Australian National University

Localized laser doped contacts for silicon solar cells:

characterization and efficiency potential

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SPREE Seminar

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Outline

- What are localized contacts?
- Efficiency potential
- Characterization methods
- Cell result / outlook

Point contact solar cell (PCSC)

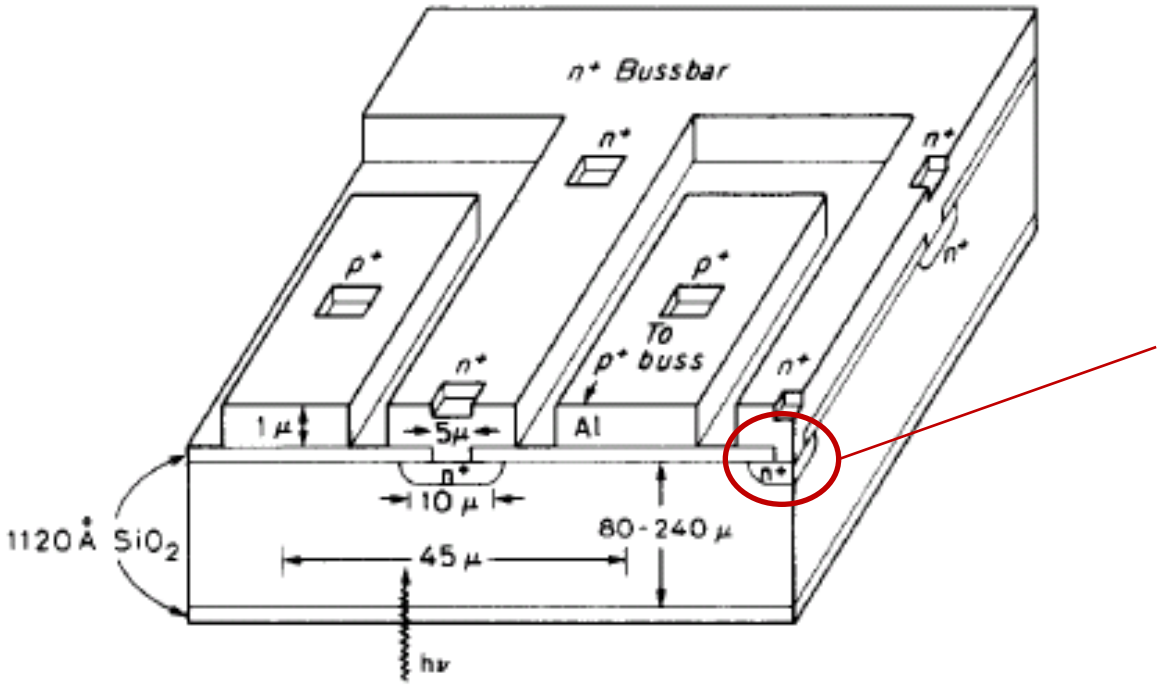


Fig. 1. Cross-sectional structure of the PCSC.

I_{0cont} $[A]$
R_{cont} $[\Omega]$

J_{0cont} $[Acm^{-2}]$
r_{cont} $[\Omega cm^2]$

Swanson, R.M., *Point-contact solar cells: Modeling and experiment.* Solar Cells, 1986. **17**(1): p. 85-118.

Localized contacts by laser

- Rear junction necessary due to small pitch for good collection
  - High lifetime bulk and good surface passivation required

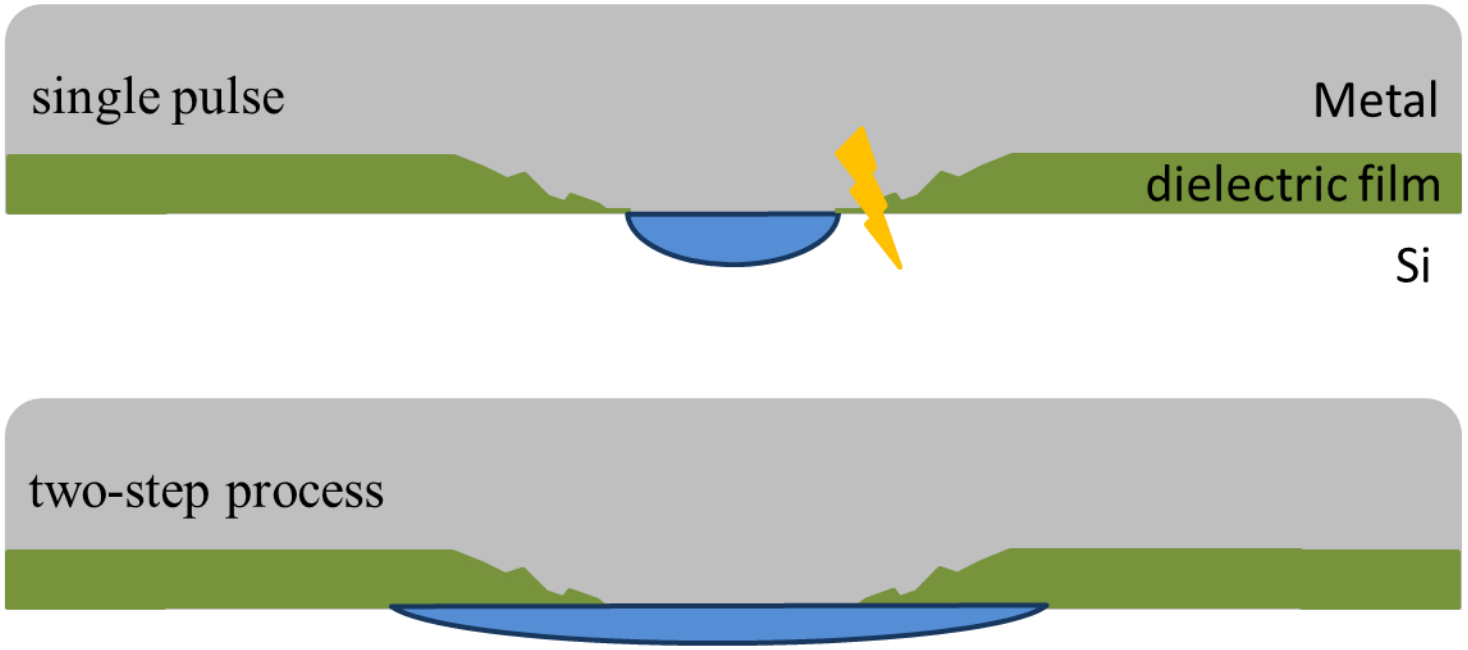
Pro's:

- Laser localized in nature, (potentially) low-cost
- Simple process sequence for combined doping / contact opening
- Low area fraction allows relatively high recombination

Challenges:

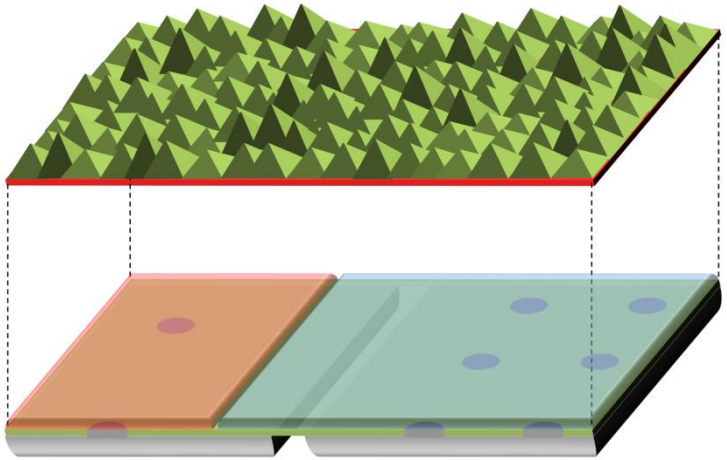
- (IBC Metallization)
- V_{oc} vs. FF and J_{sc}, any sweet spots?
- Performance of single step process / alignment for two-step process

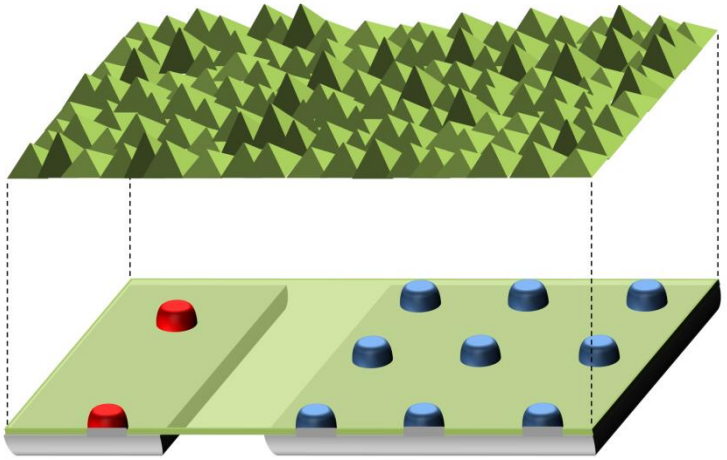
Single step vs. two step laser process



- Edges are critical, potential source of high recombination / shunts

Localized vs. large area laser-IBC





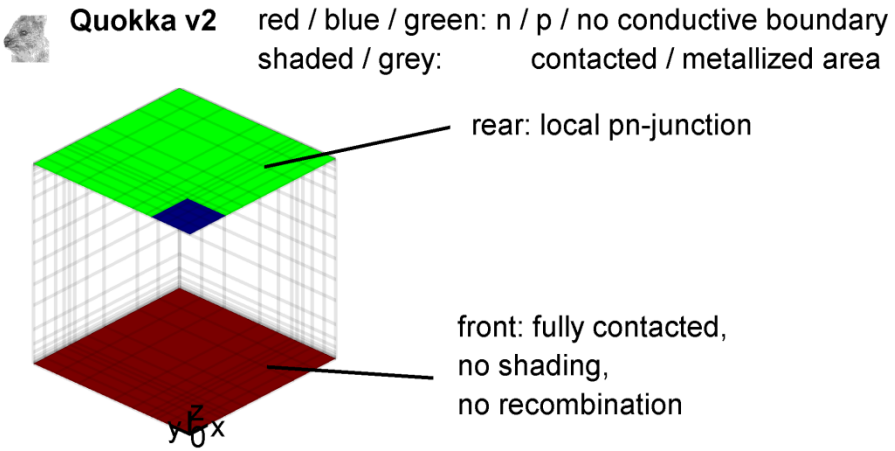
- Very good J_0 of doped area required
- 22% by University of Stuttgart[1]
- Laser doping throughput?

- "Easy" to achieve low surface recombination
- Challenge of edge regions
- High throughput potential

[1]Dahlinger, M., et al., *22.0% Efficient Laser Doped back Contact Solar Cells.* Energy Procedia, 2013. **38**(0): p. 250-253.

