Solid-State Physics

Conduction phenomena
Photoconductivity

LD Physics Leaflets

P7.2.3.1

Recording the current-voltage characteristics of a CdS photoresistor

Objects of the experiments

- Measuring the photocurrent I_{Ph} as a function of the voltage U at a constant irradiance Φ.
- Measuring the photocurrent I_{Ph} as a function of the irradiance Φ at a constant voltage U.

Principles

Photoconductivity is the effect of increasing electrical conductivity σ in a solid due to light absorption. When the so-called internal photoeffect takes place, the energy absorbed enables the transition of activator electrons into the conduction band and the charge exchange of traps with holes being created in the valence band. Therefore, the number of charge carriers in the crystal lattice and, as a result, the conductivity are enhanced:

$$\Delta\sigma = \Delta p \cdot e \cdot \mu_p + \Delta n \cdot e \cdot \mu_n \qquad \text{(I)}$$

e: elementary charge
Δp: change of the hole concentration
Δn: change of the electron concentration
μ_p: mobility of the holes
μ_n: mobility of the electrons

When a voltage U is applied, the photocurrent is

$$I_{Ph} = \frac{A}{d} \cdot \Delta\sigma \cdot U \qquad \text{(II)}$$

A: cross section of the current path
d: distance between the electrodes

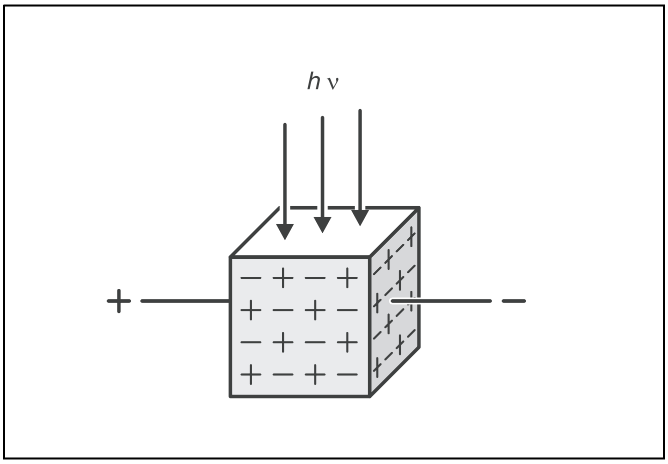
Semiconductor resistors that depend on the irradiance (photoconductive cells) are based on this principle. They have opened up a wide field of applications and are, among other things, employed in twilight switches and light meters. The semiconductor materials most commonly used are cadmium compounds, particularly CdS.

In the experiment, a CdS photoresistor is exposed to light from a lamp. The irradiance Φ at the position of the photoresistor being varied by means of two polarization filters which are placed one behind the other. If the two polarization planes of the filters are rotated against each other by the angle α, the irradiance is

$$\Phi = \Phi_0 \cdot D \cdot \cos^2\alpha \qquad \text{(III)}$$

Φ_0: irradiance without polarization filters,
D: transparency when the polarization planes are parallel

The photocurrent is studied as a function of the voltage applied to the photoresistor at a constant irradiance (current-voltage characteristic) and as a function of the irradiance at a constant voltage (current-irradiance characteristic).



Model of an ideal photoconductor: electron-hole pairs are produced throughout the crystal by the external light source and undergo recombination. Electrons leaving the crystal at the electrode (+) are replaced with electrons entering at the electrode (-).

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Apparatus

1 STE photoresistor LDR 05	578 02
1 holder for plug-in elements	460 21
1 adjustable slit	460 14
1 pair of polarisation filters	472 40
1 lens, f = + 150 mm	460 08
6 optics riders, H = 90 mm / B = 50 mm	460 352
1 precision optics bench, standardized cross section, 1 m	460 32
1 lamp housing	450 60
1 lamp, 6 V / 30 W	450 51
1 aspherical condensor	460 20
1 DC power supply 0 … 20 V	521 54
1 transformer 6/12 V~	562 73
1 digital-analog multimeter METRAHit 14 S	531 28
1 digital-analog multimeter METRAHit 18 S	531 30
connection leads	

Setup

The experimental setup is illustrated in Fig. 1. The positions of the left edges of the optics riders on the optics bench are given in cm. The shafts of the optics devices should not completely rest in the optics riders so that fine adjustment of the heights can be made in order to position all parts of the setup on one optical axis.

