# STRUKTUR DAN OPERASI SOLAR SEL

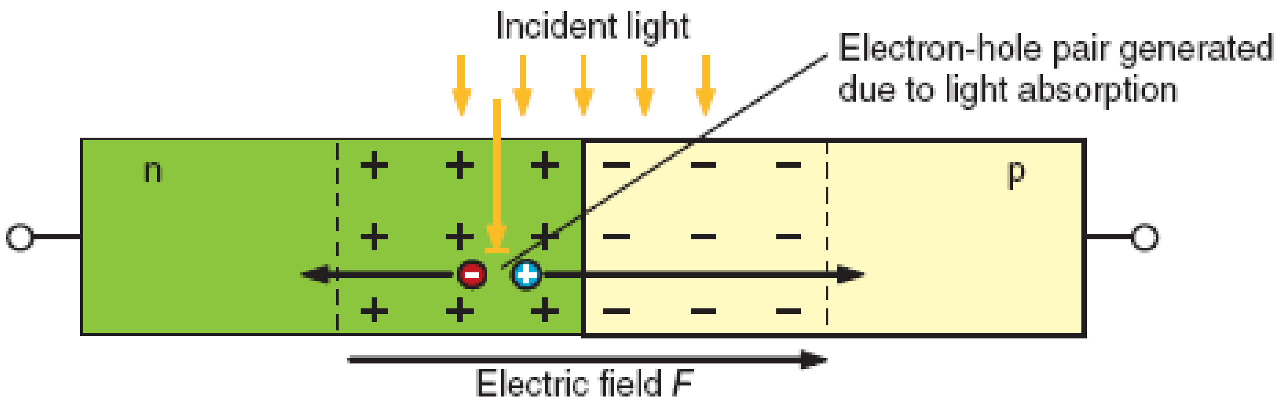


**Figure 4.1** Lighted p-n junction: The free electrons and holes generated by light absorption are separated from the field of the space charge region and "brought home"