Efficiency potential: upper limit

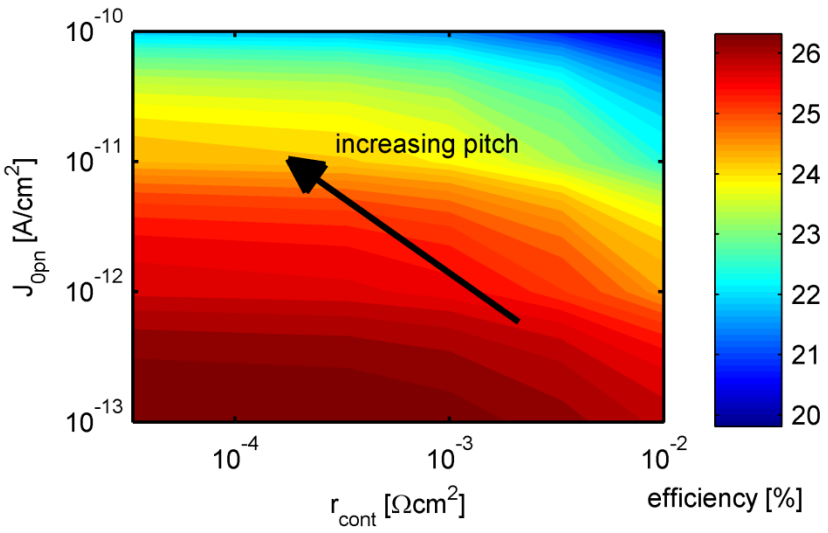
- Intrinsic 1.5 Ωcm n-type wafer, no surface recombination
- Fully contacted and transparent front surface
- 42 mA/cm^2 typical generation profile
- Variation of J_{0pn} and r_{cont}, pitch optimized for each value pair



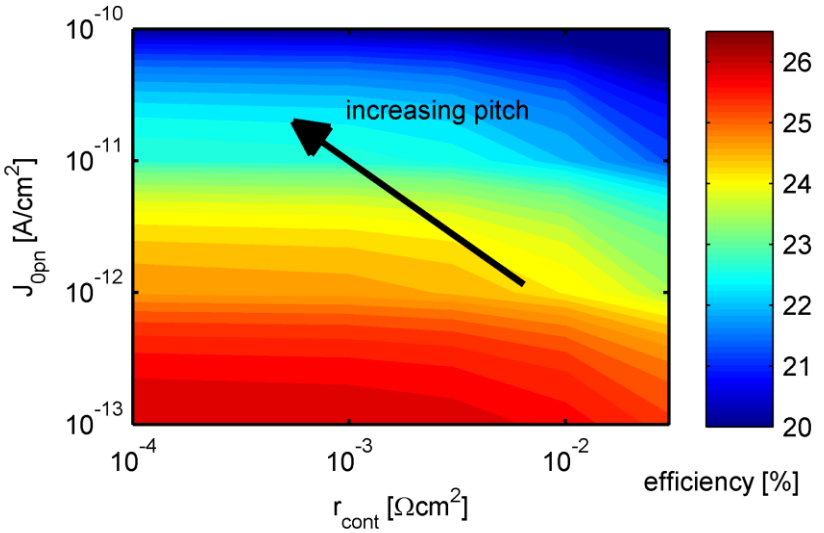
Fell, A., et al., *Characterization of Laser-Doped Localized p-n Junctions for High Efficiency Silicon Solar Cells.* Electron Devices, IEEE Transactions on, 2014. **61**(6): p. 1943-1949.

Efficiency potential: upper limit

small contact: 30x30 µm^2



large contact: 75x75 µm^2

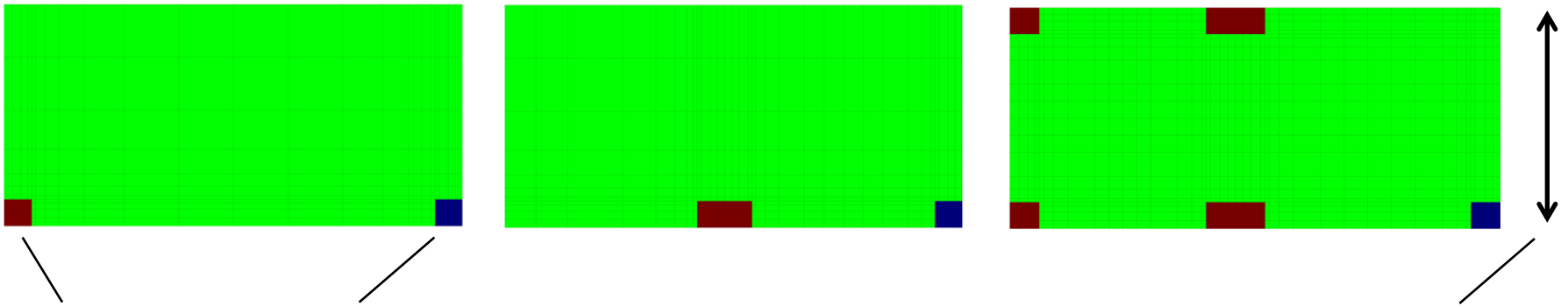


- 24% @ 10000 fA/cm^2!

