OPTOELECTRONICS
Lab Work

1. **Principles of Optics**
2. **Spectroscopy**
3. **Semiconductor Laser**
4. **Solar Cells and Photovoltaic Modules**

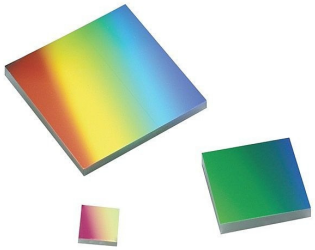
OPTOELECTRONICS
Lab Work

1. **Principles of Optics**

1. PRINCIPLES OF OPTICS

Unknown laser source

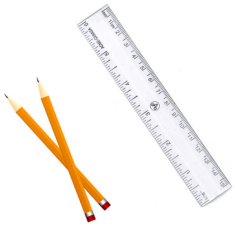
Unknown material



Diffraction grating

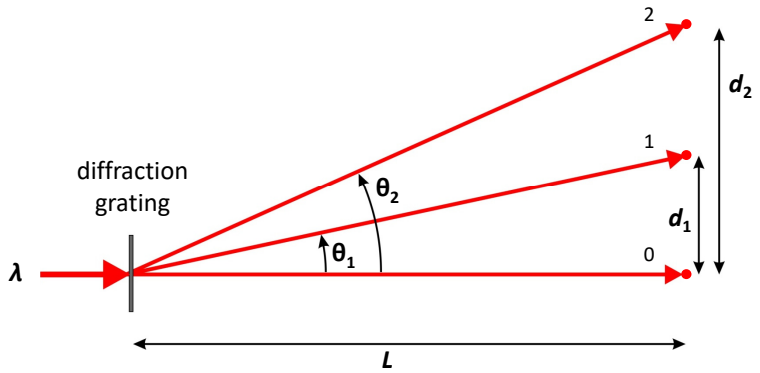
***λ* = ???**

***n* = ???**



1. PRINCIPLES OF OPTICS

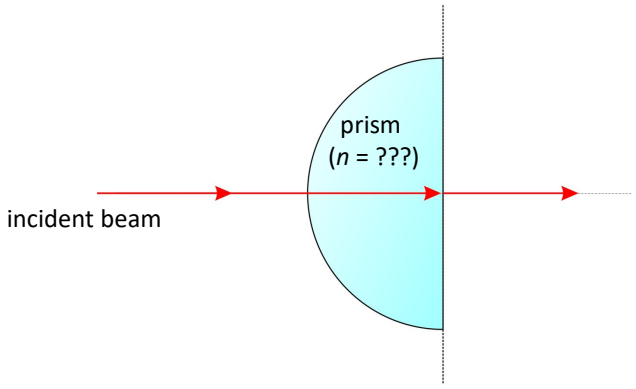
a) Determination of wavelength using a diffraction grating:



$$\theta_m = \arcsin\left(\frac{m \cdot \lambda}{P}\right) \quad \theta_m = \arctan\left(\frac{d_m}{L}\right) \quad \Rightarrow \quad \boxed{\lambda = \frac{P}{m}\sin\left(\arctan\left(\frac{d_m}{L}\right)\right)}$$

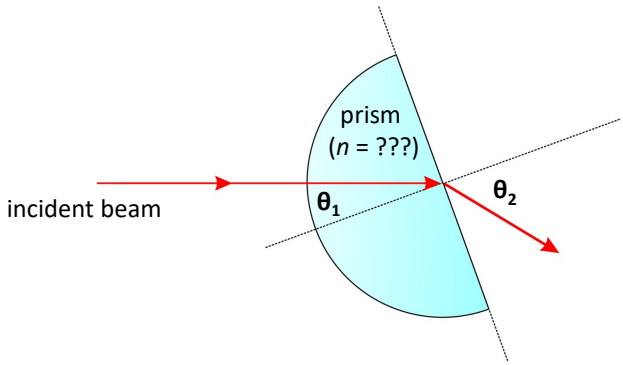
1. PRINCIPLES OF OPTICS

b) Determination of refractive index by measuring light refraction:



1. PRINCIPLES OF OPTICS

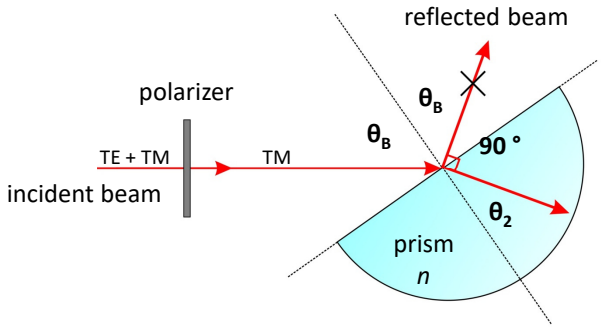
b) Determination of refractive index by measuring light refraction:



$$n \cdot \sin\theta_1 = 1 \cdot \sin\theta_2 \Rightarrow \boxed{n = \frac{\sin\theta_2}{\sin\theta_1}}$$

1. PRINCIPLES OF OPTICS

c) Determination of polarization (Brewster) angle:

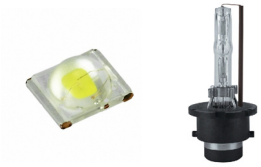


$$\theta_B = \arctan(n)$$

OPTOELECTRONICS
Lab Work

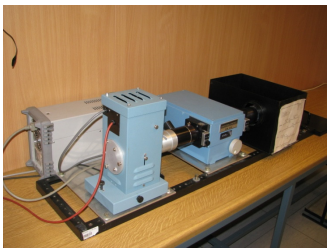
2. **Spectroscopy**

2. SPECTROSCOPY



Unknown light source

Unknown photodetector



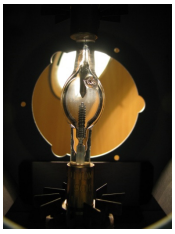
Monochromator,
known photodetector

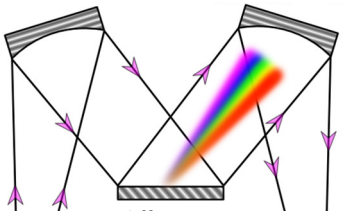
$J_{ph}(\lambda)$ = ??? [W/m^2]

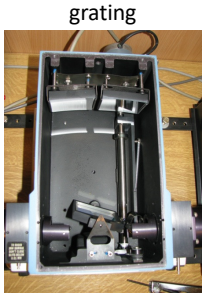
$SR(\lambda)$ = ??? [A/W]

$QE(\lambda)$ = ??? [%]

2. SPECTROSCOPY







light
source

input slit

diffraction
grating

output slit

light beam of the
selected wavelength

<u>Diffraction grating:</u> 1180 grooves per millimeter; ***P* = 847.46 nm**

2. SPECTROSCOPY

***P*(λ) [W]** → → ***I* [A]**

<u>Spectral response:</u>

$$SR\left[A/W\right] = \frac{I\left[A\right]}{P\left[W\right]}$$

← generated electrical current

← incident optical power

<u>Quantum efficiency:</u>

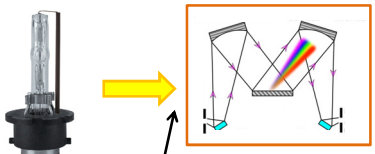
$$QE = \frac{N_e}{N_{ph}}$$

← number of generated electrons

← number of incident photons

$$QE = SR \cdot \frac{1}{\lambda} \cdot \frac{h \cdot c_0}{q}$$

2. SPECTROSCOPY



Light source with <u>unknown</u> spectrum
$J_{ph}(\lambda)$

Monochromator with known transfer function
$T(\lambda)$

Photodetector with known spectral response and known area
$SR(\lambda)$, A

Multimeter

J_{ph} [W/m^2]

