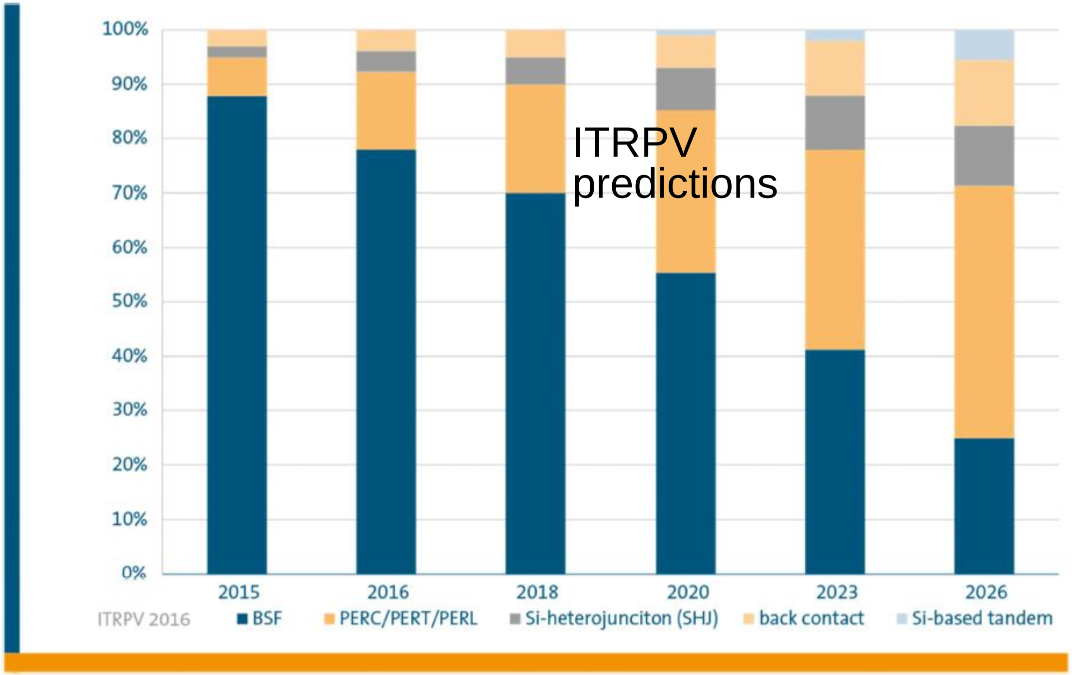
UNSW Advanced Hydrogenation

Never Stand Still | Faculty of Engineering | School of Photovoltaic and Renewable Energy Engineering

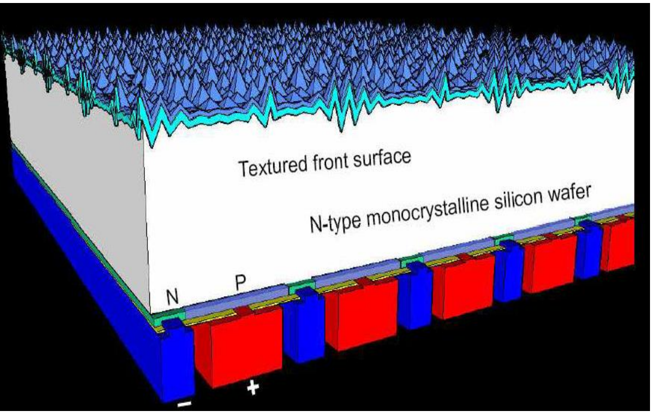
Scientia Professor Stuart Wenham

8th December, 2016

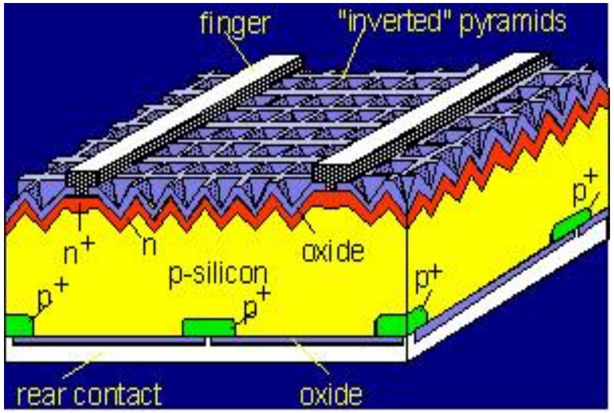
Highest Efficiency Cell Technologies



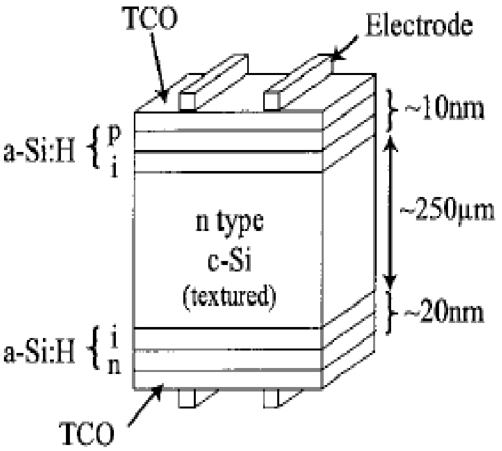
Stanford –25% rear contact



UNSW – 25% PERC

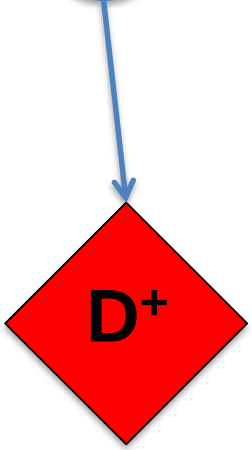


Passivated Contacts 25-26.3%

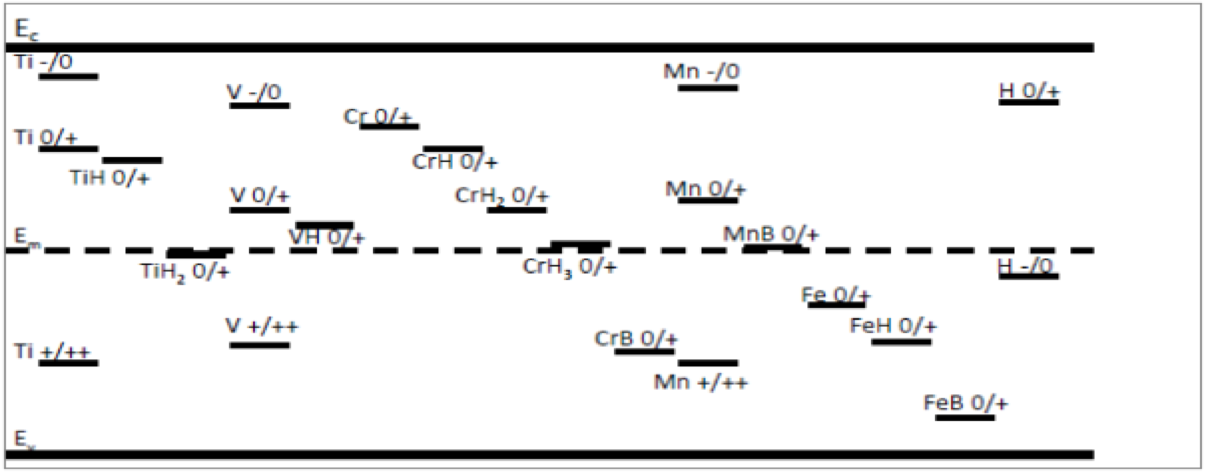


Hydrogen very important for p-type wafers

p-type Si | High mobility/reactivity | n-type Si



Fe_i^+
Cr_i^+
BO^+
Dangling bond



H-BO formation unfavorable in p-type silicon

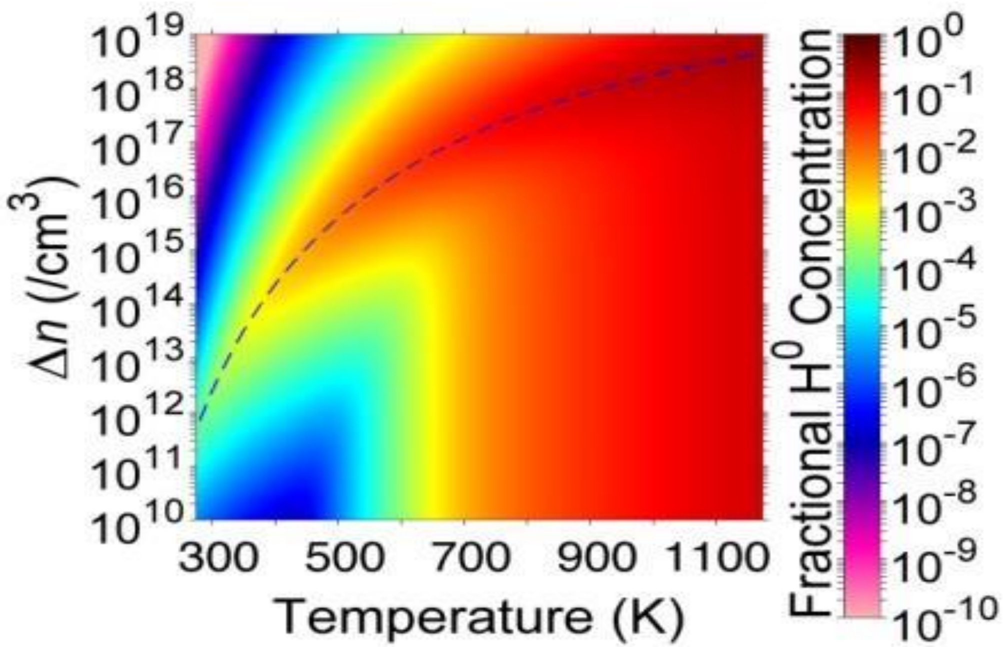
Must consider the charge state of hydrogen and defects

Advanced Hydrogenation

p-type Si — H^+

High mobility/reactivity — H^0

n-type Si — H^-

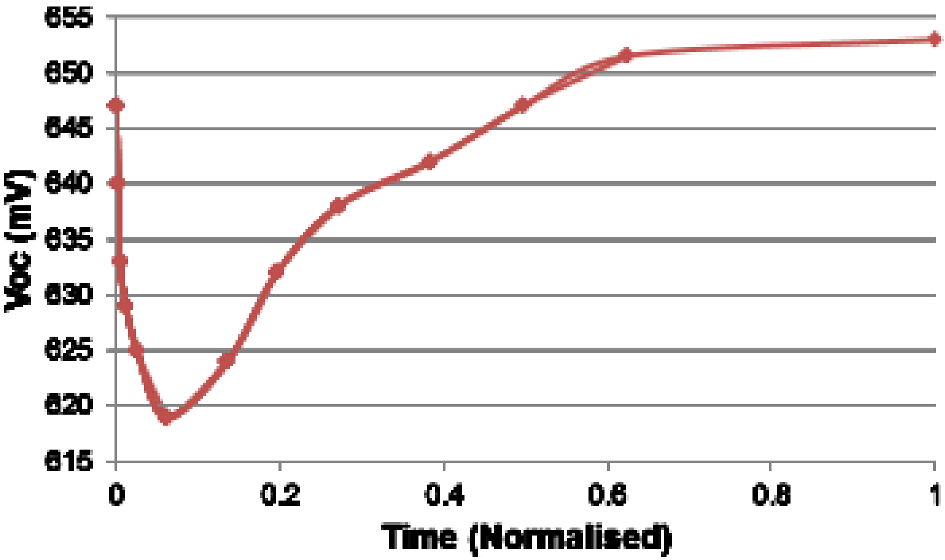


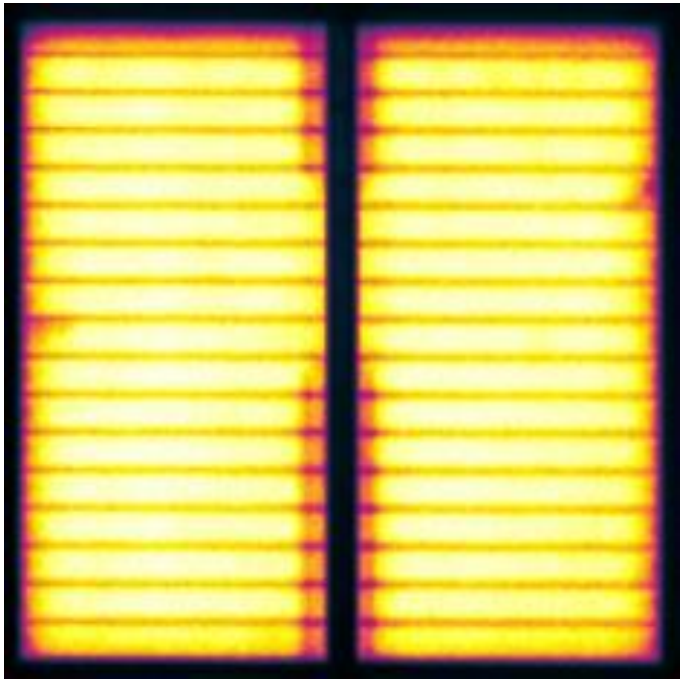
Use carrier injection and cell design to manipulate hydrogen