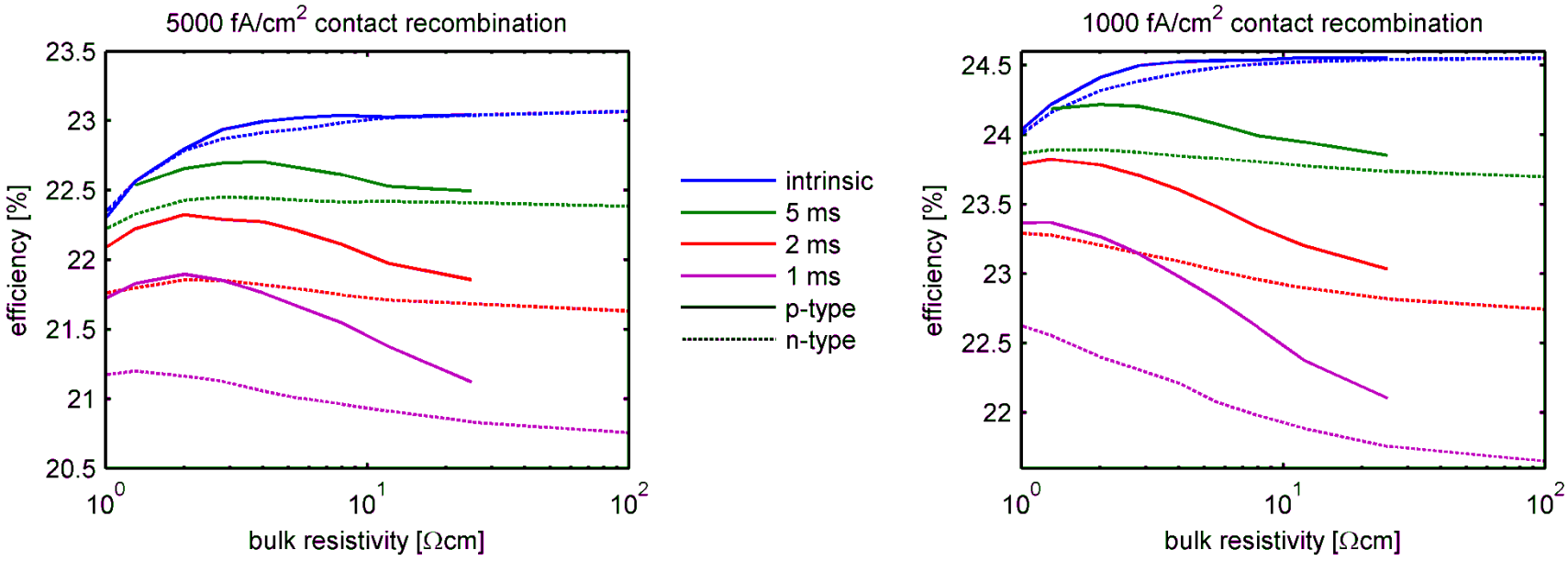
Fell, A., et al., *Characterization of Laser-Doped Localized p-n Junctions for High Efficiency Silicon Solar Cells.* Electron Devices, IEEE Transactions on, 2014. **61**(6): p. 1943-1949.

Efficiency potential: ANU IBC

- Same generation, 5 fA/cm^2 front and rear passivation
- 30x30 µm^2 contact size, negligible contact resistance
- Variation of J_{0cont}, bulk resistivity and SRH bulk lifetime (@ 1e15cm^{-3} injection level)
- For each point, optimization of n- and p-contact-fraction



Efficiency potential: ANU IBC



- To reach same efficiency, n-type requires ca. 2x bulk lifetime

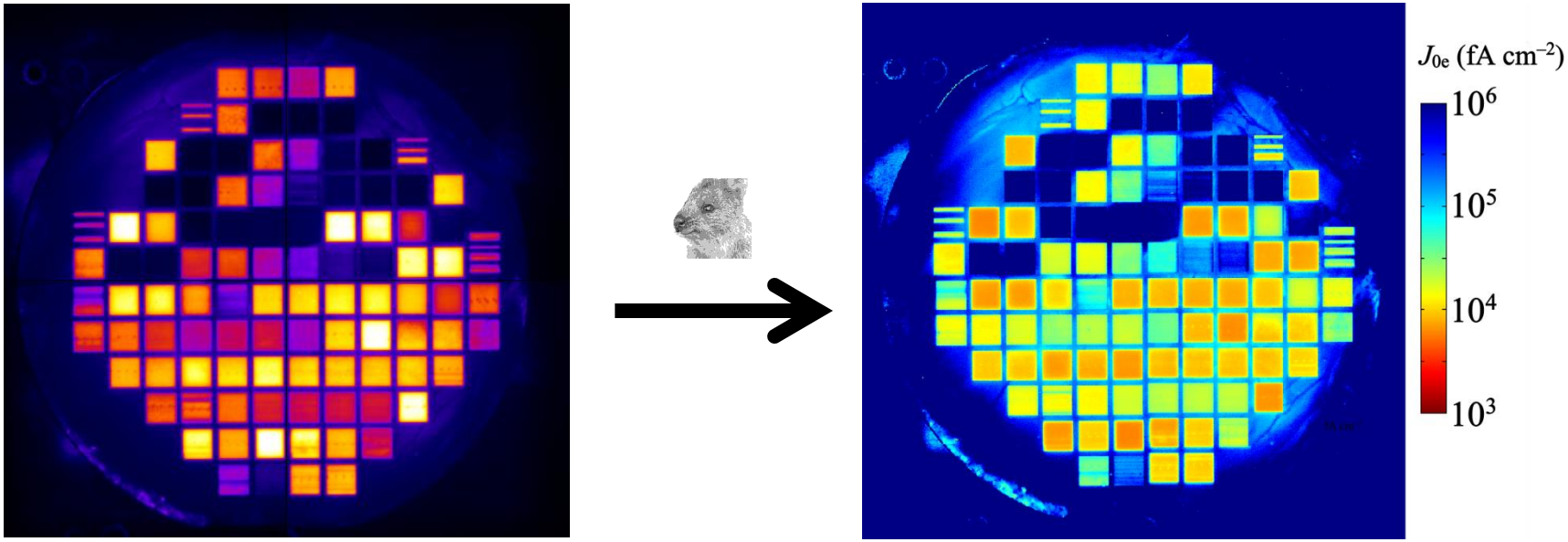
Characterization of J_{0cont} and r_{cont}