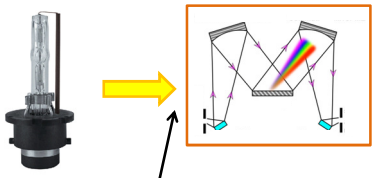
$J_{ph,\,MC}$ [W/m$_2$] $= T \cdot J_{ph}$

P [W] $= A \cdot J_{ph,\,MC} = A \cdot T \cdot J_{ph}$

I [A] $= SR \cdot P = S \cdot A \cdot T \cdot J_{ph}$

$J_{ph} = I / (SR \cdot A \cdot T)$

2. SPECTROSCOPY



Light source with known spectrum $J_{ph}(\lambda)$

Monochromator with known transfer function $T(\lambda)$

Photodetector with <u>unknown</u> spectral response and known area $SR(\lambda)$, A

Multimeter

J_{ph} [W/m^2]

$J_{ph,\,MC}$ [W/m$_2$] $= T \cdot J_{ph}$

P [W] $= A \cdot J_{ph,\,MC} = A \cdot T \cdot J_{ph}$

I [A] $= SR \cdot P = S \cdot A \cdot T \cdot J_{ph}$

$$\boxed{SR = I / (A \cdot T \cdot J_{ph})}$$

OPTOELECTRONICS
Lab Work

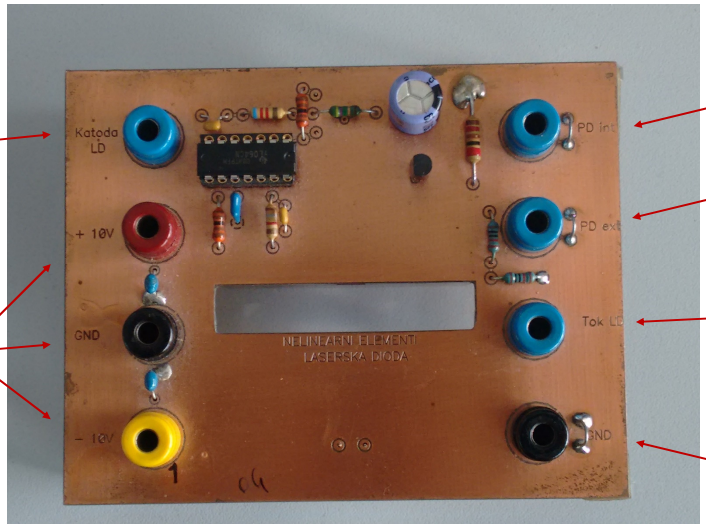
3. **Semiconductor Laser**

3. SEMICONDUCTOR LASER

- Static $I(U)$ characteristics of a semiconductor laser
- Static $P_L(I)$ characteristics of a semiconductor laser
- Transmission measurement using the DC and „Lock-in“ methods

3. SEMICONDUCTOR LASER

- Measurement board – view from top



Cathode of the laser

Power supply

Internal photodiode

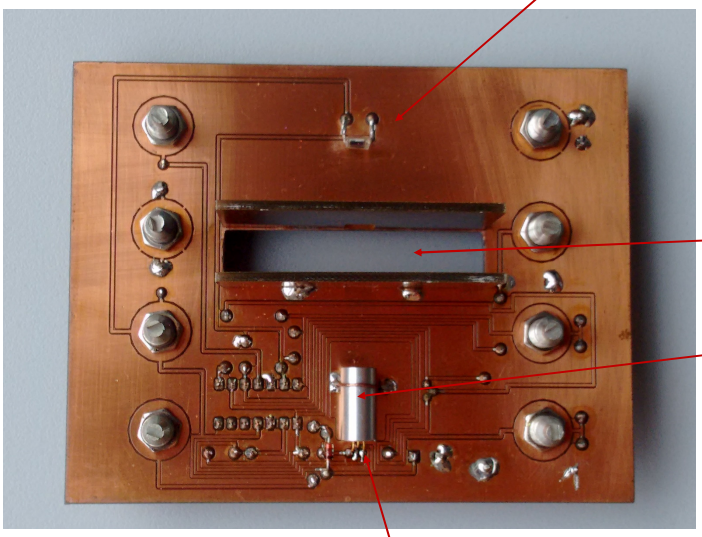
External photodiode

Current input

Common ground

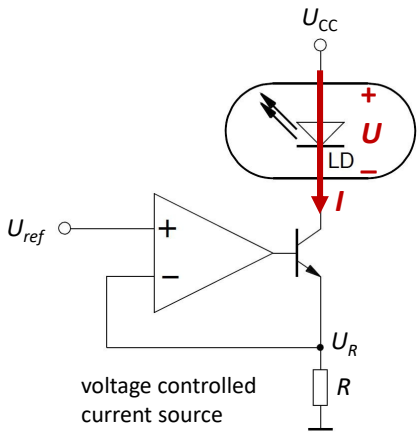
3. SEMICONDUCTOR LASER

- **Measurement board – view from bottom**



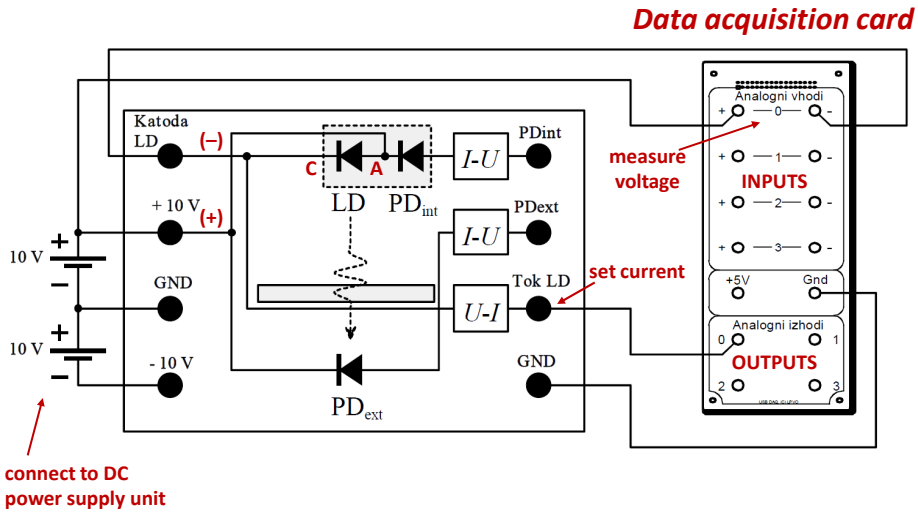
3. Static *I*(*U*) characteristics of a semiconductor laser

- **Automatic current control – ACC**



3. Static *I*(*U*) characteristics of a semiconductor laser

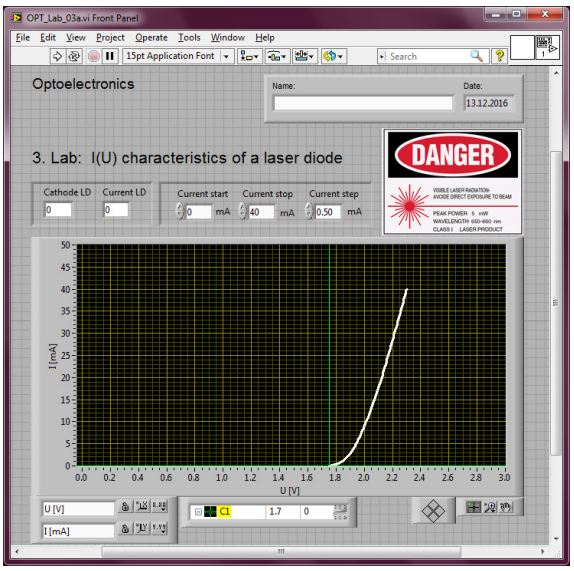
- **Connection of the DAQ interface and the measurement circuit**



