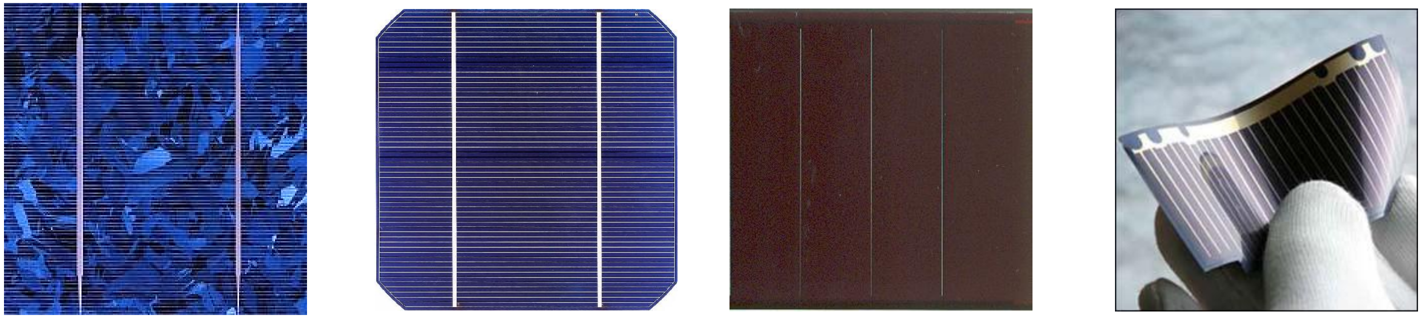
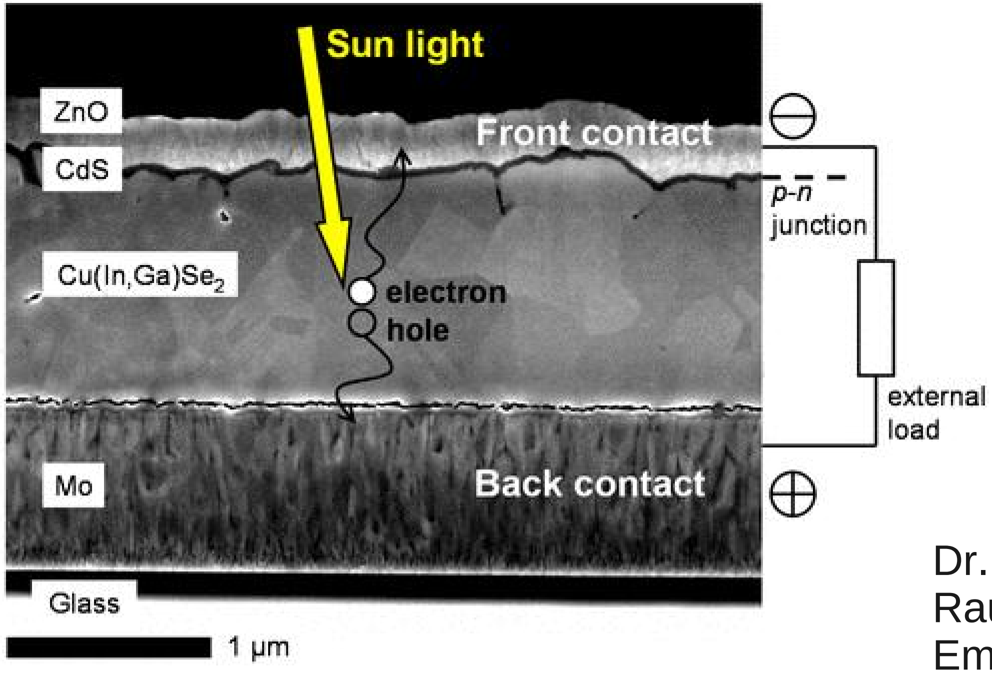
Dye Sensitized Solar Cells (27027-01)

(Dienstag, 8:00-10:00 Departement Physik, Seminarzimmer 3.12)





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Übersicht der Vorlesung

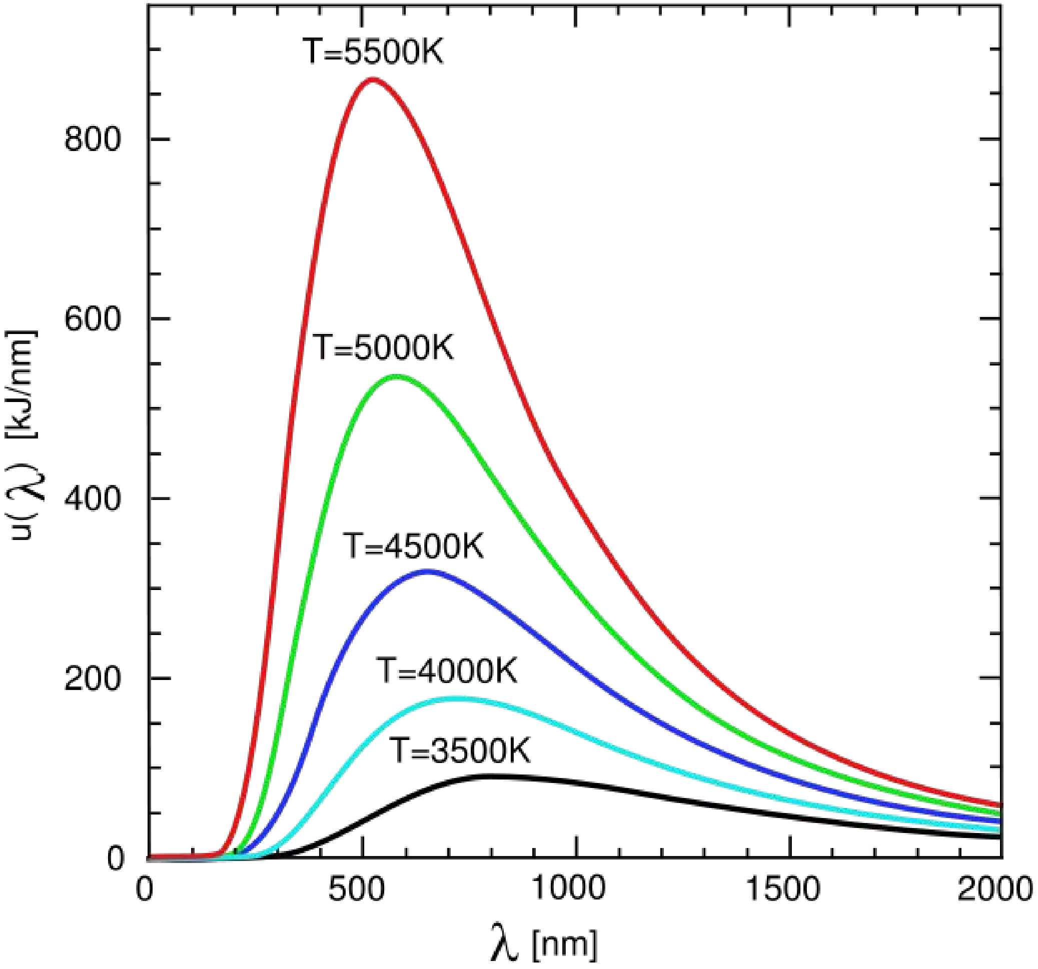
22.02.2011	allg. Einführung in die Solarenergie
01.03.2011	Physikalische Grundlagen der Photovoltaik I
08.03.2011	Physikalische Grundlagen der Photovoltaik II
15.03.2011	(Fastnachtsferien)
22.03.2011	Photochemische und photoelektrische Methoden der Energiewandlung
29.03.2011	Aufbau der Farbstoffsolarzelle, vgl. org. Solarzelle
05.04.2011	TiO_2 Nanopartikel als Substrat der Frabstoffsolarzelle
12.04.2011	Geeignete molekulare Farbstoffe zur Sensibilisierung
19.04.2011	Funktionsweise und Alternativen für den Elektrolyten
26.04.2011	(Osterferien)
03.05.2011	(FANAS meeting)
10.05.2011	Solid-State Dye-Sensitized Solar Cells
→ **17.05.2011**	Experimentelle Methoden zur Solarzellen-Charakterisierung
24.05.2011	Bau und Charakterisierung eigener Solarzellen
31.05.2011	