- Goal: fast and accurate determination of the specific properties J_{0cont} and r_{cont}
- Test structures necessary for effective exploration of the substantial available parameter space
- Common characterization techniques not applicable to these small scale features (e.g. QSSPC, TLM), and area upscaling (by e.g. overlapping) not valid due to importance of edge effects

→ **Development of dedicated test structures based on accurate but fast 2D / 3D numerical simulations (Quokka)**

Characterization of J_{0cont}

- First step: “large” processed areas by stitching for wide parameter screening

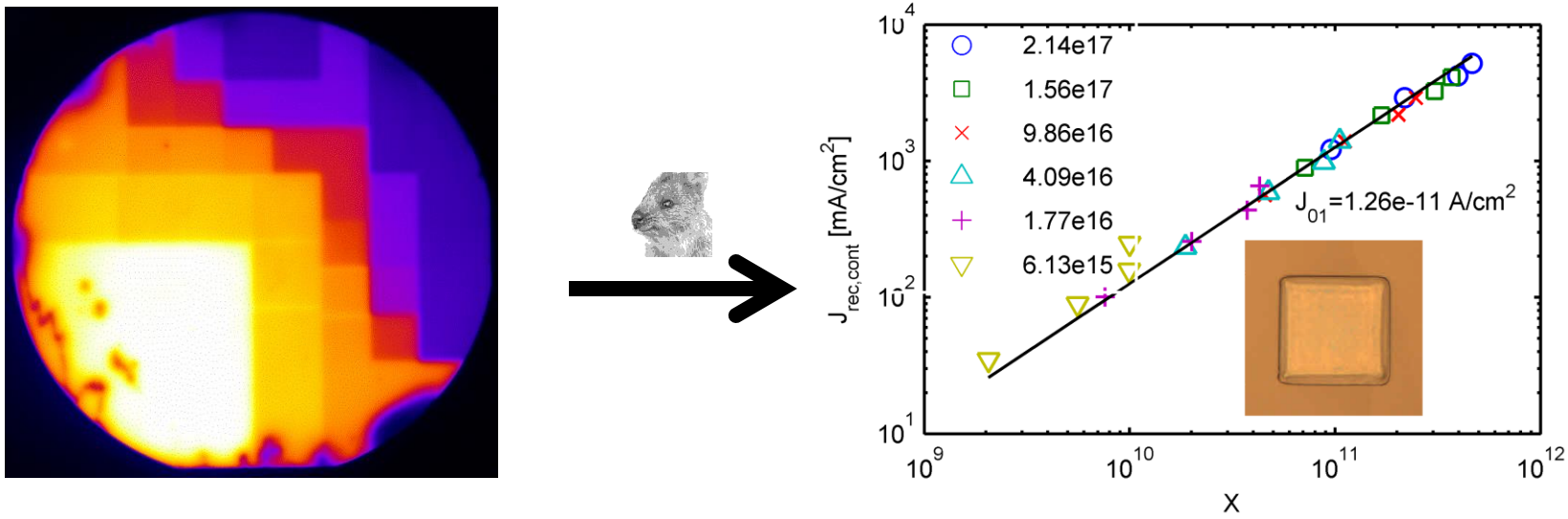


Fell, A., et al., *Quantitative surface recombination imaging of single side processed silicon wafers obtained by photoluminescence modeling.* siliconPV 2014, s’Hertogenbosch, the Netherlands

Images from: Marco Ernst et al., submitted to 6th WCPEC, Kyoto, Japan

Characterization of J_{0cont}

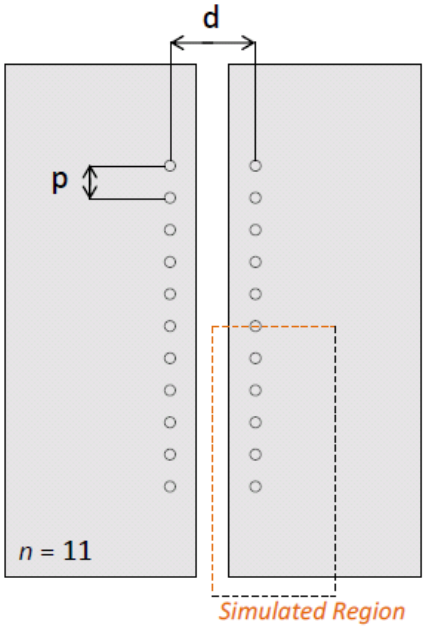
- Processing many boxes with regular pattern of features
- J_{0cont} can be determined by matching simulated and measured PL signal for varying injection levels (at the contact)

