Technology simulation: A fast track to PV efficiency enhancement

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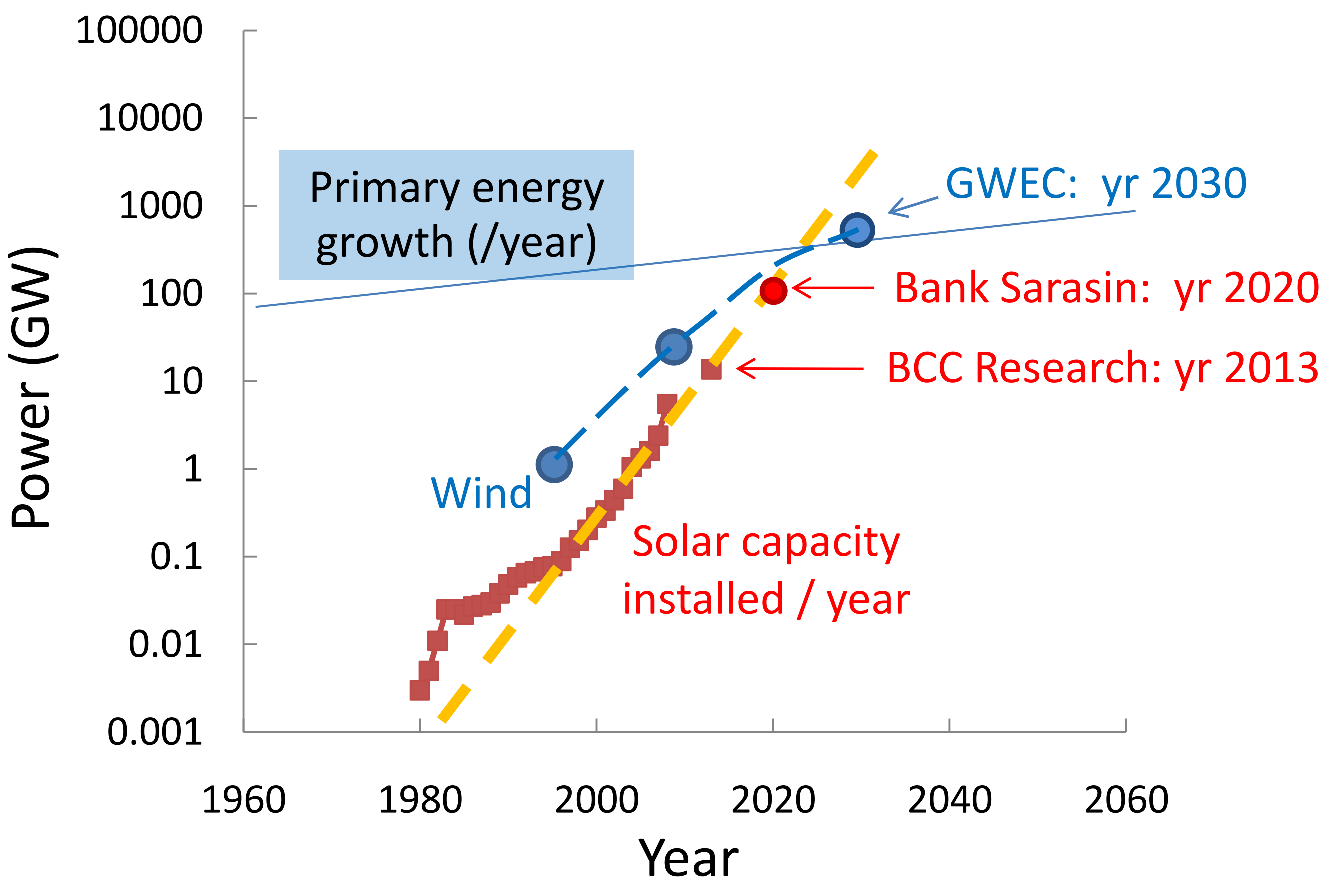
Background