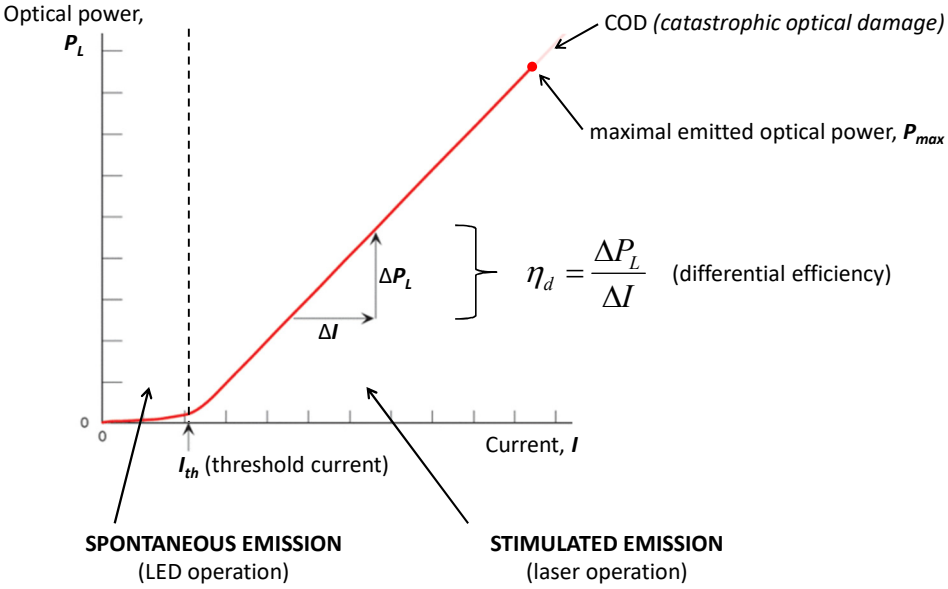
3. Static *I*(*U*) characteristics of a semiconductor laser

- **LabView program for *I*(*U*) measurement – „OPT_Lab_03a.vi“**

File →
Print Window

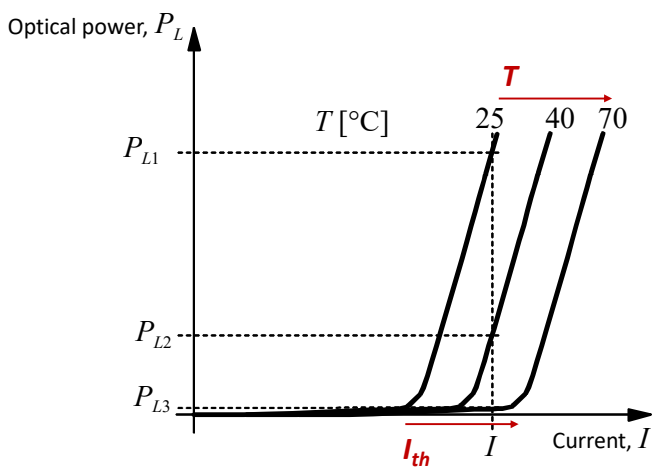


3. Static $P_L(I)$ characteristics of a semiconductor laser



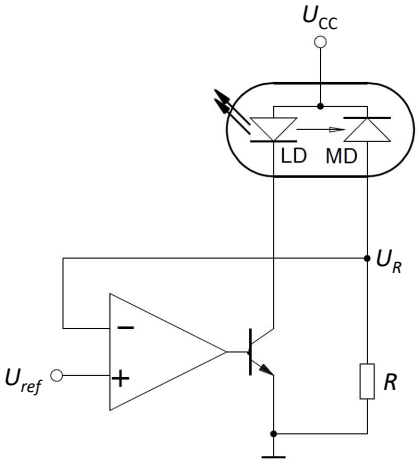
3. Static $P_L(I)$ characteristics of a semiconductor laser

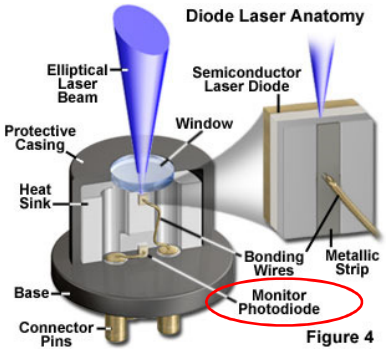
- **Temperature dependence of I_{th}**

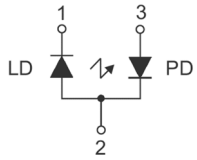


3. Static $P_L(I)$ characteristics of a semiconductor laser

- **Automatic power control – APC**



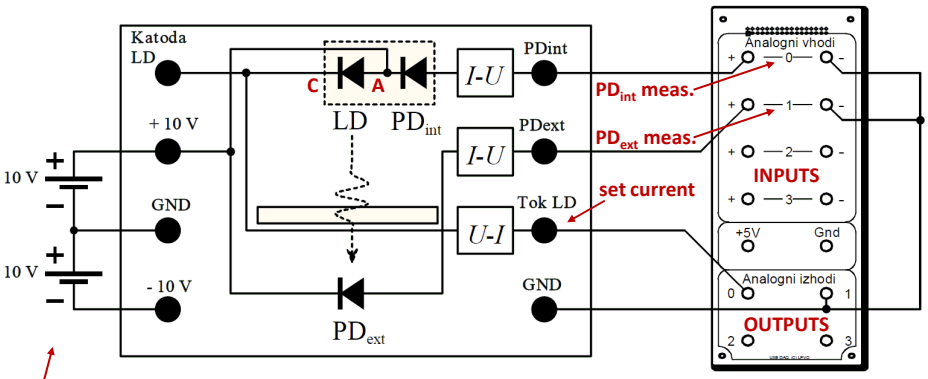




3. Static $P_L(I)$ characteristics of a semiconductor laser

- **Connection of the DAQ interface and the measurement circuit**

Data acquisition card

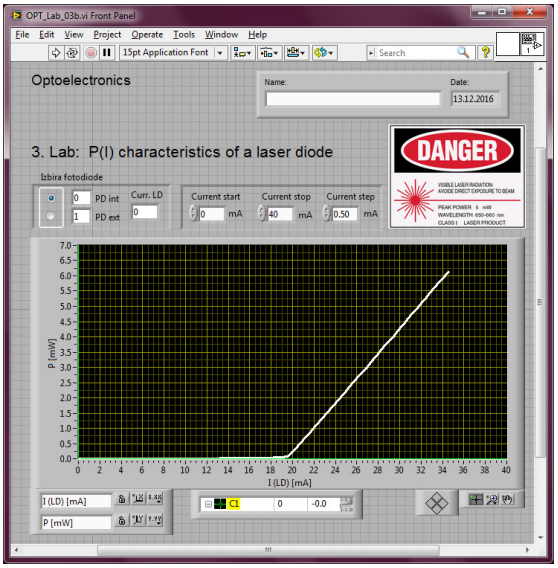


3. Static $P_L(I)$ characteristics of a semiconductor laser

- **LabView program for $P_L(I)$ measurement – „OPT_Lab_03b.vi“**

File →
Print Window

Calculate:
- $P_{L,max}$
- I_{th}
- $\eta_{differential}$
- $\eta_{electrical}$



3. Transmission measurement using the DC method

$\rightarrow I_{without\ sample}$

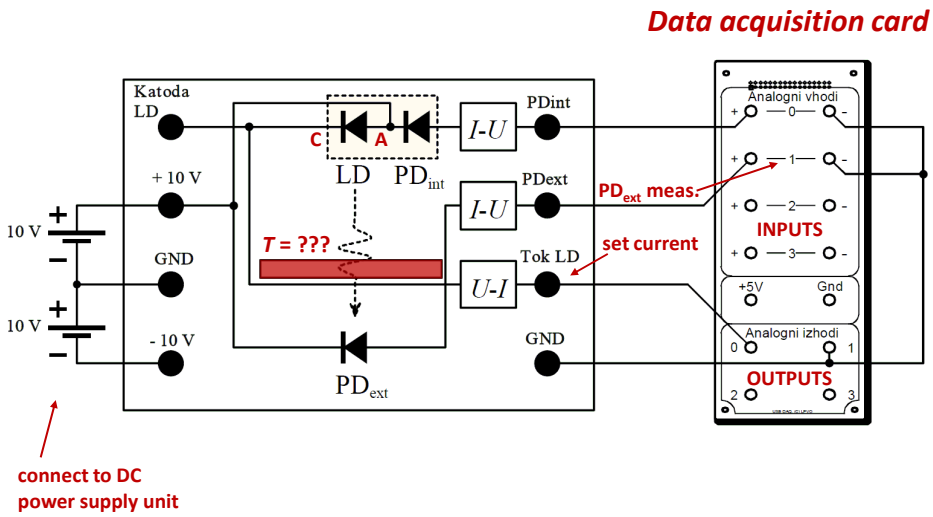
$$T = \frac{I_{with\ sample}}{I_{without\ sample}}$$