- Now many newer and better techniques for controlling the H charge state

Application to p-type Cz wafers

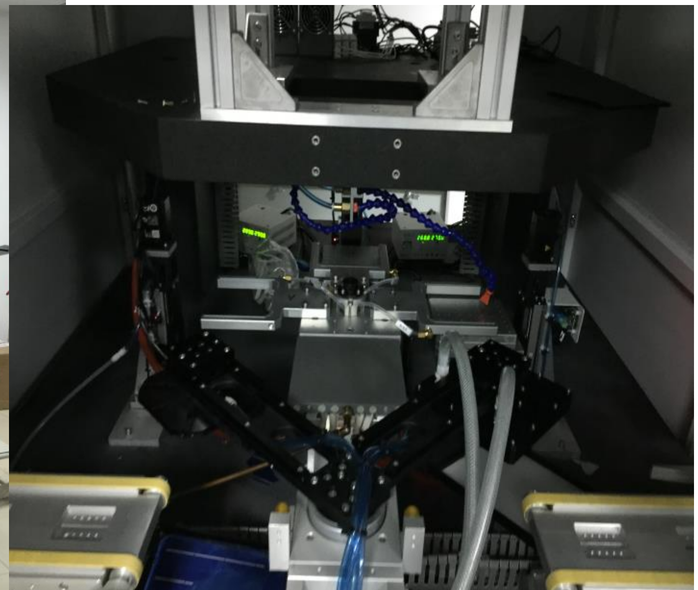
- **Main issue – solving LID (B-O defects)**
- **Accelerated defect formation**
- **UNSW Advanced Hydrogenation of B-O defects**
- **LID in p-type Cz PERC cell – Solved!!**

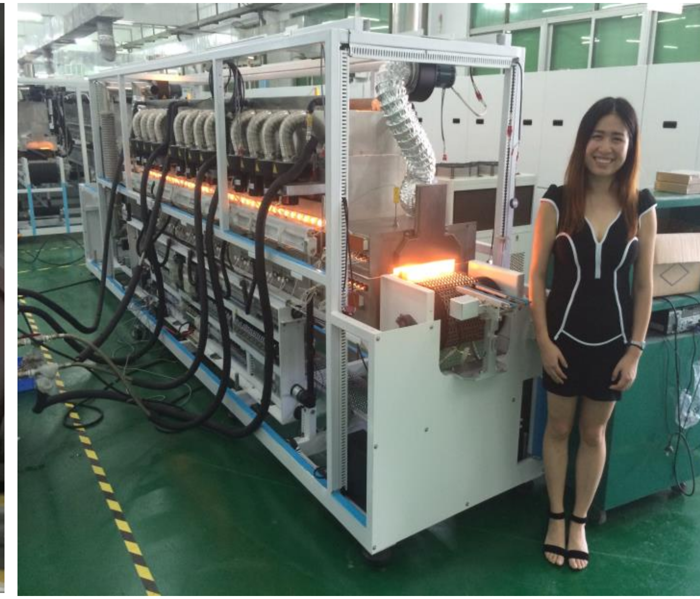


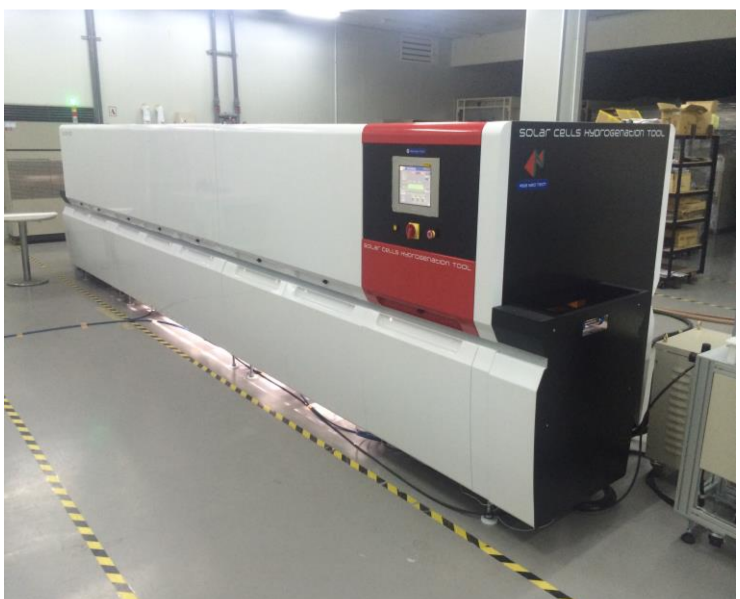


Sequential Photoluminescence Images

Advanced Hydrogenation Commercialisation

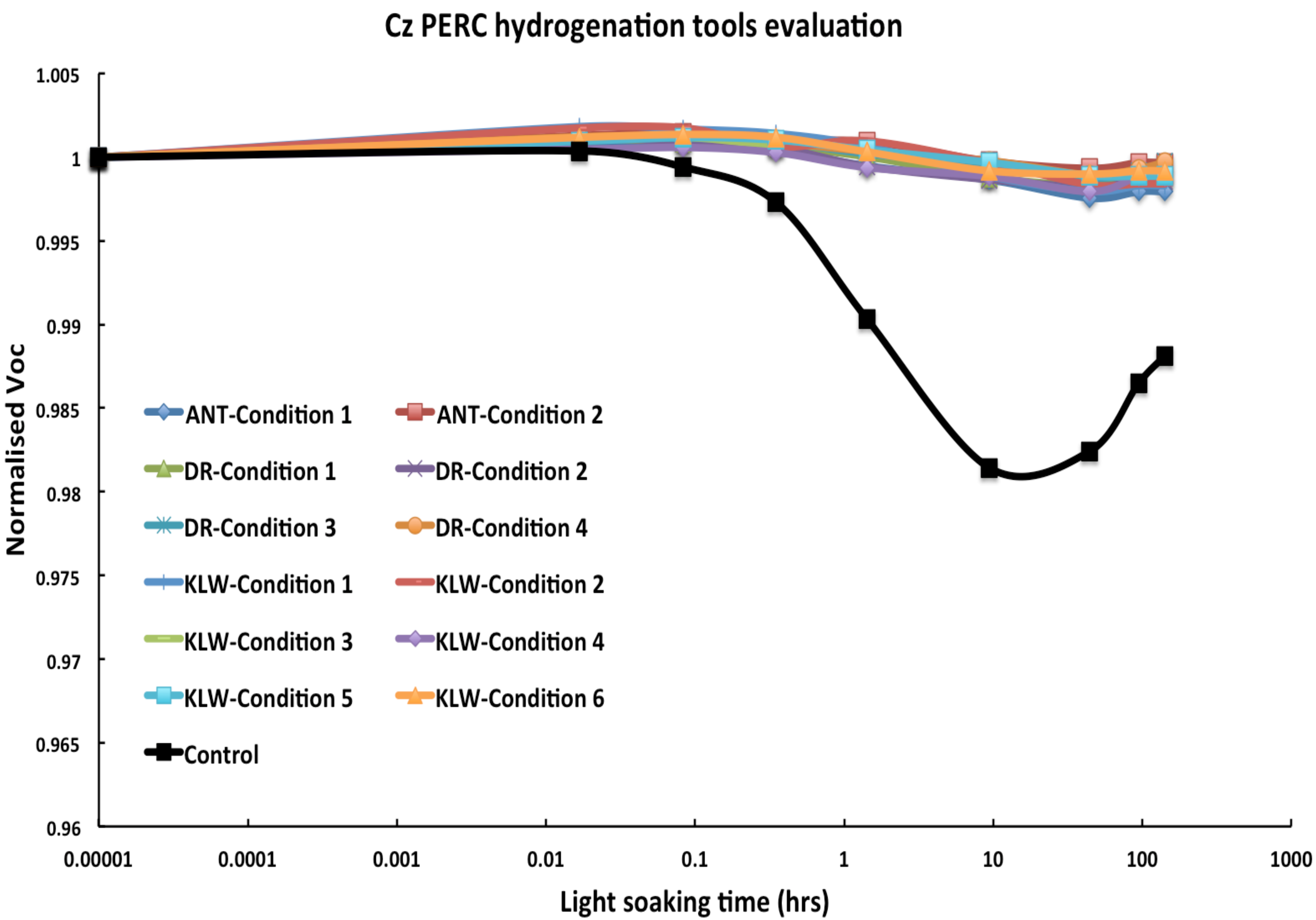






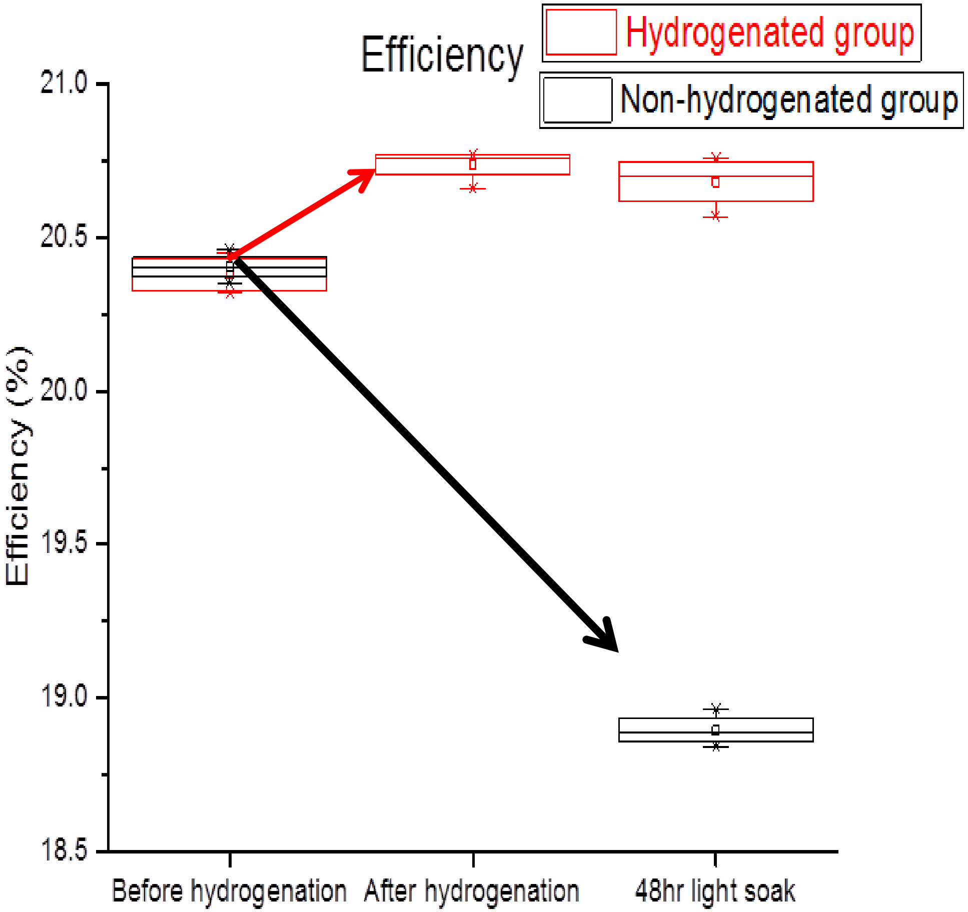
- Provide control of the hydrogen charge state
- New tools implementing UNSW hydrogenation
  - Asia Neo Tech (Taiwan – LED based tool)
  - Ke Long Wei (China – Broad spectrum tool)
  - Schmid (Germany)
  - Dr Laser (China – Laser-based tool)
  - Meyer Berger (Switzerland)
- New generation of tools in 2017 with solution for multi LID