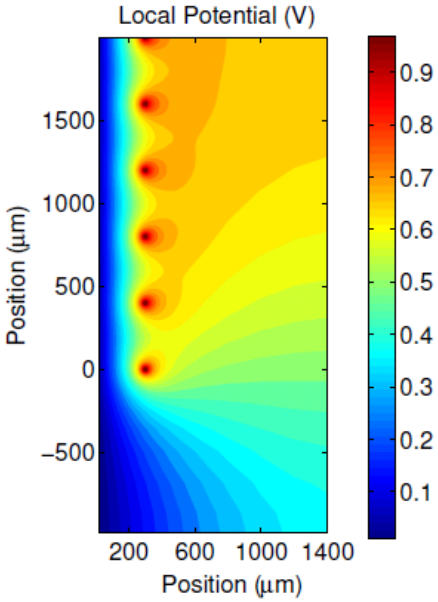


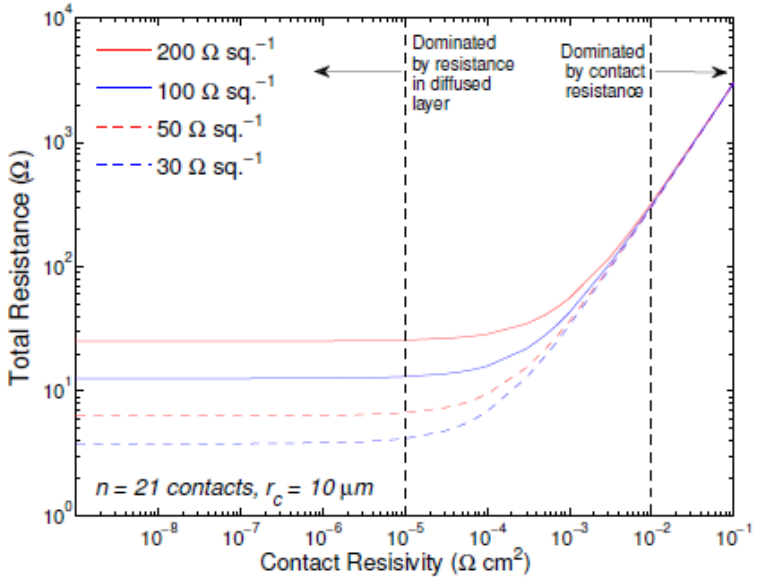
Fell, A., et al., *Determination of Injection Dependent Recombination Properties of Locally Processed Surface Regions.* Energy Procedia, 2013. **38**(Proceedings of the SiliconPV2013): p. 22-31.

Characterization of r_{cont}

- 3D numerical simulation of ohmic resistance structure for **majority carrier contact**



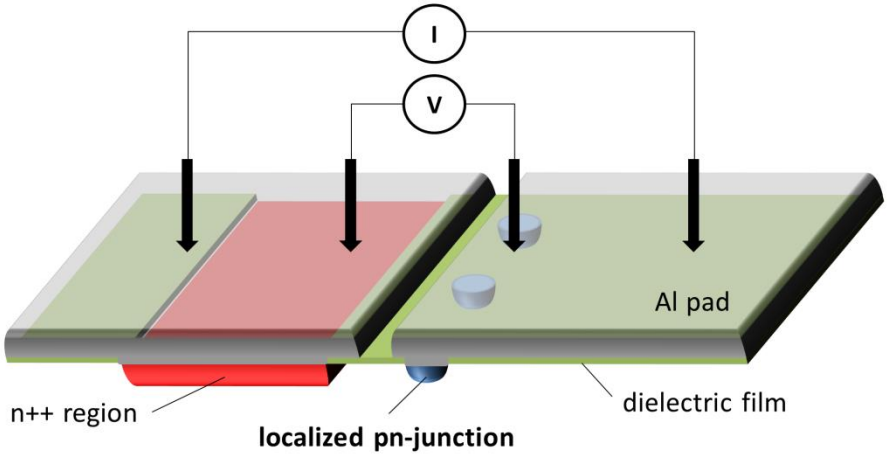


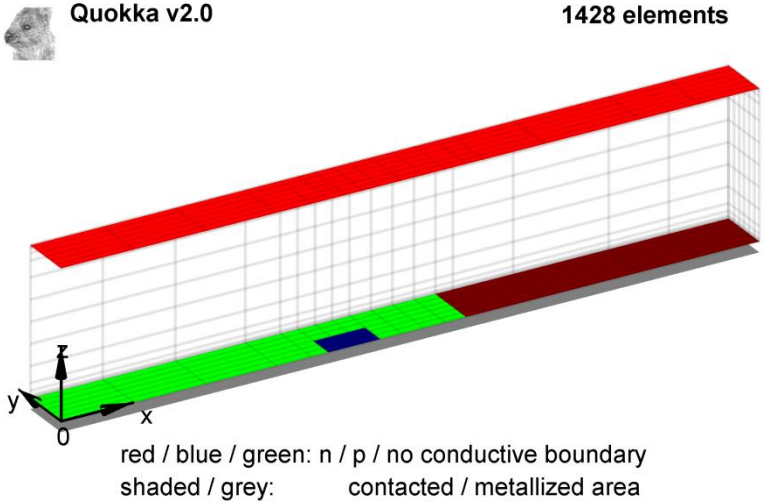


Walter, D., PhD thesis 2014

Characterization of r_{cont} (J_{0cont}, r_{shunt})

- Fabrication and simulation of device with localized **pn-junction**
- Dark IV-curve turns out to be very sensitive to r_{cont} (and J_{0cont})
- Recombination properties must be (only) coarsely known to account for contribution of spreading resistance in the bulk