T

$\rightarrow I_{with\ sample} = T \cdot I_{without\ sample}$

3. Transmission measurement using the DC method

- **Connection of the DAQ interface and the measurement circuit**



3. Transmission measurement using the DC method

- **Measurement conditions**

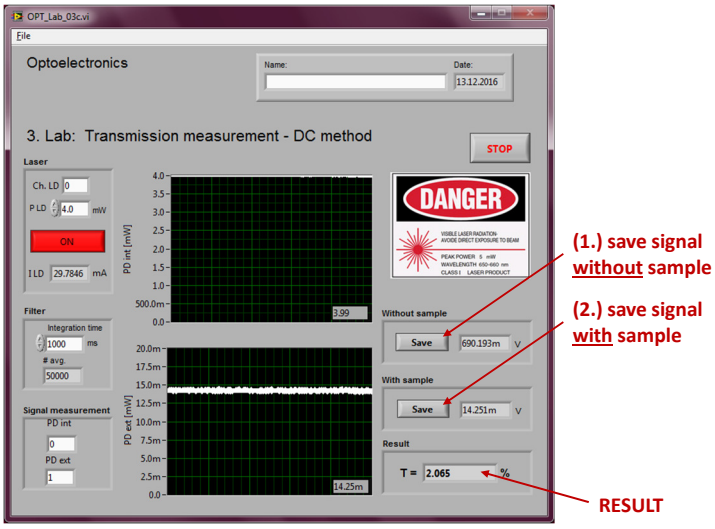
Method		DC	
Laser power		0.4 mW	4 mW
Transmittance [%]	Shading		
	Lights ON		
Maximal deviation between the results (max – min)			

signal intensity (laser power)

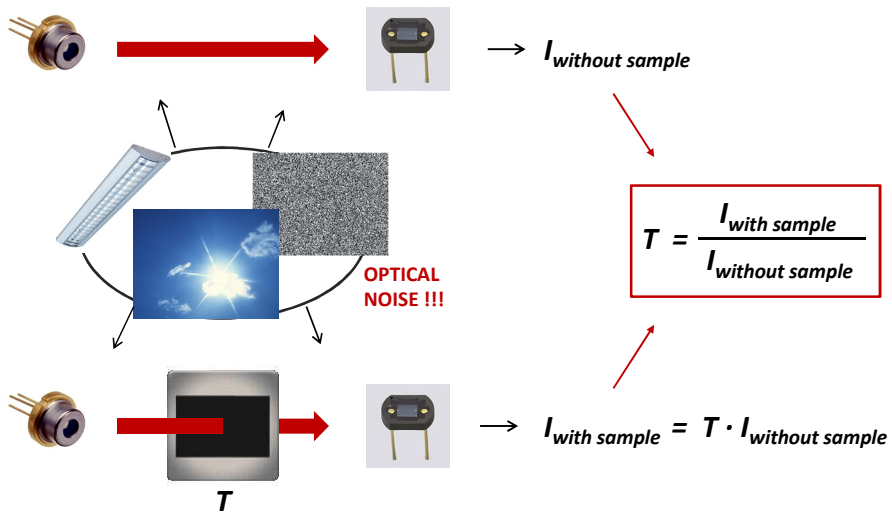
optical „noise“ in the area

3. Transmission measurement using the DC method

- **LabView program for *T* measurement – „OPT_Lab_03c.vi“**



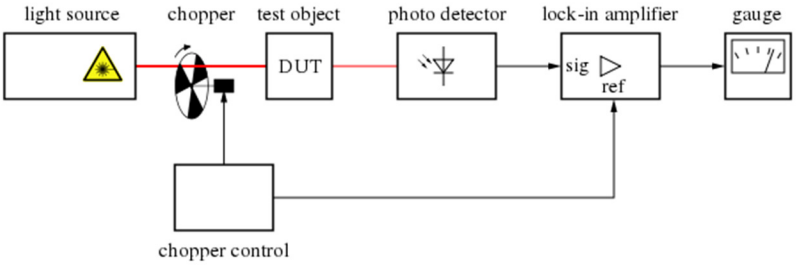
3. Transmission measurement using the DC method



3. Transmission measurement using the „Lock-in“ method

Mechanical or optical chopper

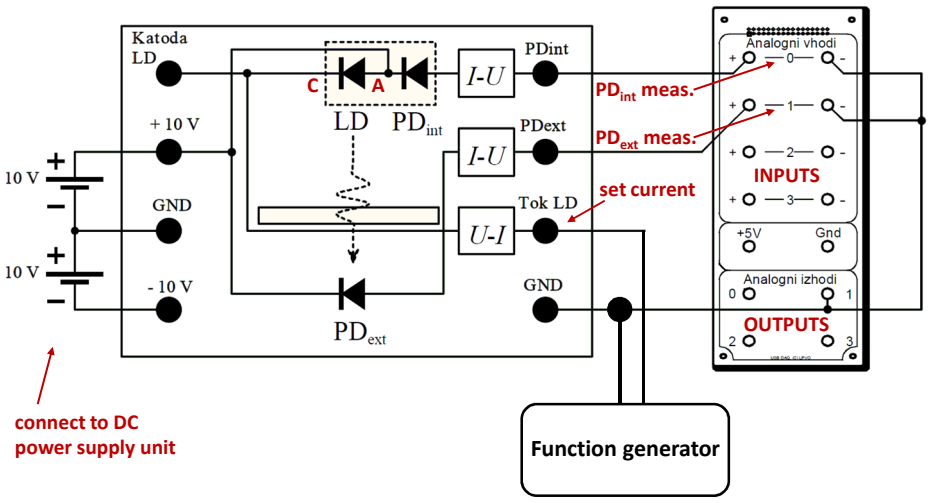
Only the signal at f_{ref} can then be filtered out, thus eliminating all noise!