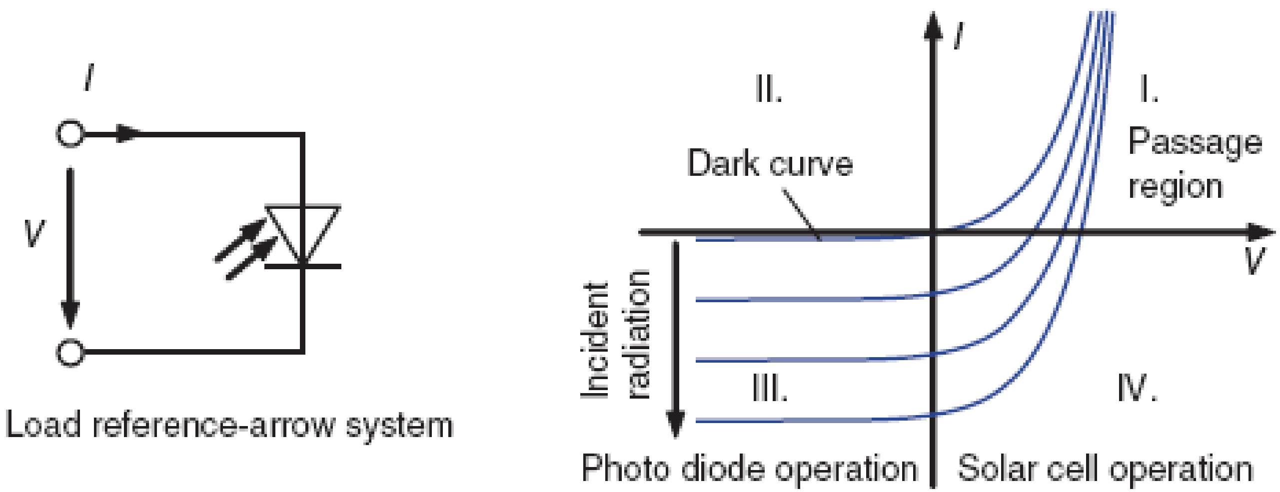


**Figure 4.2** Symbol and curves of a photodiode

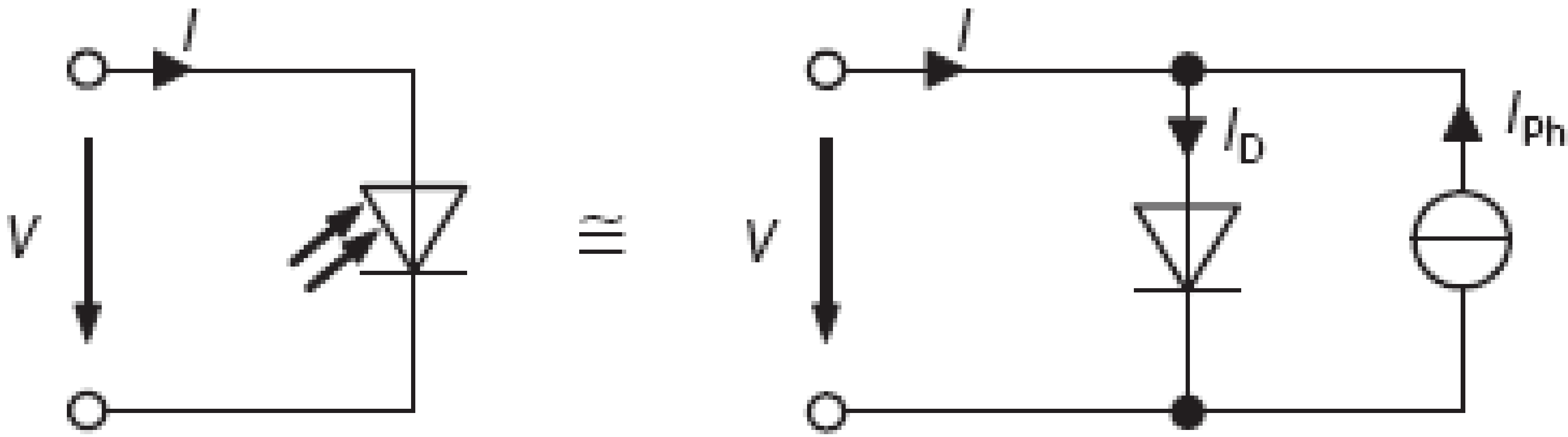


**Figure 4.3** Equivalent circuit of the photodiode

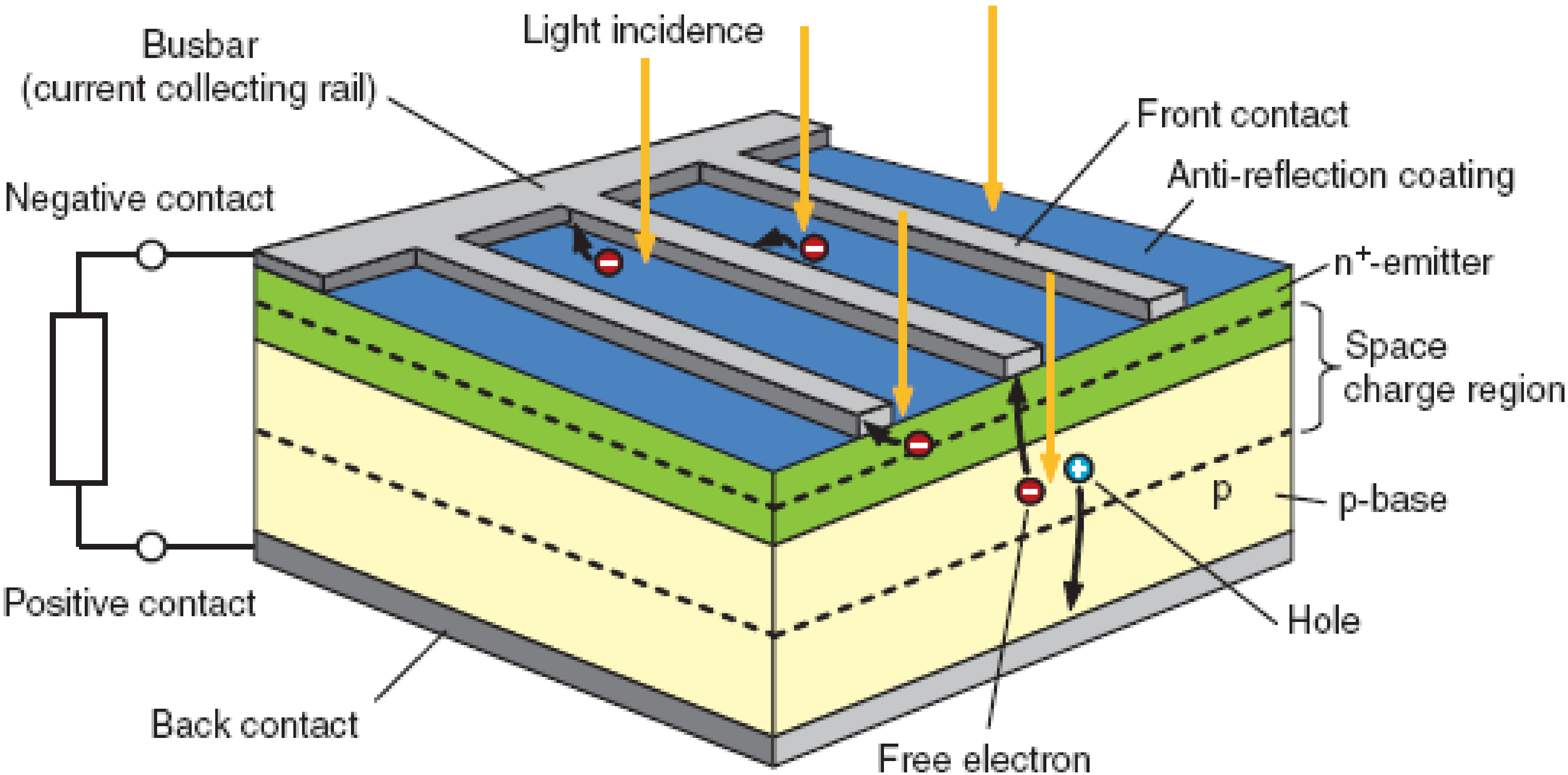


**Figure 4.4** Typical silicon solar cell

# KARAKTERISTIK SOLAR SEL

$$I = I_{\mathrm{Ph}} - I_{\mathrm{D}} = I_{\mathrm{Ph}} - I_{\mathrm{S}} \cdot \left( e^{\frac{V}{m \cdot V_{\mathrm{T}}}} - 1 \right) \qquad (4.13)$$