Evaluation of commercial prototypes



Advanced Hydrogenation of P-type Cz PERC

PERC cell producers	Hydrogenation Efficiency Increases (% absolute)	48 h light soak stable?
Manufacturer A	+0.8%	Yes
Manufacturer B	+1.0%	Yes
Manufacturer C	+0.7%	Yes
Manufacturer D	+0.9%	Yes
Manufacturer E	+1.5%	Yes
Manufacturer F	+0.8%	Yes
Manufacturer G	+1.8%	Yes
Average Increase	+1.1% absolute	Yes

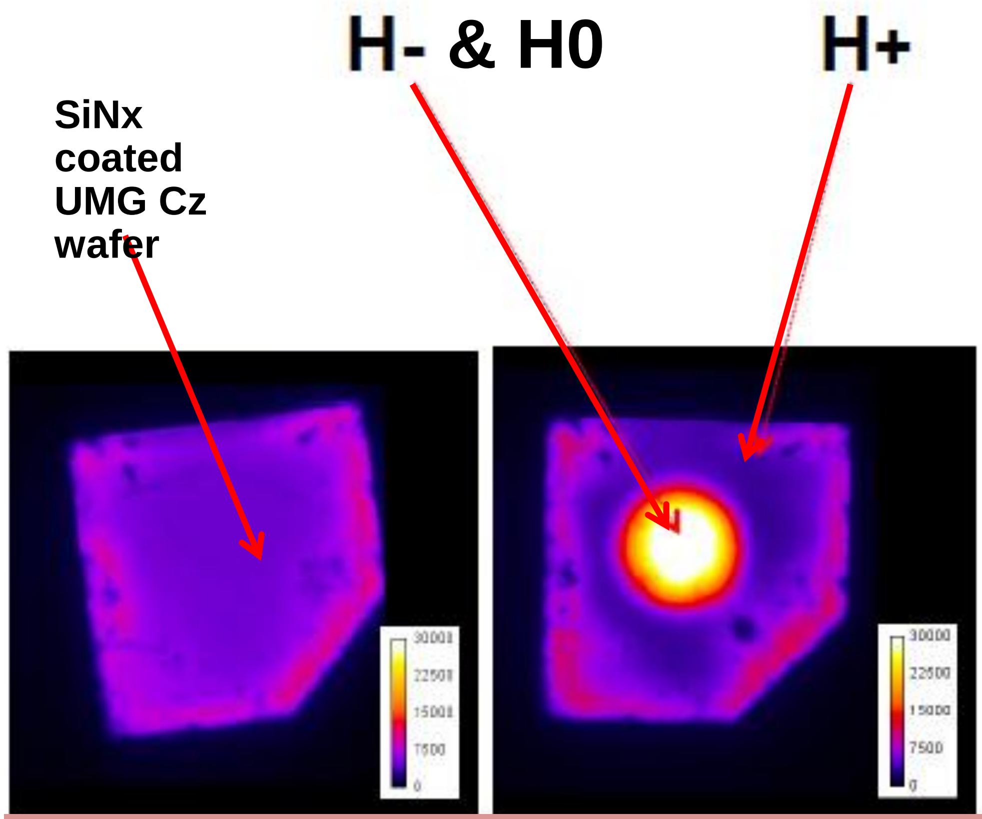


- → **8 seconds process**
- → **Final efficiency higher**
- → **Final efficiency stable**
- → **PERC cells need this**

H can passivate much more than B-O defects

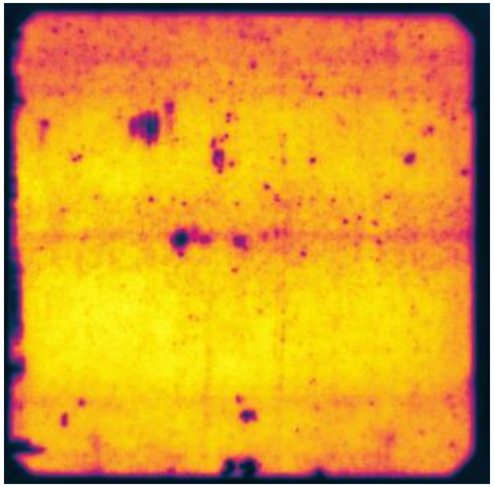
Localised Control of the H Charge State

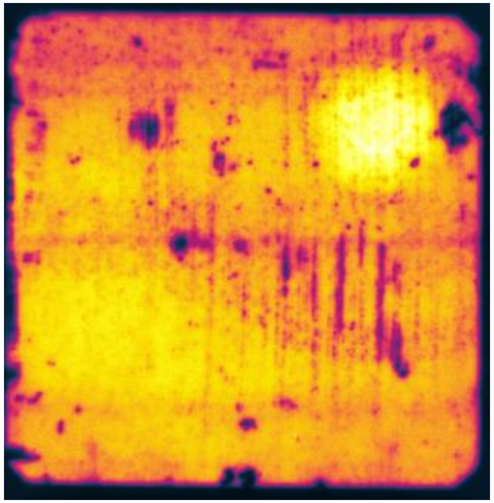
- Innovative hydrogen charge state control has large impact on both diffusivity & reactivity of hydrogen atoms in silicon
- Transformation of low quality silicon into high quality silicon (where PL count saturates)
- Simple 8 second process
- US Patent awarded Nov 2015 without modification

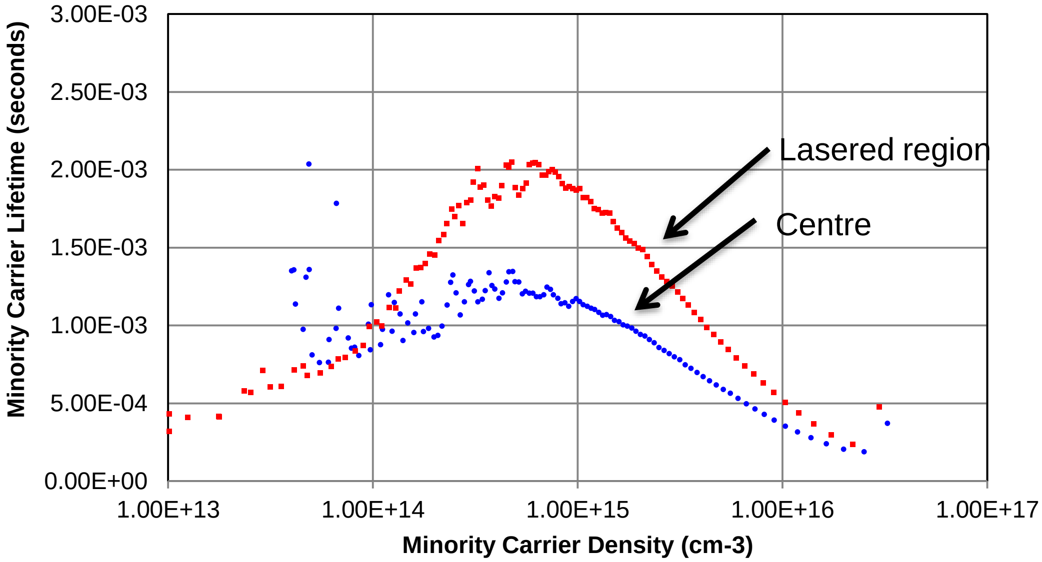


PL Images before & after localised hydrogenation. Wafer T = 250 degC

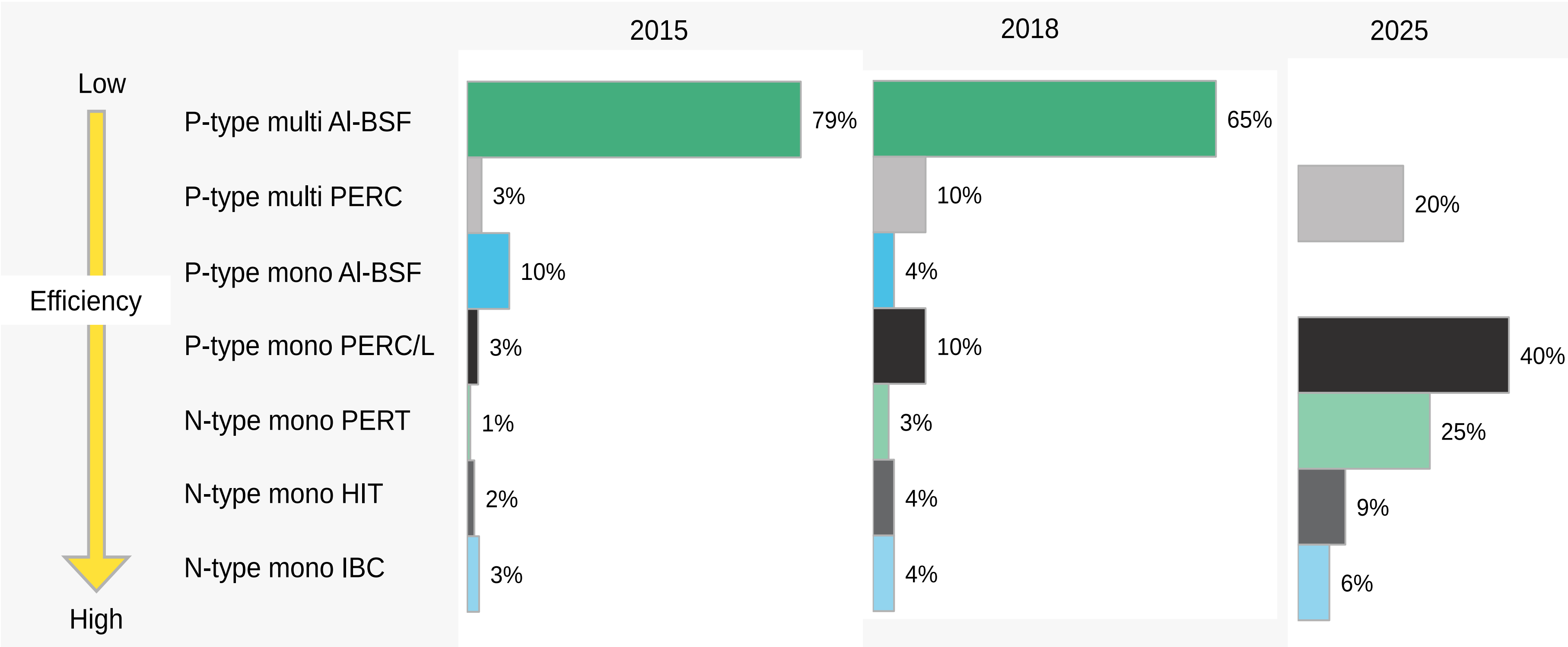
Advanced Hydrogenation also works well on n-type!