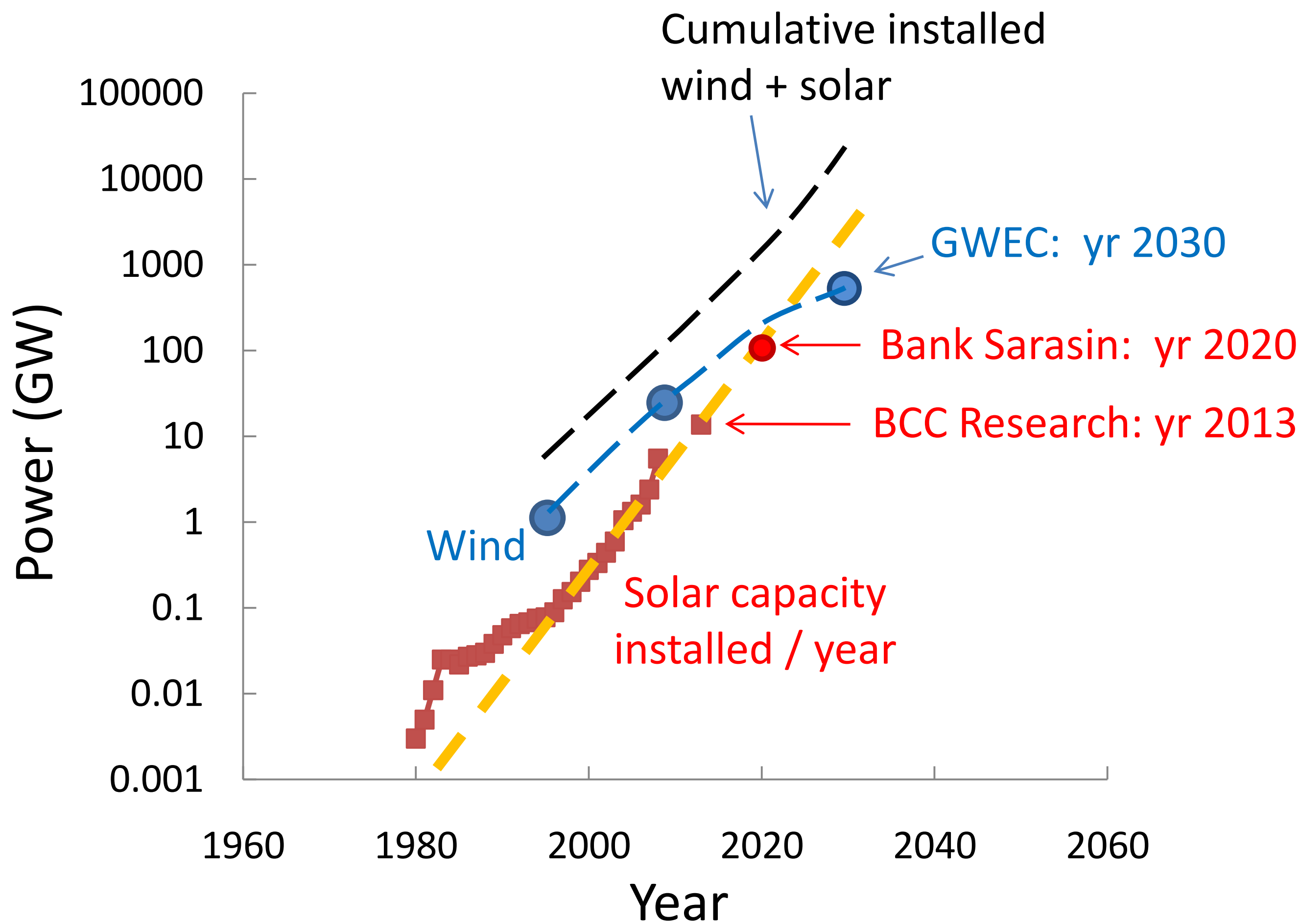
Global installed capacity / year



Capacity x2 every 30 months

Market saturation at ~1 TW/yr, ~100 G$/yr, ~ 2040

Global installed capacity / year



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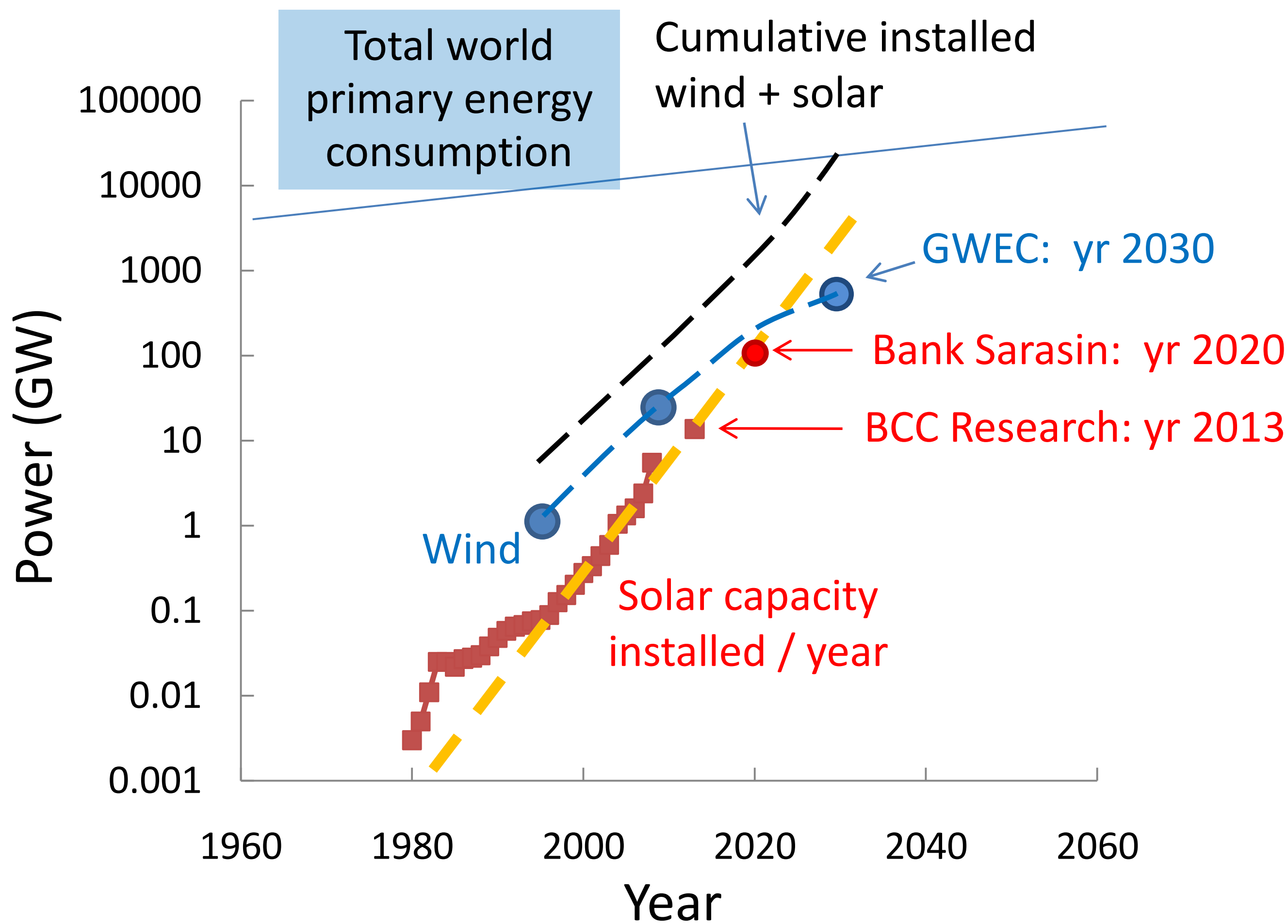