m : Faktor Ideal

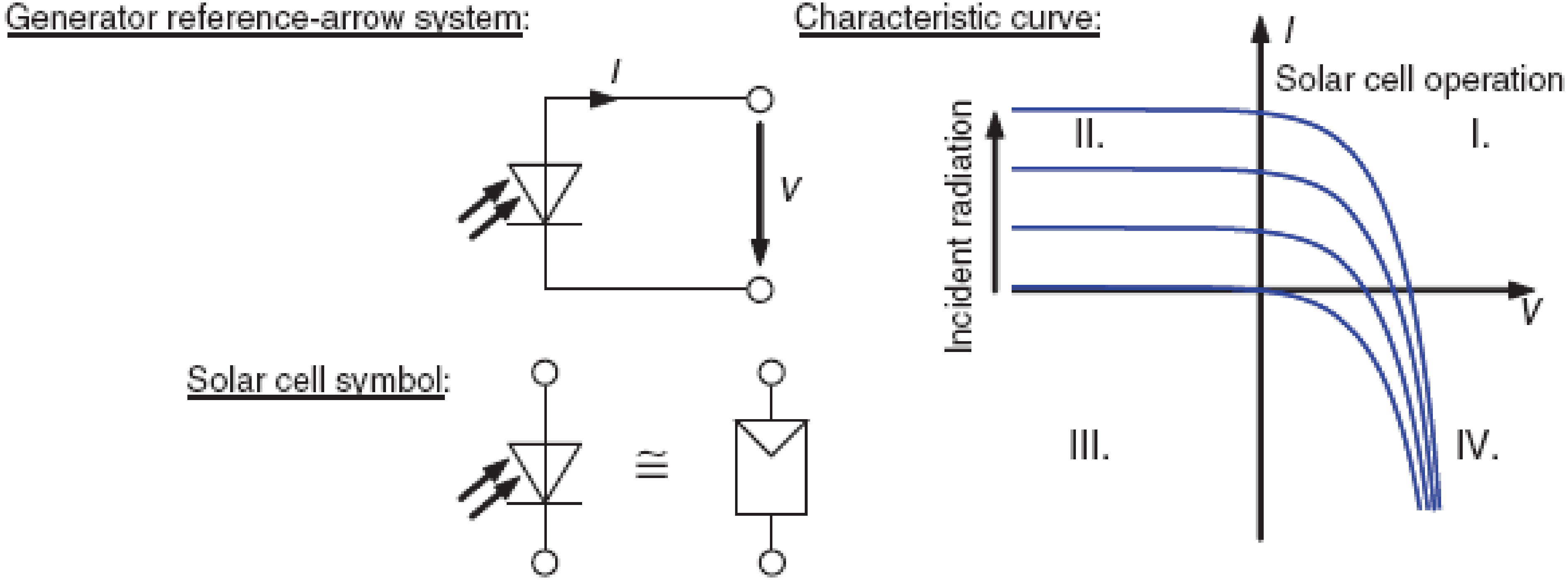


**Figure 4.10** Characteristic curves of a solar cell in the generator reference-arrow system

# ARUS *SHORT CIRCUIT (Isc)*

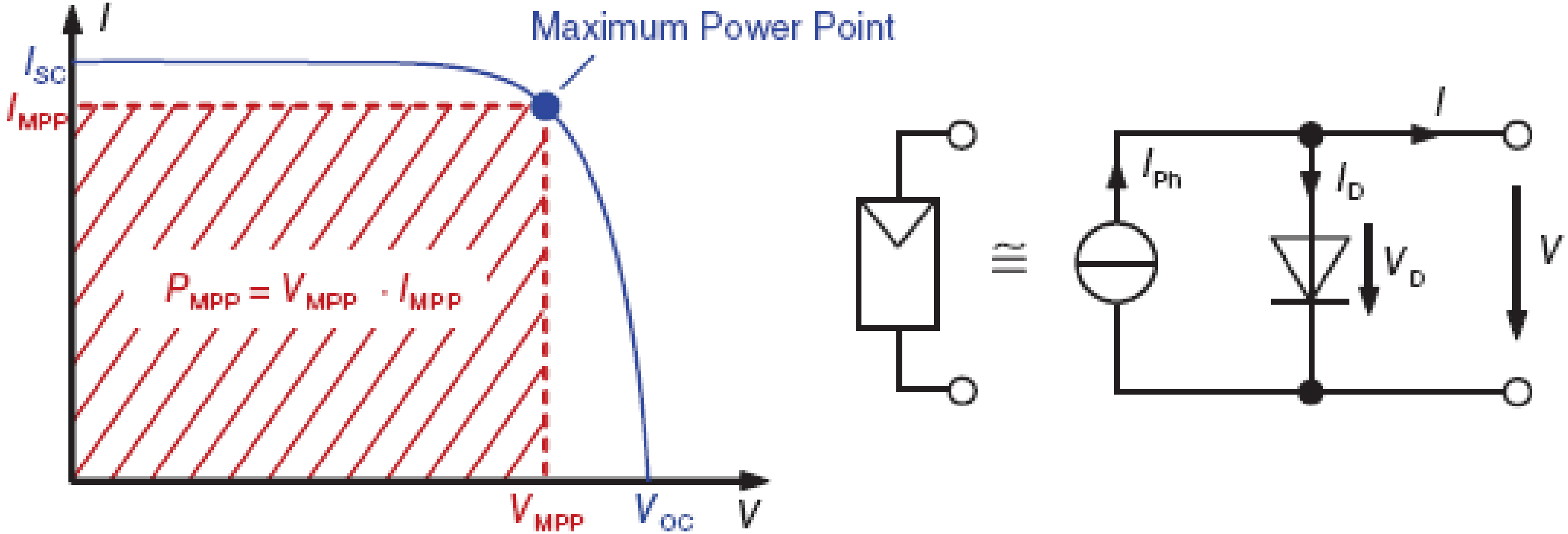


**Figure 4.11** Characteristic curve of a solar cell and its associated simplified equivalent circuit

The **short circuit current** $I_{SC}$ is delivered by the solar cells when it is short circuited at its connections; the voltage $V$ is thus 0.

With Equation 4.13 this results in:

$$I_{SC} = I(V = 0) = I_{Ph} - I_S \cdot \left(e^0 - 1\right) = I_{Ph} \qquad (4.14)$$

# TEGANGAN *OPEN SIRCUIT* (Voc)

The second extreme case occurs when the current becomes zero. In this case the resulting voltage is called **Open Circuit Voltage** $V_{OC}$.

