Evaluation of combined EBIC/FIB methods for solar cell characterization

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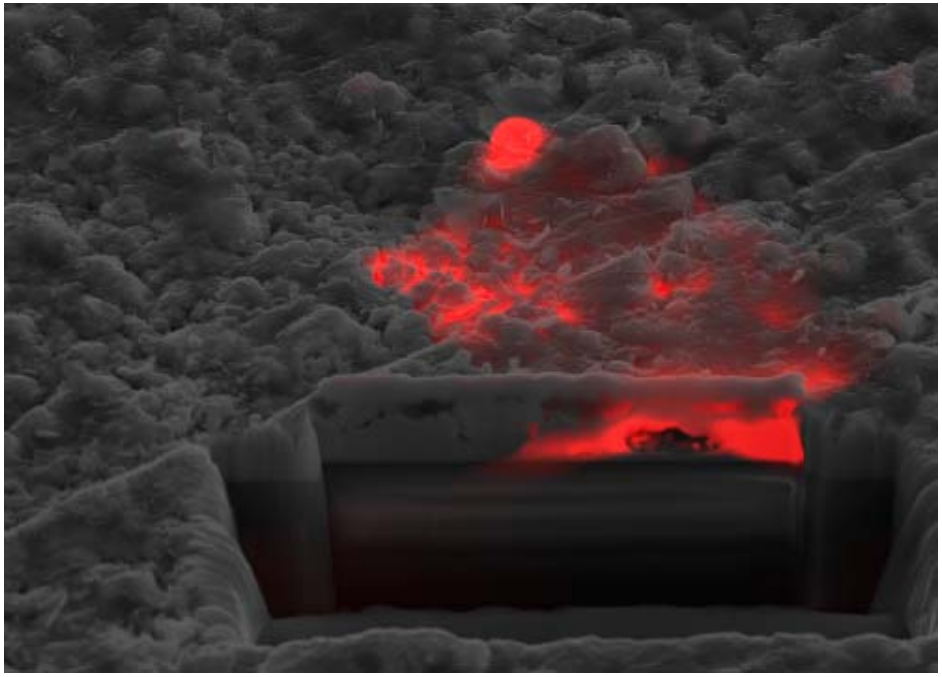
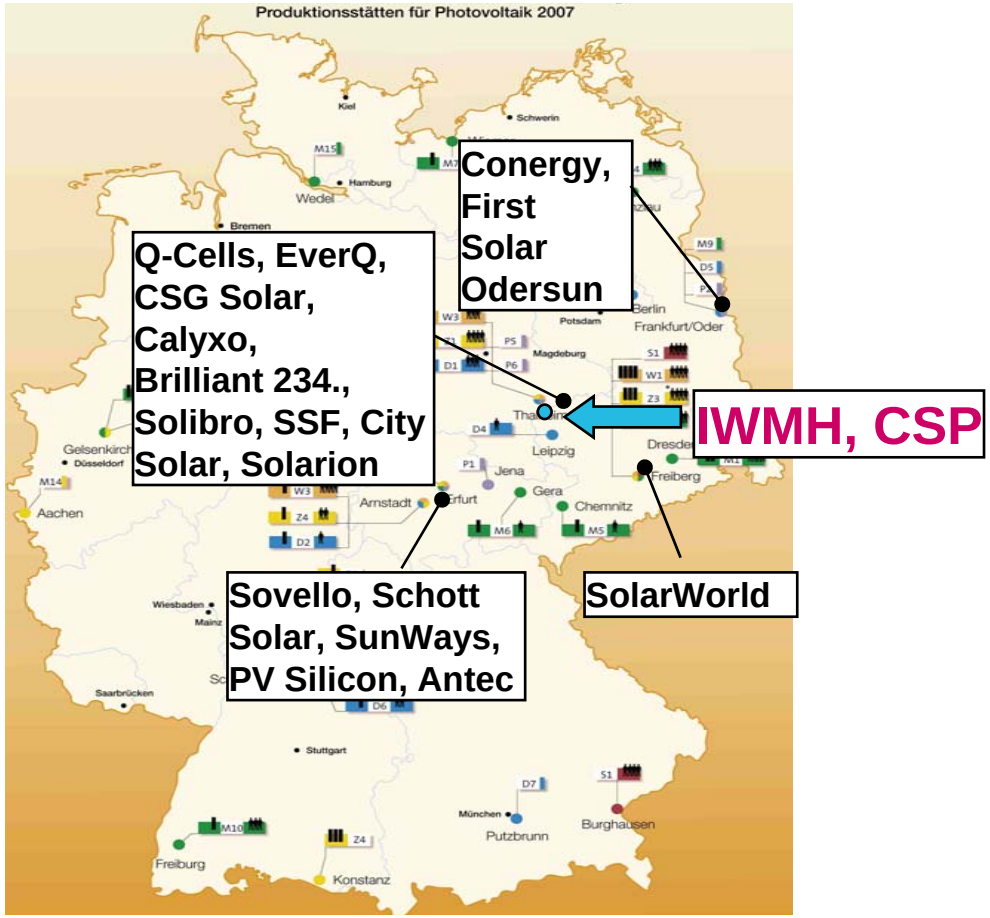
** FEI Company



