Measurement techniques for bifacial solar cells

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Bifacial PV-devices

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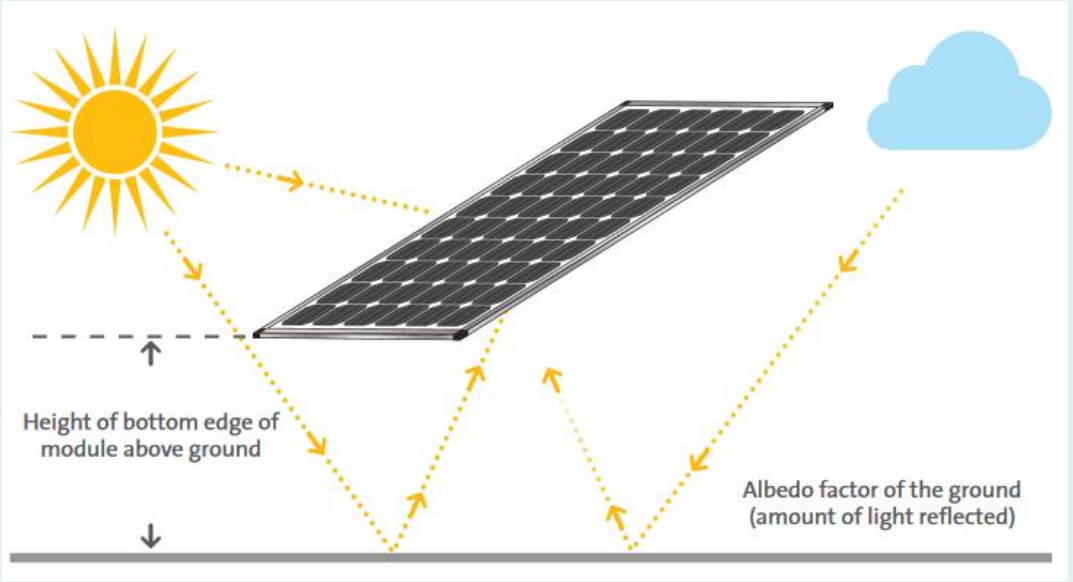
- IV measurements
  - to assess bifacial efficiency
  - To predict energy yield
- Increase in power output due to
  - Higher I_{sc} $\quad I_{sc.bi} = I_{sc.front} + x\, I_{sc.rear}$
  - Higher V_{oc} $\quad V_{oc.bi} = \frac{kT}{q} ln\left(\frac{I_{sc.bi}}{I_0} + 1\right)$
  - Higher P_{mpp} $\quad P_{mpp.bi} = I_{sc.bi}\, V_{oc.bi}\, FF_{bi}$

  x = Irradiance rear / Irradiance front



solarkingmi.com/assets/How-to-Maximize-Energy-Yield-with-Bifacial-Solar-Technology-SW9001US.pdf

- **Is a single side measurement sufficient to assess $P_{mpp.bi}$?**

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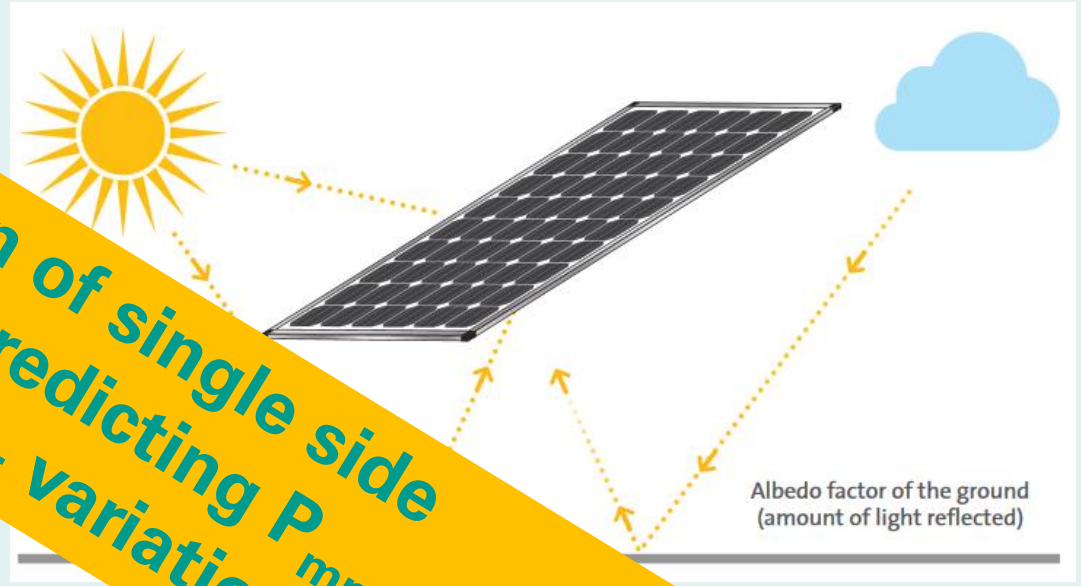
Analyze precision of single side measurement in predicting $P_{mpp.bi}$ and compare with $P_{mpp.bi}$ variations