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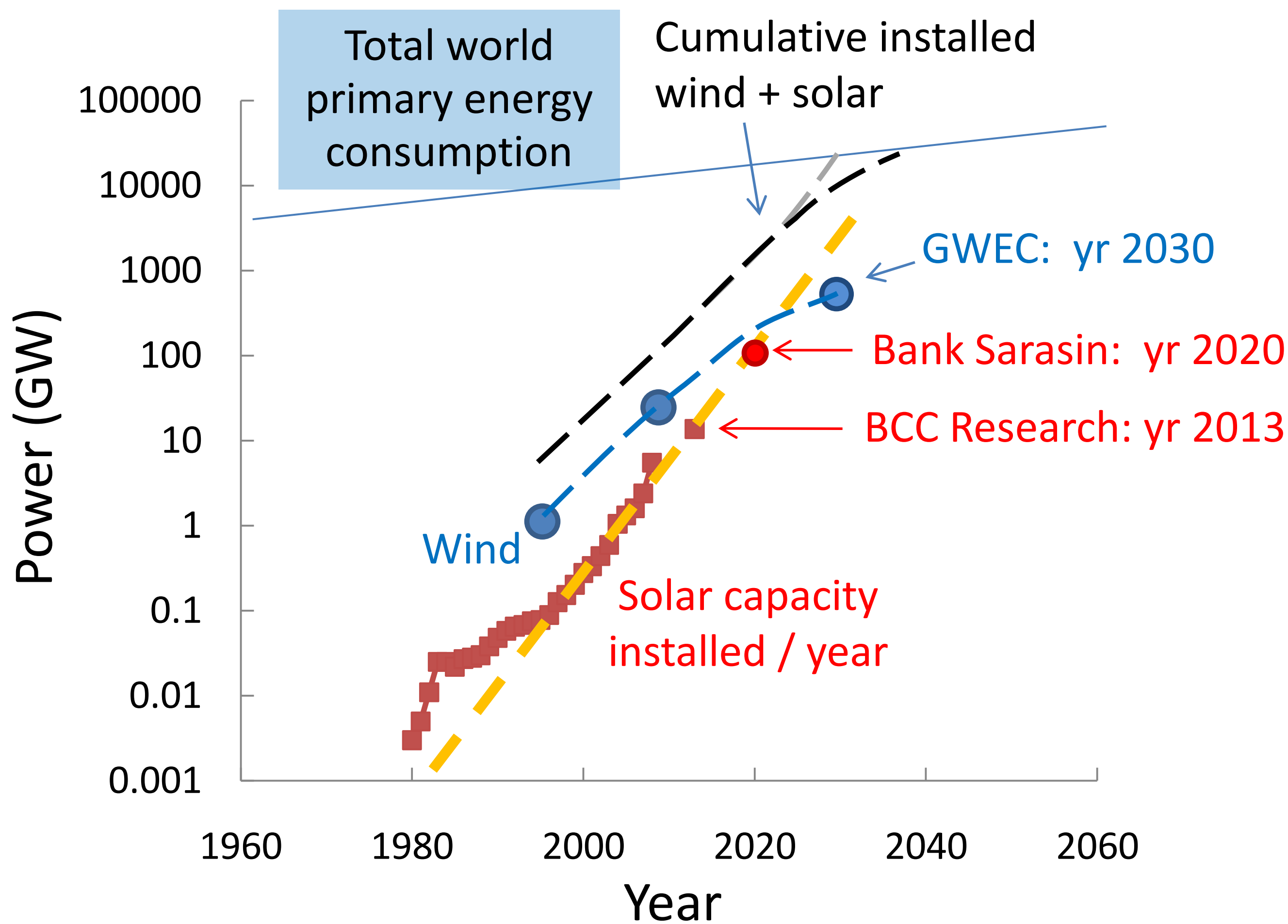

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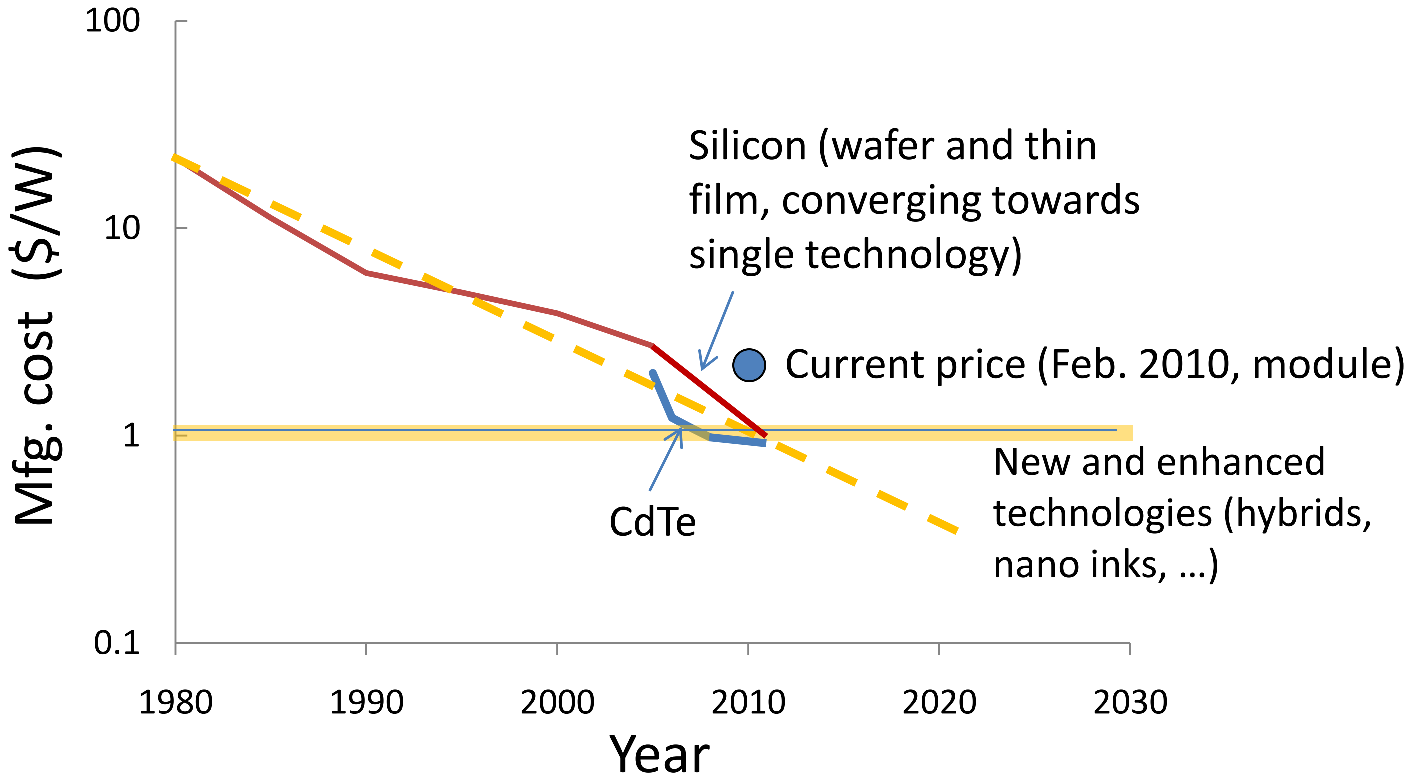
Production costs for PV