Drei-Länder FIB Workshop, 28./29. 6.2010 in Wien

Fraunhofer-Center for Silicon Pholtovoltaics (CSP)

- joint initiative of the Fraunhofer Institute for Mechanics of Materials (IWM) and Solar Energy (ISE)
- Location: Halle/Saale, Center of Germany's Solar Valley



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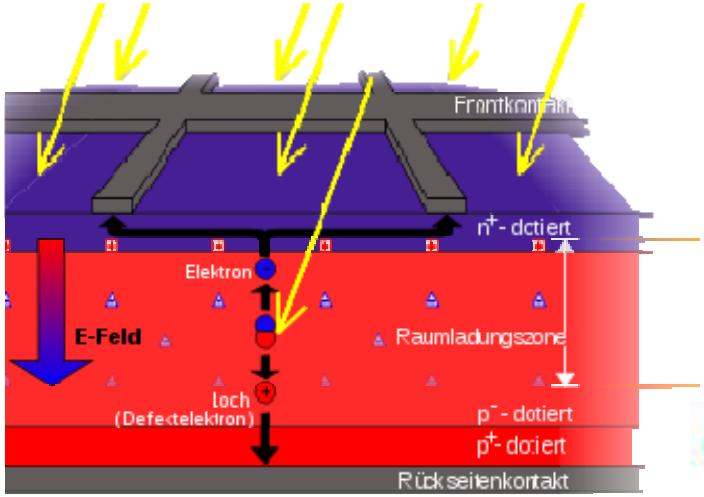
Solar Cell technologies

Si-wafer cells



sovello

Q.CELLS

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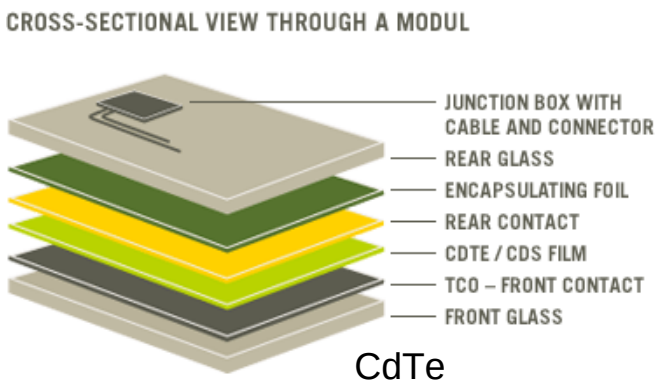
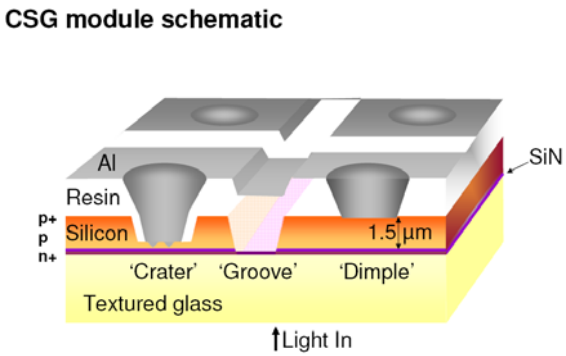
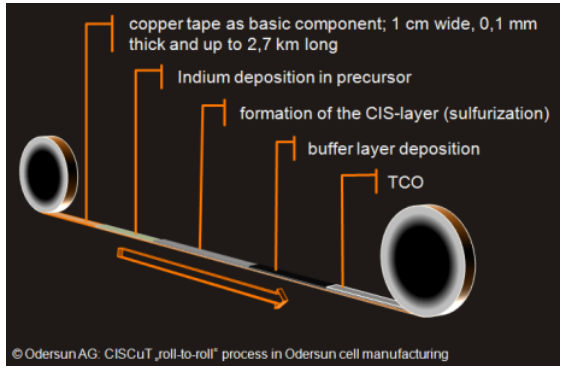


