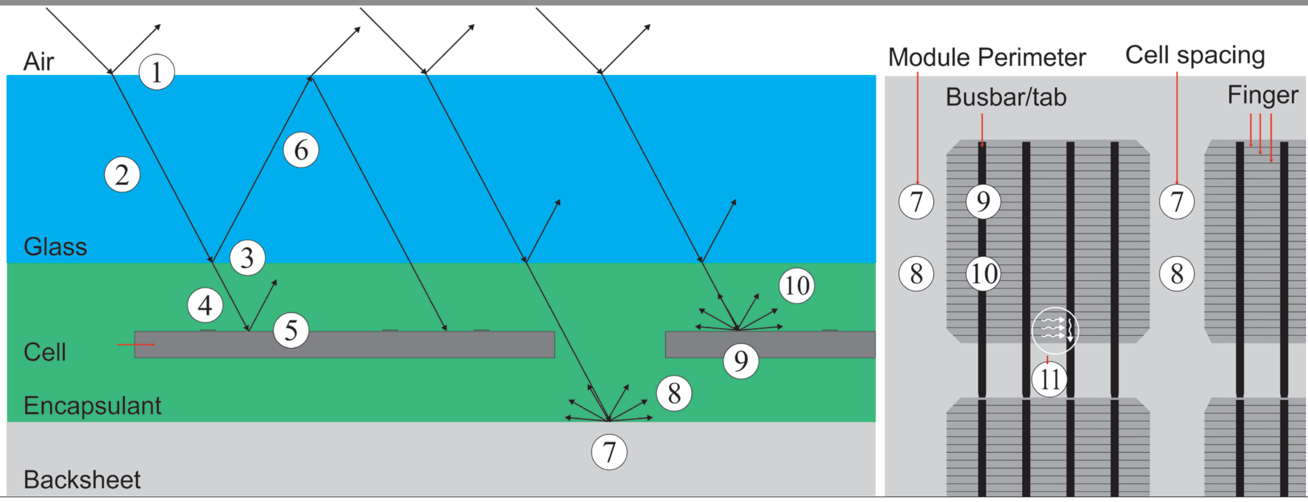
FRAUNHOFER CENTER FOR SILICON PHOTOVOLTAICS CSP



1 *Schematic cross section and top view of typical Si-based PV module and different loss and gain mechanisms:*

1 Reflection loss air/glass | 2 Absorption loss glass | 3 Reflection loss glass/encap | 4 Absorption loss encap. | 5 Coupling gain encap./cell | 6 Reflection at the inside of the glass | 7 Losses on module border and spacing | 8 Redirection gain from inactive area | 9 Shading losses of the ribbon | 10 light redirection gain from ribbon | 11 Ohmic losses in interconnection

CELL-TO-MODULE (CTM) CHARACTERIZATION AND OPTIMIZATION OF PV MODULES

CTM is defined as ratio of module power over sum of cell powers. Todays solar modules have the capability to exceed the power ot the cells, i.e. achieve a CTM>100%. This is possible with optical gains exceeding optical and electrical losses. A proper choice and mix of materials and technologies is necessary to achieve this ambitious goal.
Fraunhofer CSP can quantifiy potential gains and reducing losses in your modules or with your materials and technologies. This allows you to estimate implications on cost, value and potential margin.

Competences and Utilities

- Simulation
  - Optical
  - Electrical
- Updated measurement tools
  - Electroluminsence
  - Flasher
  - Optical spectroscopy
  - Loana loss analysis tool
- Fully automated fabrication line to produce prototype modules etc..)

Approach

- Electrical and optical characterization of each component of PV modules
- Fabrication of full scale PV modules with automated equipment to evaluate results
- Measurement and evaluation of PV modules with optimized and adapted components
- Novel module designs to achieve higher CTM ratios
- Simulation by means of analytical models and SPICE

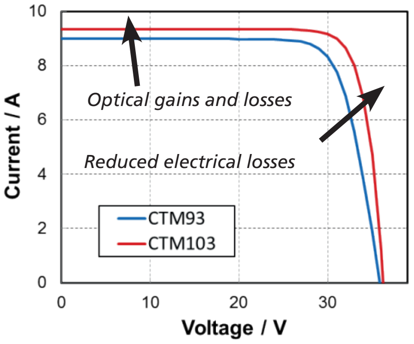
Fraunhofer Center for Silicon Photovoltaics CSP