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- **Is a single side measurement sufficient to assess $P_{mpp.bi}$?**

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Possible bifacial measurement techniques and equipment configurations

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Measurement	Standard System	System upgraded for G_E measurements	Bifacial Setup
Front STC + Calculate Bifacial Case (fixed bifaciality)	X	X	X
Front STC + Front G_E (fixed bifaciality)		X	X
Front STC + Rear STC + Mixed illumination (bifaciality measured)			X

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Setup description

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- One IUCT-3600 electronic cabinet
- 2 flash boxes, synchronized
- Decoupling of front and rear dark-chamber using 165 x 165 mm² large opening sufficient
- Triple class A from both sides
- Throughput 2200 wafers/hour @ 30 ms per level and up to 3000 wafers/hour @ 25 ms per level

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Measurement description

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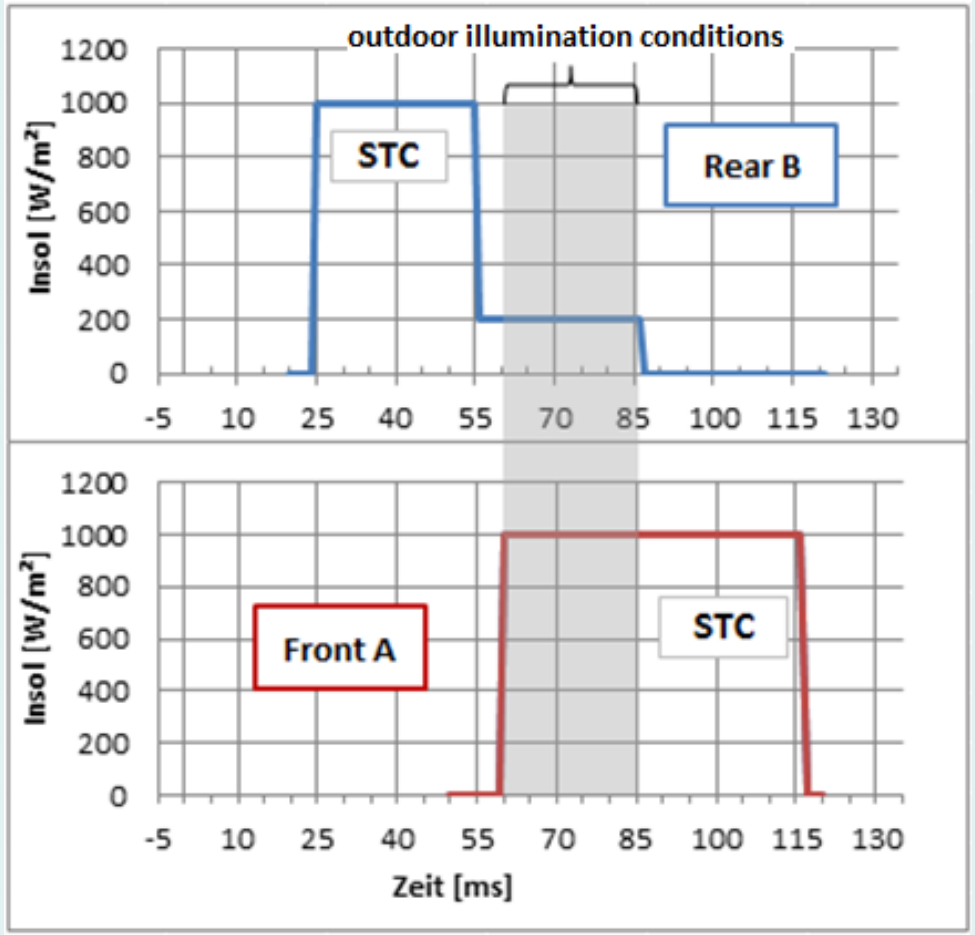
- Variable flash sequence with 3 freely chosable illumination levels, typically 30 ms each (depending on throughput)
- Maximum intensity of up to 1200 W/m² from each side
- Advanced hysteresis measurement in each level
- Combinable with EL and TG