- Mount the optics riders on the optics bench.
- Plug the photoresistor into the holder for plug-in elements, and attach it to the optics rider on the right.
- Attach the lamp with the aspherical condensor to the optics rider on the left, and connect it to the 6-V output of the transformer.
- Centre the lamp with the knurled screws, and adjust it by shifting the lamp tube so that a homogeneous ray of light illuminates the photoresistor when the filament of the lamp is aligned vertically.
- Put the lens into the setup with the convex side being directed towards the lamp, and focus the ray of light on the photoresistor by aligning the lens and by shifting the optics rider.
- Mount the two polarization filters and the adjustable slit, set the angle α between the polarization planes of the filters to 0°, and open the adjustable slit to about 0.2 mm.
- Check the illumination of the photoresistor, and, if necessary, readjust the setup.
- Close the adjustable slit completely.
- Connect the DC power supply. Connect the digital-analog multimeter METRAHit 14 S parallel for the voltage measurement (measuring range V=) and the digital-analog multimeter METRAHit 18 S in series for the measurement of the photocurrent I_{Ph} (measuring range mA=).
- Set the voltage U to 20 V.
- Open the adjustable slit slightly until a current I of at most 9 mA flows through the photoresistor. Do not change the slit width from now on.

Remarks:

The photoresistor is destroyed by overload:

Do not exceed the maximum dissipated power P = 0.2 W, e. g., I = 10 mA at U = 20 V.

The photoresistor is influenced even by slight residual lightness in the experiment room:
Darken the experiment room so that the measuring instruments can just be read, and make certain that the light conditions are constant.

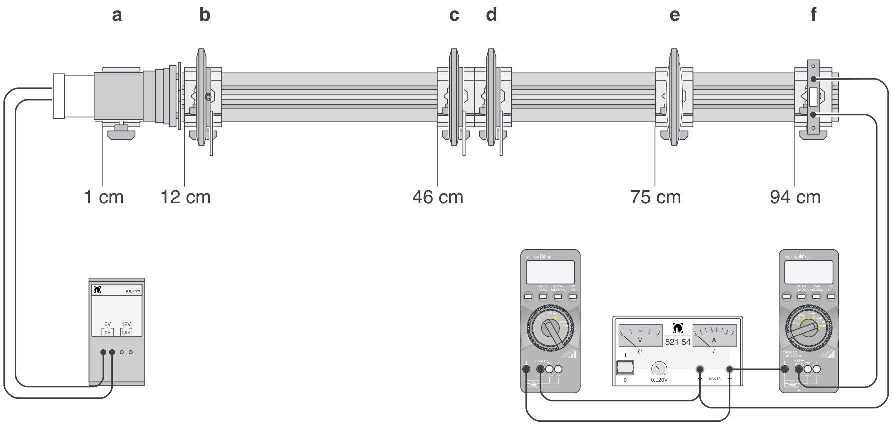


Fig. 1 Experimental setup for recording the current-voltage characteristics of a CdS photoresistor.
a Lamp
b Adjustable slit
c, **d** Polarization filters
e Lens f = + 150 mm
f Holder with STE photoresistor

Carrying out the experiment

Remark:

When the illumination is changed, the response of the photoresistor is slow. It takes some time until the new value of the resistance is reached.
Before reading the measuring values, wait until there is a stationary state.

a) Measuring the photocurrent I_{Ph} as a function of the voltage U at a constant irradiance Φ:

– Interrupt the path of the ray of light, and determine the photocurrent I_0 due to the residual lightness.
– Starting from 20 V, reduce the voltage U to 0 V in steps of 2 V. Measure the photocurrent I_{Ph}, each time and record it.
– Repeat the series of measurements with α = 30°, 60° and 90°.

b) Measuring the photocurrent I_{Ph} as a function of the irradiance Φ at a constant voltage U:

– Set the voltage U to 20 V, interrupt the path of the ray of light, and measure the photocurrent I_0 due to the residual lightness again.
– In order to vary the irradiance Φ, increase the angle α between the polarization planes of the filters in steps of 10° from 0° to 90°. Measure the photocurrent I_{Ph}, each time and record it.
– Repeat the series of measurements at U = 10 V and U = 1 V.

Measuring example

Slit width: 0.1 mm

a) Measuring the photocurrent I_{Ph} as a function of the voltage U at a constant irradiance Φ:

I_0 (U = 20 V) = 0.29 mA

Table 1: The photocurrent I_{Ph} as a function of the voltage U for different angles α between the polarization planes of the filters

$\frac{U}{V}$	$\frac{I_{Ph}}{mA}(0°)$	$\frac{I_{Ph}}{mA}(30°)$	$\frac{I_{Ph}}{mA}(60°)$	$\frac{I_{Ph}}{mA}(90°)$
20	9.80	8.12	4.41	1.39
18	8.90	7.33	3.93	1.24
16	7.96	6.53	3.49	1.09
14	7.04	5.78	3.07	0.96
12	6.05	4.98	2.61	0.82
10	5.08	4.18	2.19	0.68
8	4.13	3.34	1.76	0.55
6	3.06	2.46	1.31	0.41
4	2.00	1.66	0.87	0.27
2	1.02	0.83	0.45	0.14

b) Measuring the photocurrent I_{Ph} as a function of the irradiance Φ at a constant voltage U:

I_0 (U = 20 V) = 0.17 mA

Table. 2: The photocurrent I_{Ph} as a function of the angle α between the polarization planes of the filters at different voltages U

α	$\frac{I_{Ph}}{mA}(20\ V)$	$\frac{I_{Ph}}{mA}(10\ V)$	$\frac{I_{Ph}}{mA}(1\ V)$
0°	9.56	5.05	0.501
10°	9.27	4.93	0.489
20°	8.73	4.62	0.458
30°	7.83	4.16	0.415
40°	6.77	3.58	0.358
50°	5.45	2.89	0.289
60°	4.29	2.19	0.222
70°	2.84	1.51	0.155
80°	1.84	0.95	0.099
90°	1.28	0.67	0.071

Evaluation

a) Measuring the photocurrent I_{Ph} as a function of the voltage U at a constant irradiance Φ:

The relation between the photocurrent I_{Ph} and the voltage U applied at a constant irradiance (constant angle α between the polarization planes of the filters), i.e. the current-voltage characteristics, is shown in Fig. 2. Even at an angle $\alpha = 90°$ between the polarization planes of the filters a photocurrent flows, since in this position the polarization filters do not extinguish the ray of light completely.

The data points lie on a straight line through the origin for each characteristic in accordance with Eq. (II). The slope of each characteristic depends on the irradiance.

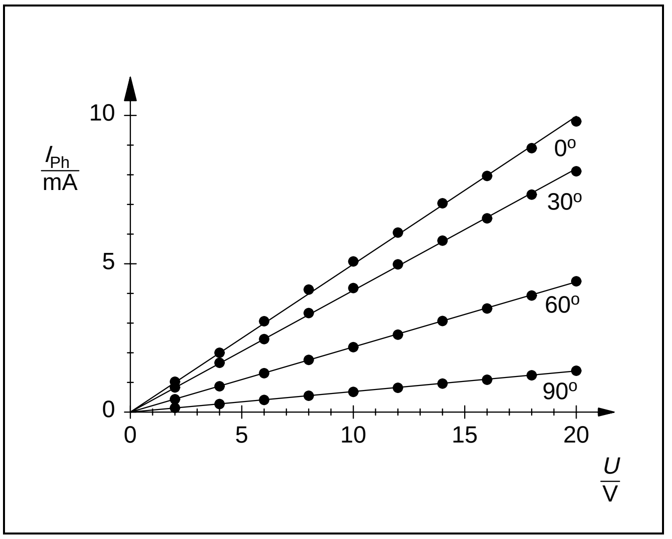


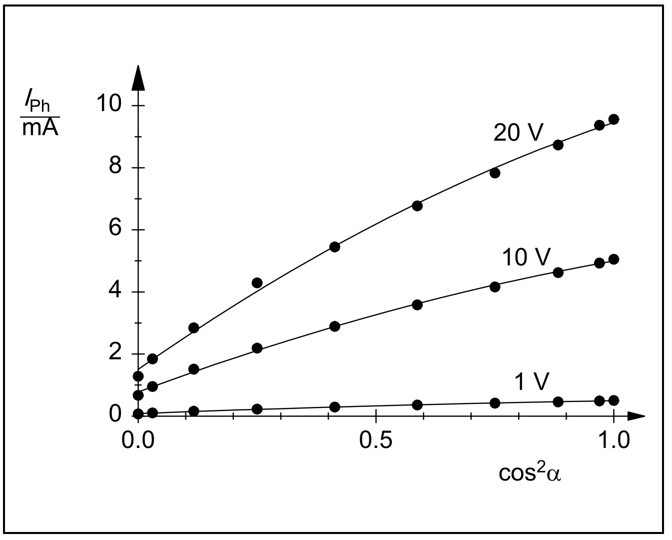
Fig. 2 Current-voltage characteristics of the CdS photoresistor.

b) Measuring the photocurrent I_{Ph} as a function of the irradiance Φ at a constant voltage U:

The relation between the photocurrent I_{Ph} and the irradiance at a constant voltage, the current-irradiance characteristics, is shown in Fig. 3. According to Eq. (III), the term $\cos^2\alpha$ is a relative measure for the irradiance (α:angle between the polarization planes of the filters).

As expected, the photocurrent increases with increasing irradiance. However, the characteristics are not perfectly linear. The slope rather decreases with increasing irradiance.

Fig. 3 Current-irradiance characteristics of the CdS photoresistor.



Results

The CdS photoresistor behaves like an ohmic resistance that depends on the irradiance.