Exponential decrease due to (i) volume scaling, (ii) technology advances



Technology roadmap similar to the ITRS (International Technology Roadmap for Semiconductors) will emerge in the next few years as technology route becomes clearer

- continued exponential scaling of production cost and volume

Role of technology simulation in cost reduction

- Design better processes and architectures to:
  - increase efficiency
  - reduce production costs (throughput, capital equipment, materials)

- Save process development cost / time by replacing real process experiments by ‘virtual’ ones.

Requires deep understanding / modelling of materials. Currently possible for silicon-based PV. Useful to model other materials in future.

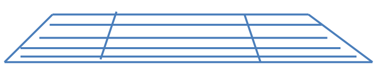
Technology simulation

Process simulation

Wafer

- Deposition
- Etch
- Diffusion
- Laser processing
- Deposition
- Diffusion
- Deposition

Cell



Structure, doping..

Device simulation

Structure, doping.. (assumed, or from process simulation)

- Apply boundary conditions (incident light, contacts)
- Compute internal currents, carrier recombination, potential distribution, etc.
- Extract cell parameters (efficiency, etc.)

Technology simulation

In the PV field only device simulation is widely used.

This is different from the semiconductor industry, where both process and device simulation are used.

Device simulation

Structure, doping.. (assumed)

Apply boundary conditions (incident light, contacts)

Compute internal currents, carrier recombination, potential distribution, etc.

Extract cell parameters (efficiency, etc.) for the assumed structure

Technology simulation

We apply integrated process and device simulation to PV

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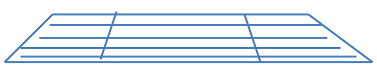

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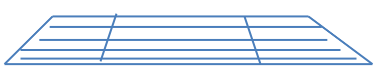

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Structure, doping.. (from process simulation)

- Apply boundary conditions (incident light, contacts)
- Compute internal currents, carrier recombination, potential distribution, etc.
- Extract cell parameters (efficiency, etc.)

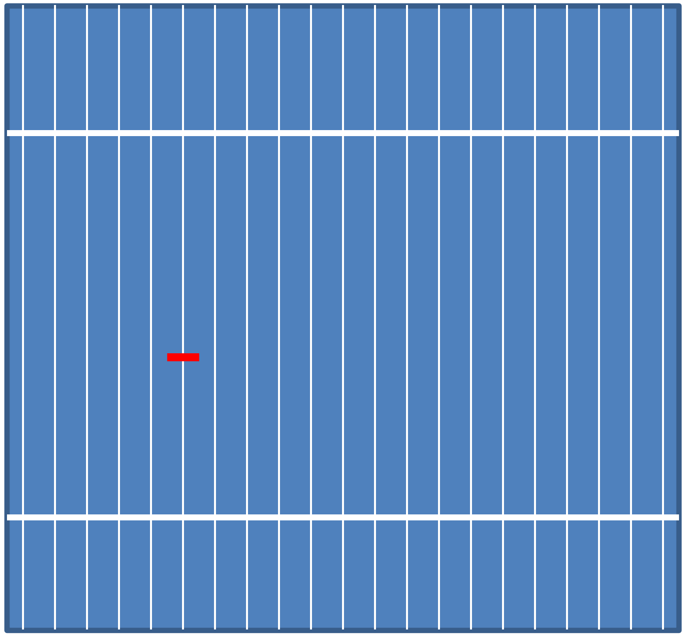
Reveals impact of process changes on cell efficiency in hours, not weeks!

An example:

Simulating the Narec LGBC cell process

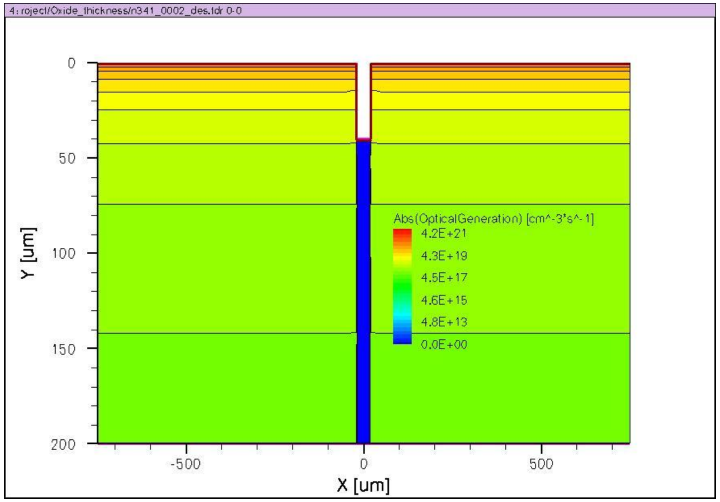
Defining a simulation element

PV cell



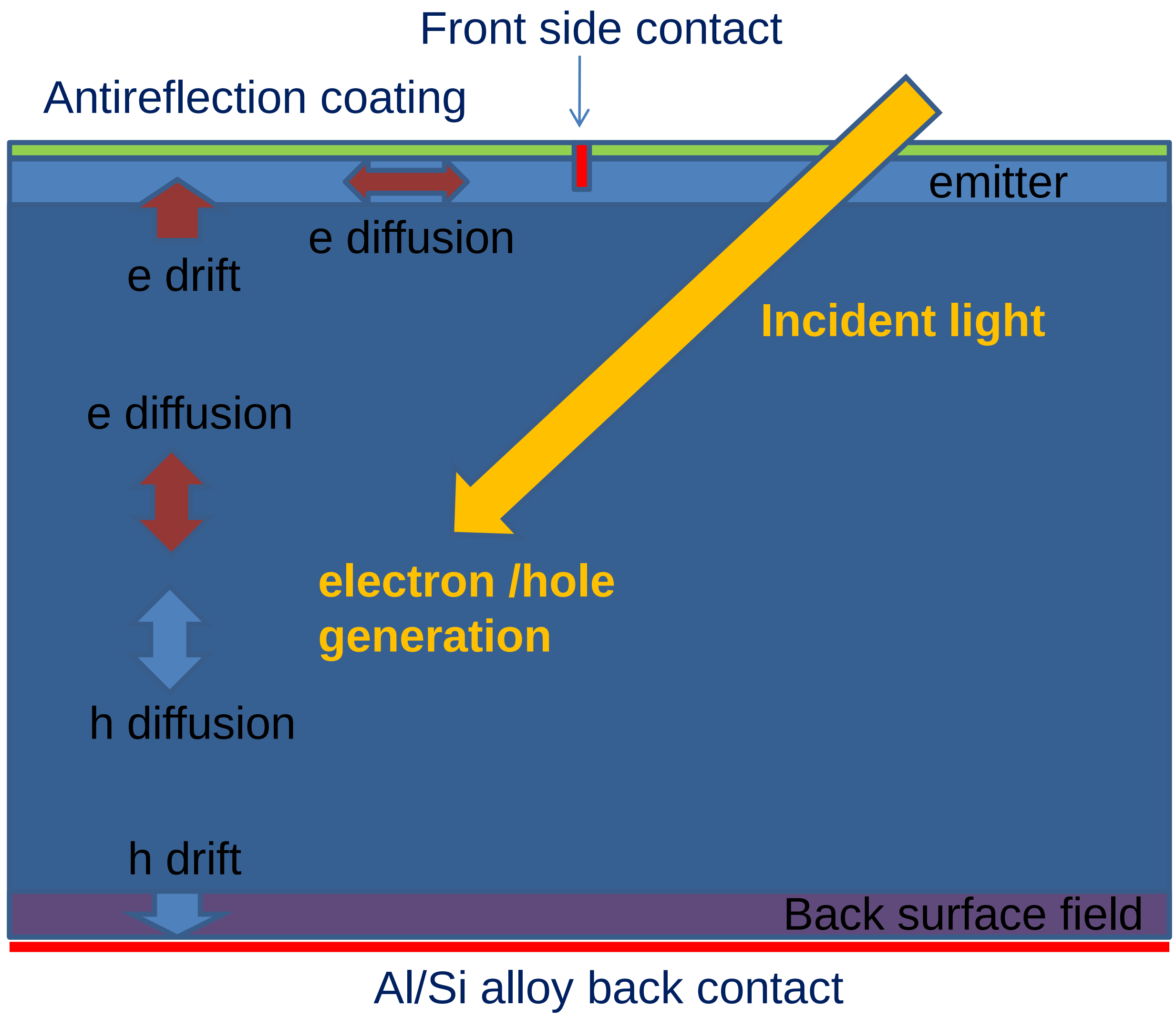
Simulation element

A section through cell at one location (e.g. red line in plan view to left), is repeated identically across the cell.



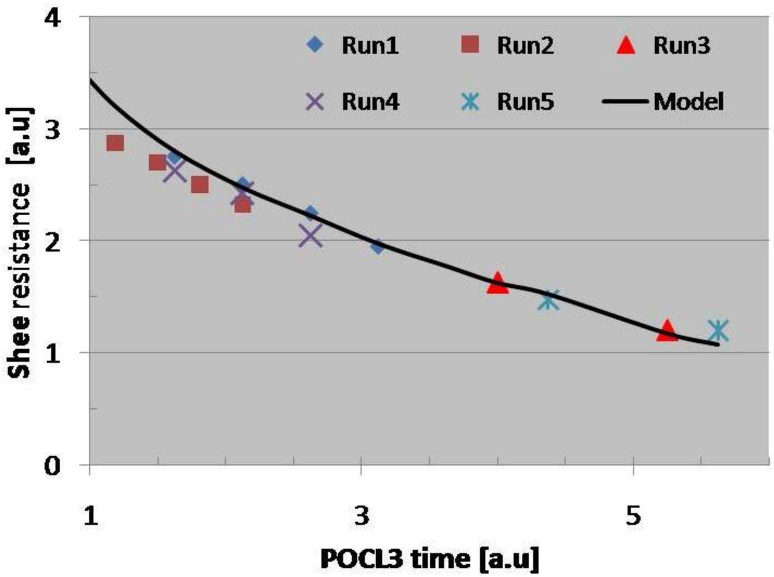
Need to look at only one small 'piece' to simulate the whole cell

