency. Light characteristics are not linear, especially in areas with bigger lightning. Different types of photoresists have different parameters.

c) Photodiodes and phototransistors are created from nanocrystal material with PN or PIN transition between semiconductors or semiconductors and metal (Scotts diodes).

High sensibility photodiodes are called avalanche photodiodes they use mechanism of amplifying charge carriers in area of PN transition. Photodiodes have low momentum (t = 1ms), good time stability, but bigger current in dark. They can work in both, resistance or gate connection. Phototransistor contains of two PN transitions with higher sensibility than photodiode, but worse dynamic properties (t = 0,5ms) and current in dark.

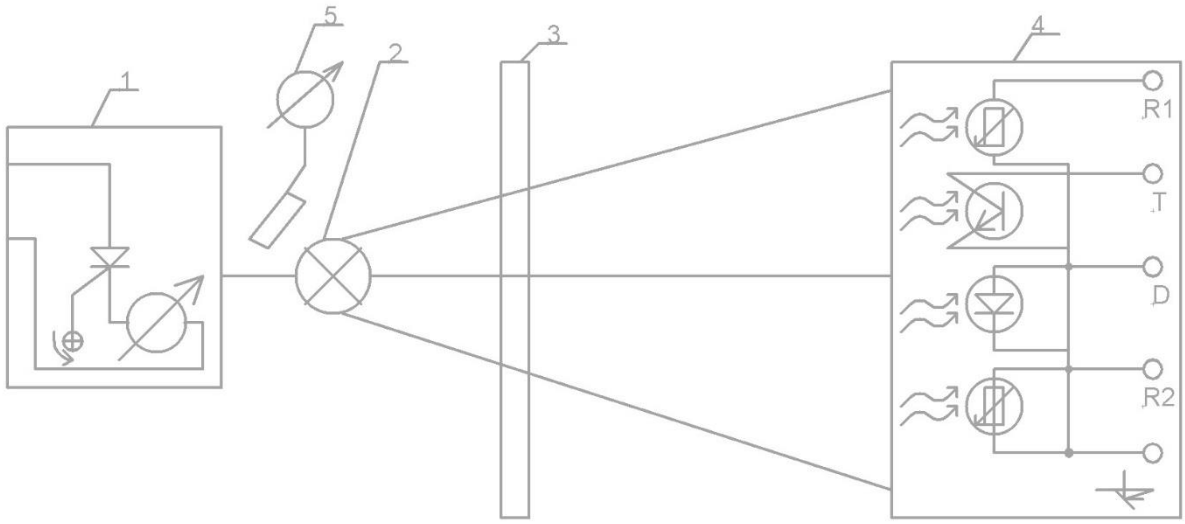
d) Gate photo components use gate effect on PN transition a work without power source (e. g Ge, Si diodes). Besides measuring purposes (lux meters,...) they are used in proper treatment and connection as unusual power source for transforming light energy to current.

Table 1 Parameters of main representatives of photodetectors

Parametr	**Fotoodpor**	**Fotodioda**	**Fototranzistor**	**Fototyristor**
Highest working temperature - °C	65 °C	100 °C	100 °C	100 °C
Highest working voltage - V	500	< 50	50	400
Current load - mA	100	1	10	500
Maximal loose performance - mW	500	50	50	500
Maximal frequency - kHz	1	103 ÷ 106	80	1
Spectral area - μm	CdS 0,5 ÷ 0,75 PbS 0,4 ÷ 3	Si 0,4 ÷ 0,9 Ge 0,4 ÷ 2	Si 0,4 ÷ 1	Si 0,4 ÷ 1

Measuring procedure

1. Get familiar with given components used for detection of light and use catalog to determine their parameters.
2. Measure on measuring device with regulated light source and built-in photodetectors, which are connected according to Pic. 2
3. Connect in resistance mode according to PPic. 1 photo resistor, phototransistor and photodiode and measure their light characteristics in dependence on light intensity E [Lx]. Measuring with color filters do for all photo components under same light intensity.
4. Connect in gate connection photodiode according to Pic. 1d and measure its light characteristic for performance load Rz = 0.
5. Determine impact of light filters on light characteristics of given photodetectors.
6. Determine coefficients of regress lines light characteristics of given detectors and make final evaluation and comparison.



Pic. 2 Measuring device for photoelectric detectors 1. Regulated power source 2. Bulb 3. Color filter 4. Panel with photodetectors 5. Lux meter with probe

Table 2 Table of measured values

Selected photodetector		
Measure	Current I [mA]	Light intensity E (Lux]
1	X	80
2	y	160
3	z	320

Control questions

1. Explain concept of inner and outer photo effect and its application on specific photodetectors.
2. What is light characteristic of detector and how do we measure it?
3. What is spectral characteristics of photodetector and what does it mean?
4. Try to remember time constant of photodetectors.