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Decoupling of front and rear dark chamber

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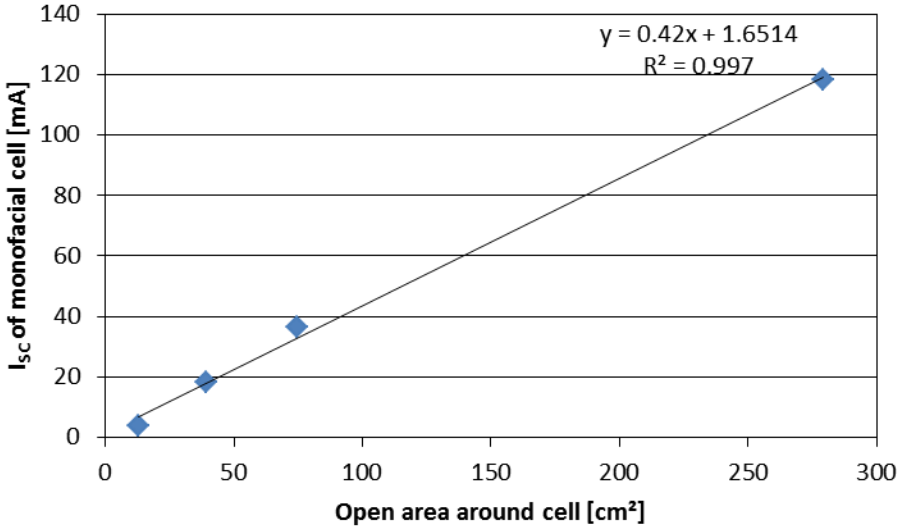
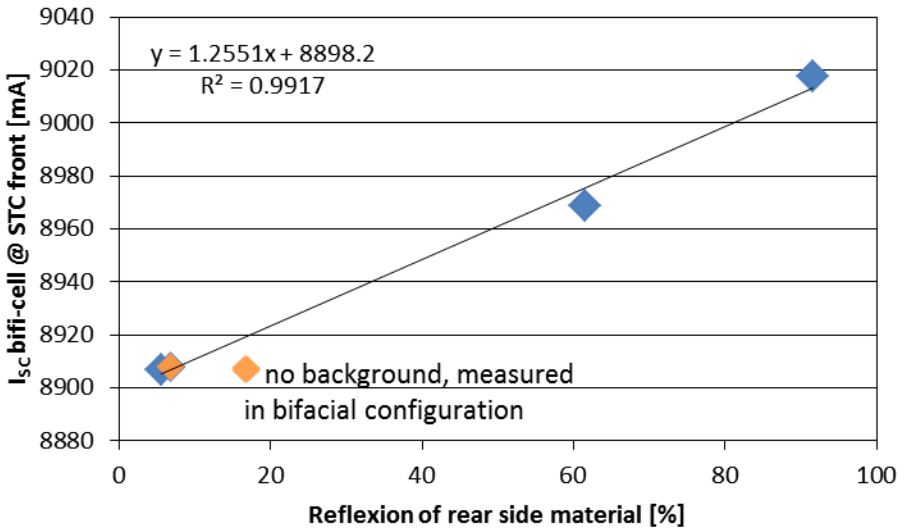
- Determine two contributions:
  - Light passing besides a cell: Variation of open gap besides a monofacial cell + measurement of I_{SC}
  - Light transmitted through the cell: Rear side reflectivity variation behind a bifacial cell
- Light passing besides the cell: I_{SC} < 20 mA for opening area < 40 cm²
- Light transmission through cell: I_{SC} < 10 mA, comparable to black background
- Monitor cell on both sides correct 50% of crosstalk





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Calculated impact on η_{front} and η_{rear}