Basic structure of cell and its operation

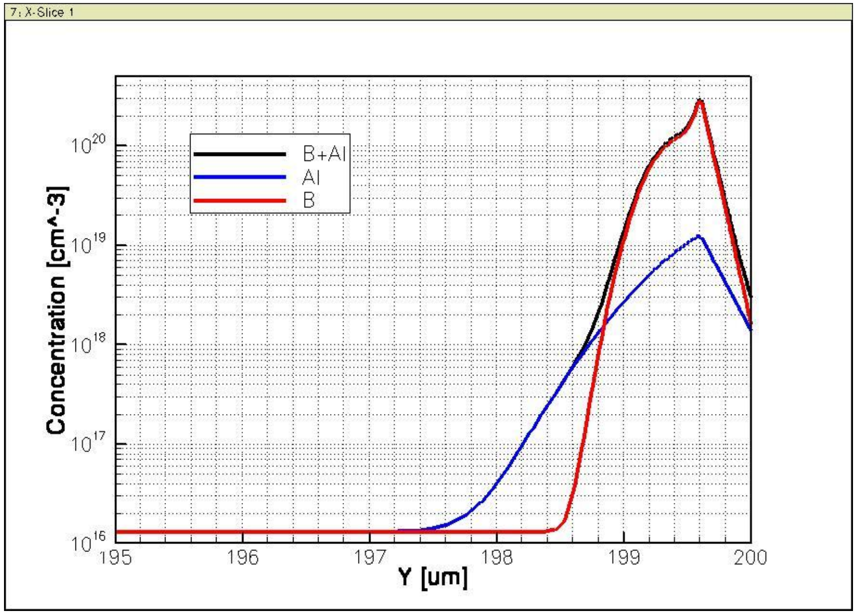


Process simulation

All cell fabrication steps are simulated in full detail.
Figures below show examples of doping in different parts of the cell.

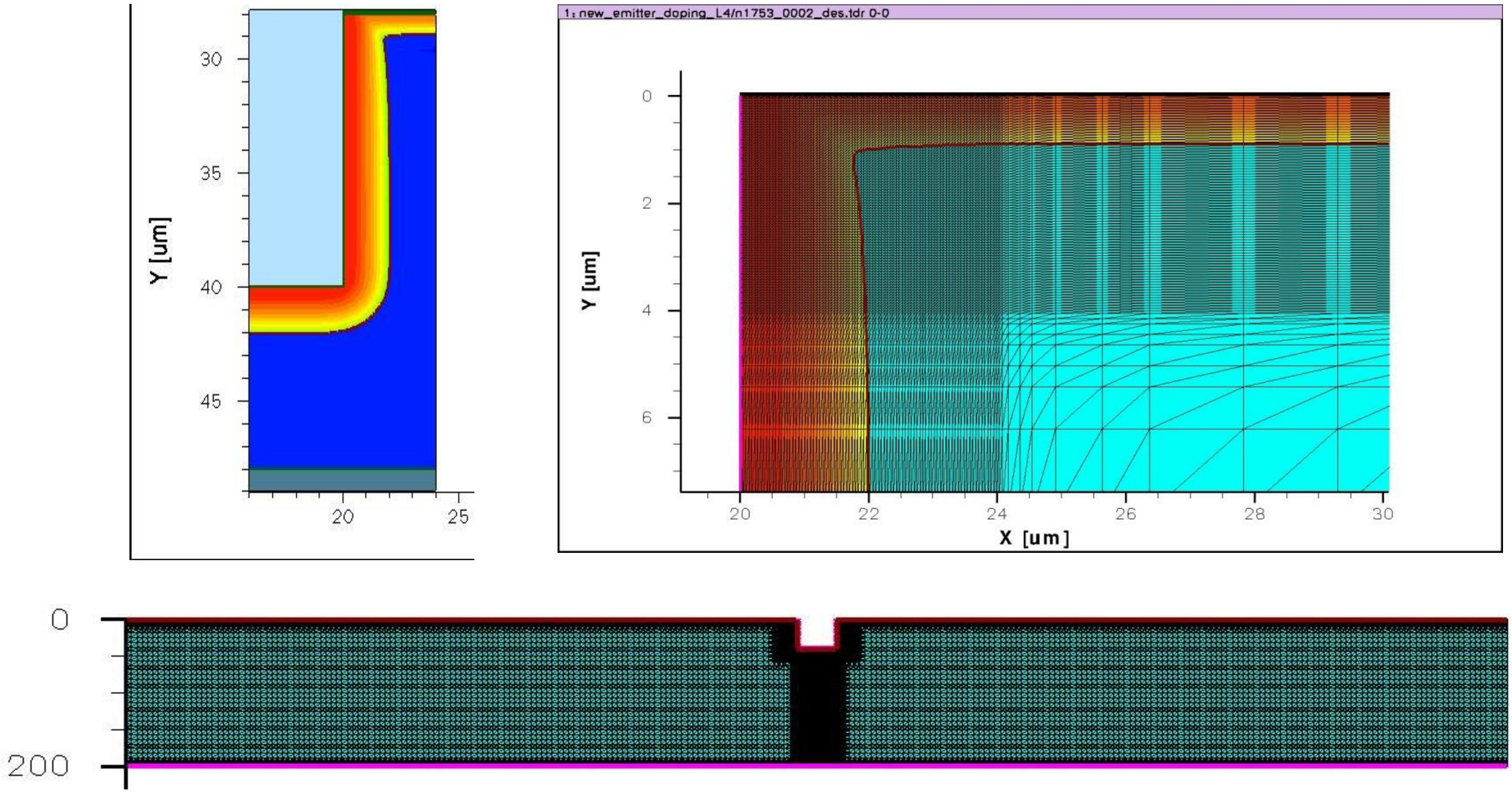


Experimentally measured and simulated emitter sheet resistance at end of process, as function of time used for the deposition step.