Experimentelle Methoden zur Solarzellen-Charakterisierung

Methods

- IV-Characteristic
- Quantum Efficiency
- Surface Photovoltage
-

Solar Spectrum

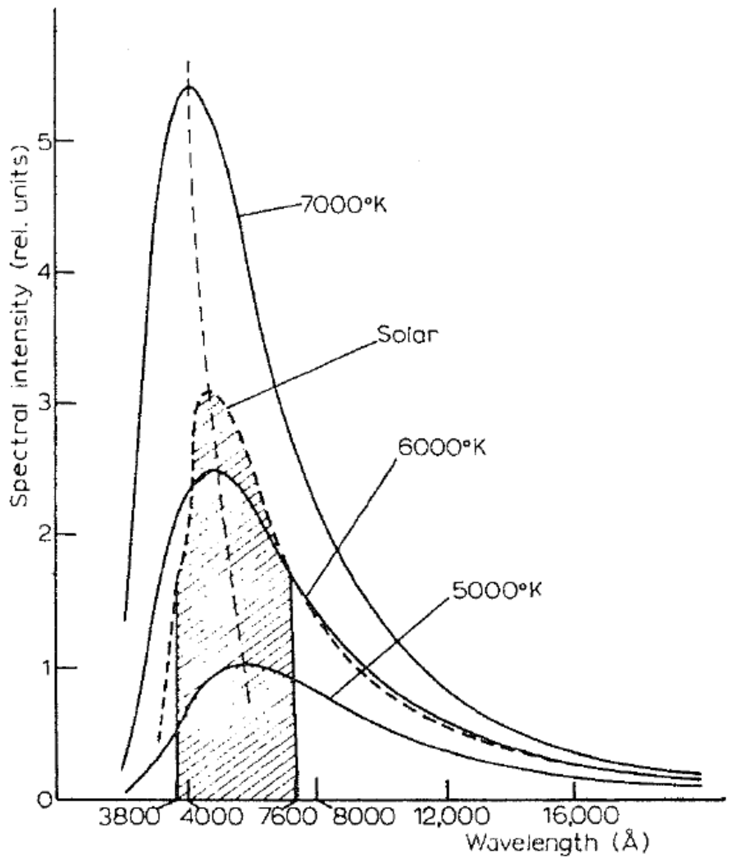


Consider the sun as a black-body radiator at T_S = 6000 K.
Spectral radiance from Planck's law:

$$I(\nu) = \frac{2h}{c^2} \frac{\nu^3}{\exp\{h\nu/kT_S\} - 1}$$

Sadewasser, HZB

Solar Spectrum



There are deviations of the solar spectrum outside the earth's atmosphere compared to black-body radiation.

These are due to:

- variation in temperature
- effects of the solar atmosphere
- Fraunhofer absorption lines (due to various elements in the solar atmosphere)

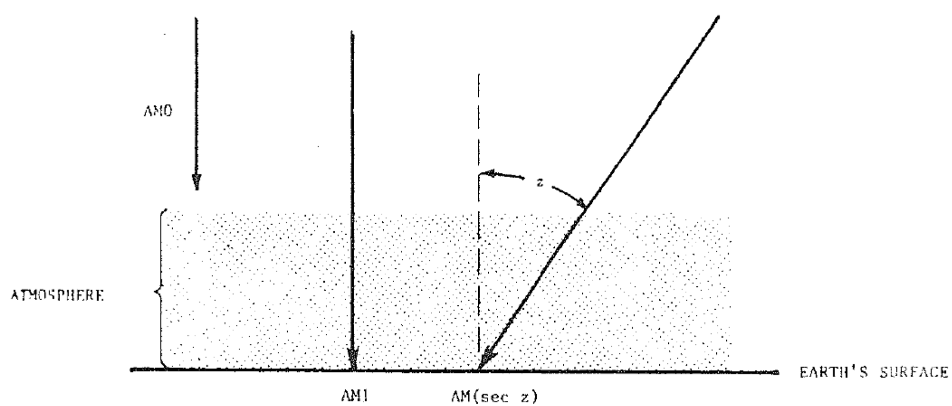
Sadewasser, HZB

Effect of the earth’s atmosphere

intensity and spectral distribution of the solar spectrum at the earth’s surface depend on:

- path length through the atmosphere
- composition of the atmosphere

The path length can be described by the zenit angle z, which depends on time of day, season, latitude and longitude.



define an equivalent relative air mass m_r:

outer space: AM0

for zenit angle z = 0: AM1

important is AM1.5 = average air mass during daylight hours

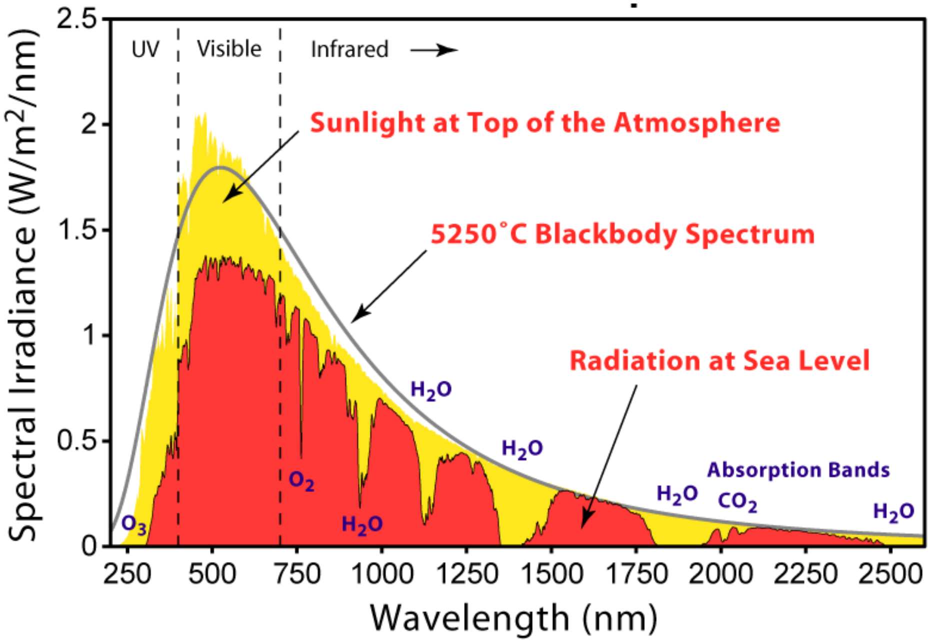
→ value at which solar cell efficiencies are measured and compared.