3. Transmission measurement using the „Lock-in“ method

- **Connection of the DAQ interface and the measurement circuit**

Data acquisition card



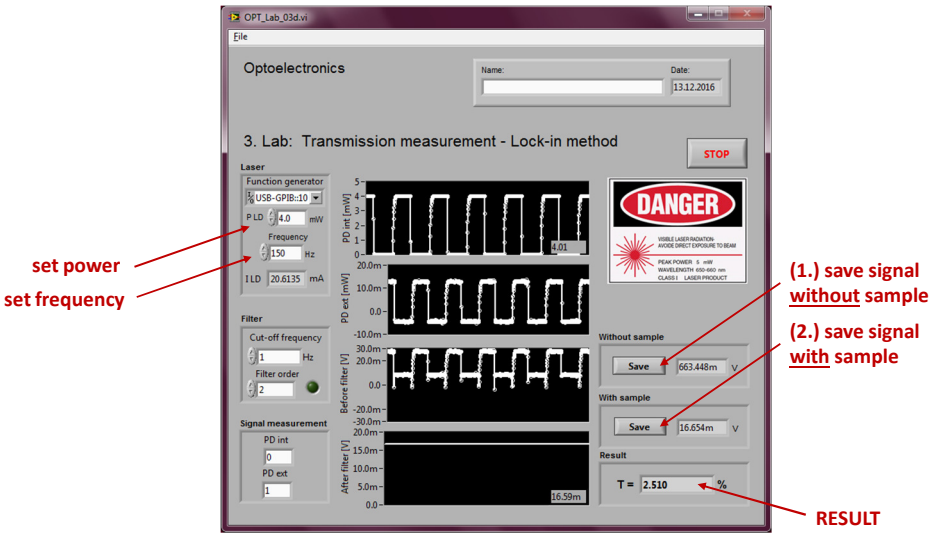
3. Transmission measurement using the „Lock-in“ method

- **Measurement conditions**

Method		DC		lock-in			
				f = 100 Hz		f = 150 Hz	
Laser power		0.4 mW	4 mW	0.4 mW	4 mW	0.4 mW	4 mW
Transmittance [%]	Shading						
	Lights ON						
Maximal deviation between the results (max – min)							

3. Transmission measurement using the „Lock-in“ method

- **LabView program for *T* measurement – „OPT_Lab_03d.vi“**



OPTOELECTRONICS
Lab Work

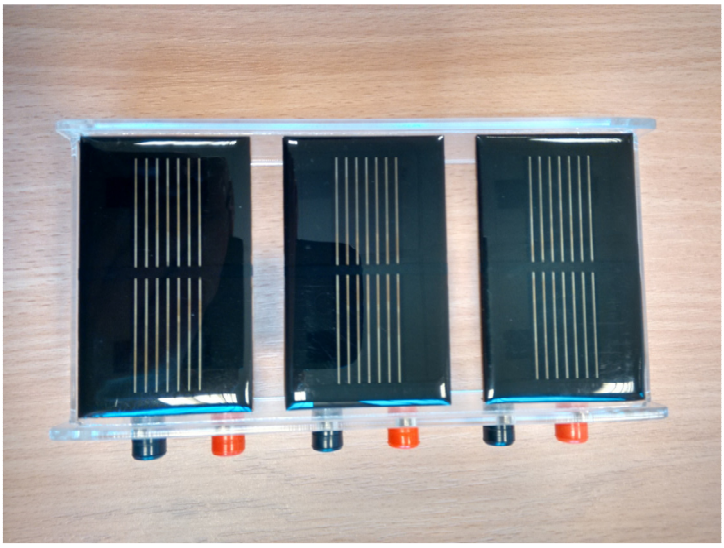
4. **Solar Cells and Photovoltaic Modules**

4. SOLAR CELLS AND PHOTOVOLTAIC MODULES

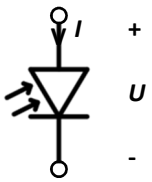
- ***I*(*U*) characteristics of a solar cell in dark**
- ***I*(*U*) characteristics of a solar cell under illumination**
- **Parallel and serial connection of solar cells**

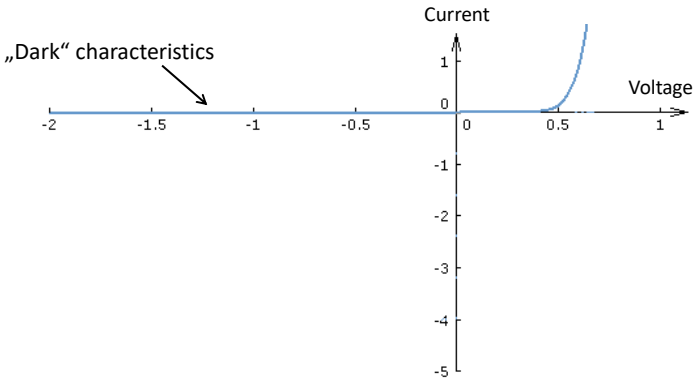
4. SOLAR CELLS AND PHOTOVOLTAIC MODULES

- **Board with solar cells**



4. *I*(*U*) characteristics of a solar cell in dark



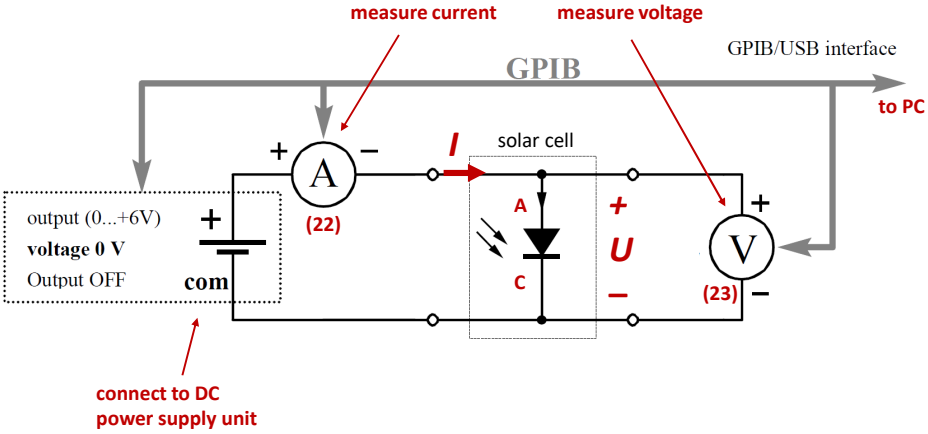


Dark characteristics: $$I = I_S\left(e^{\frac{U}{n \cdot U_T}} - 1\right)$$ → diode equation

n – diode ideality factor (1 ... 2)
I_S – diode saturation current

4. *I*(*U*) characteristics of a solar cell in dark

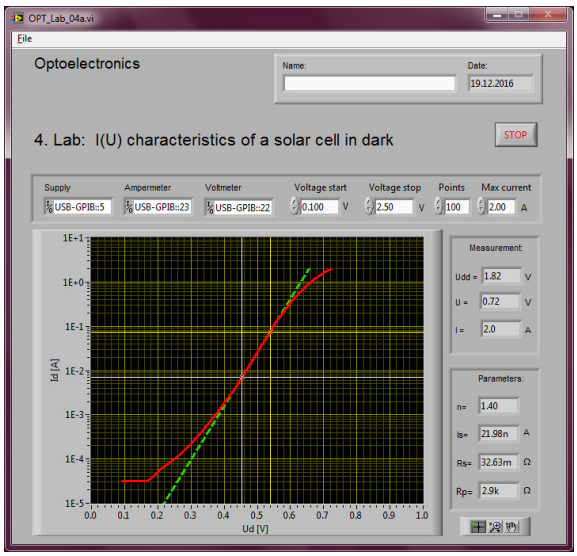
- **Connection of the measurement circuit**



4. *I*(*U*) characteristics of a solar cell in dark

- **LabView program for *I*(*U*) measurement – „OPT_Lab_04a.vi“**

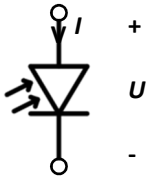
File →
Print Window

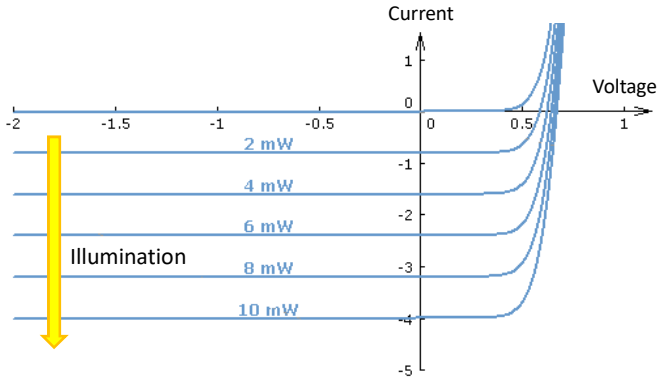


$$I = I_S\left(e^{\frac{U}{n \cdot U_T}} - 1\right)$$

→ diode ideality factor
→ saturation current
→ series resistance
→ parallel resistance

