

IPT Solar cell characterizer

Problem 14

April 22, 2019

Benjamin L. Larsen
Danish Team

International physicists' tournament

Danmarks
Tekniske
Universitet



IPT Solar cell
characterizer

B. Larsen

Problem

Colour temperature
and black body
radiation

Planck's law for solar
cells

Light sources

Experimental setup

Solar cell
characterisation

Results

Problem

Colour temperature and black body radiation

Planck's law for solar cells

Light sources

Experimental setup

Solar cell characterisation

Results

Problem 14: Solar cell characterise

IPT Solar cell
characterizer

B. Larsen

Problem

2

Colour temperature
and black body
radiation

Planck's law for solar
cells

Light sources

Experimental setup

Solar cell
characterisation

Results

Propose and implement a method to determine the irradiance and colour temperature of a light source by using solar cell materials? How accurately can they be measured? What are the limitations of your method? What are the relevant parameters?

Colour temperature and black body radiation

IPT Solar cell
characterizer
B. Larsen

Problem

Colour temperature
and black body
radiation

Planck's law for solar
cells

Light sources

Experimental setup

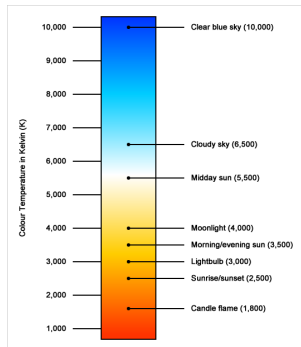
Solar cell
characterisation

Results

3

- ▶ Colour temperature is defined as the temperature of a black body that emits light of the same colour as the light source:
- ▶ Black body radiation: non-reflective, depends only on temperature.
- ▶ Planck's law for the spectrum:

$$\rho(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{\exp \frac{h\nu}{k_b T} - 1} \quad (1)$$



Planck's law for solar cells

IPT Solar cell
characterizer
B. Larsen

Problem

Colour temperature
and black body
radiation

Planck's law for solar
cells

Light sources

Experimental setup

Solar cell
characterisation

Results

4

► Stefan-Boltzmann

$$\int_0^{\infty} \rho(\nu, T) d\nu = \sigma T^4 \quad (2)$$

- Irradiance of black body: $I = \frac{P}{A} = \sigma T^4$
- Solar cell can only utilise photons with energy above bandgap and only gain this energy

$$I(\nu_g, T) = \eta(T) \frac{2h\nu_g}{c^2} \int_{\nu_g}^{\infty} \frac{\nu^2}{\exp \frac{h\nu}{k_b T} - 1} d\nu \quad (3)$$

- $\nu_g = \frac{h}{E_{bg}} \approx 2.7 \cdot 10^{14}$ Hz bandgap 1.11 eV for crystalline silicon (real solar cells might have slightly higher bandgap)

Planck's law for solar cells (con.)

IPT Solar cell
characterizer
B. Larsen

Problem

Colour temperature
and black body
radiation

Planck's law for solar
cells

Light sources

Experimental setup

Solar cell
characterisation

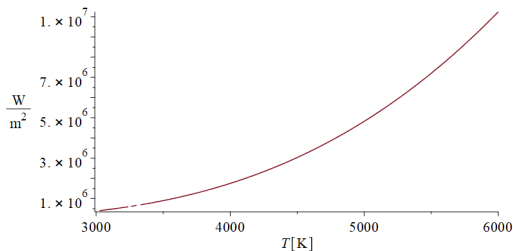
Results

5

$$\eta(T) = 1$$

$$\frac{2h\nu_g}{c^2} \int_0^\infty \frac{\nu^2}{\exp \frac{h\nu}{k_b T} - 1} d\nu - \frac{2h\nu_g}{c^2} \int_0^{\nu_g} \frac{\nu^2}{\exp \frac{h\nu}{k_b T} - 1} d\nu \quad (4)$$

$$= \frac{4\zeta(3)\nu_g k_b^3}{c^2 h^2} T^3 - \frac{2h\nu_g}{c^2} \int_0^{\nu_g} \frac{\nu^2}{\exp \frac{h\nu}{k_b T} - 1} d\nu \quad (5)$$

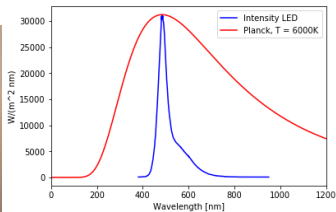


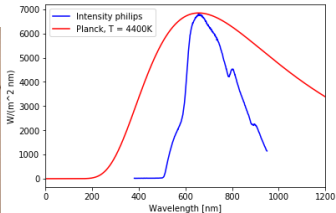
$$\eta(T) = \frac{\frac{2h\nu_g}{c^2} \int_{\nu_g}^{\infty} \frac{\nu^2}{\exp \frac{h\nu}{k_b T} - 1} d\nu}{\sigma T^4} \quad (6)$$

