Organic Electronic Devices

Week 4: Organic Photovoltaic Devices
Tutorial 4.1: Homework Solutions

Bryan W. Boudouris
Chemical Engineering
Purdue University
Solutions to Problem 1

• Problem Statement

Given the data in the accompanying Excel file, estimate the short-circuit current density, open-circuit voltage, and fill factor of the device if the active area is 0.044 cm\(^2\). Note that the data are given as voltage and raw current. Finally, calculate that power conversion efficiency of the device, if the intensity of the incoming radiation was 100 mW cm\(^{-2}\).

• Solution

The short-circuit current density is the current density at no applied voltage.

\[
J_{sc} = \frac{|I(V = 0)|}{0.044 \text{ cm}^2} = \frac{4.3 \times 10^{-4} \text{ A}}{0.044 \text{ cm}^2} = 9.77 \text{ mA cm}^{-2}
\]

The open-circuit voltage is the voltage where the overall current is zero.

\[
V_{oc} = |V(I = 0)| = 0.59 \text{ V}
\]
Solutions to Problem 1 (Continued)

• Problem Statement

Given the data in the accompanying Excel file, estimate the short-circuit current density, open-circuit voltage, and fill factor of the device if the active area is 0.044 cm². Note that the data are given as voltage and raw current. Finally, calculate that power conversion efficiency of the device, if the intensity of the incoming radiation was 100 mW cm⁻².

• Solution

The fill factor is a measure of the “squareness” of the curve.

\[
FF = \frac{J_{MPP} \times V_{MPP}}{J_{sc} \times V_{oc}} \times 100\% = \frac{9.49 \, mA \, cm^{-2} \times 0.42 \, V}{9.77 \, mA \, cm^{-2} \times 0.59 \, V} \times 100\% = 69.1\%
\]

The power conversion efficiency is:

\[
\eta = \frac{J_{SC} \times V_{OC} \times FF}{P_{in}} = \frac{9.77 \, mA \, cm^{-2} \times 0.59 \, V \times 69.1\%}{100 \, mW \, cm^{-2}} = 3.98\%
\]
Solutions to Problem 2

• Problem Statement

Assume that a solar cell is behaving as an ideal diode at T = 300 K. The photocurrent density is 10 mA cm$^{-2}$ and the reverse bias saturation current density in the dark is 10$^{-4}$ mA cm$^{-2}$. Predict what the open-circuit voltage of the device will be.

• Solution

\[
V_{oc} = \frac{n kT}{q} \ln \left( \frac{J_{photo}}{J_s} + 1 \right)
\]

Because the cell is behaving ideally, the ideality factor (n) is equal to 1.

\[
V_{oc} = \frac{(1)(0.026 \cdot C - V)}{1 \cdot C} \ln \left( \frac{10 \text{ mA cm}^2}{10^{-4} \text{ mA cm}^2} + 1 \right)
\]

\[
V_{oc} = 0.30 \text{V}
\]
Solutions to Problem 3

• Problem Statement

Two organic photovoltaic cells are stacked together to make a tandem solar cell. The fill factors of each of the devices are ~70% each. The open-circuit voltage and the short-circuit current density of the front cell are 0.85 V and 10.0 mA cm\(^{-2}\), respectively. The open-circuit voltage and the short-circuit current density of the back cell are 0.70 V and 12.5 mA cm\(^{-2}\), respectively. Predict the open-circuit voltage and short-circuit current density of the tandem cell composed of these two cells.

• Solution

• If the fill factor of the first sub-cell (FF\(_1\)) is similar to the fill factor of the second sub-cell (FF\(_2\)) then the short-circuit current density of the tandem cell will be limited by the short-circuit current density of the lower-performing cell.

• The open-circuit voltage of the tandem cell can be as high as the summation of the open-circuit voltage values of the two individual sub-cells.
If the fill factor of the first sub-cell (FF₁) is similar to the fill factor of the second sub-cell (FF₂) then the short-circuit current density of the tandem cell will be limited by the short-circuit current density of the lower-performing cell.

The open-circuit voltage of the tandem cell can be as high as the summation of the open-circuit voltage values of the two individual sub-cells.

\[ FF_1 \approx FF_2 = FF; \quad (J_{sc})_{min} \approx J_{sc}; \quad V_{oc} \approx V_{oc_1} + V_{oc_2} \]

\[ \eta_{Tandem} \approx \frac{(J_{sc})_{min} \times FF \times [V_{oc_1} + V_{oc_2}]}{P_{in}} \]

\[ J_{sc} \approx 10 \text{ mA cm}^{-2}; \quad V_{oc} \approx 0.85V + 0.70V = 1.55V \]

\[ \eta_{Tandem} \approx \frac{10 \text{ mA cm}^{-2} \times 70\% \times [1.55V]}{100 \text{ mW cm}^{-2}} = 10.85\% \]
Solutions to Problem 4

• Problem Statement

Select at least 4 properties of materials used as electrode-modifying layers (i.e., organic-metal interlayers) in organic photovoltaic devices.

• Solution

Properties of Interlayer Materials

• The interlayer materials should have a transport level (in most cases this is the work function) of the transport layer match the LUMO level of the electron-accepting material or the HOMO level of the hole-transporting layer.

• The interlayer materials should be relatively good conductors of charge in order to prevent an increase in the series resistance.

• The interlayer materials should be able to be coated in a relatively straightforward manner and as thin films (~20 nm).

• The interlayer materials should form continuous thin films in order to prevent pinhole defects.