In order to determine the open circuit voltage we resolve Equation 4.13 according to $V$ and set $I = 0$. The result is $I_{Ph} = I_{SC}$:

$$V_{OC} = V(I = 0) = m \cdot V_T \cdot ln\left(\frac{I_{SC}}{I_S} + 1\right) \quad (4.15)$$

Already with very small currents the value of 1 for $I_{SC}/I_S$ can be ignored so that, in a simplified manner the equation becomes:

$$V_{OC} = m \cdot V_T \cdot ln\left(\frac{I_{SC}}{I_S}\right) \quad (4.16)$$

# FILL FACTOR

The *fill factor* $FF$, describes the relationship of MPP power and the product from open circuit voltage and short circuit current (see Figure 4.12). As depicted, $FF$ shows the size of the area under the MPP working point compared to the area $V_{OC} \cdot I_{SC}$:

$$FF = \frac{V_{MPP} \cdot I_{MPP}}{V_{OC} \cdot I_{SC}} = \frac{P_{MPP}}{V_{OC} \cdot I_{SC}} \quad (4.17)$$

The fill factor is a measure for the quality of a cell; typical values for silicon cells are between 0.75–0.85 and in the region of thin film materials they are between 0.6–0.75.

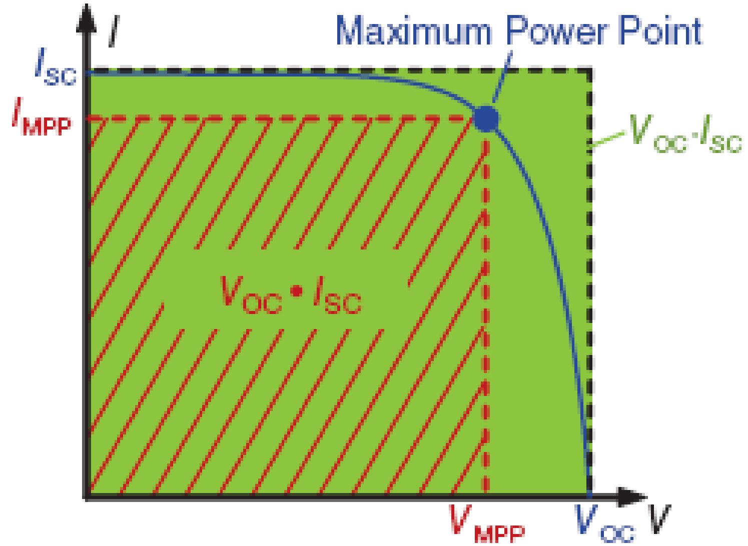


**Figure 4.12** The fill factor gives the relationship of the shaded to the gray background surface

# EFFISIENSI

The efficiency of a solar cell describes what portion of the optical power $P_{Opt}$ incident on the cell is output as electrical energy $P_{MPP}$ again.

$$\eta = \frac{P_{MPP}}{P_{Opt}} = \frac{P_{MPP}}{E \cdot A} = \frac{FF \cdot V_{OC} \cdot I_{SC}}{E \cdot A} \tag{4.19}$$

with

$A$: cell area

**Typical efficiencies** of crystalline silicon cells are **between 15 and 22%**. The calculation of the efficiency is described in Section 4.6 in greater detail.