CdTe

Thin film cells (CdTe, CIS/CIGS,a-Si, CSG …)



csgsolar



CIS reel to reel technology ODERSUN

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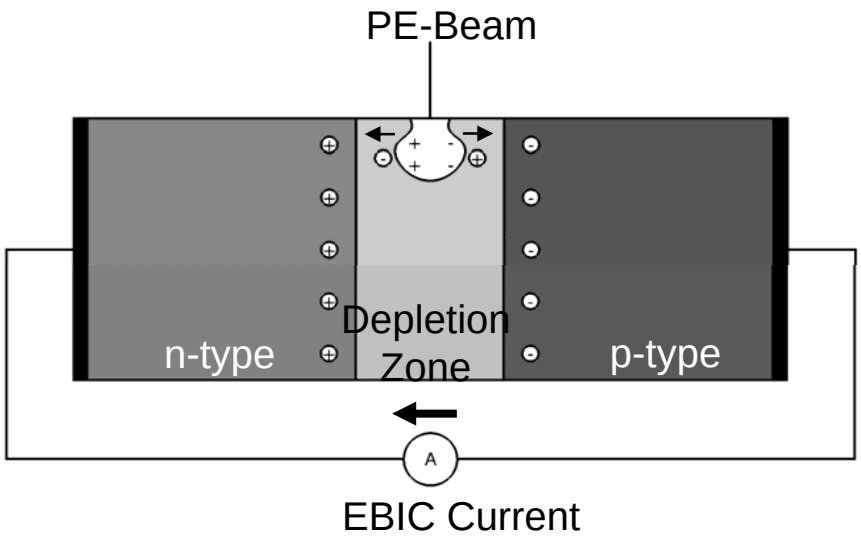
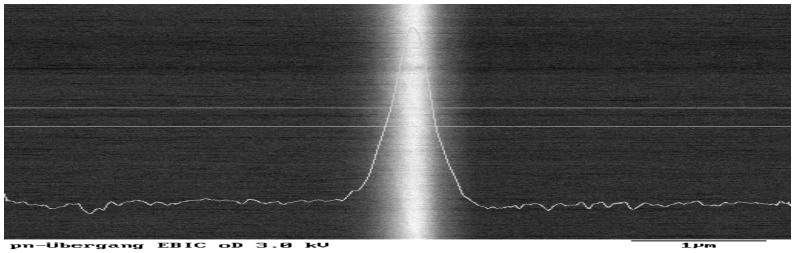
EBIC Principle

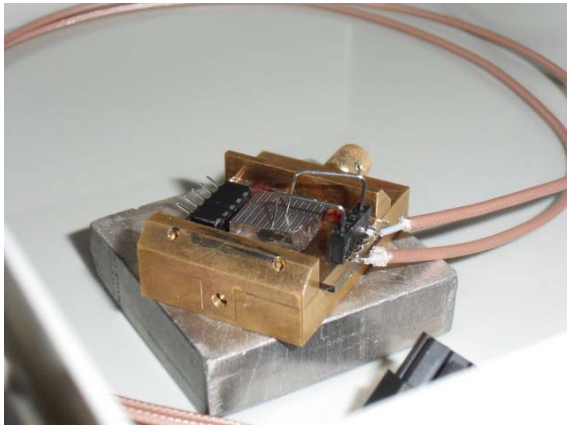




- Primary electrons generate electron-hole pairs in semiconductor material
- Electrons and holes were separated within the internal electrical field of a depletion zone generating an EBIC current
- EBIC signal as input for SEM imaging system
- depletion zones and electrically defects can be characterized