4. *I*(*U*) characteristics of a solar cell under illumination

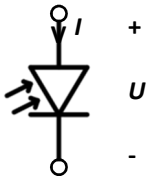


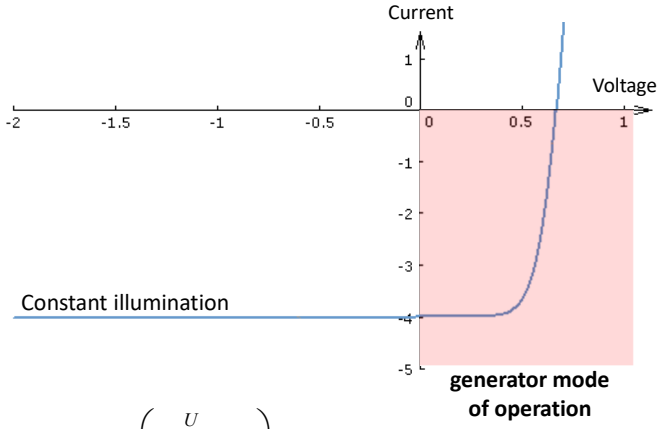


Dark characteristics: $I = I_S\left(e^{\frac{U}{n \cdot U_T}} - 1\right)$

Normal characteristics: $I = I_S\left(e^{\frac{U}{n \cdot U_T}} - 1\right) - I_{SC}$

4. *I*(*U*) characteristics of a solar cell under illumination

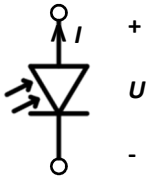


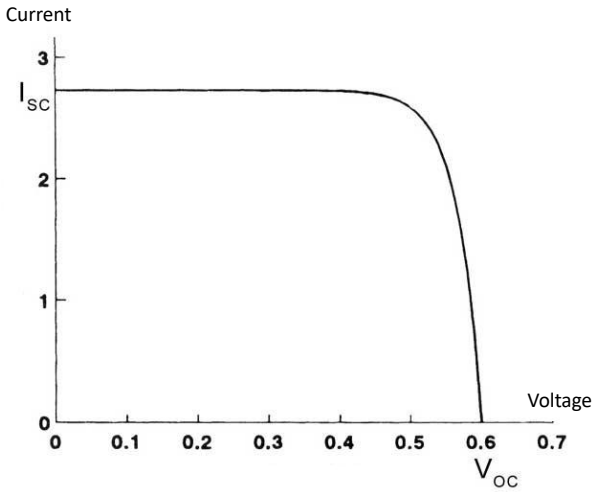


Dark characteristics: $I = I_S\left(e^{\frac{U}{n \cdot U_T}} - 1\right)$

Normal characteristics: $I = I_S\left(e^{\frac{U}{n \cdot U_T}} - 1\right) - I_{SC}$

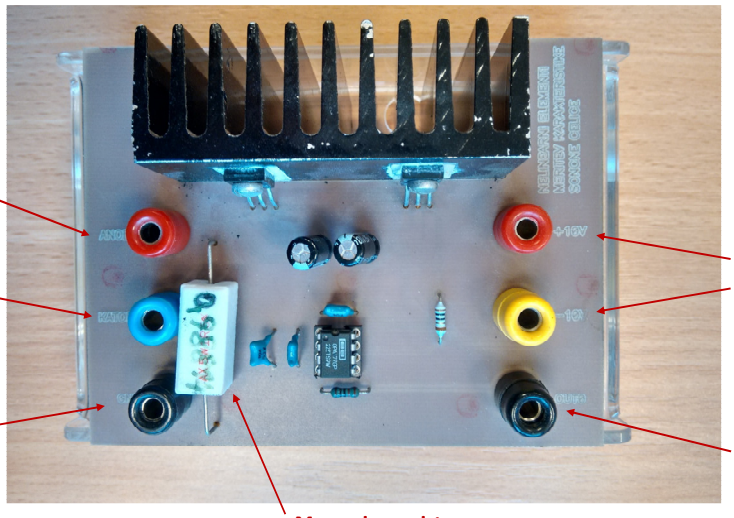
4. *I*(*U*) characteristics of a solar cell under illumination





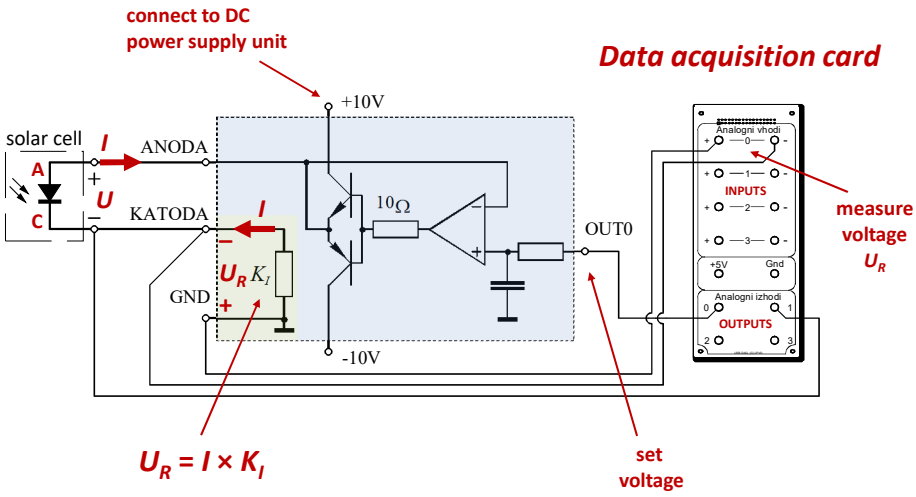
4. *I*(*U*) characteristics of a solar cell under illumination

- **Measurement board – view from top**



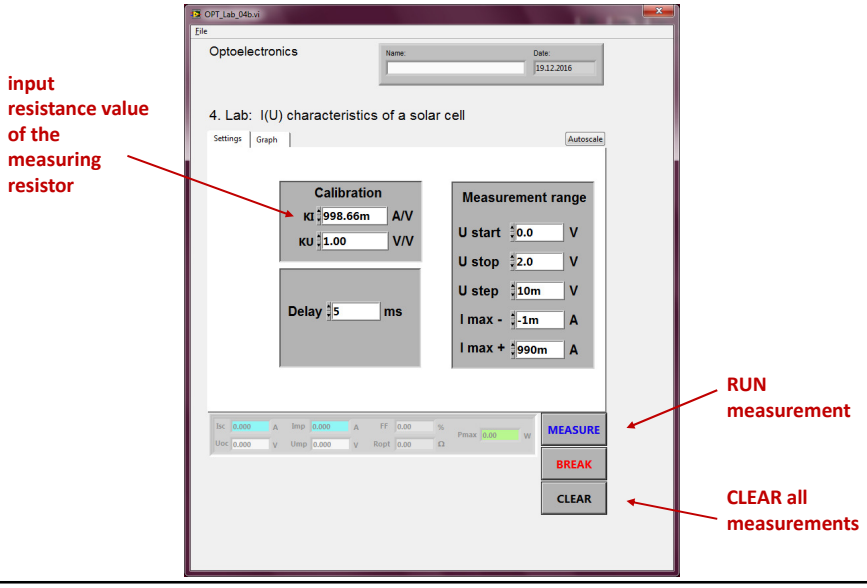
4. *I*(*U*) characteristics of a solar cell under illumination

