Parasitic resistance effects of split-spectrum solar cell performance

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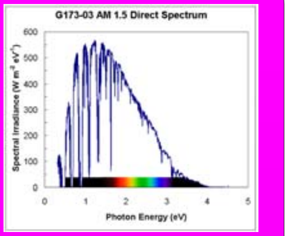
Introduction

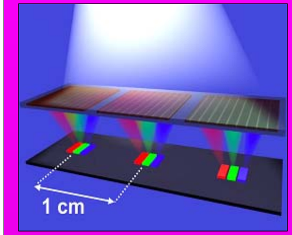
General principle of a semiconductor solar cell

Solar cells absorb photons of energy greater than the band-gap (E_g), and convert the energy of each photon to electrical energy, which is less than the band-gap.



AM 1.5 solar spectrum provides incident photons to the solar cells. Solar cells absorb photons with energy greater than the band-gap.

How can we effectively use a broad range of the solar spectrum?



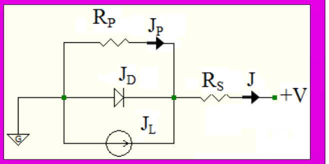
A lateral array of solar cells. Each color represents a cell optimized for the split region of the solar spectrum.

Split the solar spectrum with diffractive elements and focus it on lateral arrays of solar cells optimized for the narrow bands. This allows for more efficient energy conversion than a single type of cell that covers the whole spectrum.

Limitations to consider

We explore inevitable parasitic factors, specifically series and parallel resistances.

Series resistance (R_S) models the resistance of the cell material and contacts.



Solar cell circuit schematic. Note: $J_L < 0$. Cell voltage (V) is measured across a load.

Parallel resistance (R_P) accounts for current leakage through the diode junction due to defects.

As a specific case, we consider an array of three InGaN cells having band-gaps of 0.7, 1.38, and 2.0 eV. This array is determined as having the highest efficiency assuming 100 sun concentration [1]

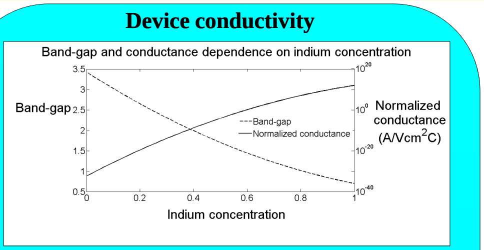
Model

We obtain the current density (J) of the solar cell by adding photo current density and the parasitic terms to the Shockley model of an ideal p-n junction diode.

$$J = J_L + J_S\left(e^{(V - JR_S)/V_T} - 1\right) + \frac{V - JR_S}{R_P} \qquad (\text{A/cm}^2)$$

J_L: photo current density (A/cm^2)
J_S: saturation current density (A/cm^2)
R_S: series resistance (Ωcm^2)
R_P: parallel resistance (Ωcm^2)
V: cell voltage (V)
V_T: thermal voltage (V)

Device conductivity



Small-gap devices have high conductivity whereas large-gap devices have low conductivity

Impact of parasitic elements in general

Open circuit voltage $J(V=V_{OC}) = 0$

V_{OC} is largest for $R_P \rightarrow \infty$ and decreases with decreasing R_P, i.e. increasing junction leakage. For sufficiently small R_P, V_{OC} will show significant reduction.

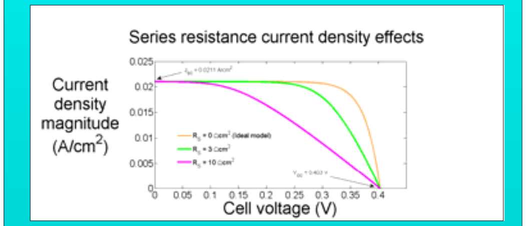
Short circuit current density $J_{SC} = J(V = 0)$

J_{SC} is affected by both R_S and R_P. Its magnitude is largest for $R_S = 0$ and $R_P \rightarrow \infty$

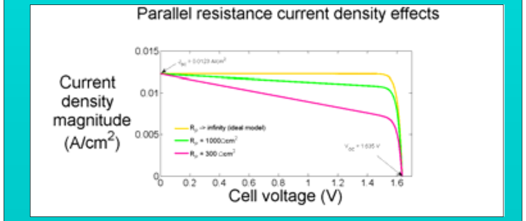
Specific results

Current density

Smaller gap devices have higher conductivity and consequently exhibit increased current sensitivity to series resistance. Analogously, junction leakage greatly affects the current for highly resistive devices.