Sadewasser, HZB

Solar Radiation Spectrum

On the path through the atmosphere the light experiences:

- Rayleigh scattering (at small particles)
- electronic absorption bands, i.e. oxygen, nitrogen, ozone, …
- molecular rotational and vibrational bands, i.e. H_2O, CO_2, …
- refraction and turbulence, i.e. variations in index of refraction n with temperature and pressure (small effect)



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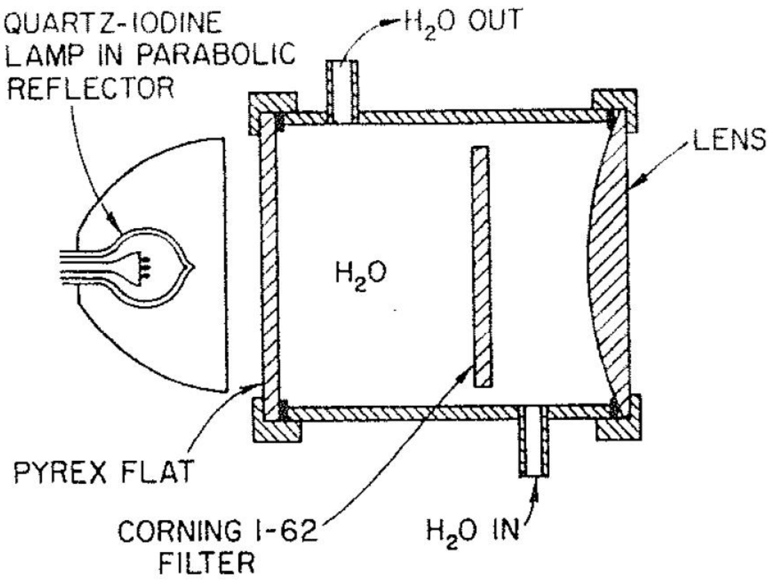
Solar simulation



intensity: 100 mW/cm^2

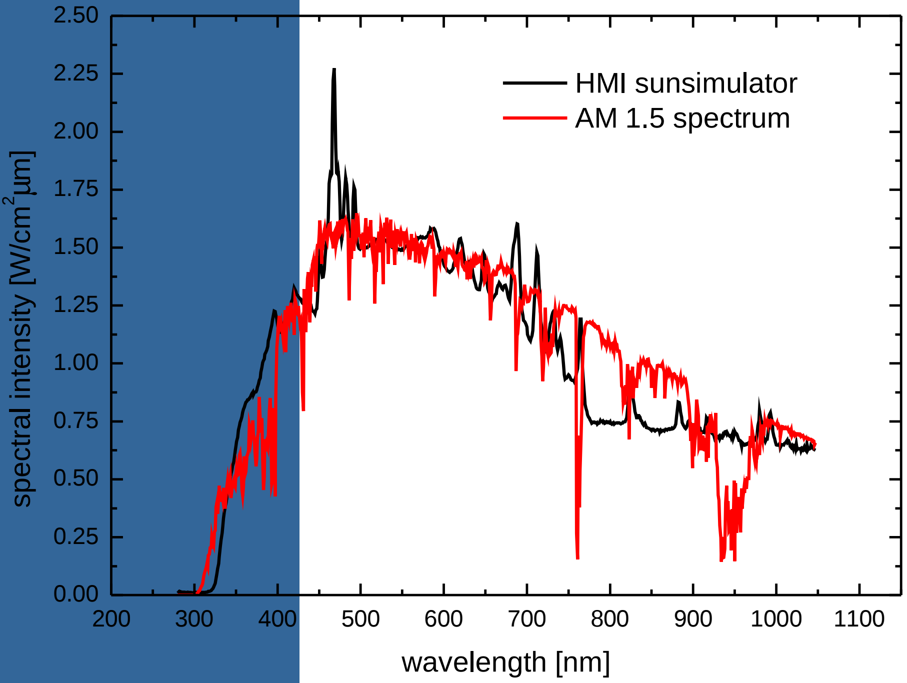
use xenon arc lamp or tungsten iodine lamp and appropriate filters to adjust to the solar spectrum.

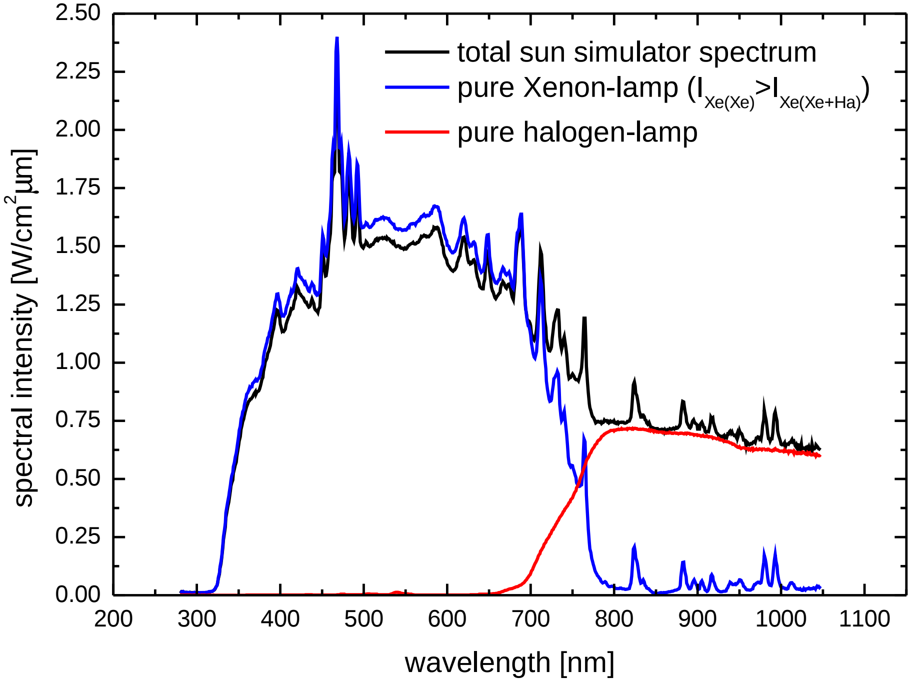
- Water filter to absorb high wavelengths radiation
- Corning I-62 filter as color compensation filter

Sadewasser, HZB

Solar Simulator (HZB)

system with two lamps, a xenon arc lamp and a halogen lamp





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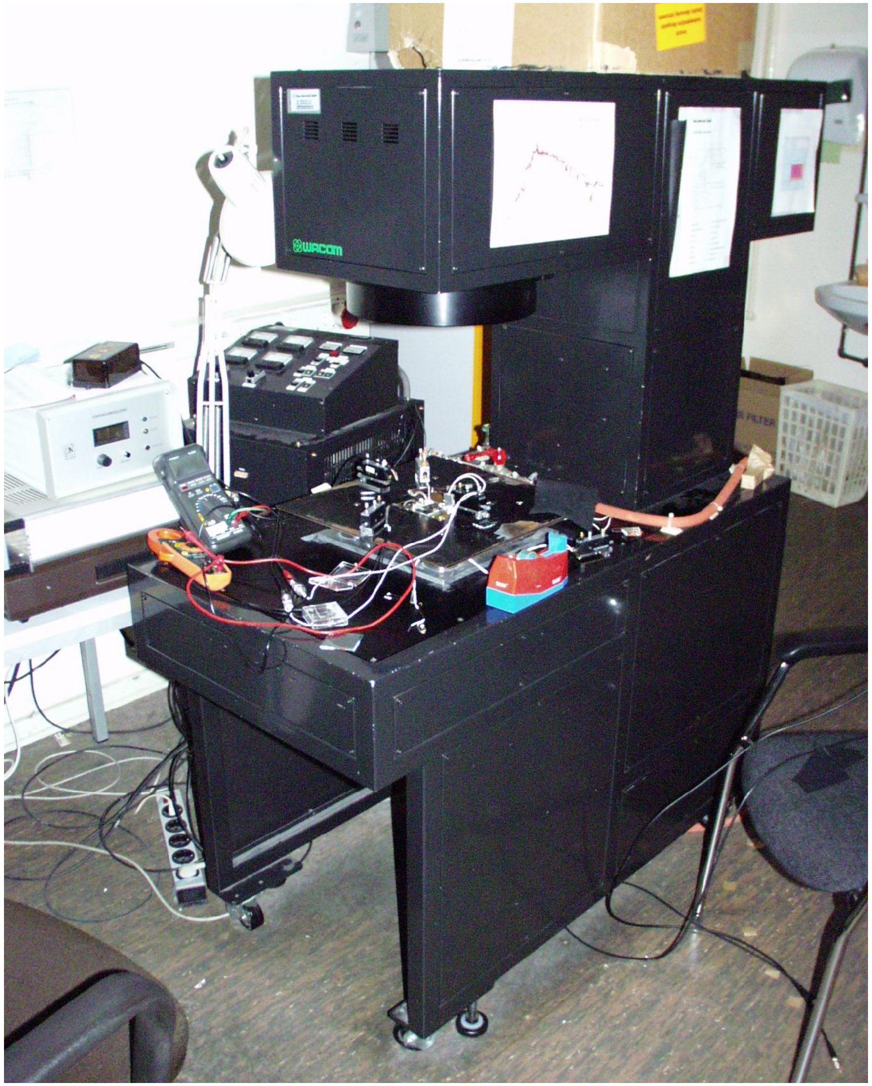
Solar Simulator (HZB)