We can then find the total irradiance from the solar cell

$$I(\nu_g, T) = \frac{\left(\frac{2h\nu_g}{c^2} \int_{\nu_g}^{\infty} \frac{\nu^2}{\exp \frac{h\nu}{k_b T} - 1} d\nu \right)^2}{\sigma T^4} \quad (7)$$

- Light source and spectrum compared to Planck's with same colour temperature





Iridescent filament lamp

IPT Solar cell
characterizer
B. Larsen

Problem

Colour temperature
and black body
radiation

Planck's law for solar
cells

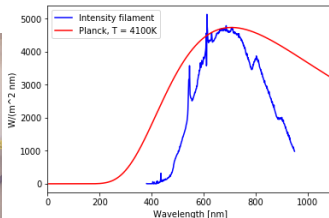
Light sources

Experimental setup

Solar cell
characterisation

Results

9



Experimental setup

IPT Solar cell
characterizer
B. Larsen

Problem

Colour temperature
and black body
radiation

Planck's law for solar
cells

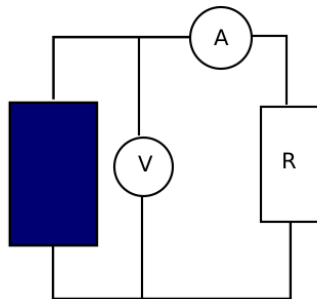
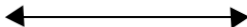
Light sources

Experimental setup

Solar cell
characterisation

Results

10





- ▶ Single crystalline
- ▶ Area of solar cell: $A_{sol} = 11.0 \text{ mm}^2$, distance $d = 105 \text{ mm}$,
Area filament $A_{fil} = 46.4 \text{ mm}^2$

Solar cell characteristic

IPT Solar cell
characterizer
B. Larsen

Problem

Colour temperature
and black body
radiation

Planck's law for solar
cells

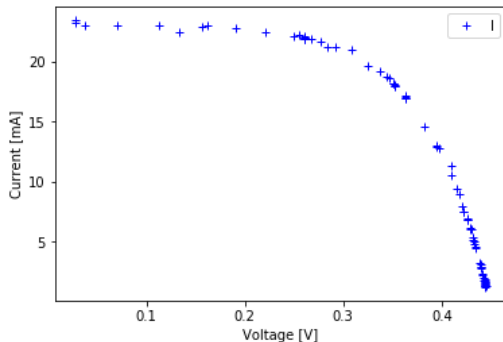
Light sources

Experimental setup

Solar cell
characterisation

Results

- Varying resistance
- Finding optimal peak power point



Max Power

IPT Solar cell
characterizer

B. Larsen

Problem

Colour temperature
and black body
radiation

Planck's law for solar
cells

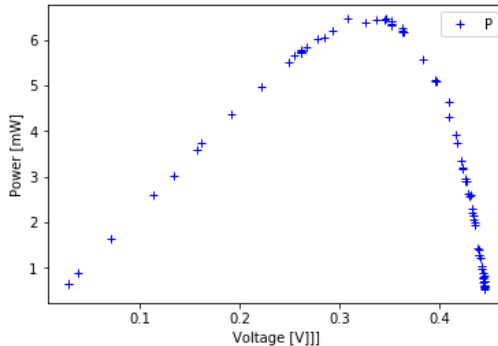
Light sources

Experimental setup

Solar cell
characterisation

Results

13



- max power at 6.46 mW, irradiance $\frac{PA_{sphere}}{A_{sol}A_{fil}} = 1.67 \cdot 10^5$ W/m²

► Solving:

$$1.67 \cdot 10^5 \text{ W/m}^2 = \frac{\left(\frac{2h\nu_g}{c^2} \int_{\nu_g}^{\infty} \frac{\nu^2}{\exp \frac{h\nu}{k_b T} - 1} d\nu \right)^2}{\sigma T^4} \quad (8)$$

- Gives $T = 3837 \text{ K}$
- Spectrum measurement gave $T = 4100 \text{ K}$
- Most likely due to the iridescent lamp not being black body radiation.
- Efficiency $\eta(3837\text{K}) = 0.117$

IPT Solar cell
characterizer

B. Larsen

Problem

Colour temperature
and black body
radiation

Planck's law for solar
cells

Light sources

Experimental setup

Solar cell
characterisation

Results

- ▶ Assume uniform light emission
- ▶ Actual black body
- ▶ Several different light sources
- ▶ Colour filters
- ▶ Band gap dependency

15

- ▶ No lamps are real black-bodies
- ▶ Band gap and efficiency of solar cell is important parameters
- ▶ Effective working point
- ▶ Colour temperature a lot lower than the spectrum indicates (3837 K and 4100 K)

Thanks for listening! / Any questions?

Danmarks
Tekniske
Universitet