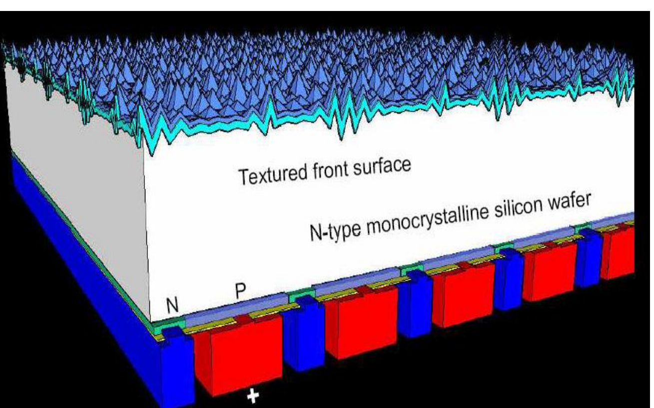




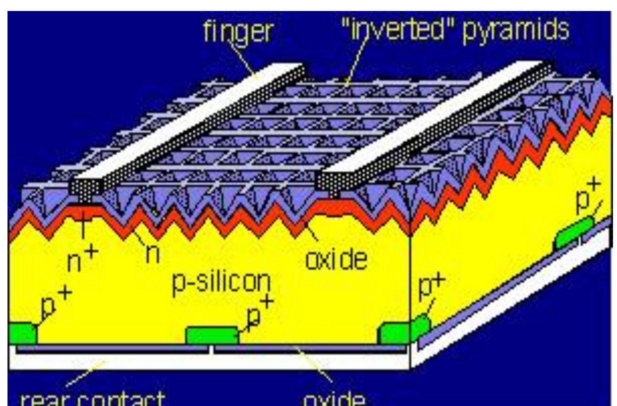
Cell Technology Trends – Bloomberg New Energy



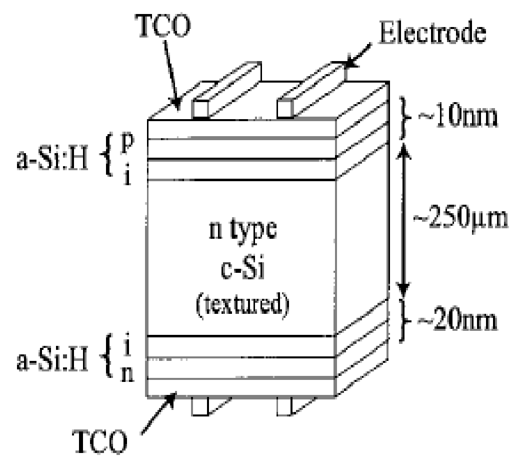
Stanford –25% rear contact



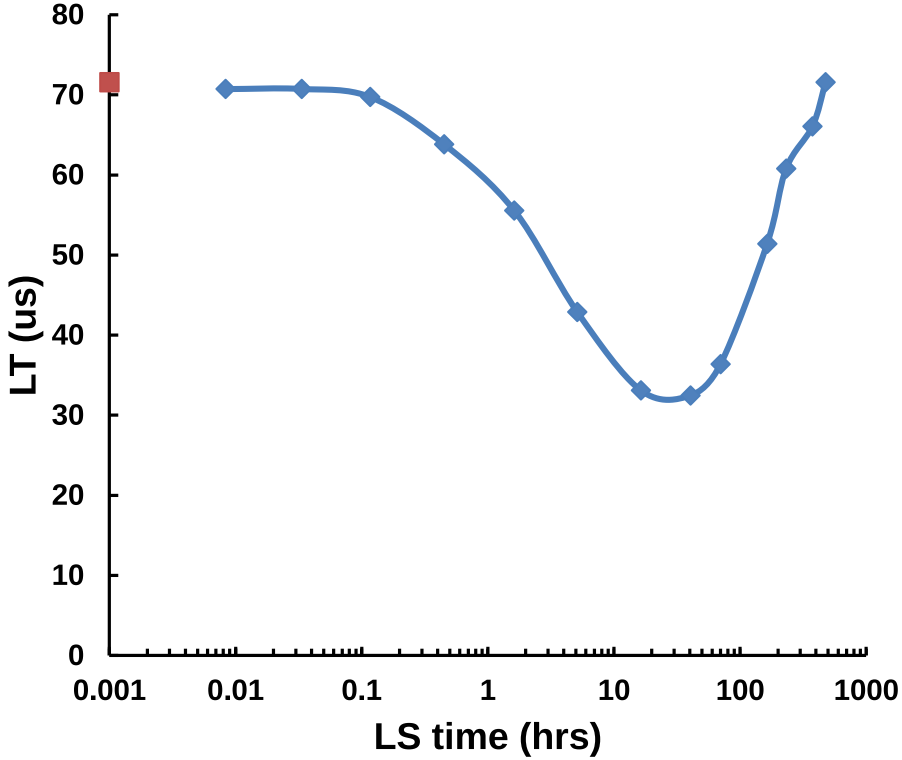
UNSW – 25% PERC

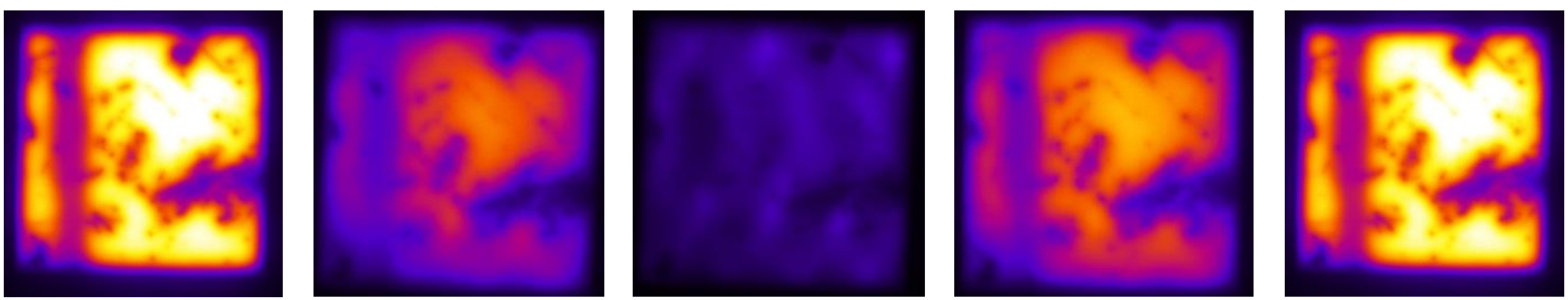


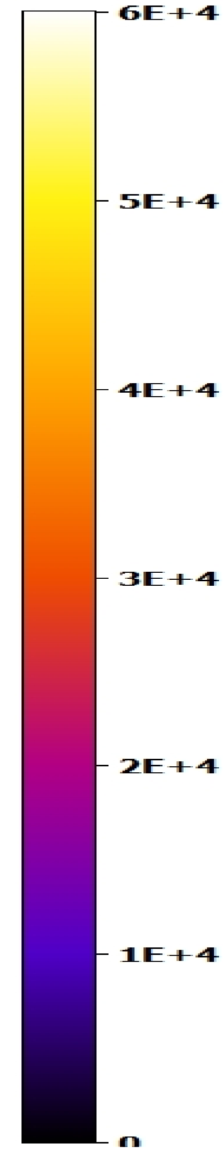
Passivated Contacts 25-26.3%



LID in multi-PERC is a serious problem



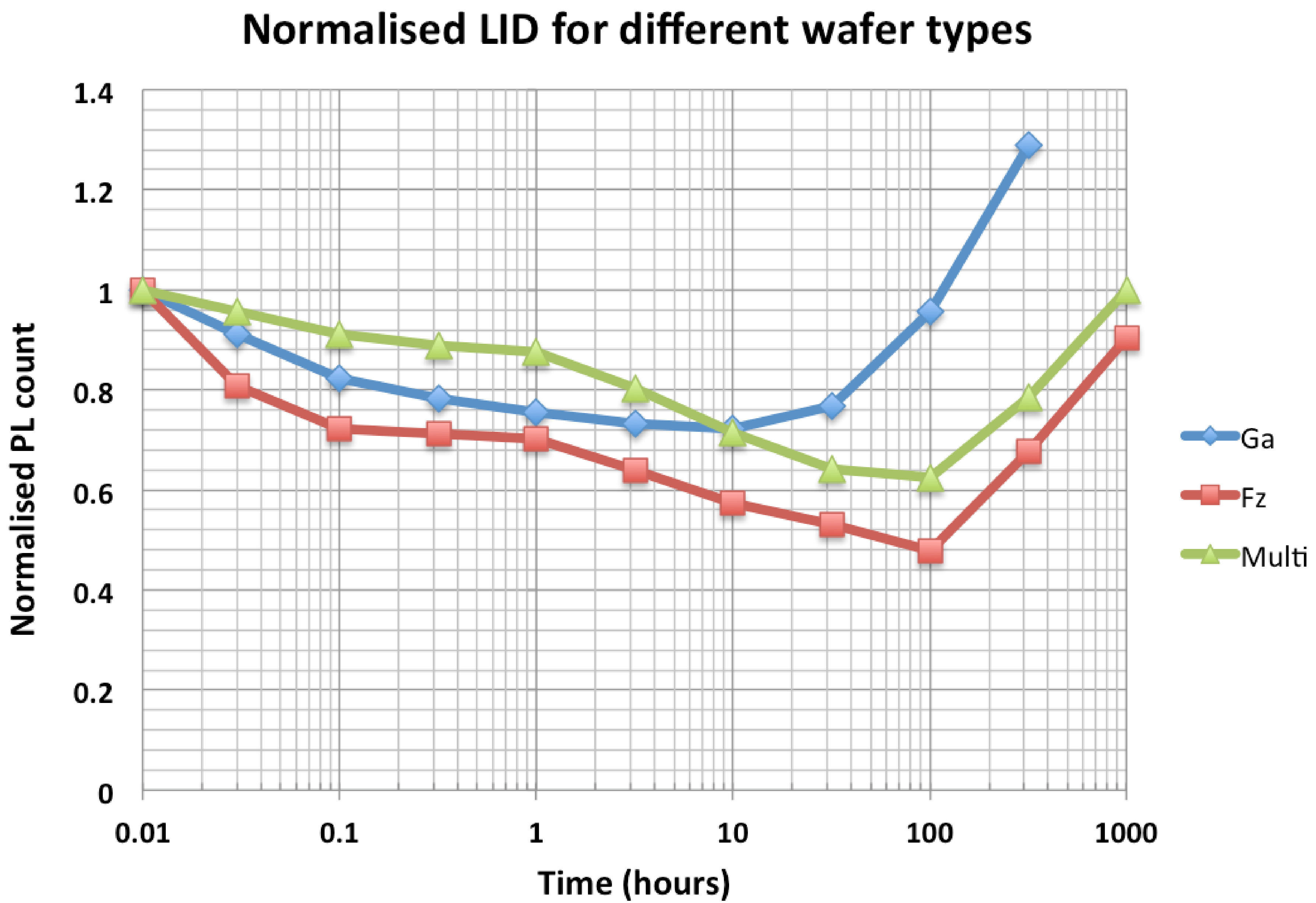




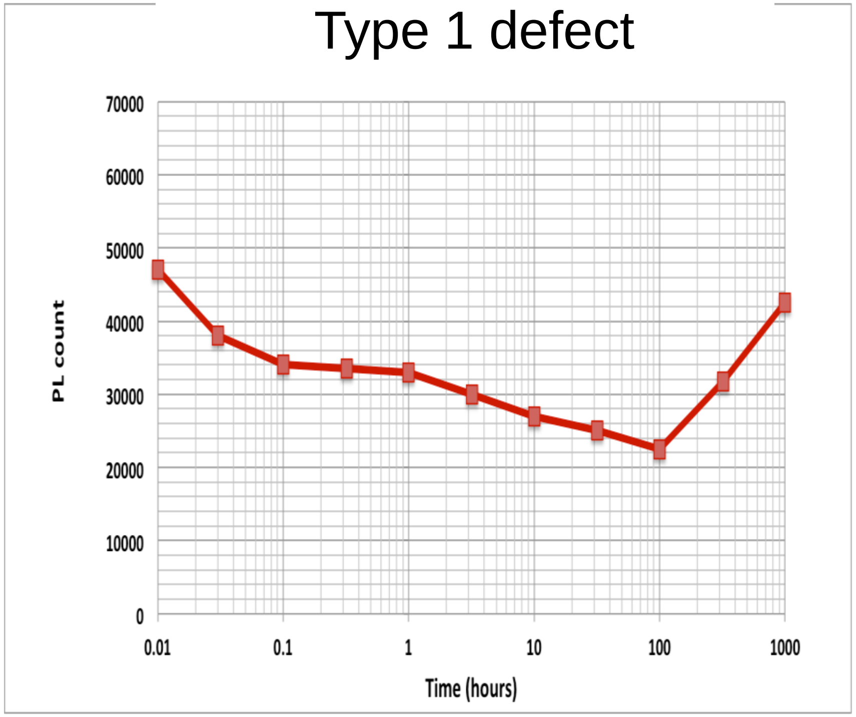
Aft Firing | 16.4hrs | 40.4hrs | 232hrs | 800hrs