Sadewasser, HZB

Characteristics of a Solar Cell

IV-curve of a solar cell, standard diode model:

$$J_{dark}(V) = J_0(e^{qV/k_BT} - 1)$$

Current-Voltage characteristics under illumination:

$$J(V) = J_0(e^{qV/k_BT} - 1) - J_{Ph}$$

$$\Rightarrow \qquad V_{OC} = \frac{k_BT}{q}\ln(\frac{J_{Ph}}{J_0} + 1)$$

k_B: Boltzmann constant, T: temperature, J_{Ph}: photo current, J_0: saturation current

1 diode model

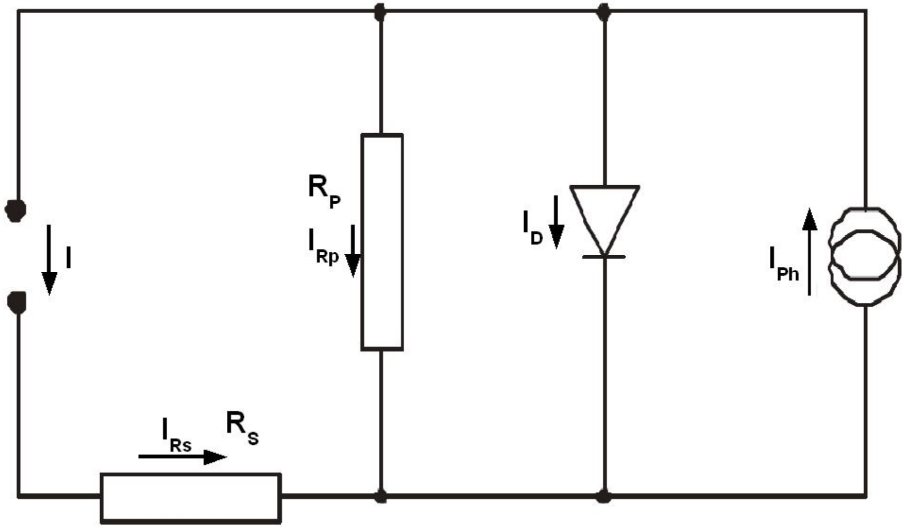
Real solar cells have electrical losses, which can be modeled by a combination of serial and parallel resistors:

$$J(V) = J_0\left(e^{q\frac{V-R_SJ}{Ak_BT}} - 1\right) + \frac{V-R_SJ}{R_P} - J_{Ph}$$

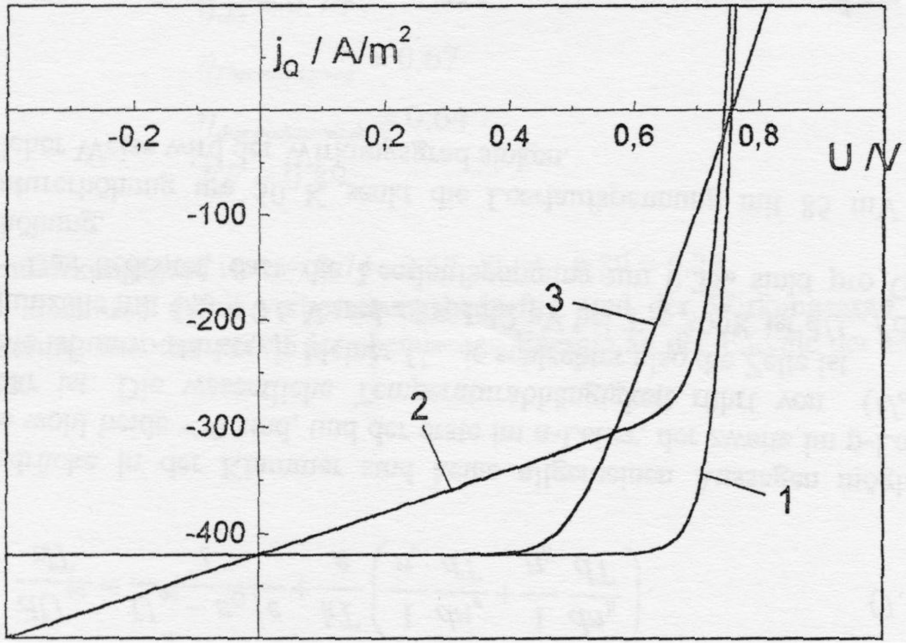
R_S: serial resistance

R_P: parallel resistance

A: diode quality factor



Influence of the leakage currents



1: $R_S = 0\ \Omega$, $R_P = \infty$

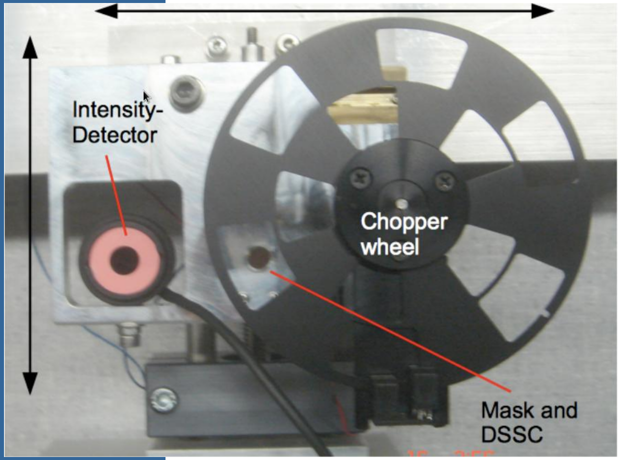
2: $R_S = 0\ \Omega$, $R_P = 50\ \Omega$

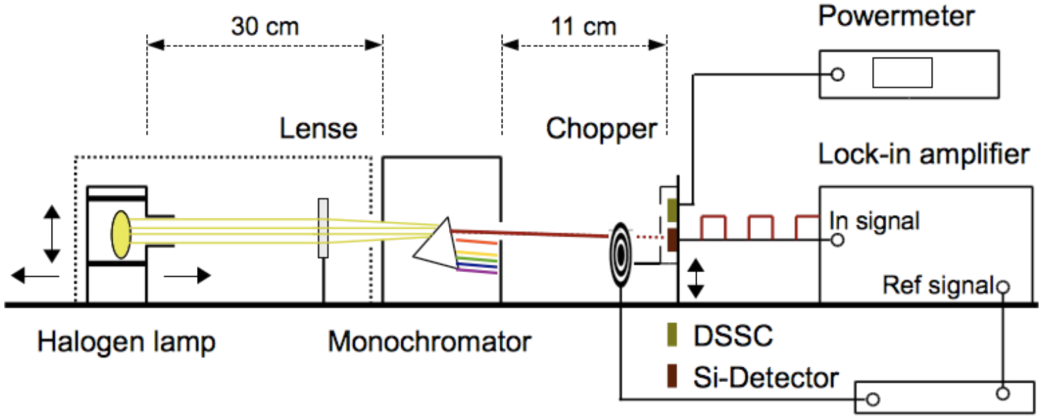
3: $R_S = 5\ \Omega$, $R_P = \infty$

Non perfect values reducing the fill factor and therefore the power conversion efficiency

Quantum Efficiency (spectral response)