# PENGARUH SUHU

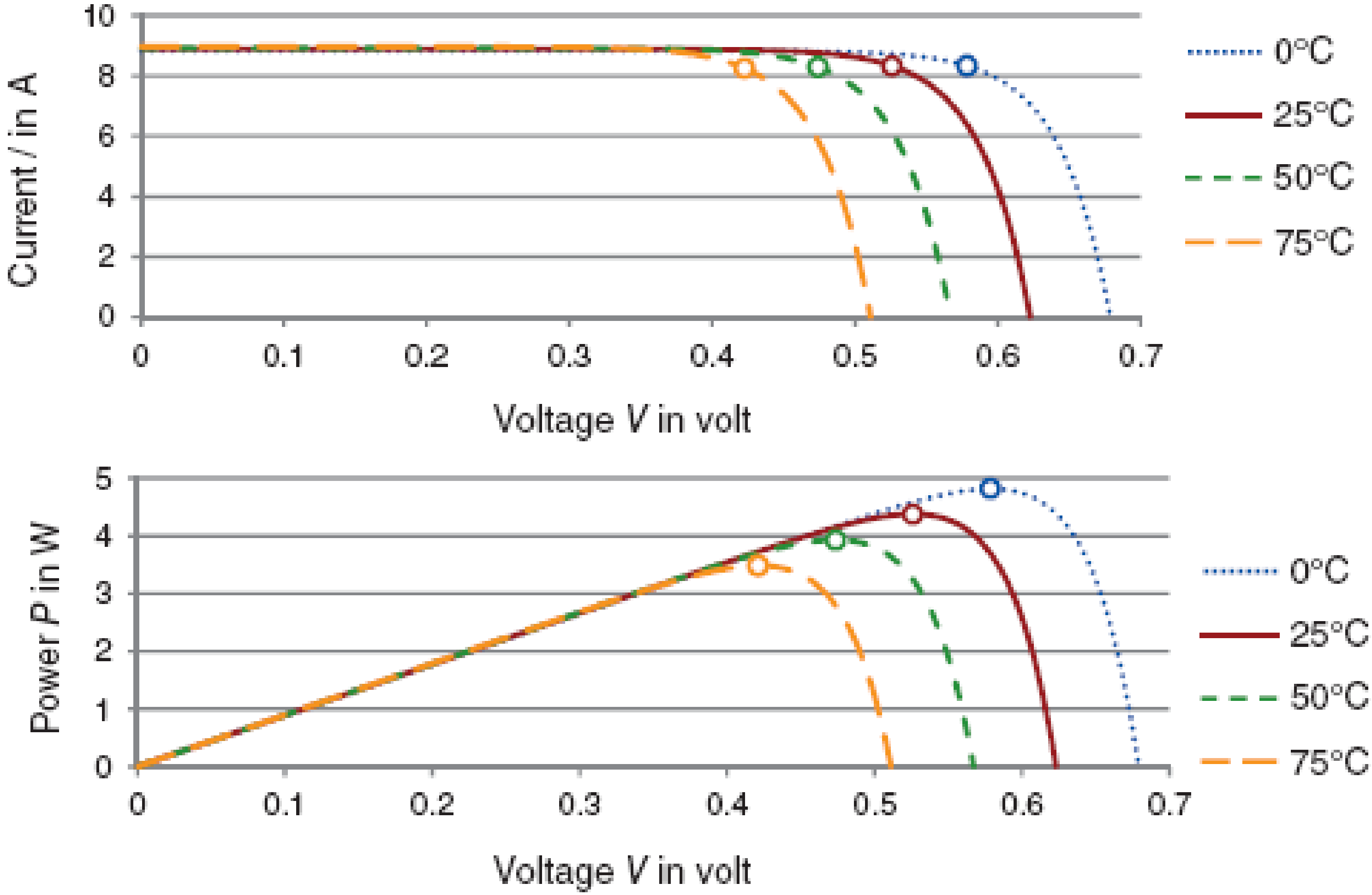


**Figure 4.13** Temperature-dependency of a Si solar cell as an example of the Bosch Solar Cell M-3BB: The circles indicate the position of the MPP [37]

# MODEL RANGKAIAN SOLAR SEL

This model is already known from Figure 4.11 and Equation 4.13:

$$I = I_{\mathrm{Ph}} - I_{\mathrm{D}} = I_{\mathrm{Ph}} - I_{\mathrm{S}} \cdot \left( e^{\frac{V}{m \cdot V_{\mathrm{T}}}} - 1 \right) \quad (4.27)$$