- **Connection of the DAQ interface and the measurement circuit**



4. *I*(*U*) characteristics of a solar cell under illumination

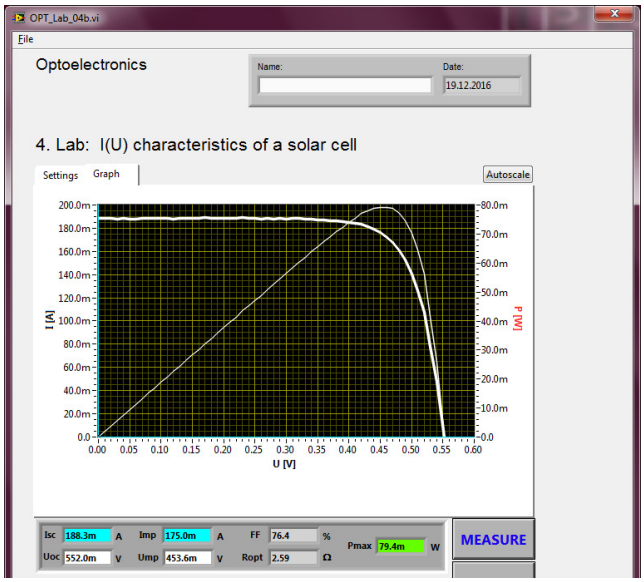
- **LabView program for *I*(*U*) measurement – „OPT_Lab_04b.vi“**



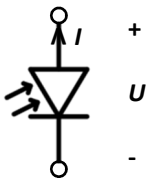
4. *I*(*U*) characteristics of a solar cell under illumination

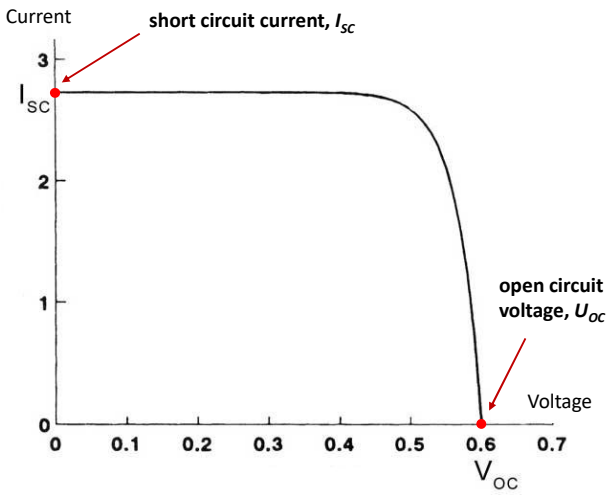
- **LabView program for *I*(*U*) measurement – „OPT_Lab_04b.vi“**

File → Print Window

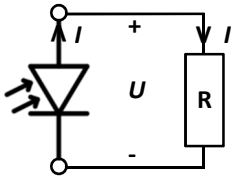


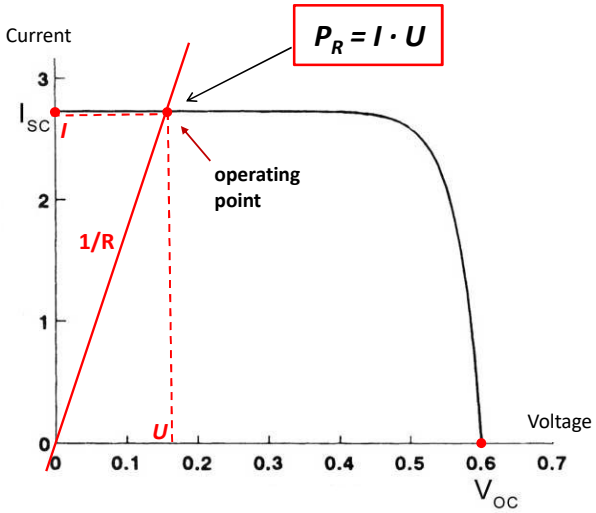
4. *I*(*U*) characteristics of a solar cell under illumination



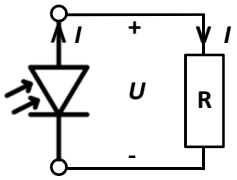


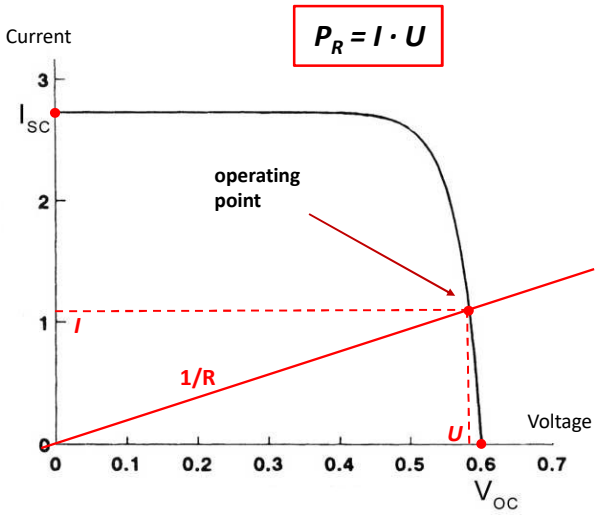
4. *I*(*U*) characteristics of a solar cell under illumination



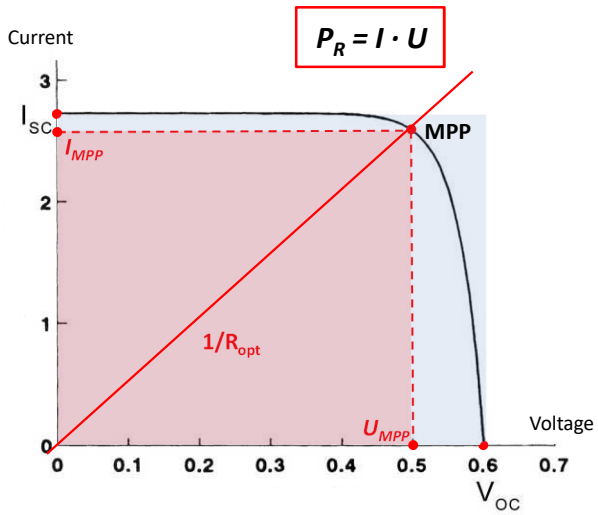


4. *I*(*U*) characteristics of a solar cell under illumination





4. *I*(*U*) characteristics of a solar cell under illumination



- Fill factor:

$$FF = \frac{I_{MPP} \cdot U_{MPP}}{I_{SC} \cdot U_{OC}}$$

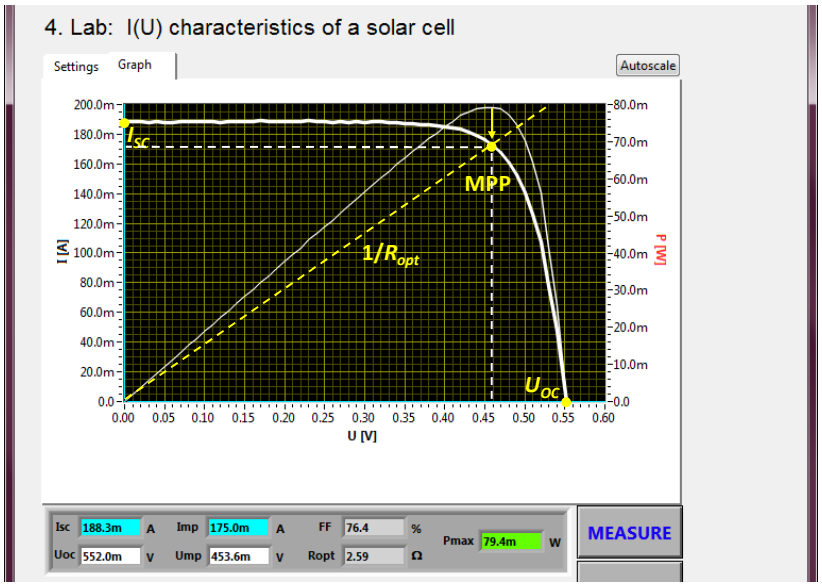
- Converstion efficiency:

$$\eta = \frac{P_{MPP}}{P_{opt}} \quad \begin{matrix}\text{(electrical power)} \\ \text{(optical power)}\end{matrix}$$