- Relation between collected charge carriers and the incident photon flux in a certain wavelength region
  - External spectral response (all photons) **EQE**
  - Internal spectral response (only absorbed photons) **IQE**





Other name....: Incident-photon-to-collected electron efficiency (**IPCE**)

IPCE

- Determination of injection efficiency and electron diffusion length (steady state conditions necessary)

$$IPCE(\lambda) = \frac{J_{sc}}{qI_0} \qquad \text{(EQE)}$$

- The IPCE can also be expressed by the efficiency of three separate physical processes:

$$IPCE(\lambda) = \eta_{lh}(\lambda)\eta_{inj}(\lambda)\eta_{col}(\lambda)$$

η_{lh}	Light harvesting efficiency
η_{inj}	Electron injection efficiency from dye to TiO_2
η_{col}	Electron collection efficiency

APCE

- Absorbed-photon-to-collected-electron efficiency

$$APCE(\lambda) = \frac{IPCE(\lambda)}{\eta_{lh}}$$

- Sate of the art: APCE~100%, IPCE~ 85%

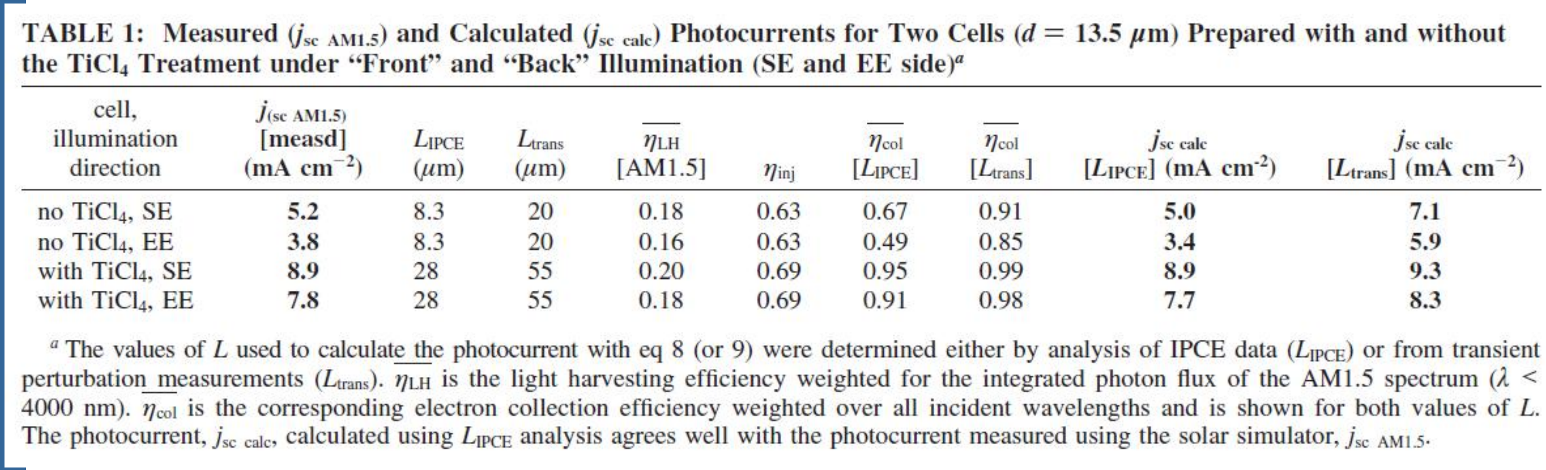


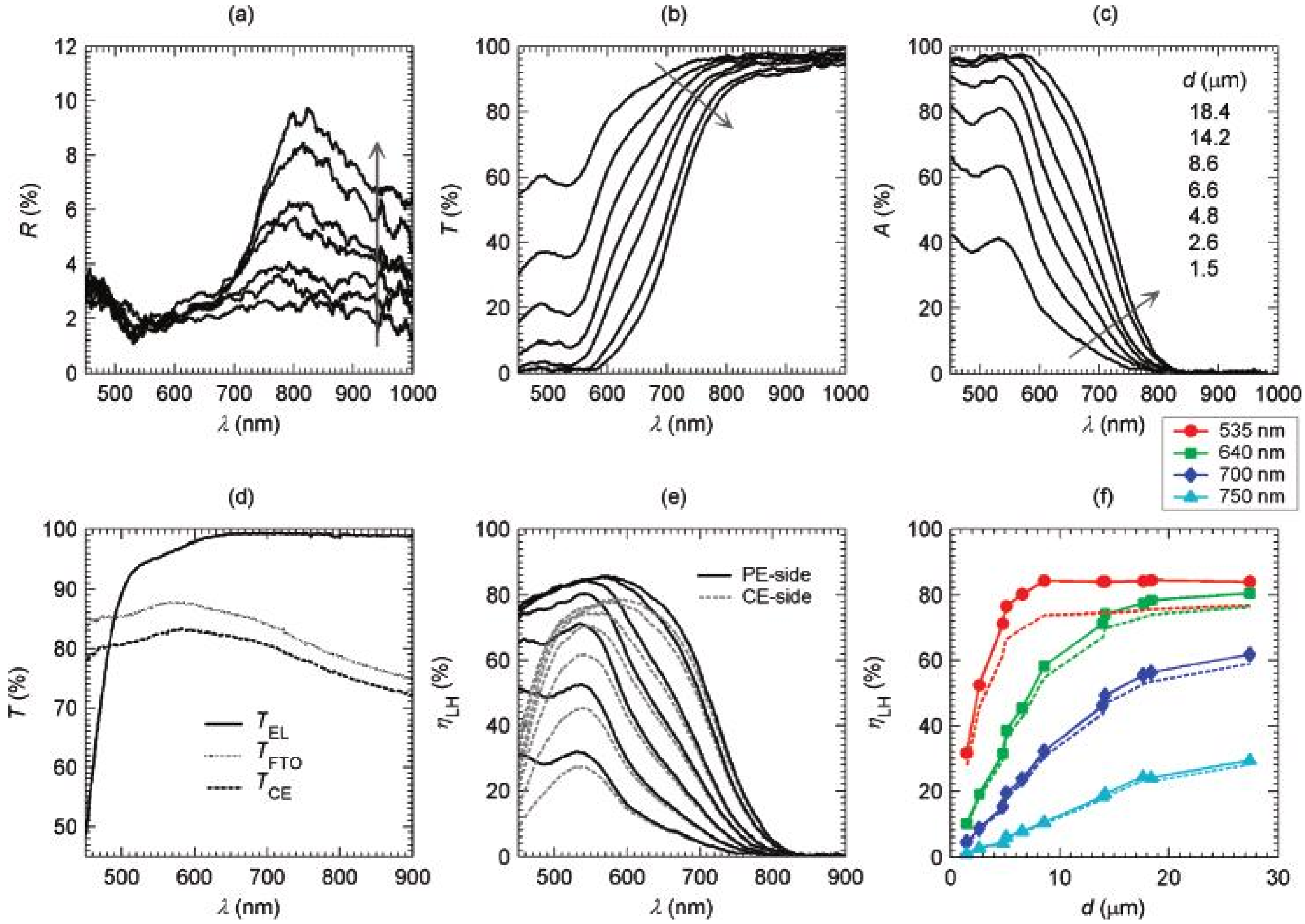
TABLE 1: Measured ($j_{\mathrm{sc\ AM1.5}}$) and Calculated ($j_{\mathrm{sc\ calc}}$) Photocurrents for Two Cells (d = 13.5 μm) Prepared with and without the $TiCl_4$ Treatment under “Front” and “Back” Illumination (SE and EE side)[a]

cell, illumination direction	$j_{\mathrm{(sc\ AM1.5)}}$ [measd] (mA cm^{-2})	L_{IPCE} (μm)	L_{trans} (μm)	$\overline{\eta_{\mathrm{LH}}}$ [AM1.5]	η_{inj}	$\overline{\eta_{\mathrm{col}}}$ [L_{IPCE}]	$\overline{\eta_{\mathrm{col}}}$ [L_{trans}]	$j_{\mathrm{sc\ calc}}$ [L_{IPCE}] (mA cm^{-2})	$j_{\mathrm{sc\ calc}}$ [L_{trans}] (mA cm^{-2})
no $TiCl_4$, SE	**5.2**	8.3	20	0.18	0.63	0.67	0.91	**5.0**	**7.1**
no $TiCl_4$, EE	**3.8**	8.3	20	0.16	0.63	0.49	0.85	**3.4**	**5.9**
with $TiCl_4$, SE	**8.9**	28	55	0.20	0.69	0.95	0.99	**8.9**	**9.3**
with $TiCl_4$, EE	**7.8**	28	55	0.18	0.69	0.91	0.98	**7.7**	**8.3**