Otto-Eissfeldt-Strasse 12
06120 Halle (Saale) | Germany

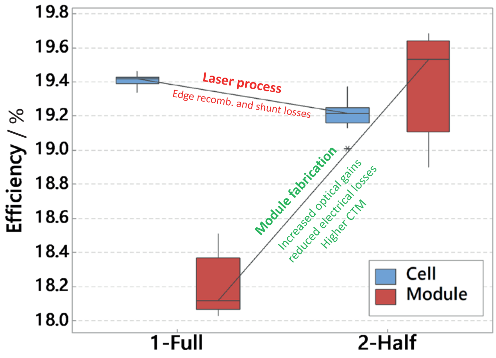
Contact

Hamed Hanifi
Phone +49 345 5589 5515
hamed.hanifi@csp.fraunhofer.de

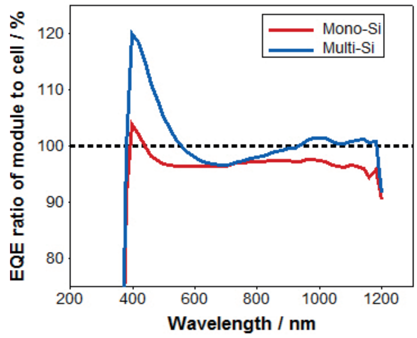
www.csp.fraunhofer.de



2 *Measured IV curves of optimized half-cell vs full-cell module.*



3 *Measured efficieny of half-cells and full-cell cells and modules*



4 *Spectral resolved EQE ratios of module to cell with different cell technologies.*

Optimizing Optics

Reducing reflection losses at all module material interfaces and absorption losses inside the materials typically increases your module power (see Fig. 7). It is important to understand that optimization of individual components does interact with other components. Spectral response of cells and module materials must be adapted to one another (see Fig. 5).

Optical gains from high reflection backsheets might require optimization of your cell gaps.

Bifacial modules require their very own optimization of optical properties.

Shading from your cell connection tabs interacts with your metallization geometry but also your electrical losses (see Fig. 2).

Reducing Electrical Losses

Electrical losses occur predominately in cell connector tabs. Increasing the width of the tabs reduced the electrical losses but increases optical shading losses at the same time. Proper optimization of your tab width is a challenges between STC power, energy yield at the field of application of your modules and module and cell layout. More busbars allow for narrower individual tabs.

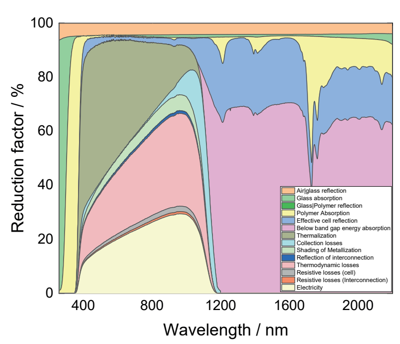
Half cells decrease electrical losses even further. More than 1.4% abs. per module can be gained with half cells (see Fig. 3).

Half cell modules offer shading tolerance and are especially suitable for desert applications and bifacial modules. But mechanical properties of cell cutting process must be optimized to avoid cell breakage in production and in the field.

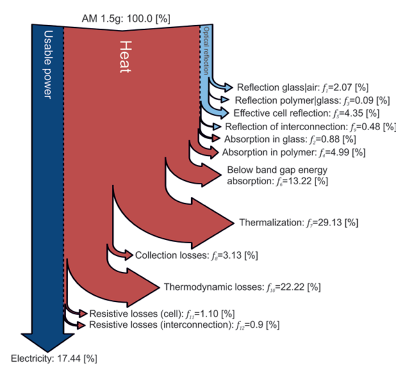
Understanding CTM

CTM is determined on standard and minimodule size by determining cell and module power. LED based flashers allow for quick spectral response analysis on cell and module level (see Fig. 4). Spacially resolved charcacterization methods like LBIC and EL are used to quantify losses of individual components.

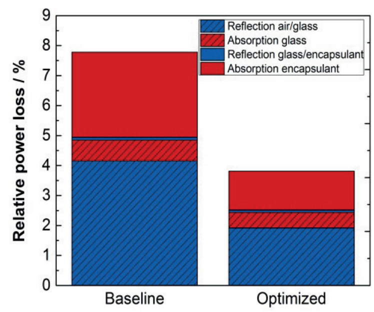
Spectral and electrical measurement of module components together with electrical and optical simulations provides an extended datasheet (see Fig. 5) to understand lost and gain mechanisms of PV modules under any reference spectrum (eg. AM1.5g or desert spectrum) and optimize the module components, module design and electrical interconnection for each region accordingly.



5 *Spectral resolved losses of a one-cell mini-module.*



6 *Spectral resolved losses of a one-cell mini-module.*



7 *Relative power loss on top stack for optimized and standard modules.*