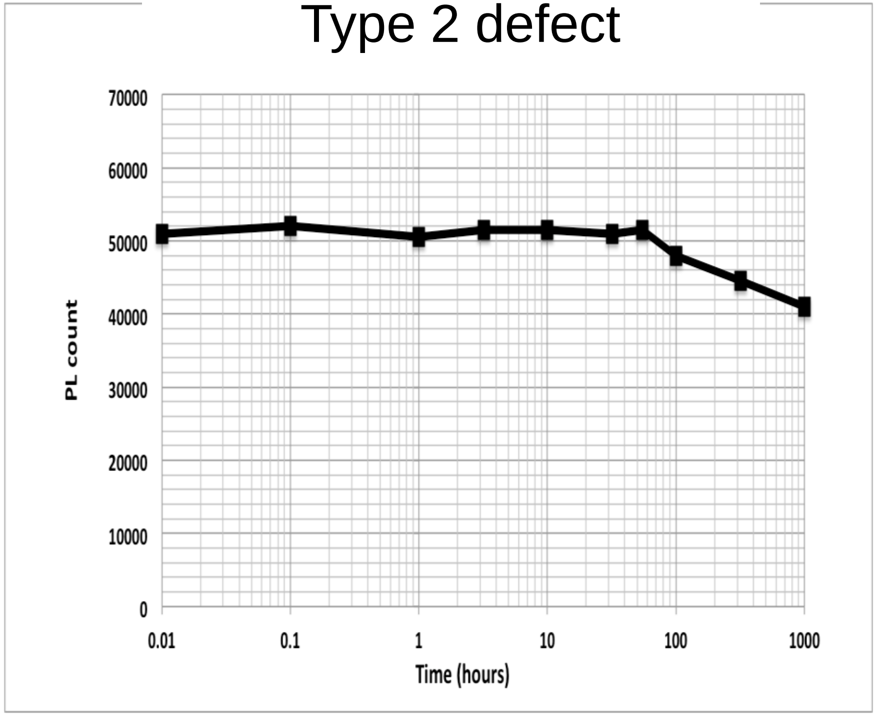
PL response as function of light-soaking time

Defect causing LID in mc-Si PERC also occurs in mono-Si

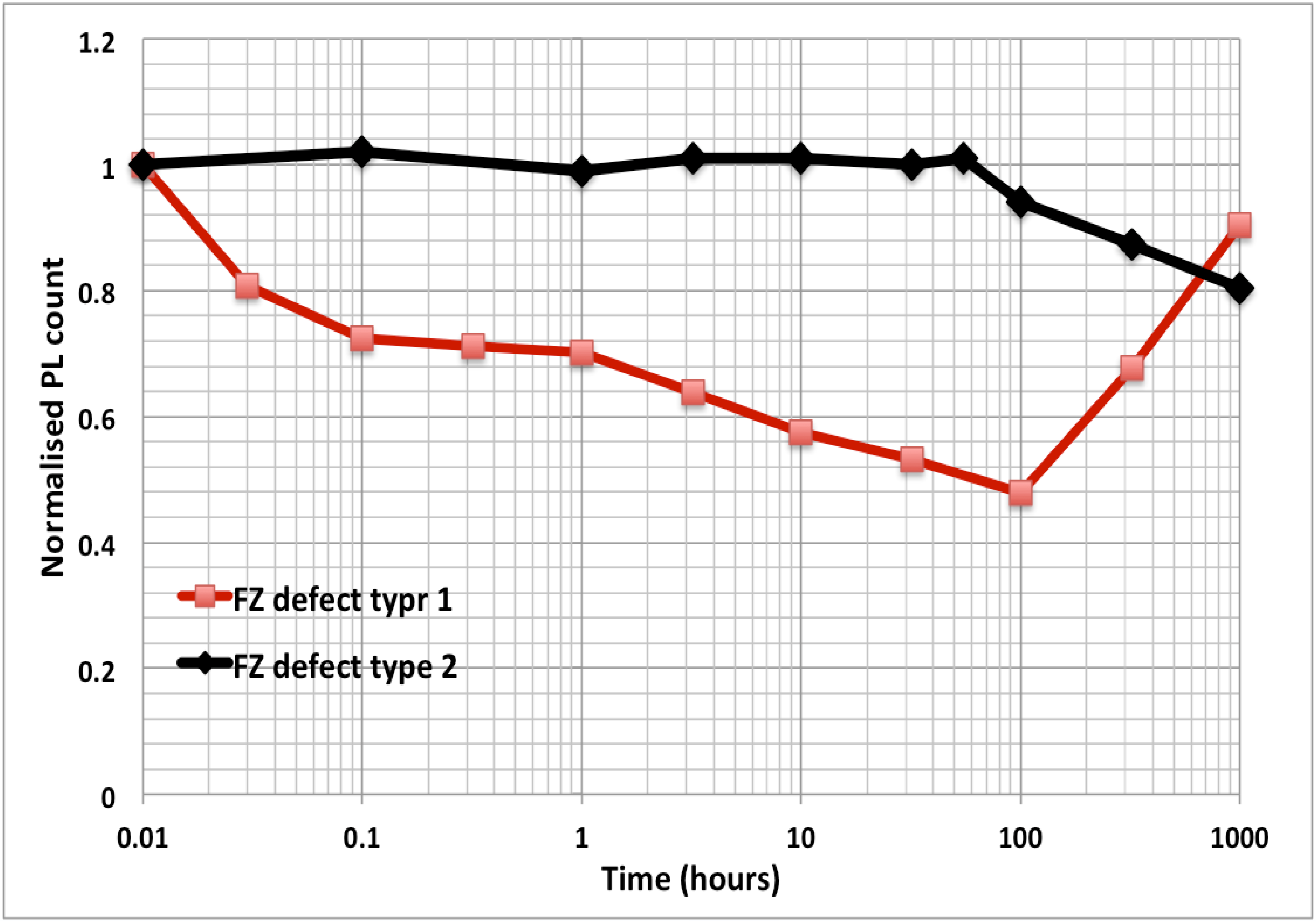


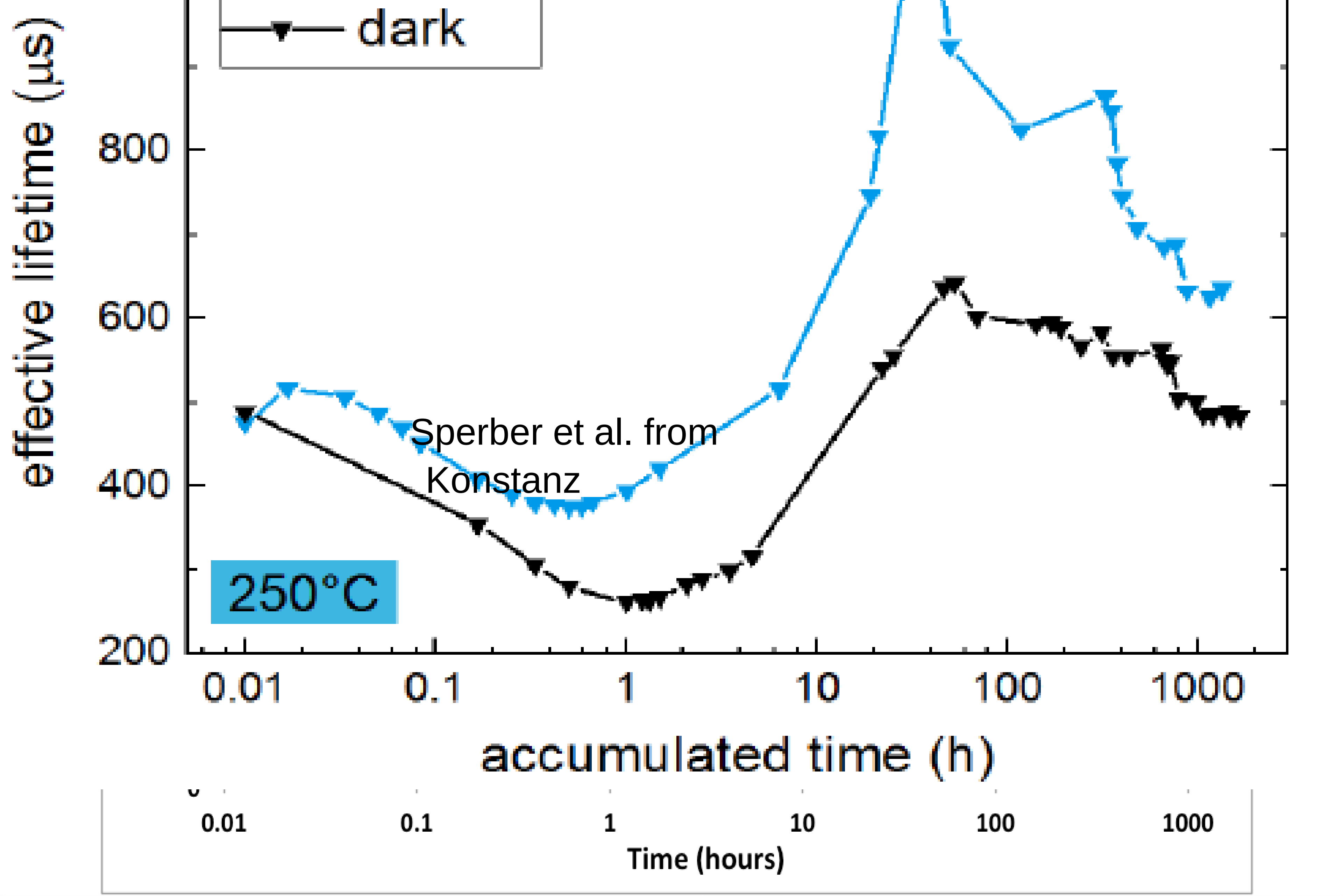
Comparison of Type 1 & 2 Defects





Identification of same defect in FZ wafers

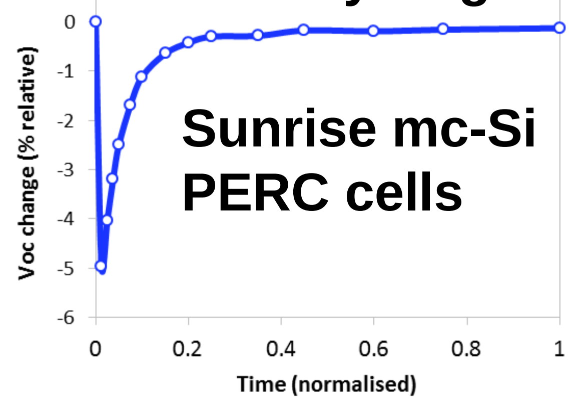


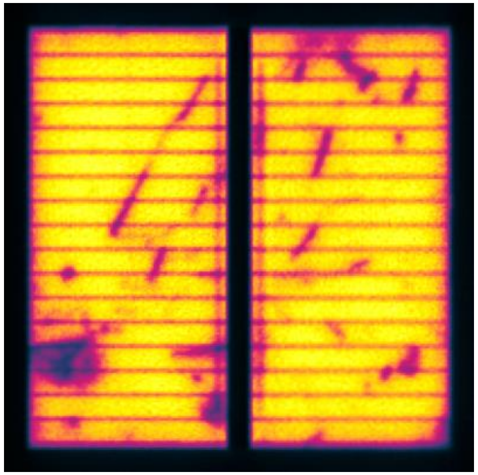

dark
effective lifetime (µs)
800
600
400
200
Sperber et al. from
Konstanz
250°C
0.01
0.1
1
10
100
1000
accumulated time (h)
0.01
0.1
1
10
100
1000
Time (hours)

Elimination of LID in mc-Si PERC cells

- Identification of the defect in mc-Si
- Multiple energy levels in band-gap
- H accelerates evolution of defect
- H ultimately passivates defect
- Need >1,000 hours of light-soaking
- Common in n-type material
- Can occur in any wafers including mono wafers