[a] The values of L used to calculate the photocurrent with eq 8 (or 9) were determined either by analysis of IPCE data (L_{IPCE}) or from transient perturbation measurements (L_{trans}). $\overline{\eta_{\mathrm{LH}}}$ is the light harvesting efficiency weighted for the integrated photon flux of the AM1.5 spectrum (λ < 4000 nm). $\overline{\eta_{\mathrm{col}}}$ is the corresponding electron collection efficiency weighted over all incident wavelengths and is shown for both values of L. The photocurrent, $j_{\mathrm{sc\ calc}}$, calculated using L_{IPCE} analysis agrees well with the photocurrent measured using the solar simulator, $j_{\mathrm{sc\ AM1.5}}$.

P. R. F. Barnes et al., J. Phys. Chem. C 113, 1126, (2009).

Light-harvesting efficiency and optical properties



J. Halme et al., J. Phys. Chem. C 112, 5623, (2008).

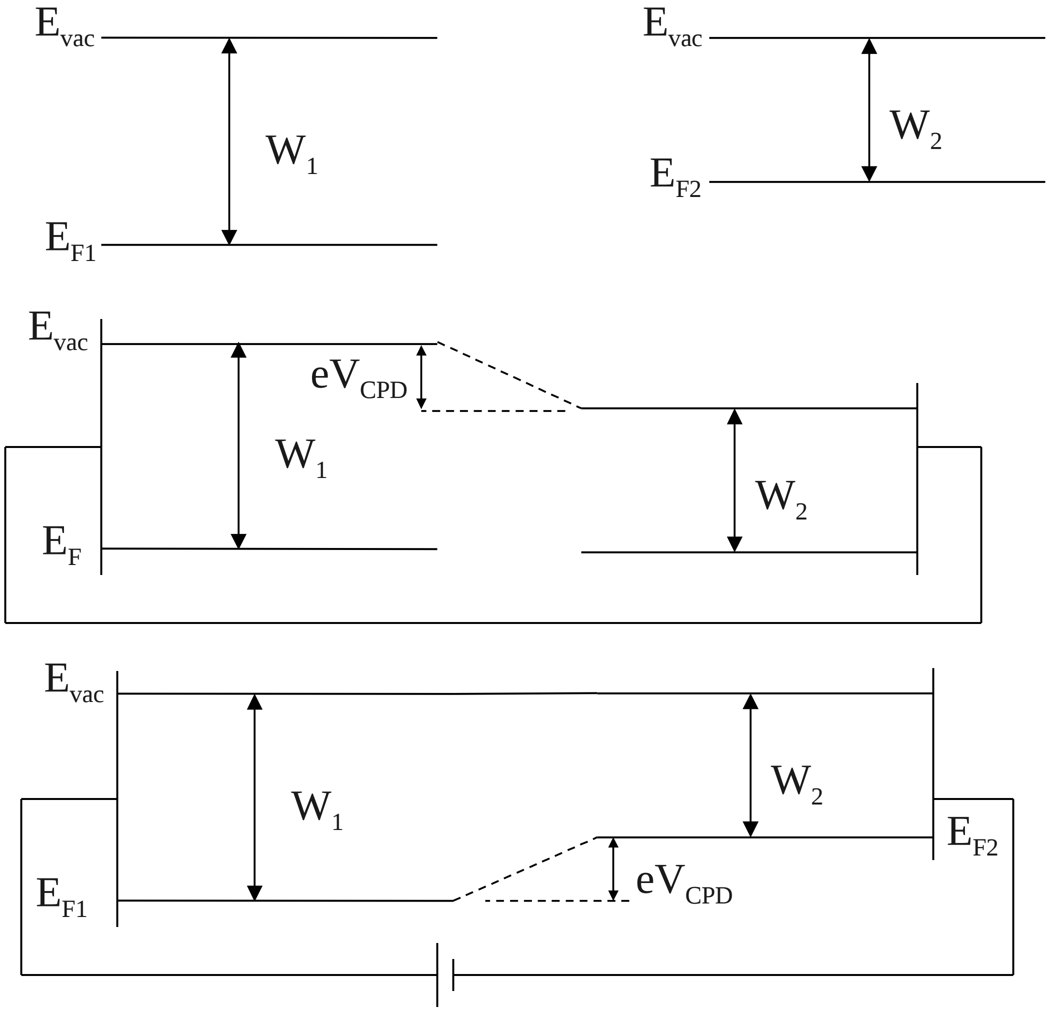
Surface Photovoltage

The surface photovoltage (SPV) is defined as the illumination-induced change in the surface potential.

This effect, observed at Si and Ge surfaces, was first reported in a short note by Brattain in 1947

Kelvin Probe

- Determining relative changes in work functions is done by measuring the work function difference between two materials.



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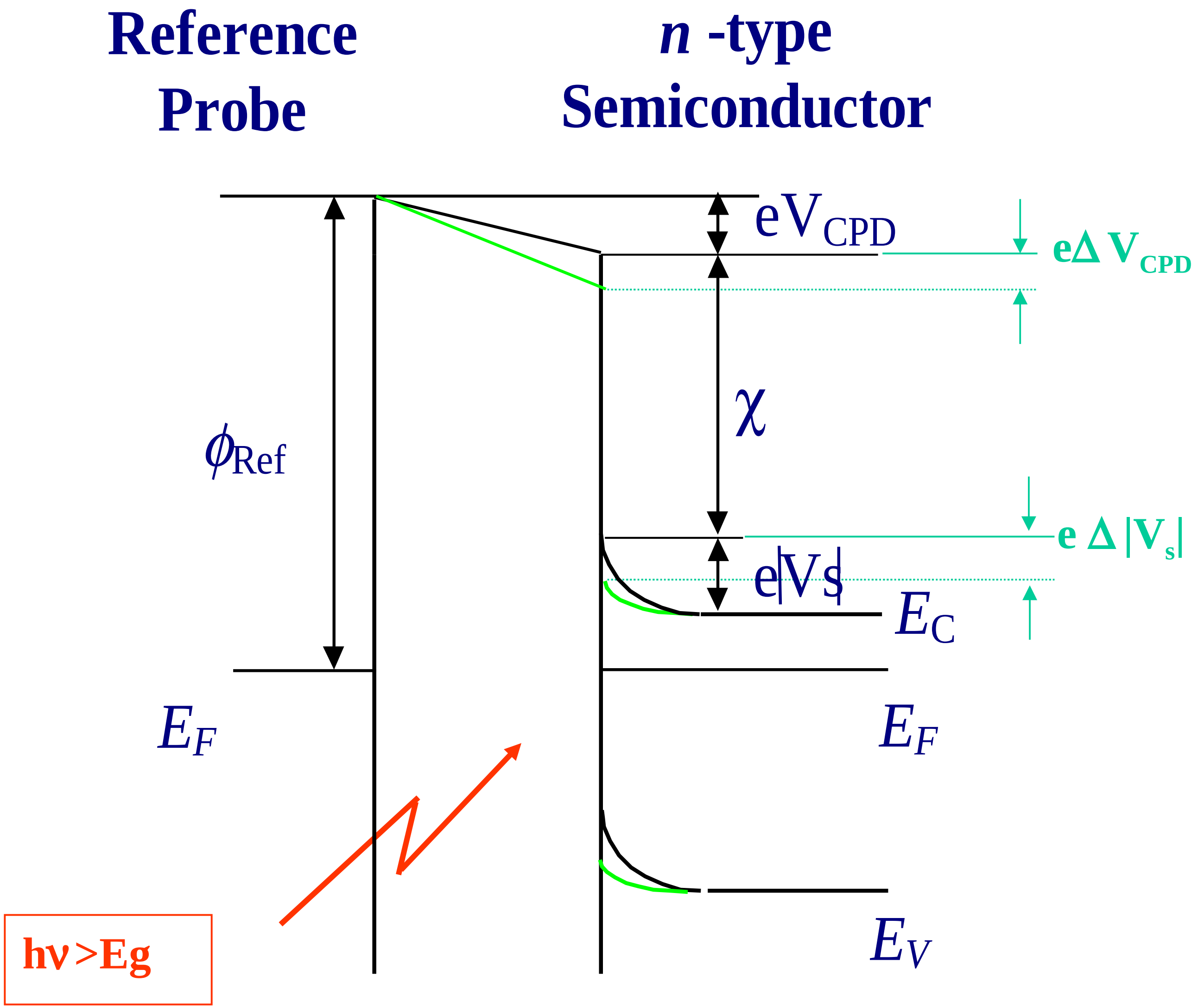
Surface Photovoltage -SPV