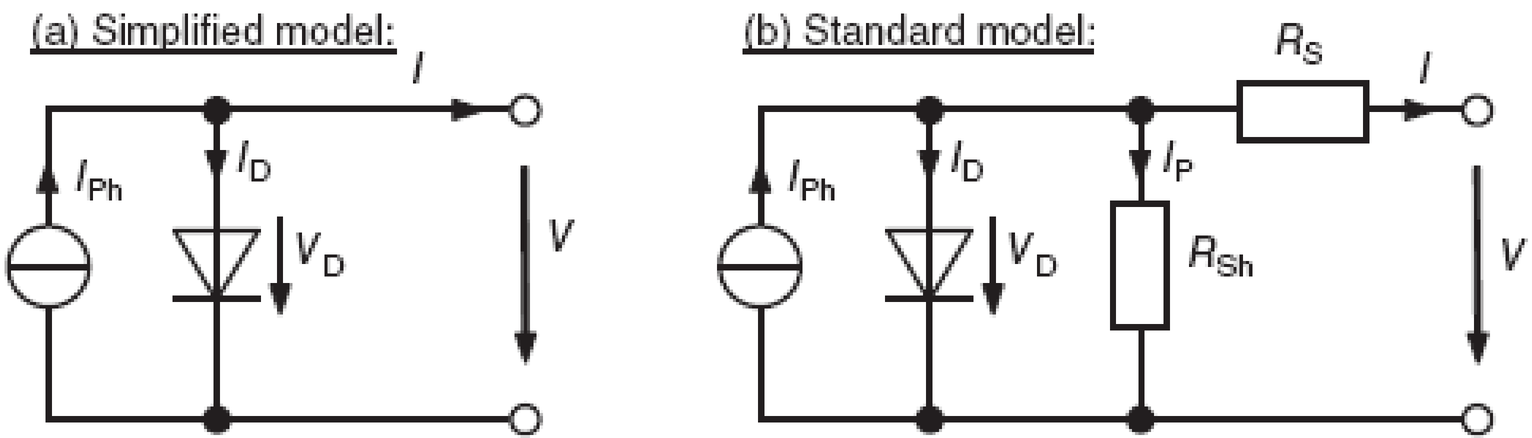


**Figure 4.14** Simplified and standard equivalent circuit for electrical description of solar cells and solar modules

# MODEL STANDAR (SATU DIODE)

The **standard model**, also called the **single-diode model** goes deeper into electrical losses in the solar cell (Figure 4.14(b)). The **series resistance $R_S$** describes especially the ohmic losses in the front contacts of the solar cell and at the metal-semiconductor interface. In contrast, leak currents at the edges of the solar cell as well as any point short circuits of the p-n junction are modeled by the **shunt resistance $R_{Sh}$**.

For deriving the characteristic curves of the standard model the current $I$ becomes $I = I_{Ph} - I_D - I_{Sh}$ and we find $I_{Sh}$ as:

$$I_{Sh} = \frac{V_D}{R_{Sh}} = \frac{V + I \cdot R_S}{R_{Sh}} \tag{4.28}$$

This gives the **characteristic curve equation of the standard model**:

$$I = I_{Ph} - I_S \cdot \left( e^{\frac{V + I \cdot Rs}{m \cdot V_T}} - 1 \right) - \frac{V + I \cdot R_S}{R_{Sh}}$$