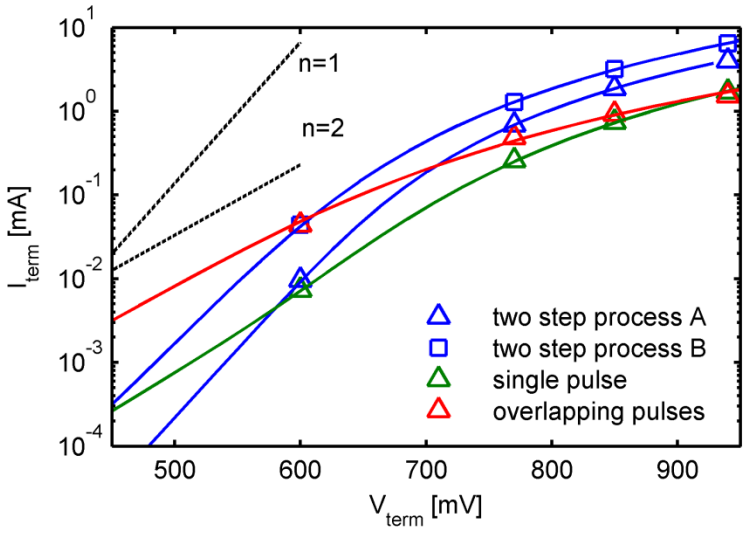


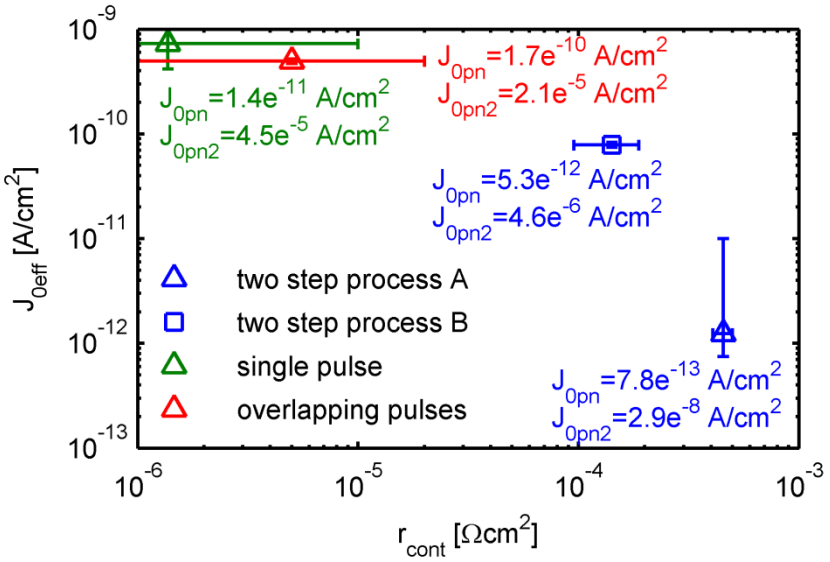


Fell, A., et al., *Characterization of Laser-Doped Localized p-n Junctions for High Efficiency Silicon Solar Cells.* Electron Devices, IEEE Transactions on, 2014. **61**(6): p. 1943-1949.

Characterization of r_{cont} (J_{0cont}, r_{shunt})

- Experiment: doping from spin-on-dopant with 532nm overlapping laser pulses and single pulses through SiO_2 / Si_3N_4 stack

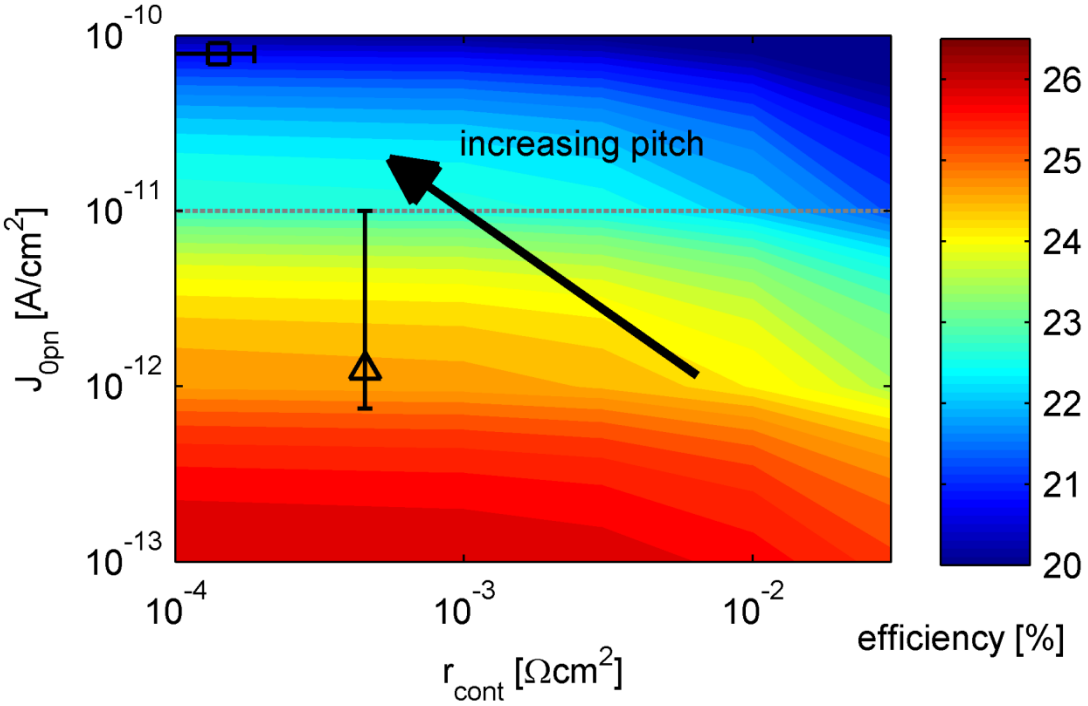




- High and non-ideal recombination for single step process

Fell, A., et al., *Characterization of Laser-Doped Localized p-n Junctions for High Efficiency Silicon Solar Cells.* Electron Devices, IEEE Transactions on, 2014. **61**(6): p. 1943-1949.