UNSW laser hydrogenation



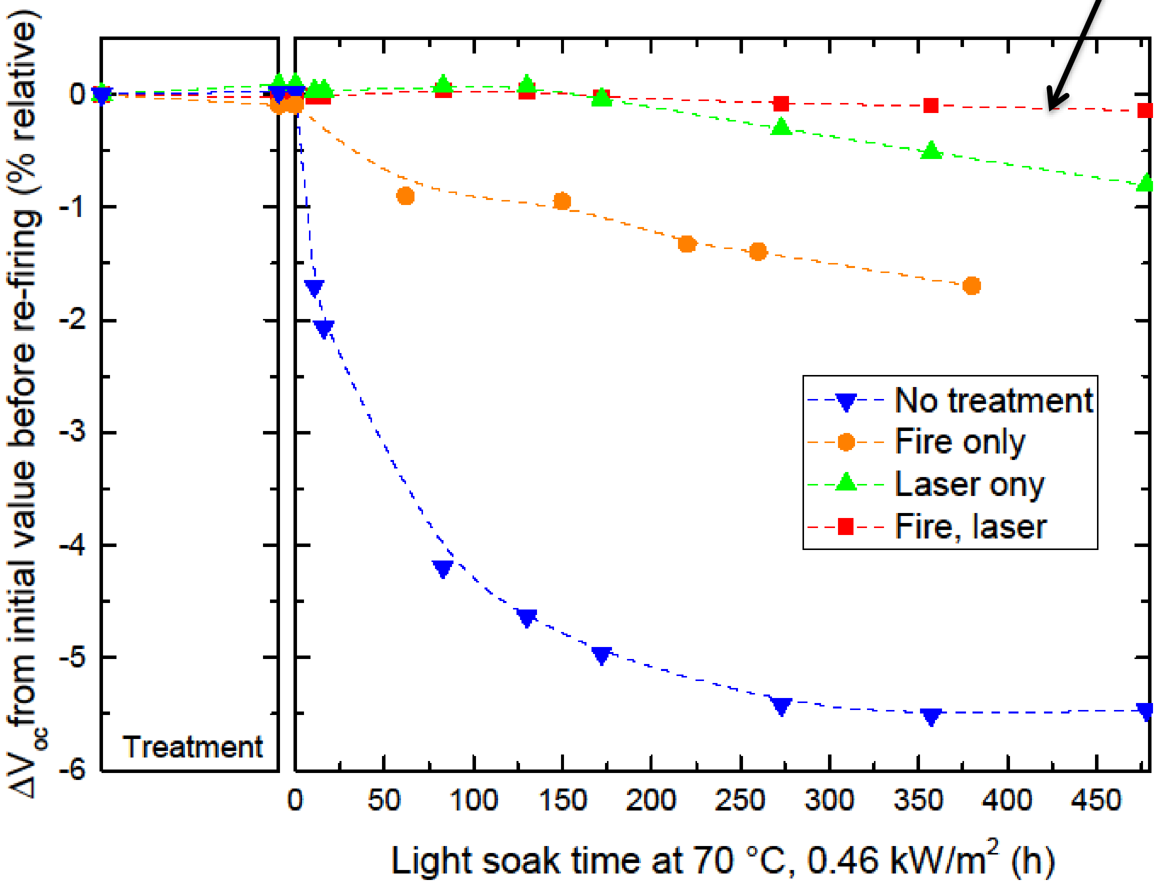


Top: Relative change in V_{oc} of a mc-Si PERC cell with continual laser treatment

Bottom: Associated photoluminescence images

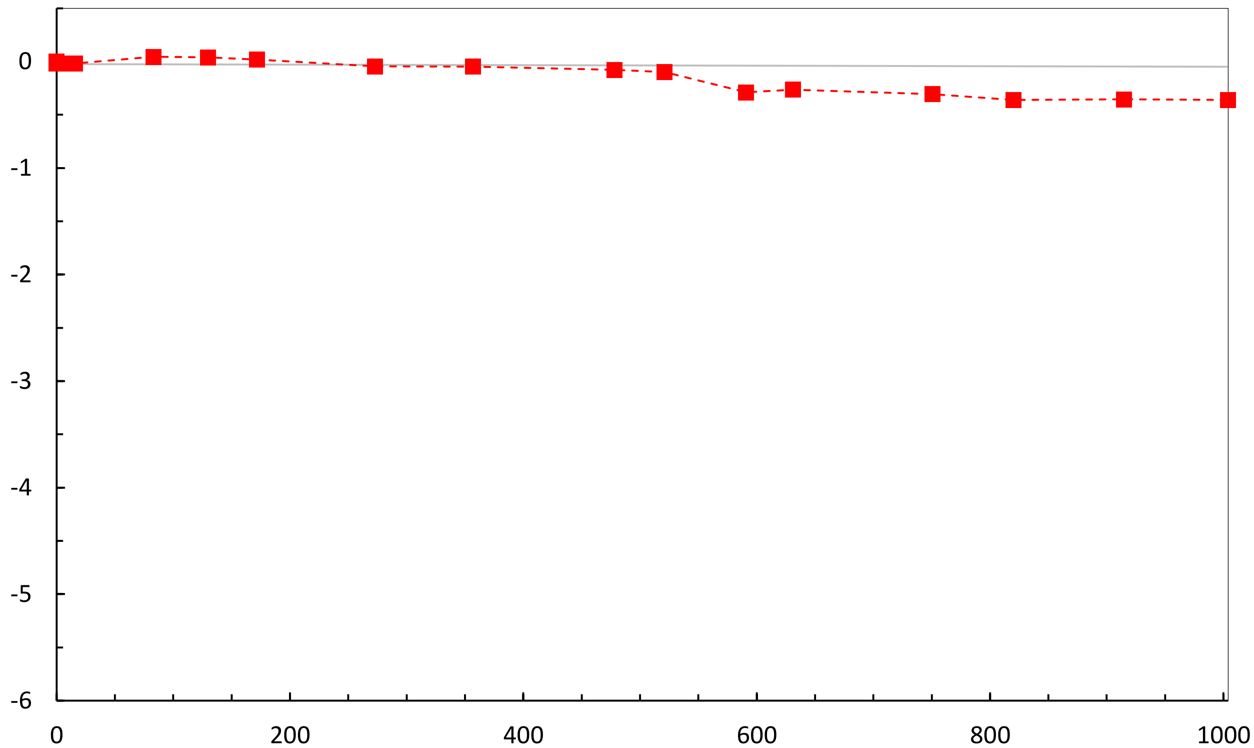
Best published stability – Re-fire and laser

Type 2 defect appears to be mitigated



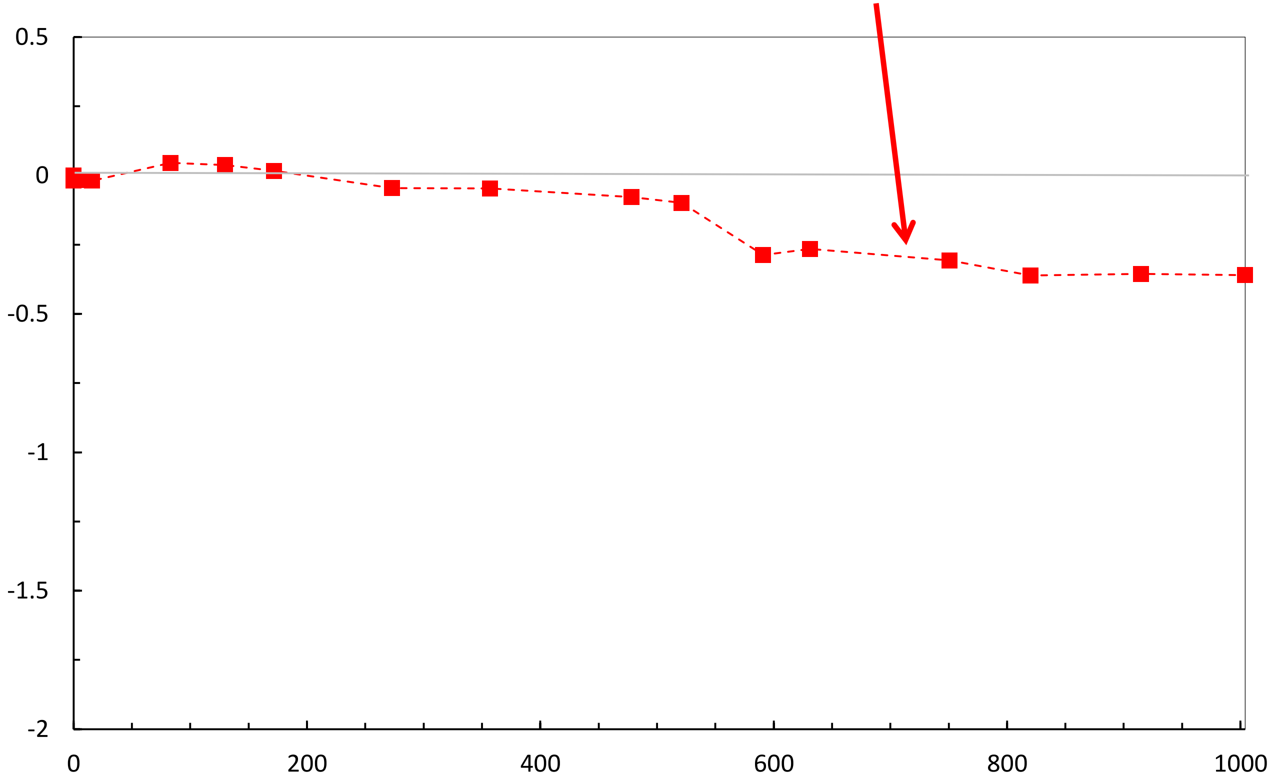
C. Chan et. al. "Rapid stabilization of HP mc-Si PERC cells" JPV 2016

Best published stability – Re-fire and laser



Best published stability – Re-fire and laser

Zoom in on y-axis shows gradual decline as type 2 defect appears:

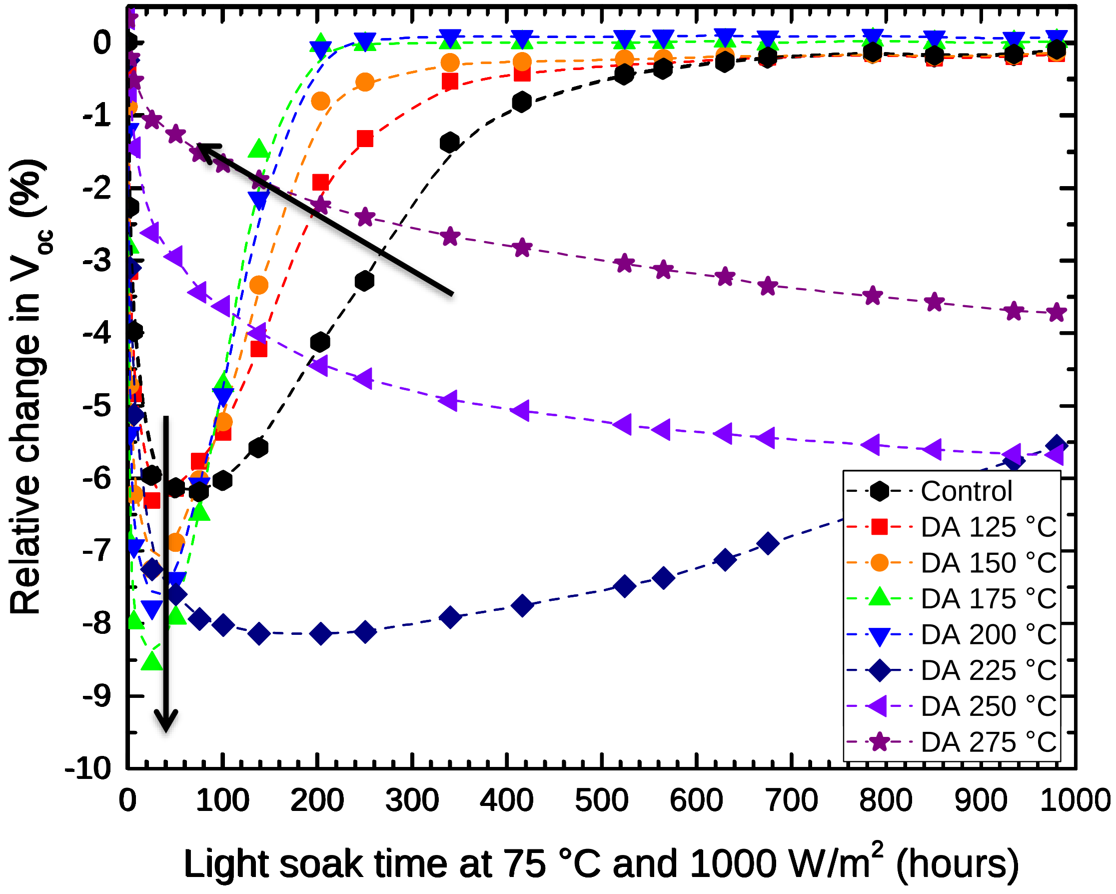


Dark annealing as an accelerated ageing test

Dark annealing can accelerate the evolution of the degradation

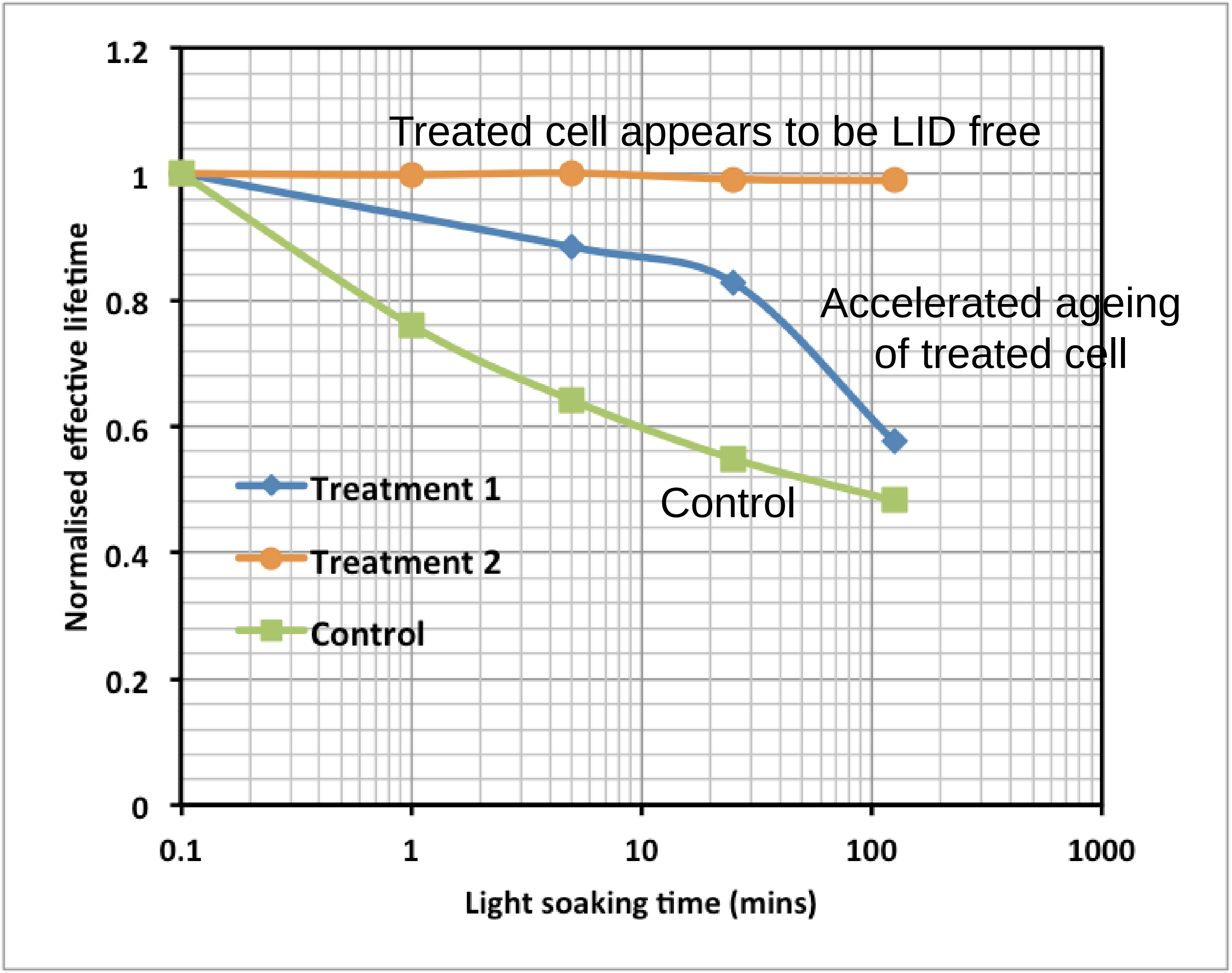
- 8 identical sister mc-Si PERC cells
- Each dark annealed at a different temperature for 2.5 hours, then light soaked at standard 75 C 1kW/m2
- Dark annealing first accelerates type 1 defect forming and recovering
- **Eventually, the dark annealing eliminates the type 1 defect, and only the type 2 defect remains**

→ Dark annealing can be used as an accelerated test for future Type 2 degradation



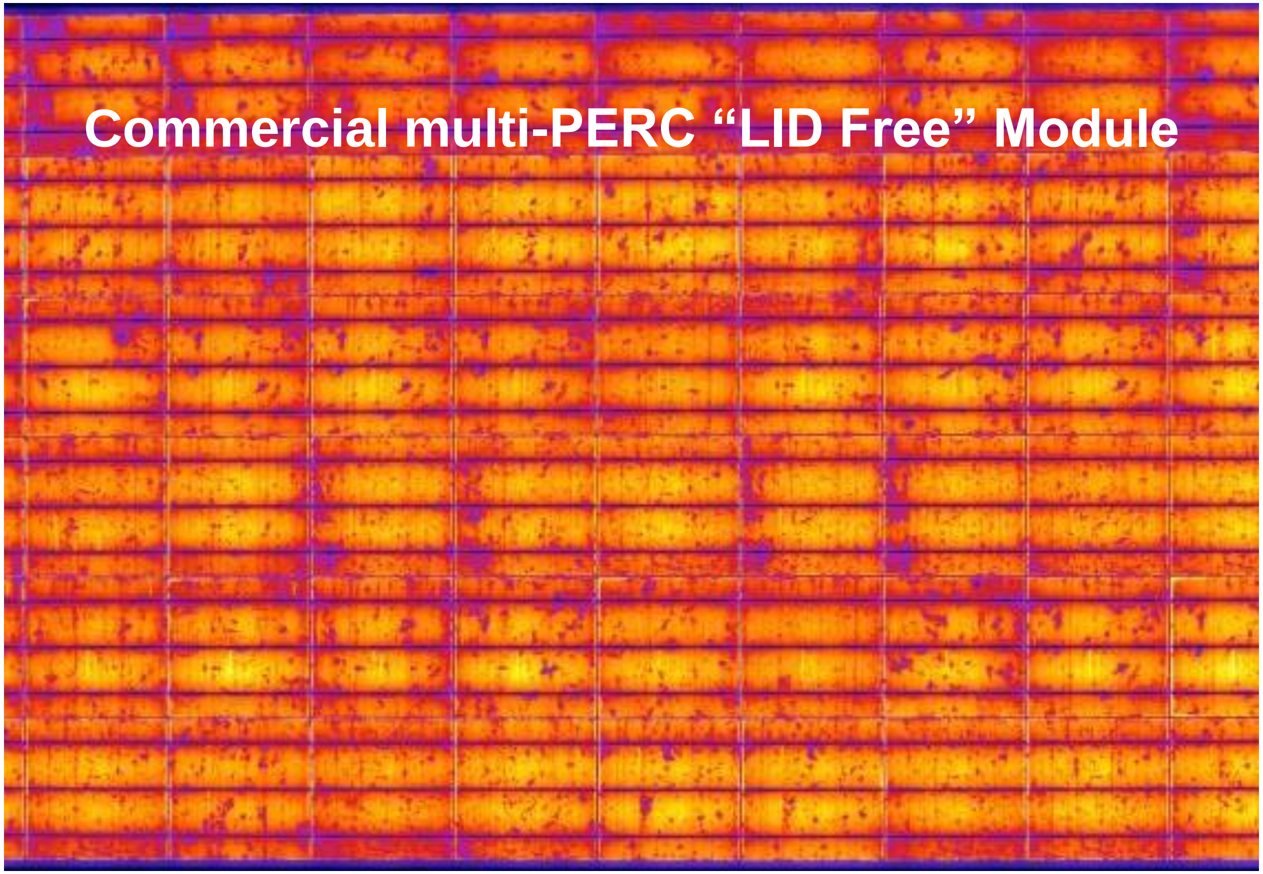
[UNSW unpublished]

Standard light-soaking is not suitable

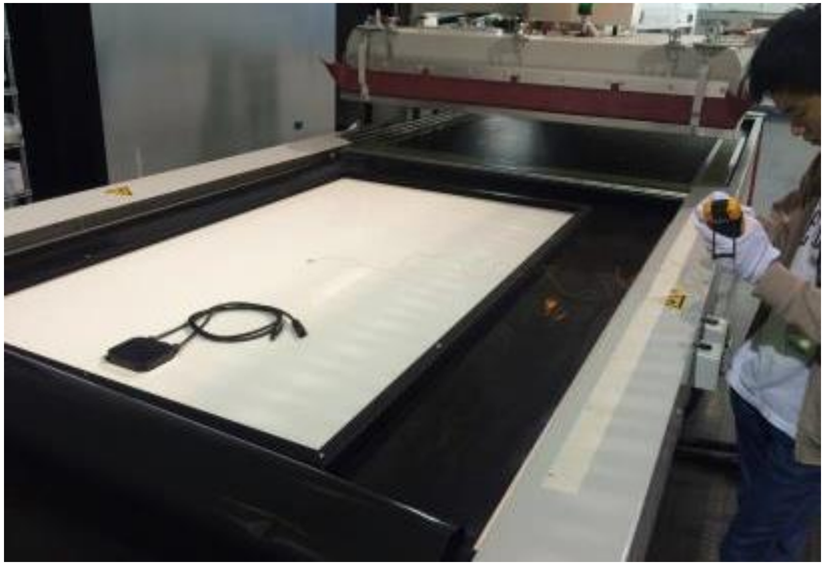


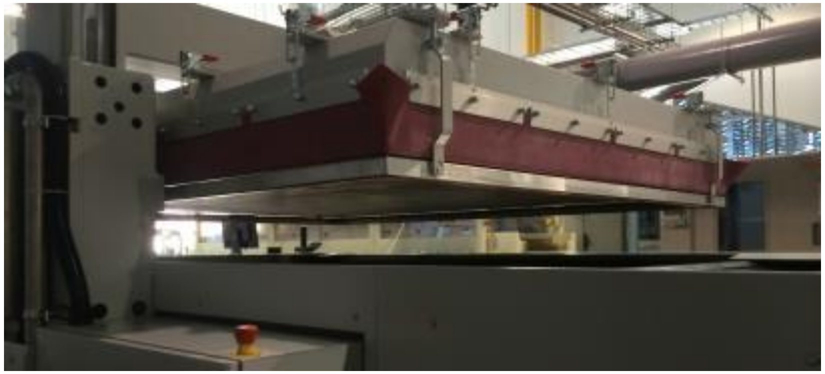
Accelerated testing on "LID free" modules