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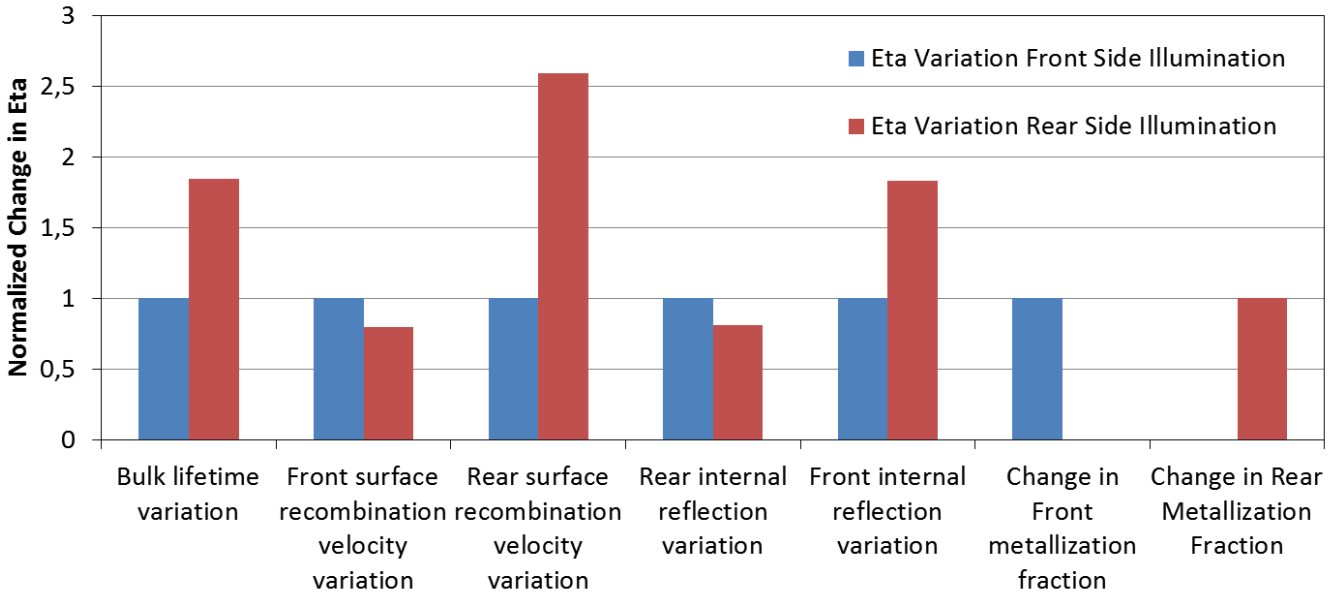
- Impact of solar cell parameters on η_{front} and η_{rear} is different
- Strong impact of bulk lifetime, surface recombination velocity and optical parameters
- Numerical values depend on cell architecture and performance



PC1D simulation of impact of parameter variations on front and rear efficiency

IV – parameters of base-cell simulated:
V_{OC}: 668.7 mV; J_{SC}: 39.56 mA/cm²; Eta: 22.04 %

K. Ramspeck et al., 3rd bifiPV workshop Miyasaki, Japan, 2016

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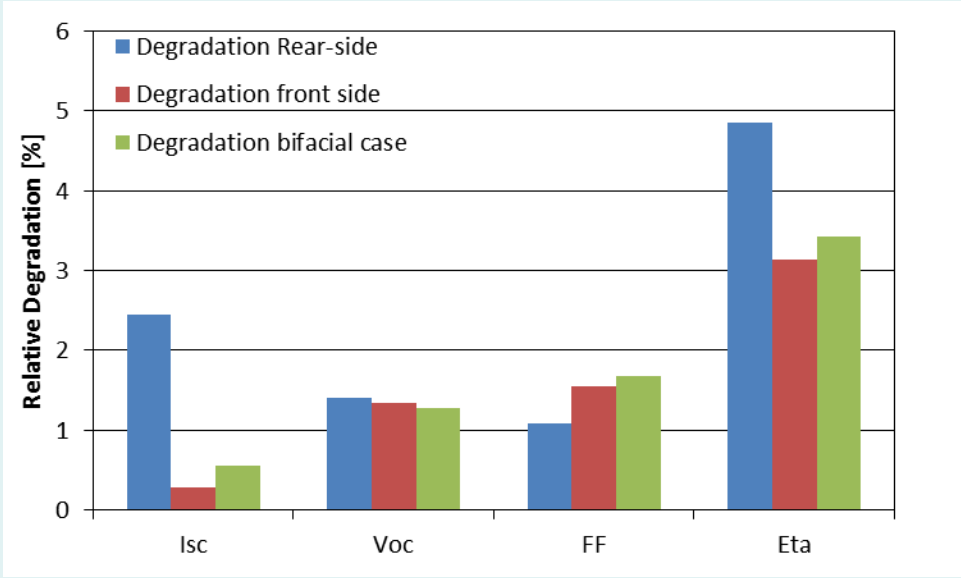
Degradation experiment to perform a parameter variation .h.a.l.m.