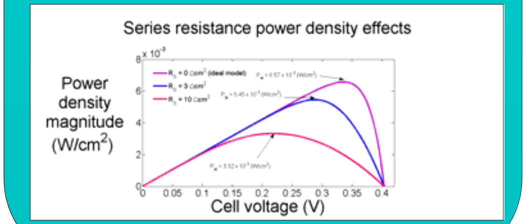
Series resistance most affects the 0.70 eV cell.



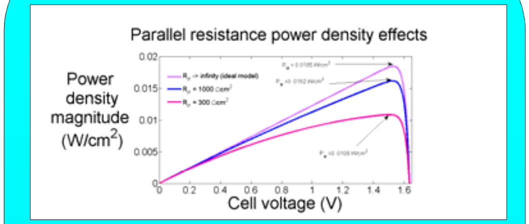
Parallel resistance most affects the 2.00 eV cell.

Power density (P)

P = J*V



Series resistance of 10Ωcm² reduces the maximum power point by about 50%, 14%, and 8%, from the ideal model, for the 0.7, 1.38, and 2.00 eV cells, respectively

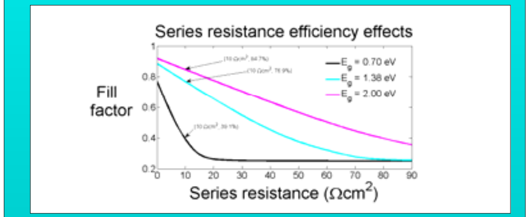


Parallel resistance of 300Ωcm² reduces maximum power point by about 5%, 25%. 41%, from the ideal mode, for the 0.7, 1.38, and 2.00 eV cells, respectively.

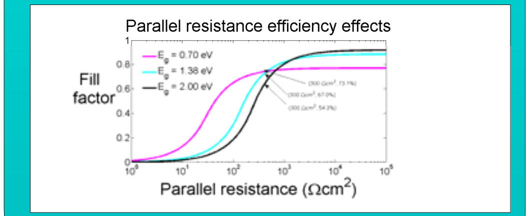
Solar cell efficiency

Fill factor (FF) expresses the solar cell conversion efficiency by relating the actual maximum obtainable power (P_{Max}) to the value (V_{OC}*J_{SC})

$$FF = \frac{P_{Max}}{V_{OC} J_{SC}}$$



An indium solar cell (E_g = 0.70 eV) shows the greatest sensitivity to series resistance with the fill factor reducing by 50.9% for 10 Ωcm². The 1.38 and 2.00 eV cells reduce by only 23.1 and 15.3 %, respectively.



Parallel resistance has most affect on the 2.00 eV cell, with the fill factor reducing by 45.7% for 300 Ωcm², whereas for the 1.38 and 0.70 eV cells, the fill factor reduces by 33 and 26.9 %, respectively.

Conclusion

Highly conductive low band-gap cells show greatest sensitivity to resistance of cell material and contacts.

Conversely, highly resistive high band-gap cells exhibit greatest performance degradation due to junction leakage.

In general parasitic resistances degrade solar cell performance. The type of resistance most significant in performance degradation depends on the cell material, i.e. E_g.

- **Reference: [1] Torrey, E.R., Krohn, J., Ruden, P.P., Cohen, P.I., Proceedings of the 35th IEEE Photovoltaic Specialists Conference, 2978 (2010)**

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