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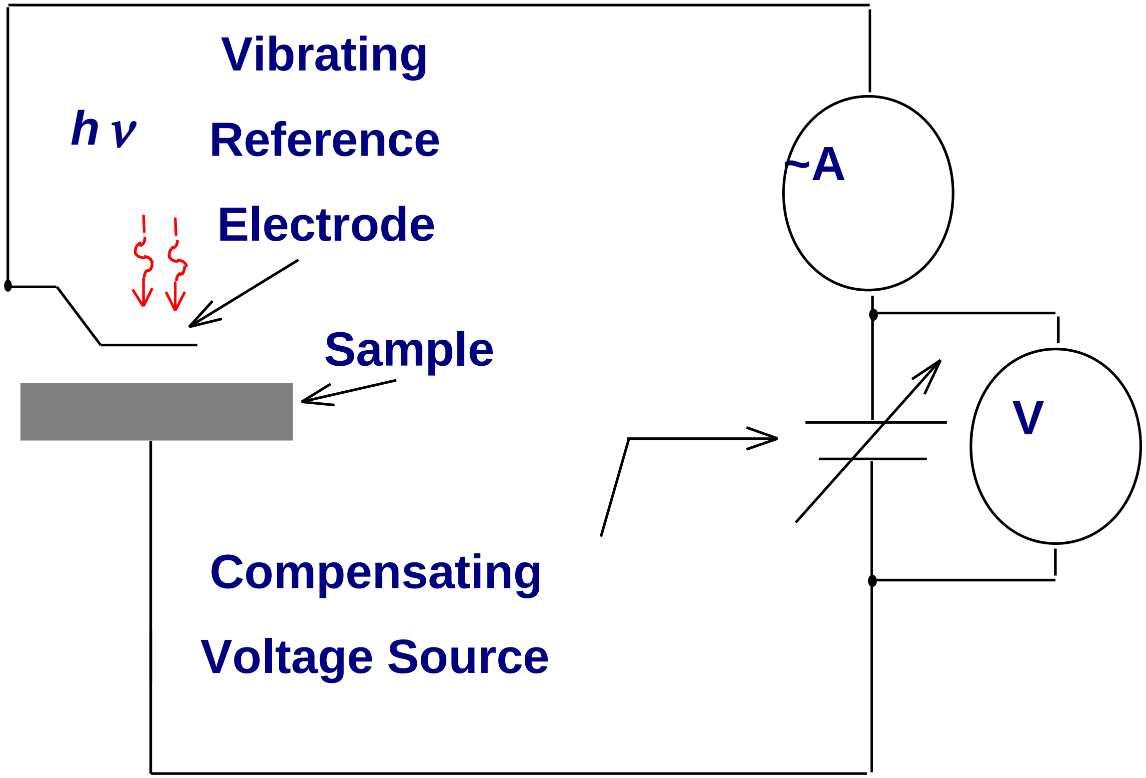
The Basic Kelvin Probe



$$i = (V_{CPD} + V_{DC})\frac{dC}{dt}$$

$V_{dc} = -V_{CPD}$

$i_{ac=0}$

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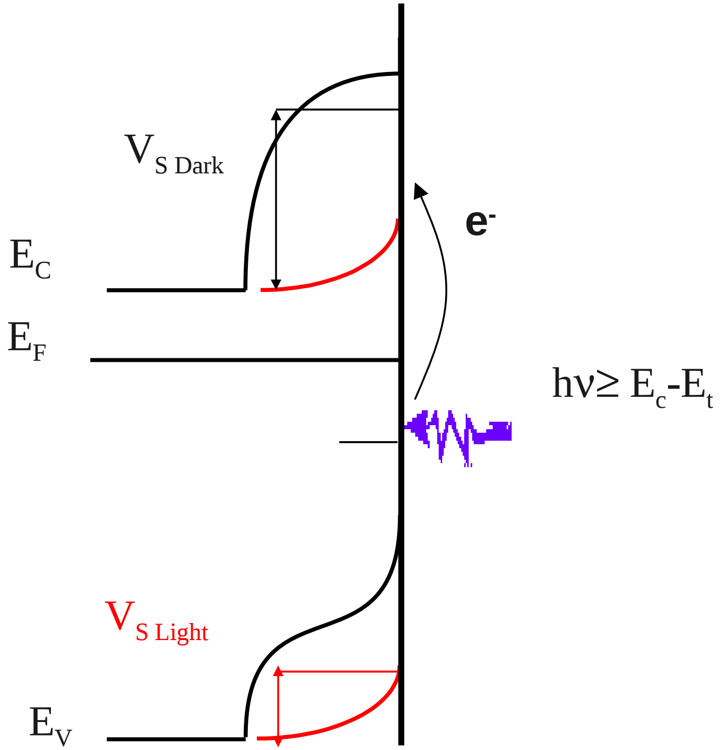
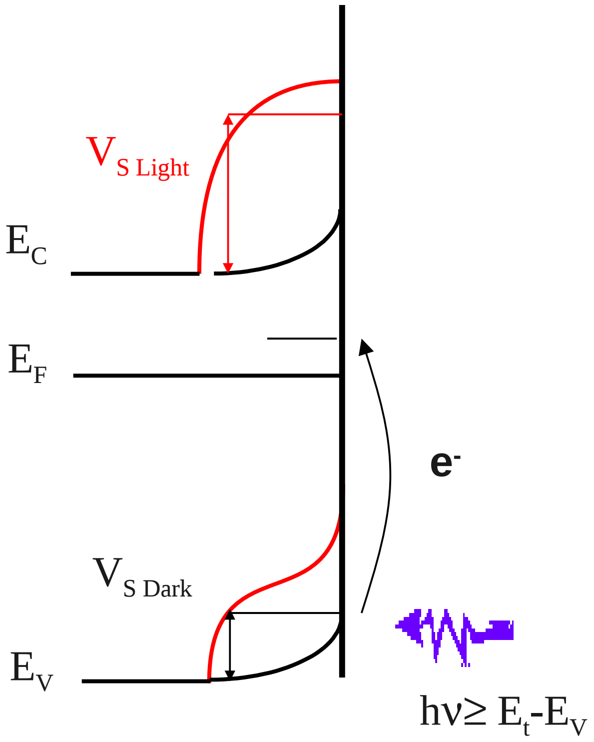
Surface Photovoltage Spectroscopy (SPS)