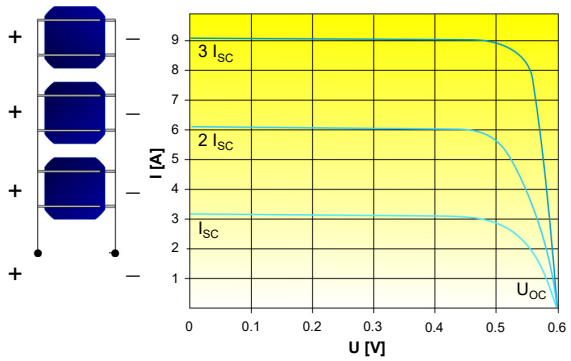
$$\eta = \frac{I_{MPP} \cdot U_{MPP}}{P_{opt}} = FF \cdot \frac{I_{SC} \cdot U_{OC}}{P_{opt}}$$

4. *I*(*U*) characteristics of a solar cell under illumination

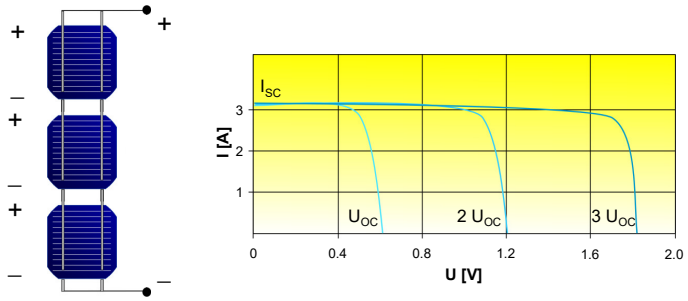
- **Results:**



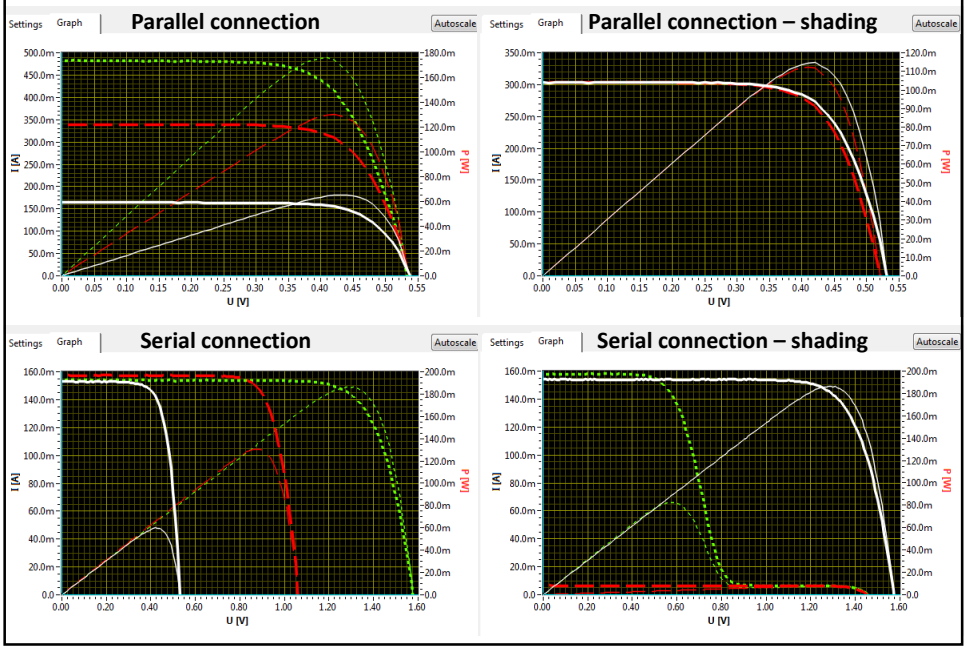
4. Parallel connection of solar cells



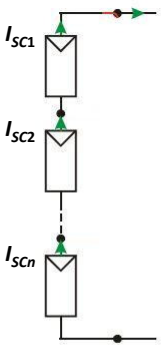
4. Serial connection of solar cells



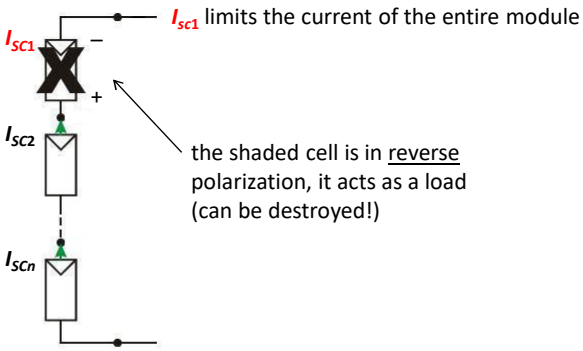
4. Connection of solar cells – measurement results



4. Serial connection of solar cells – the problem of <u>shading</u>



4. Serial connection of solar cells – the problem of shading



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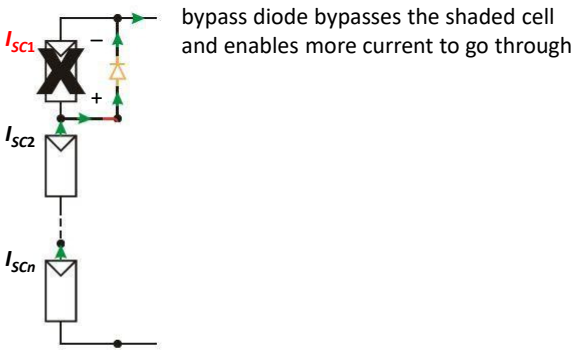
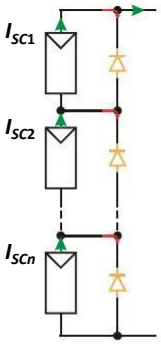


4. Serial connection of solar cells – the problem of shading

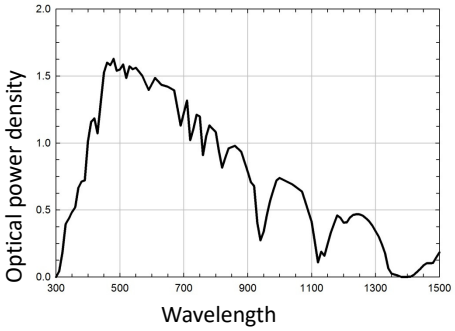


4. Reference measurement of solar cells and PV modules

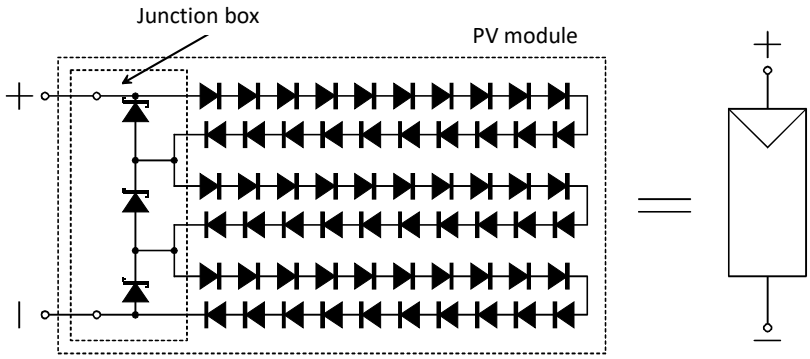
STC (Standard Test Conditions):

- Reference spectrum **AM1.5**
- Optical power J_{ph} **= 1000 W/m²**
- Temperature T **= 25 °C**

Reference spectrum AM1.5



4. Photovoltaic module



- 60 identical solar cells connected in series
- a string of 20 cells is bypassed by a bypass diode inside the junction box