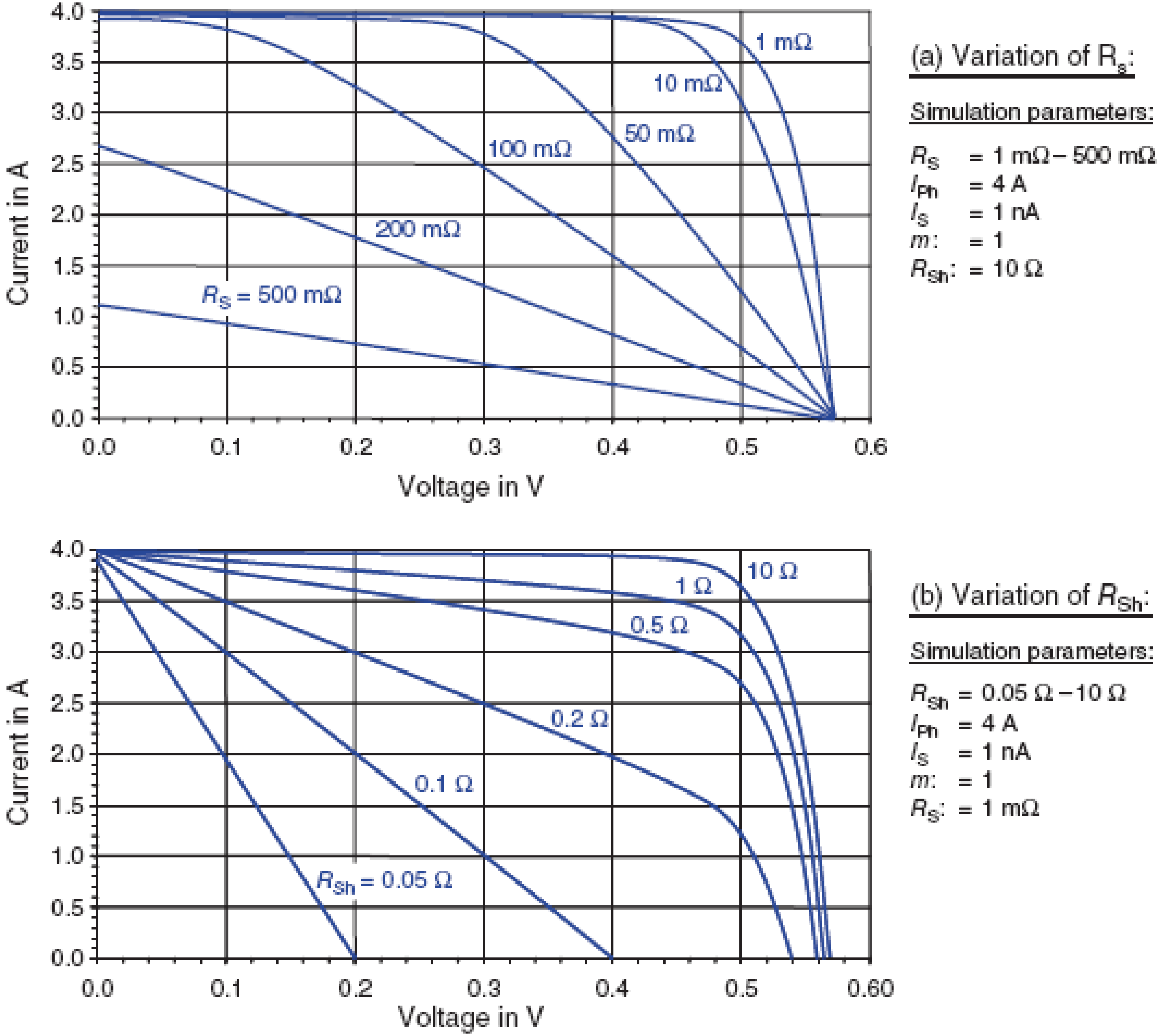


**Figure 4.15** Influence of series resistance $R_S$ and shunt resistance $R_{Sh}$ on the solar cell characteristic curve: The fill factor decreases significantly with rising $R_S$ and falling $R_{Sh}$

# MODEL DUA DIODE

In these cases one makes use of the **two-diode model** in which the **diffusion current** is modeled by means of a diode with an **ideality factor of 1** and a **recombination current** through an additional diode with an **ideality factor of 2** (Figure 4.16).

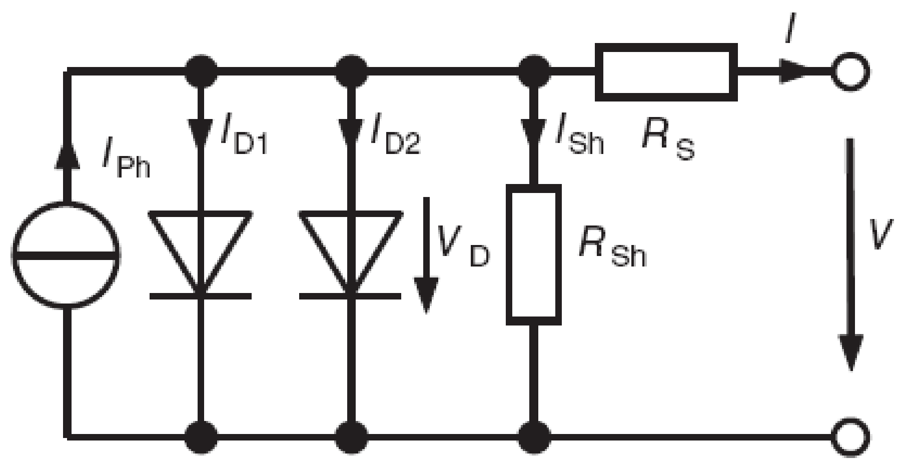


**Figure 4.16** The two-diode model for possible exact modeling of the solar cell characteristic curve

$$I = I_{\mathrm{Ph}} - I_{\mathrm{S1}} \cdot \left( e^{\frac{V + I \cdot R_{\mathrm{S}}}{V_{\mathrm{T}}}} - 1 \right) - I_{\mathrm{S2}} \cdot \left( e^{\frac{V + I \cdot R_{\mathrm{S}}}{2 \cdot V_{\mathrm{T}}}} - 1 \right) - \frac{V + I \cdot R_{\mathrm{S}}}{R_{\mathrm{Sh}}}$$