- Degradation of one solar cell by multiple flashing
- I_{SC} degradation takes place mainly on the rear side (factor of 8 stronger than front)
- Relative efficiency degradation is much stronger on rear than on front – impact in mixed case is 0.3% here
- Mixed I_{SC} degradation is 2 times stronger than I_{SC} degradation of front side



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Measurement results – Bifaciality variations

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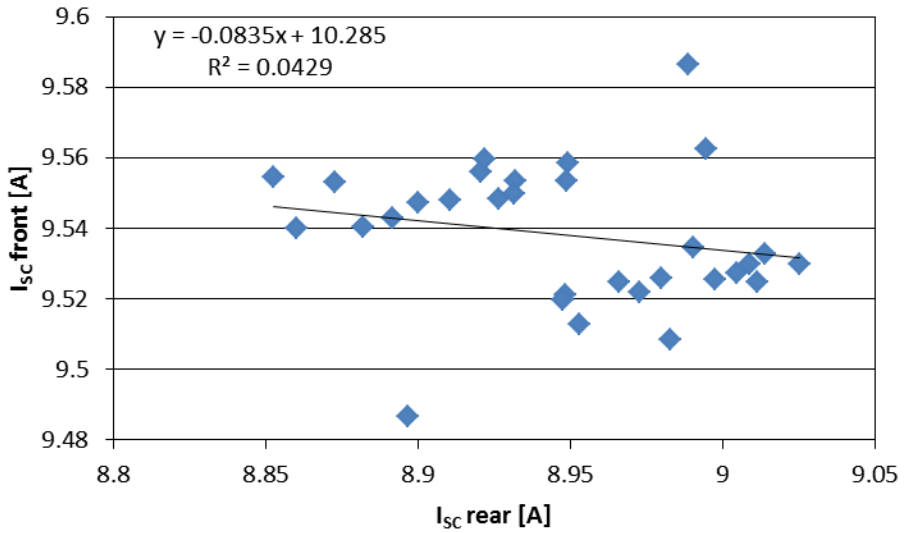
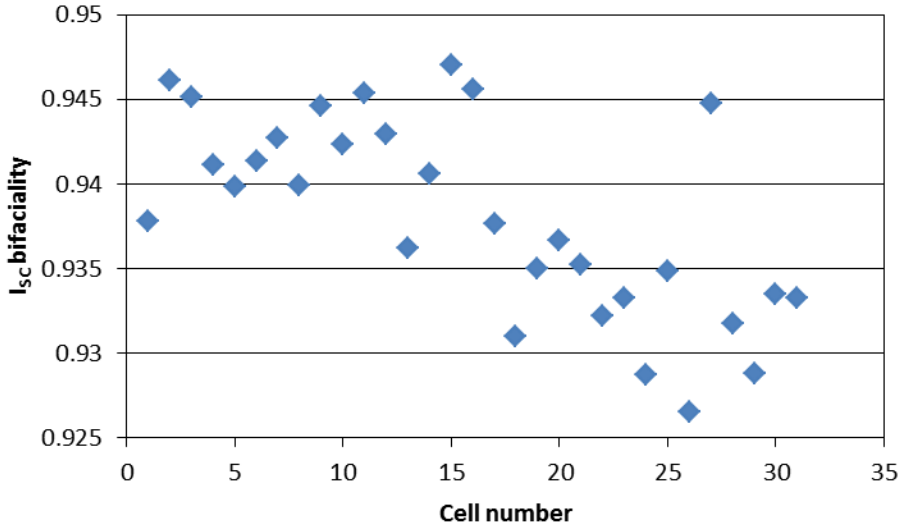
- 31 bifacial cells out of one box of one efficiency BIN class bought from industrial manufacturer
- **No correlation between I_{SC} – front and I_{SC} – rear**
- Bifaciality variation of 2 %
- FF (front to rear) and V_{OC} (front to rear) are linearly related to each other as expectable