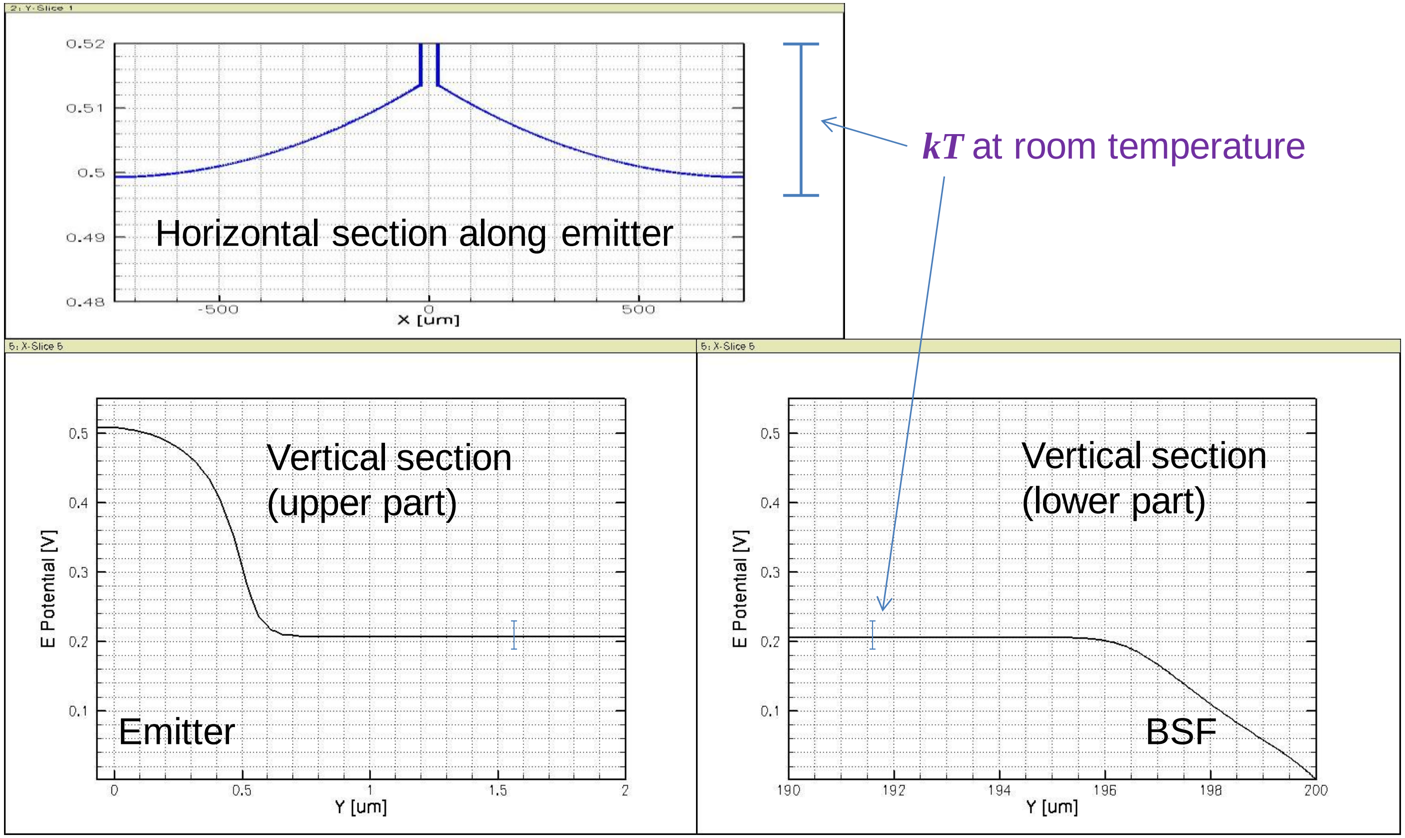
Simulated back surface field doping profiles using Al (existing process, blue curve), or an alternative Al:B alloy (black curve).

Structure transferred to device simulation



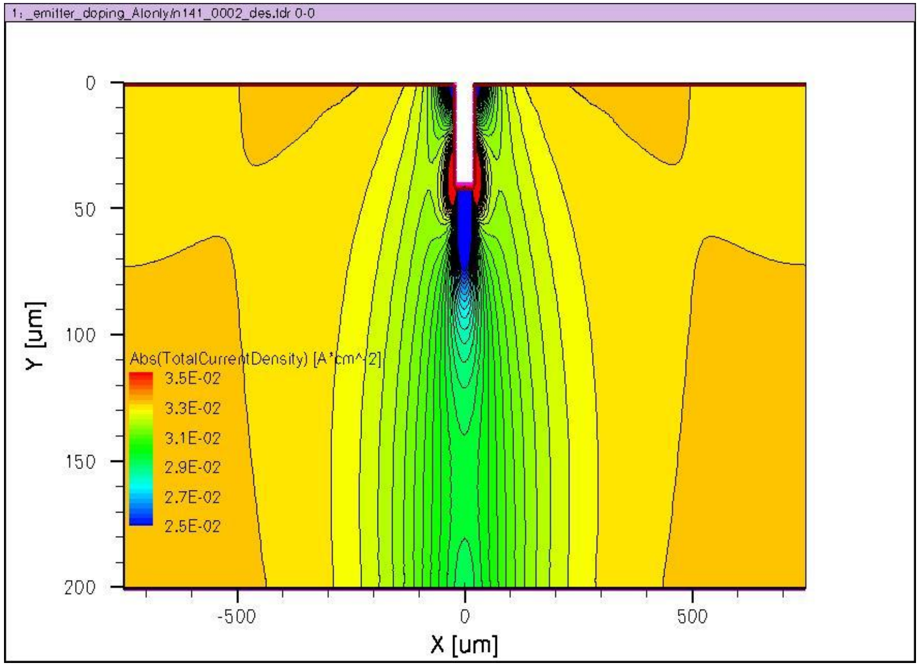
Geometry of simulated cell element. Details (at top) show the doping and mesh close to the groove. The emitter junction is marked by a solid line.