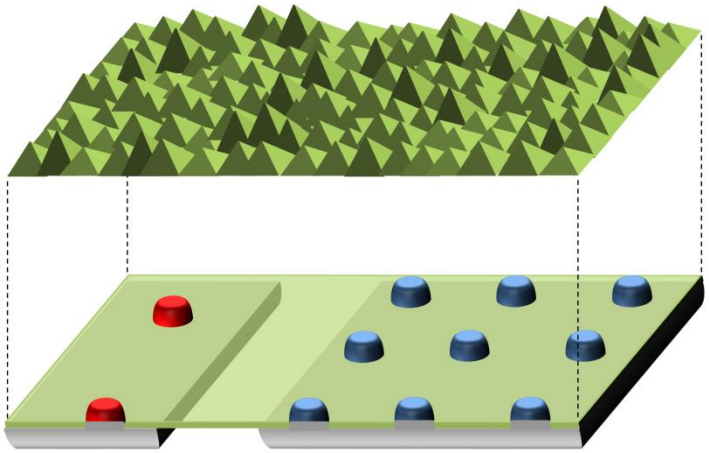
“Measured” efficiency potential



- 22% - 24% seem realistically achievable in adopted ANU IBC design

Fell, A., et al., *Characterization of Laser-Doped Localized p-n Junctions for High Efficiency Silicon Solar Cells.* Electron Devices, IEEE Transactions on, 2014. **61**(6): p. 1943-1949.

First all-laser-processed cell batch

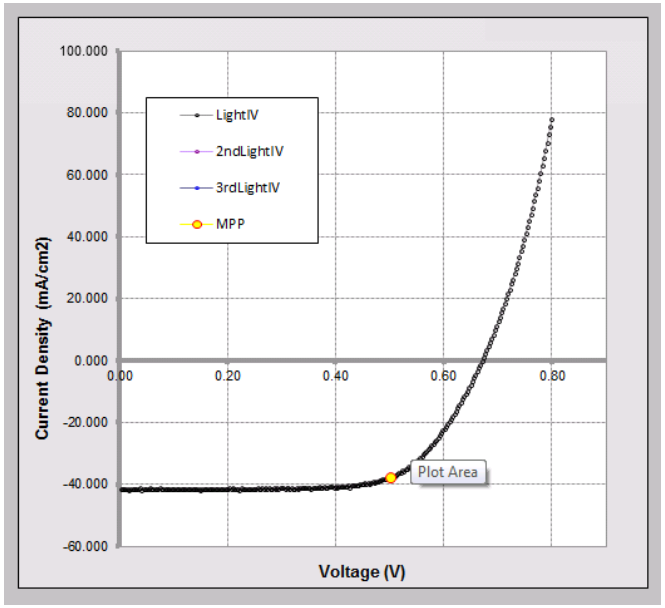


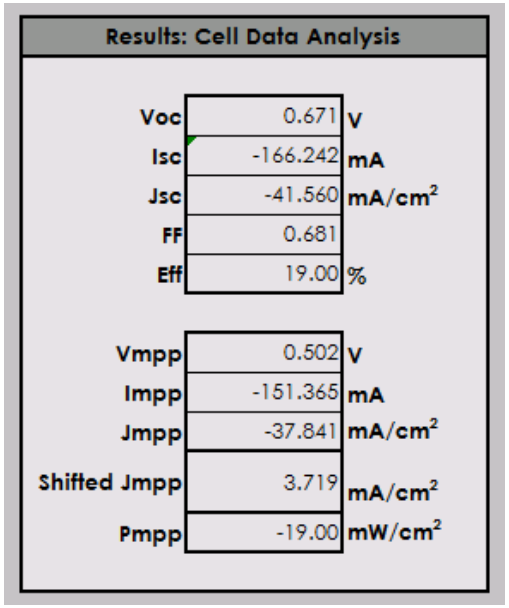
- rear n-type laser doping (P-SOD)
- rear p-type laser doping (B-SOD)
- front + rear SiO_2 / Si_3N_4
- front + rear SiO_2 / Si_3N_4
- front strip + texture
- front passivation + AR + resist
- rear laser contact opening
- HF etch
- Al evaporation + photolit. pattern
- sinter + measure

Franklin, E., et al., *Design, Fabrication and Characterization of a 24.4% Efficient Interdigitated Back Contact Solar Cell.* 2014, Progress in Photovoltaics: Research and Applications, in revision

First all-laser-processed cell batch

- Very good J_{sc} in overall > 41 mA/cm^2, ok V_{oc} up to 670 mV, low to very low FF
- Likely non-ohmic contact problem (non-ideal Shottkey shunts?)
- Best cell 19%, not bad for a first (very quick!) batch





Conclusions

- All-laser-doped cell has attractive features:
  - Low thermal budget, low cost AND high efficiency IBC design (up to ca. 24%)
  - Requirements on the quality of local contacts less strict than (personally) expected
- Still early stage of fundamental research
- Suitable characterization methods established to explore large parameter spaces
- Currently proper effort ongoing into a two-step IBC cell design with hopefully > 22% efficiency
- Future work will explore single step processes for simplification

Thank you for your attention

Particular thanks to the IBC group for cell processing.
Having an accessible ~24% baseline cell process is invaluable!

Many thanks to the Australian Renewable Energy Agency (ARENA) for funding under the fellowship 5-F007 and other projects