- Accelerated by 150 ° C dark anneal for 10 hours prior to light soaking



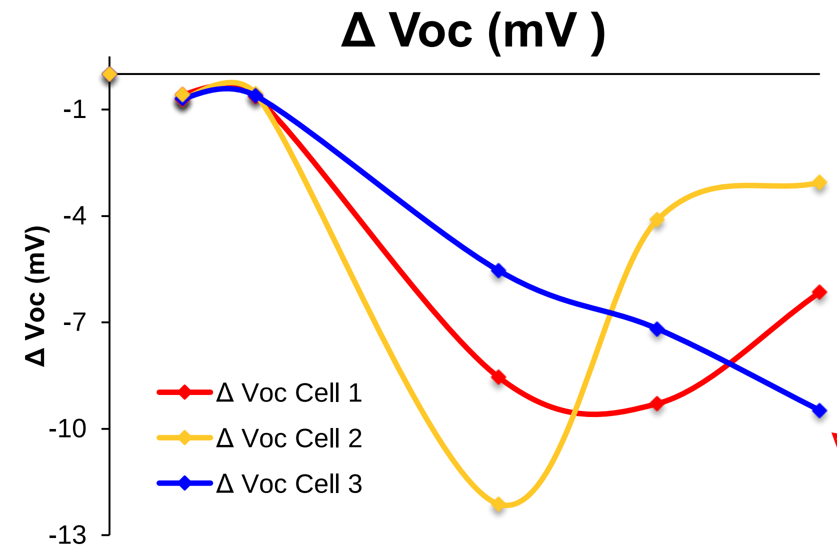
Dark anneal & Light Soak

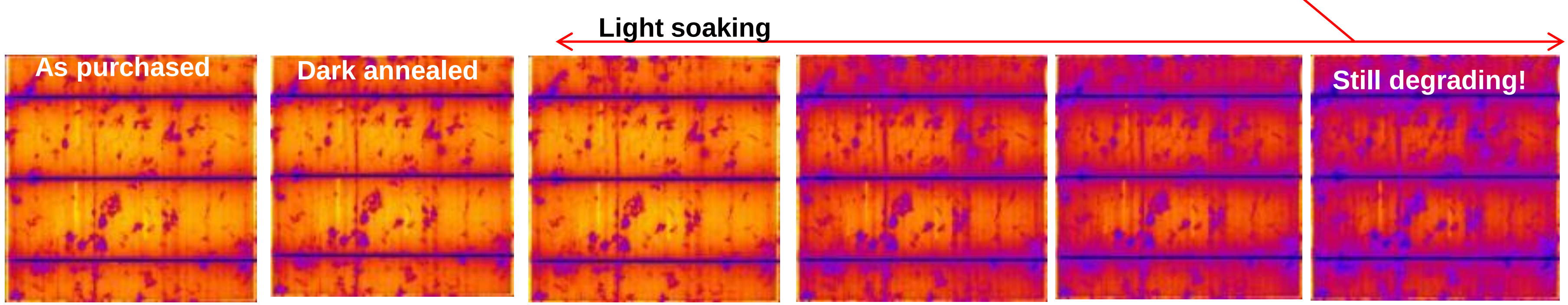




Accelerated testing on “LID free” modules

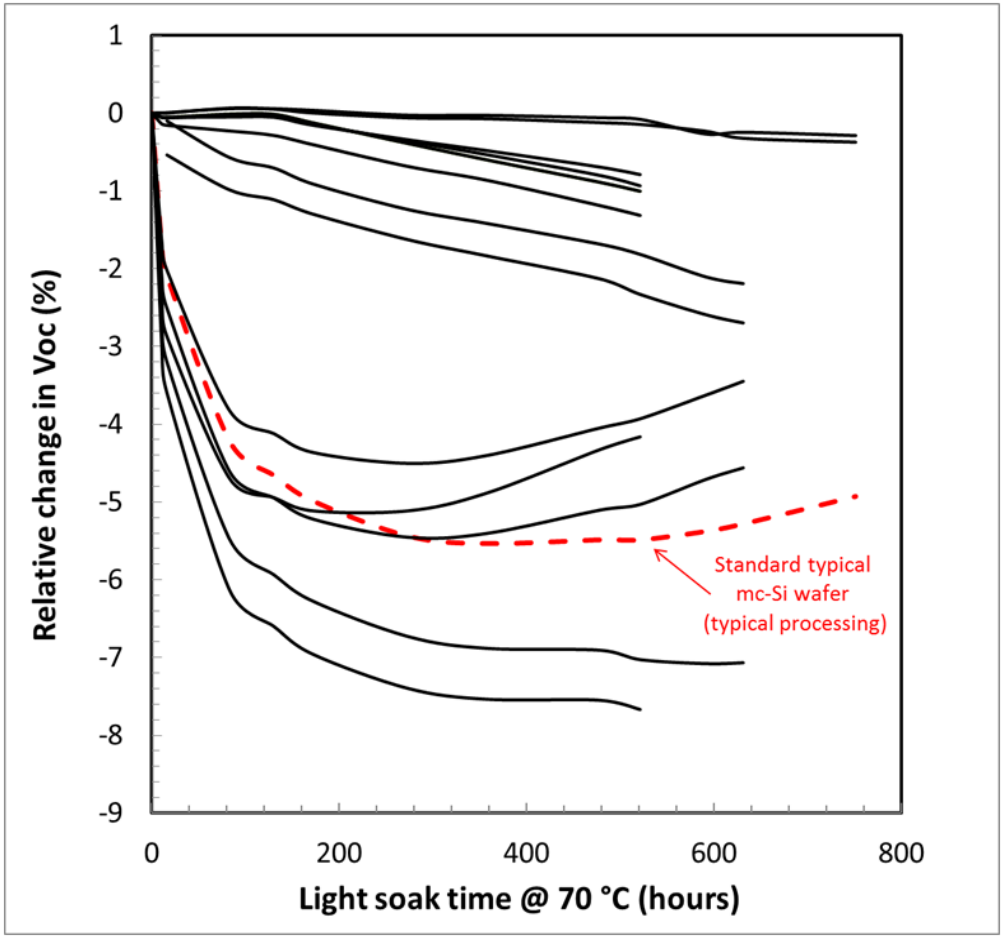
Cell 3


Δ Voc (mV)
Δ Voc (mV)
-1
-4
-7
-10
-13
Δ Voc Cell 1
Δ Voc Cell 2
Δ Voc Cell 3


Light soaking
As purchased
Dark annealed
Still degrading!

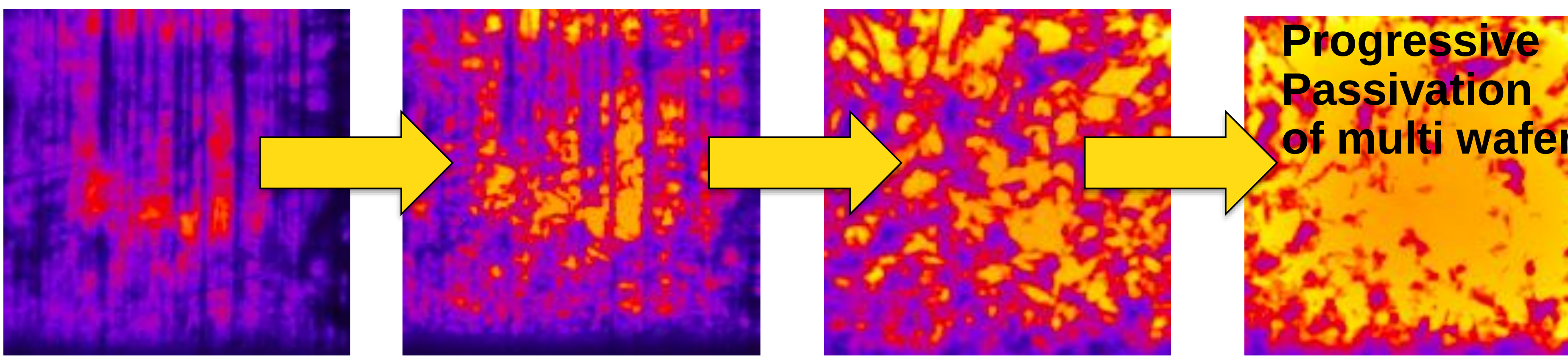
Identification of the defect causing LID in mc-Si PERC

- Defect takes on 2 forms:
  - – type 1 and type 2
- 2 energy levels in band-gap make its behaviour confusing
- Unique approach to H charge state control fixes defects
- Can be added to any wafer
- Present in Cz
- Common in n-type material
- Damages bulk lifetimes
- Damages AlOx passivation

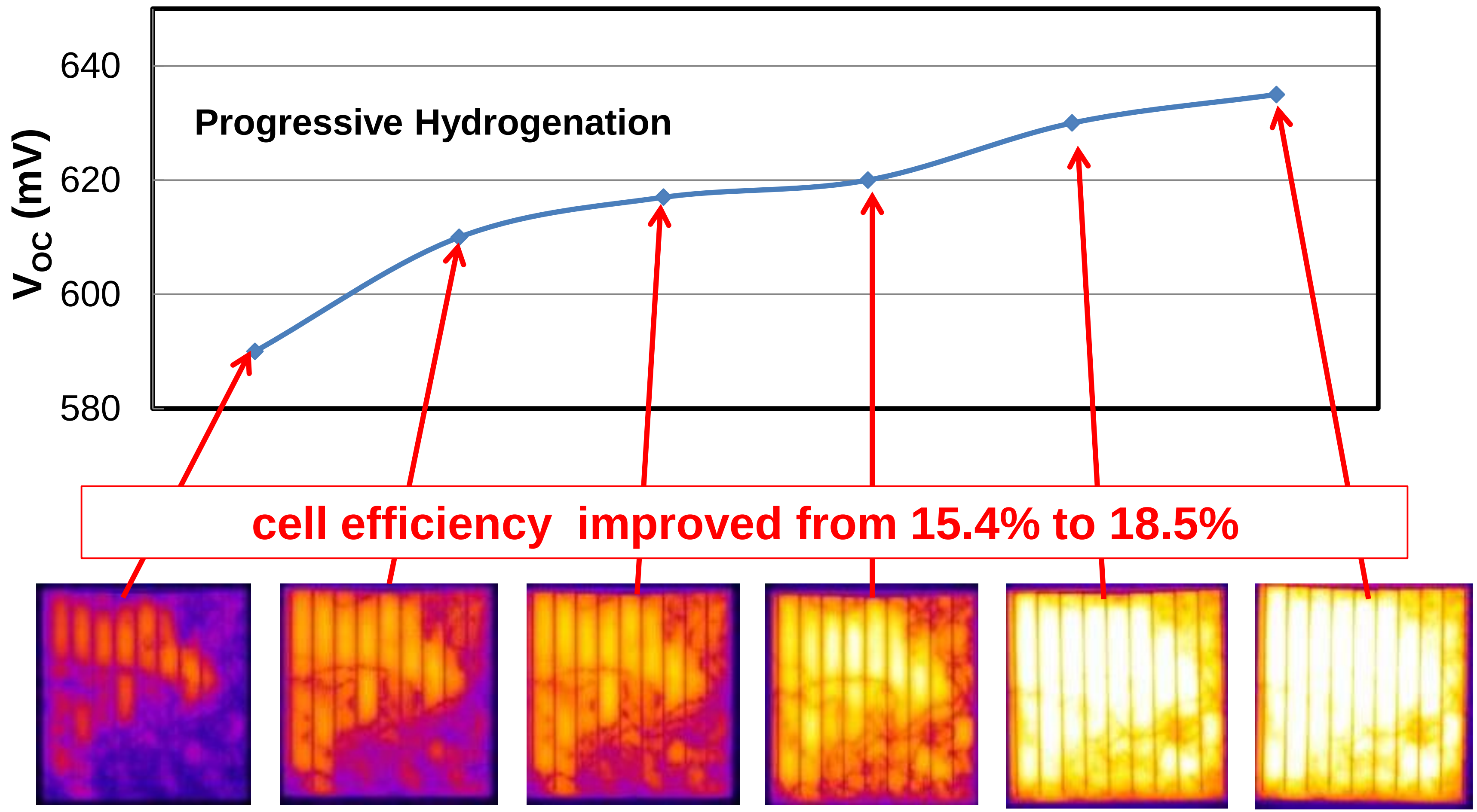


Greatest opportunity is with multicrystalline silicon

- Large range of types of defects
  - Crystallographic defects e.g. grain boundaries, dislocations etc
  - Contaminants
  - Variability across wafers and between wafers
- LID has major impact
- PERC cells >20% efficiency if not for LID
- Large range of defects makes H passivation more complicated but also increases its importance



Progressive improvement through repeated Hydrogenation



Progressive photoluminescence images (open circuit) for cells progressively hydrogenated

Advanced hydrogenation solves Rs and LID in multi

- Solutions will be published in 2017
- Consortium of 20 companies funding & commercialising the technology
- Industry partners like more patents
- Strong patent portfolio

Advanced hydrogenation of silicon solar cells

US 9190556 B2

CLAIMS (21)

The invention claimed is:

1. A method of processing silicon, with a hydrogen source present, for use in the fabrication of a photovoltaic device having at least one rectifying junction, the method comprising heating at least a region of the device to at least 100° C. while simultaneously illuminating at least some of the device with at least one light source whereby the cumulative power of all the incident photons with sufficient energy to generate electron hole pairs within the silicon is at least 20 mW/cm^2.

6 new patents for manipulating H and the H charge state

- Autogeneration of H0 for enhanced hydrogen passivation
- Controlling the location of hydrogen within silicon
- Enhanced generation of H0 in n-type silicon
- Novel thermal manipulation of hydrogen
- Use of hydrogen sinks to control hydrogen flow
- Solving LID in multicrystalline silicon wafers

Summary

- Hydrogen passivation is greatly enhanced through control of the H charge state to improve diffusivity and reactivity
- Large consortium of industry partners supporting the work
- Key patents awarded
- Commercial tools now available
- It appears most defect types can be passivated
- B-O related LID rapidly mitigated - 8 sec for full recovery
- Defect X causing LID in mc-Si has been identified
- Defect X also relevant to mono and needs different hydrogen passivation process

Thank you

Thank you

LONGi 隆基

GCL

TW SOLAR

CECENERGY
PTE LTD

MEYER BURGER

Sunrise
Global Solar Energy

CanadianSolar

SUNTECH
BE UNLIMITED

SCHMID

ACAP

LERRI Solar

tindo solar

Sunport

APOLLON SOLAR

CSUN
energy for the future

ARENA

Australian Governmei
Australian Renewable Energy Agency

ROTH & RAU
CELL & COATING SYSTEMS

KUTTLER
AUTOMATION SYSTEMS