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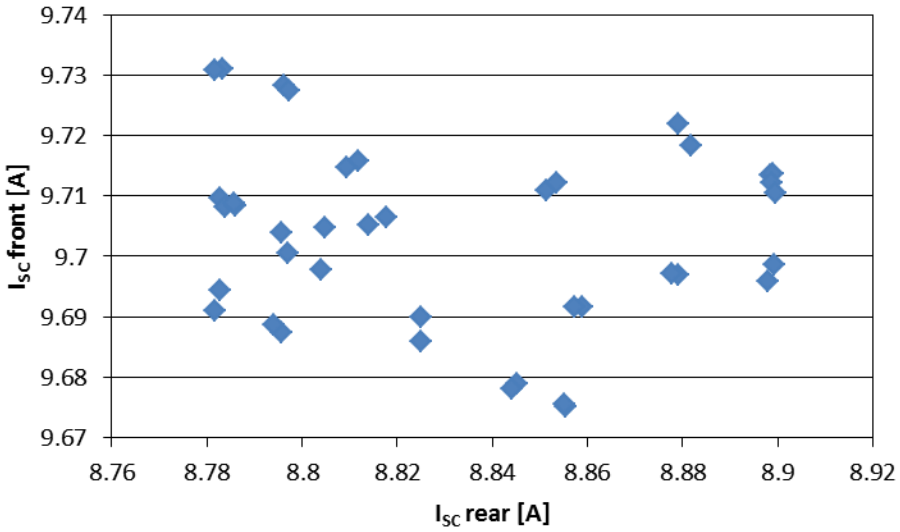
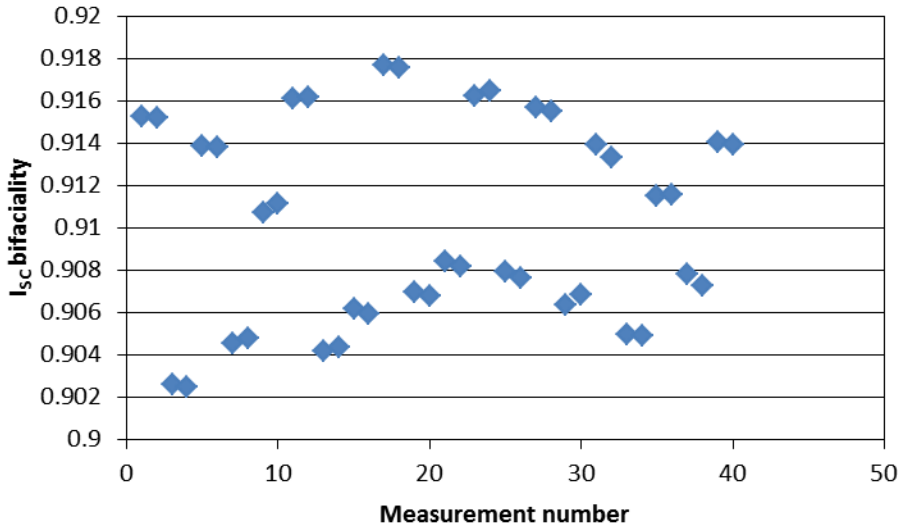
Measurement results – Bifaciality variations

- 20 cells from production, different cell concept and different manufacturer, each measured twice
- **No correlation between I_{SC} - front and I_{SC} – rear**
- Bifaciality varies by about 2 %
- Measurement repeatability is very high





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Measurement results – Bifaciality variations

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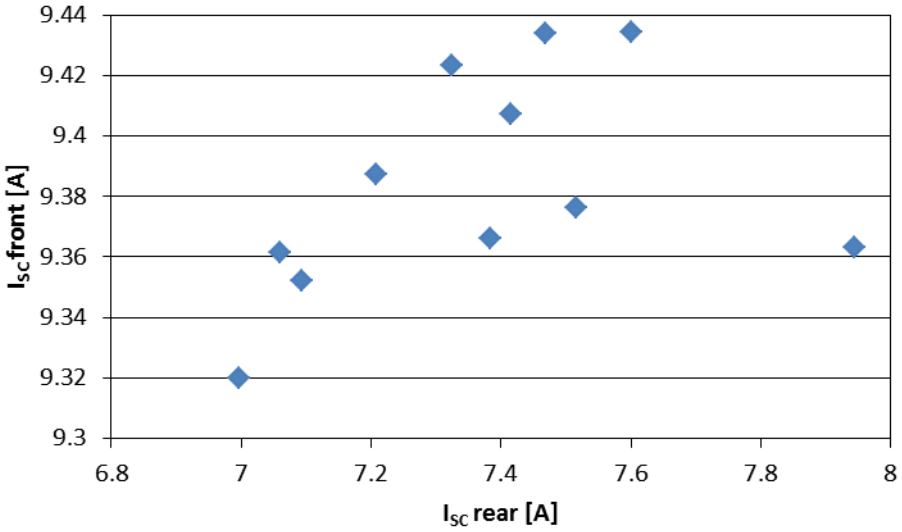
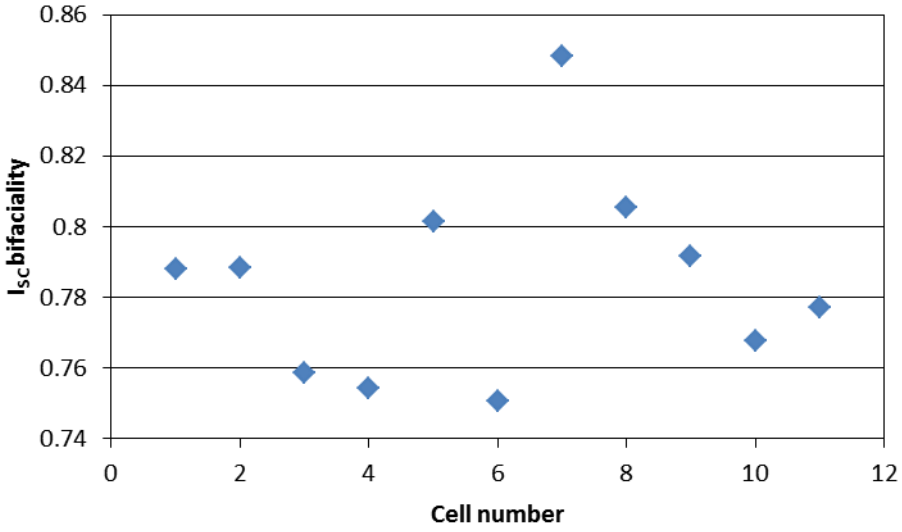
- 11 cells from laboratory production (?)
- **No correlation between I_{SC} - front and I_{SC} – rear**
- Bifaciality varies by about 10%
- Narrow distribution of front side I_{SC} and efficiency