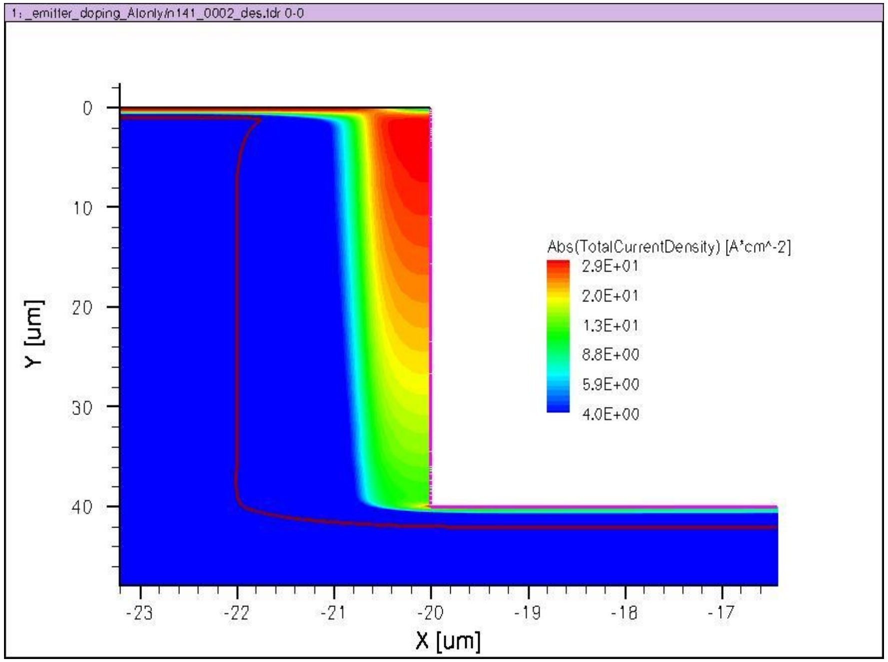
Device simulation results



Potential distribution inside the cell at the 'maximum power point', shown along various sections. Such information is hard to gather from experiments, but obtained quickly by simulations

Device simulation results





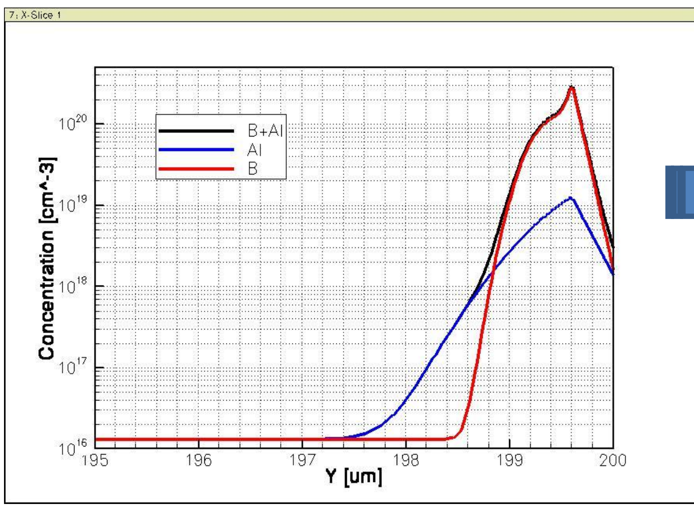
Simulation results for total absolute current in the full simulation element (for a 200μm-thick wafer)

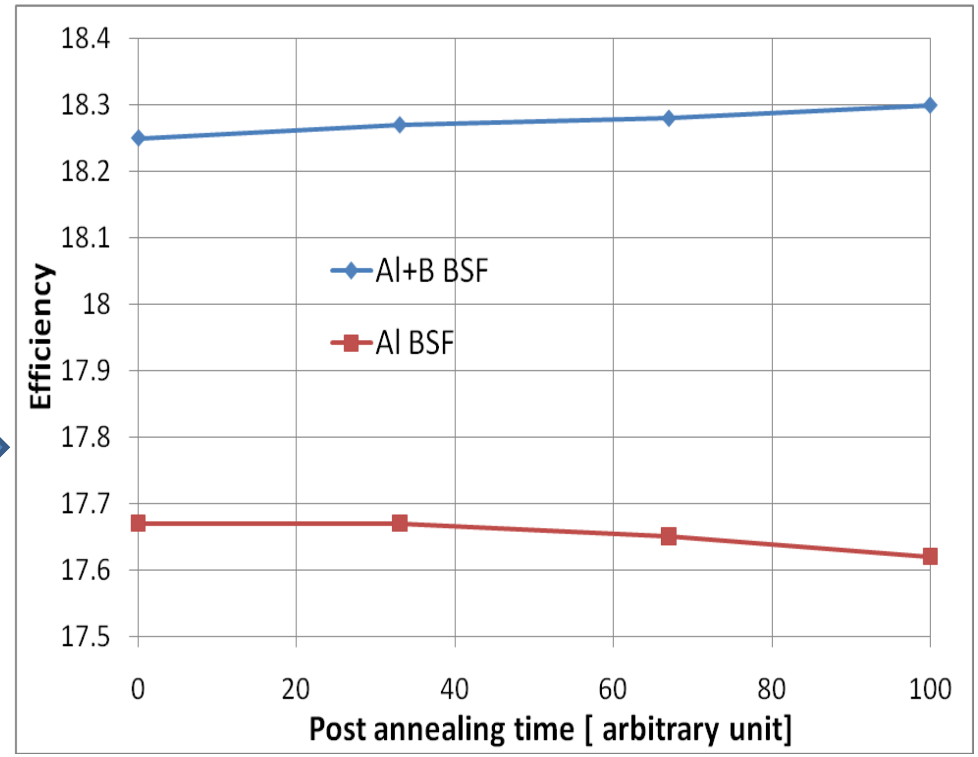
Current flow into groove. Contact resistance causes current to enter the contact over an extended area.

Investigating how process conditions affect cell parameters

Vary process parameters,
look at impact on cell efficiency.

One example from many simulated in this work:





Different simulated back surface field (BSF) doping conditions (left) give rise to strongly different simulated cell efficiencies (right). Adding boron to Al strongly increases efficiency. This may be further improved using a short post-anneal.

Predictions now being tested experimentally in the line…

Conclusions

Physically accurate technology simulation has been applied to an established cell process and the operation of the resultant solar cells.

Process variations are investigated in order to establish key technology issues and assess potential to improve the technology.

Simulation eliminates the need for extensive in-line experimentation and cell characterisation. Informs well focussed trial experiments.

The approach offers a way to fast-track development + optimization of new Si-based PV technologies, such as metal wrap-through cells and thin film Si PV.

It is likely to become a regular feature of future efficiency improvement roadmaps in the PV industry.