Surface state depopulation



Surface state population



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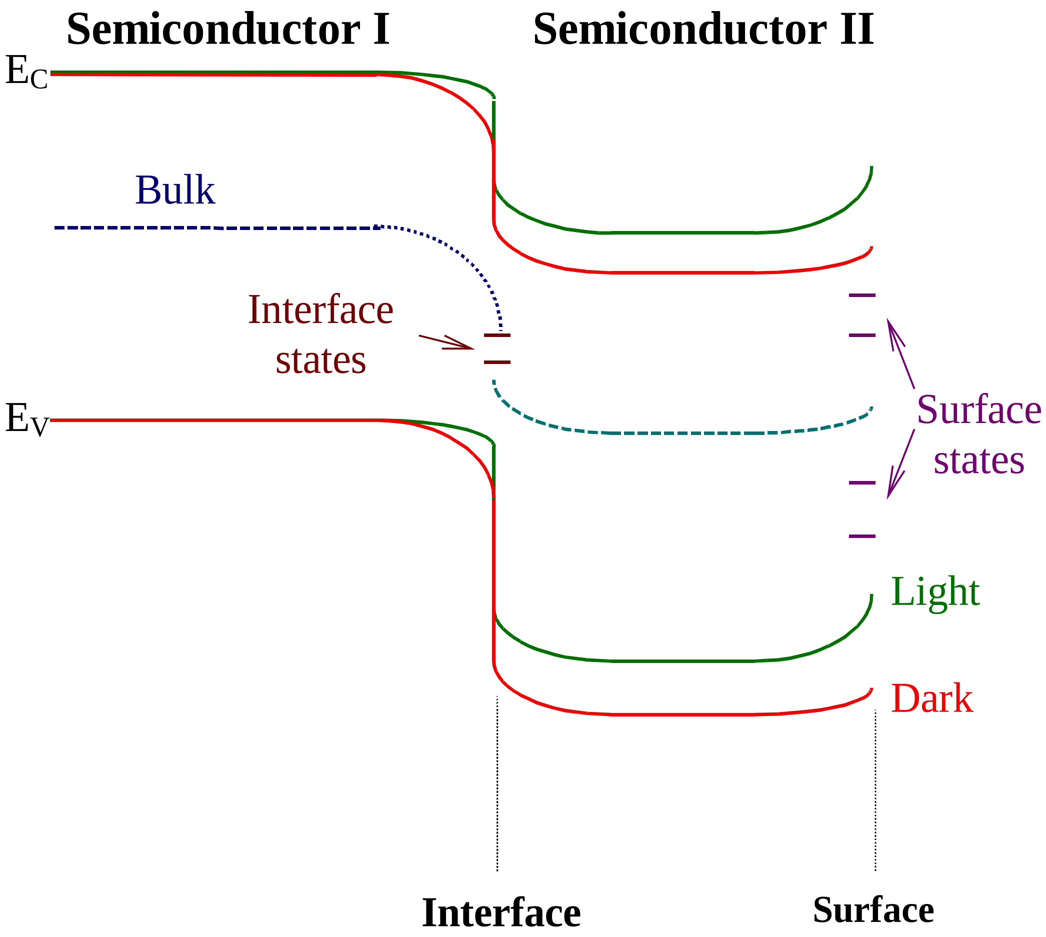
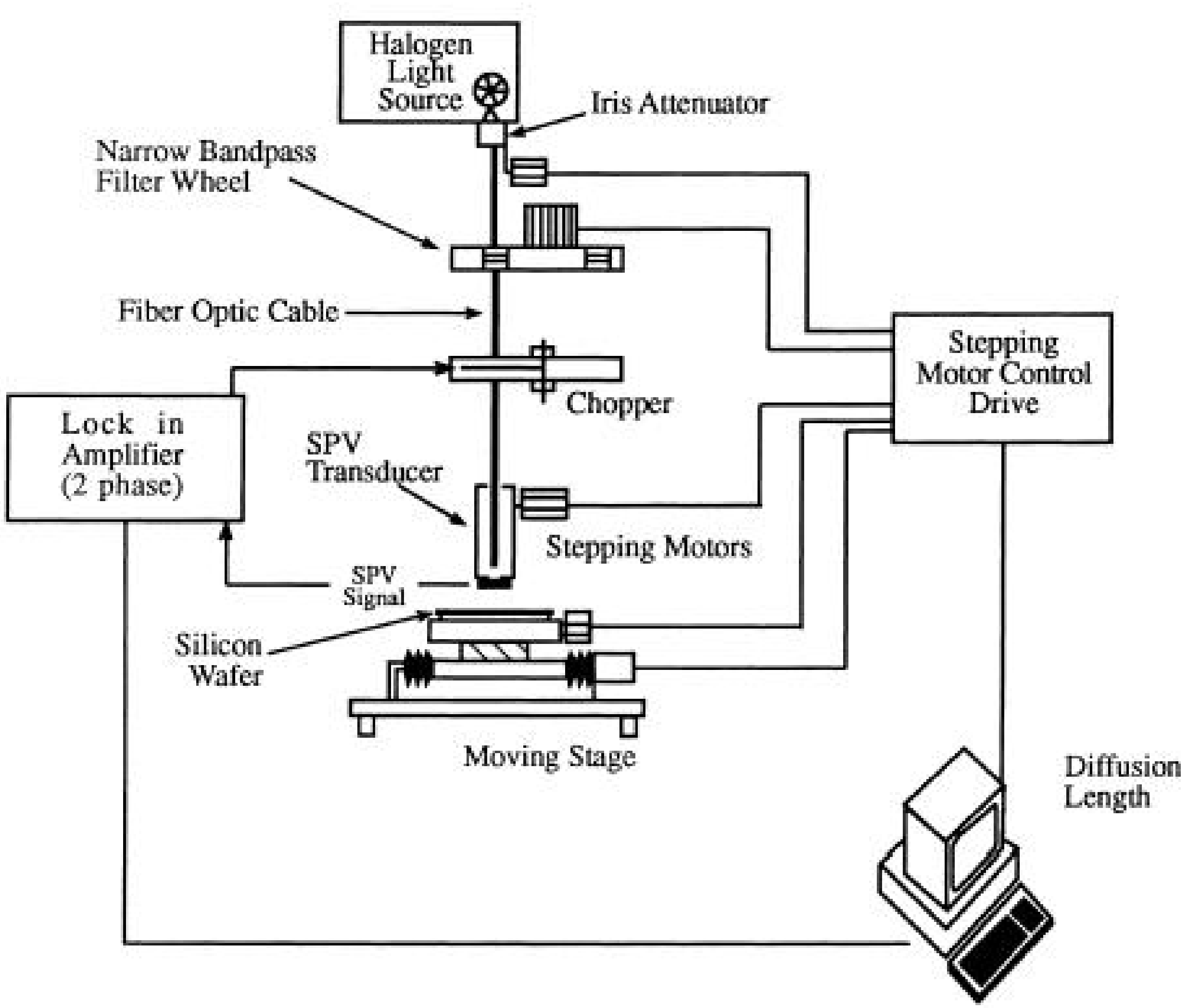
SPV of Buried Interfaces



Surface photovoltage spectroscopy is sensitive to electric fields in buried layers as well as at the surface.

Commercialization, Industrial Applications



(a)

Intensity modulated photocurrent spectroscopy (IMPS)

- provides new insight into the dynamics of electron transport and collection in DSSCs

Principle of IMPS:

Modulation of the light, illuminating an electrochemical cell. The quotient of one electric magnitude (current or voltage) with the dynamic light intensity P^* leads to the IMPS spectrum H^*.

Photovoltaik

Principle of EIS:

Modulation of the current I or the voltage U at an electrochemical cell C. The quotient of the dynamic magnitudes leads to the Impedance Z^* (or Admittance $Y^*=1/Z^*$).