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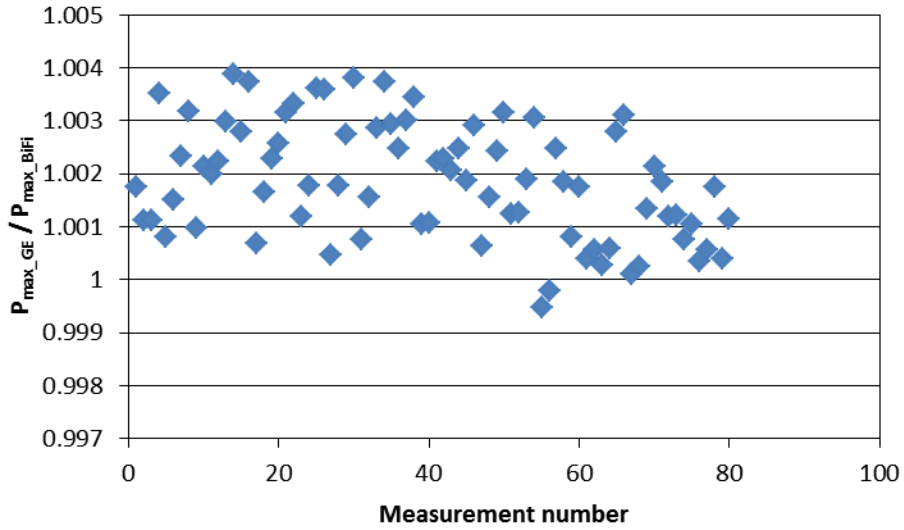
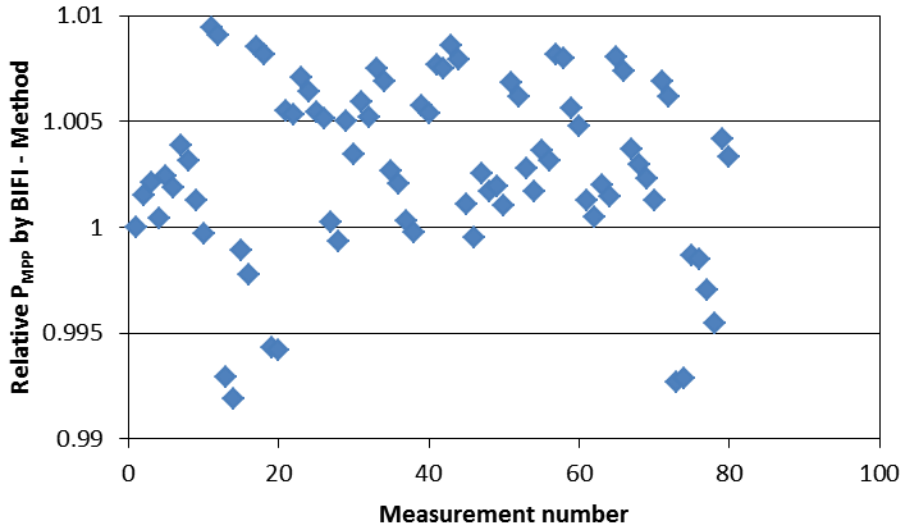
Comparison of bifacial illumination and G_E approach .h.a.l.m.

- Measured on 40 industrial fabricated bifacial cells
- Scatter caused by G_E compared to bifacial measurement: +/- 0.2%
- Equivalent to scatter of +/- 0.05%$_{abs}$ in efficiency
- Scatter covers >20% of total P_{MPP} variation of bifacial measurement
- Scatter scales linearly with intensity of rear side illumination used, here: 200 W/m²





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Comparison of STC + calculation and G_E approach

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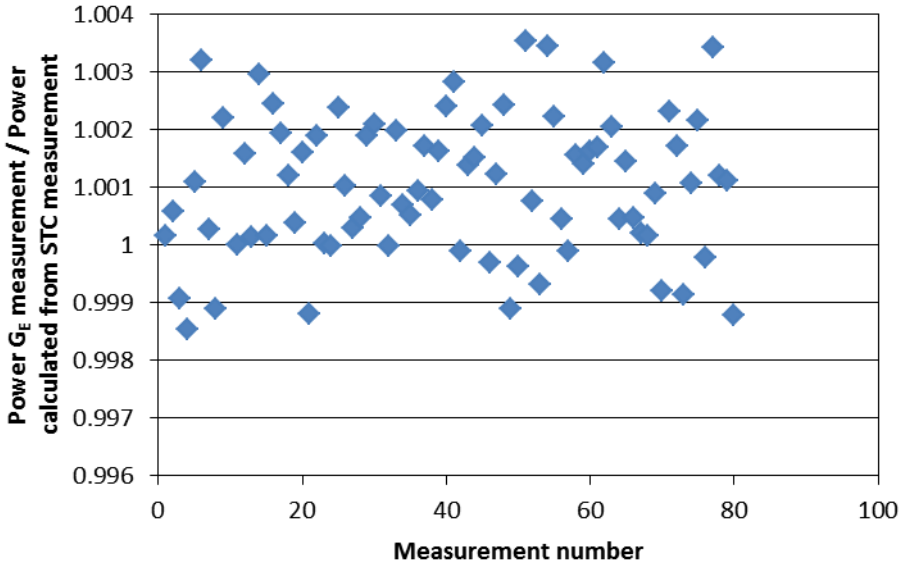
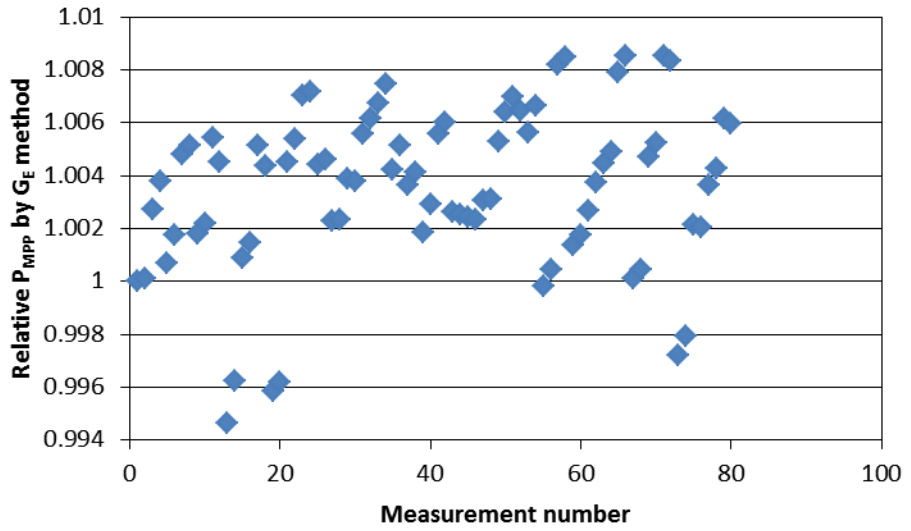
- Calculation of IV-curve @ GE from STC IV-data
- Scatter in calculated P_{MPP} is +/- 0.6%
- Scatter caused by calculation of $P(G_E)$ from STC adds +/- 0.2% uncertainty
- This is similar as the uncertainty added by G_E method compared to illumination from both sides





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Conclusion

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- Degradation experiment: I_{SC_rear} degrades 8x as strong as I_{SC_front}
- **No correlation between I_{SC_front} and I_{SC_rear} in all cell groups**
- Uncertainty added by G_E approach accounts for 20-30% of total efficiency spread
- STC front measurement + calculation of G_E: additional uncertainty of same size

Categorie	Standard System (Front STC + calculation)	System upgraded for G_E (Front STC + Front G_E)	Bifacial Setup (Front STC, Rear STC, Bifacial)
System invest	++	-	--
Precision	--	-	++
Process control	--	--	++
Sorter invest	++	++	0
Consumables	++	0	-
Process optimization	--	--	++

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