EBIC/FIB setup

FEI Quanta3D FEG dualbeam FIB



Sample holder with manual prober needles

Sample holder with mounted Kleindiek manipulator

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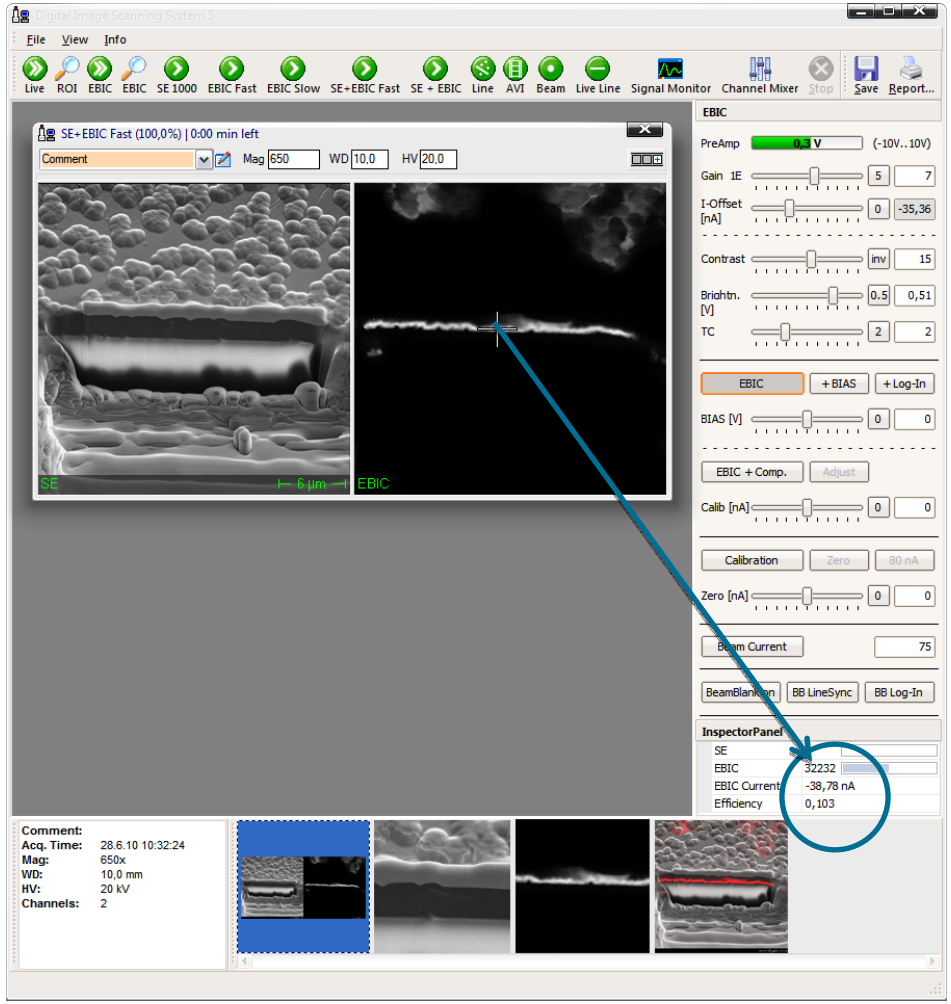
DISS5 *EBIC*



- variable gain 1 E3….1 E10 V/A
- adjustable input offset -1…1 µA
- variable contrast 1…100x
- variable brightness -1…1 V
- adjustable low-pass-filter
- adjustable BIAS -10…10 V
- preconfigured operation modes:
  - •EBIC
  - •EBIC +BIAS
  - •EBIC +Log-In amplifier
  - •EBIC +Compensation
  - •Calibration
  - •Beam current measurement
- display of EBIC-current for each pixel
- calculation of efficency
- saveable preamp settings
- preamp settings and calculations in the image

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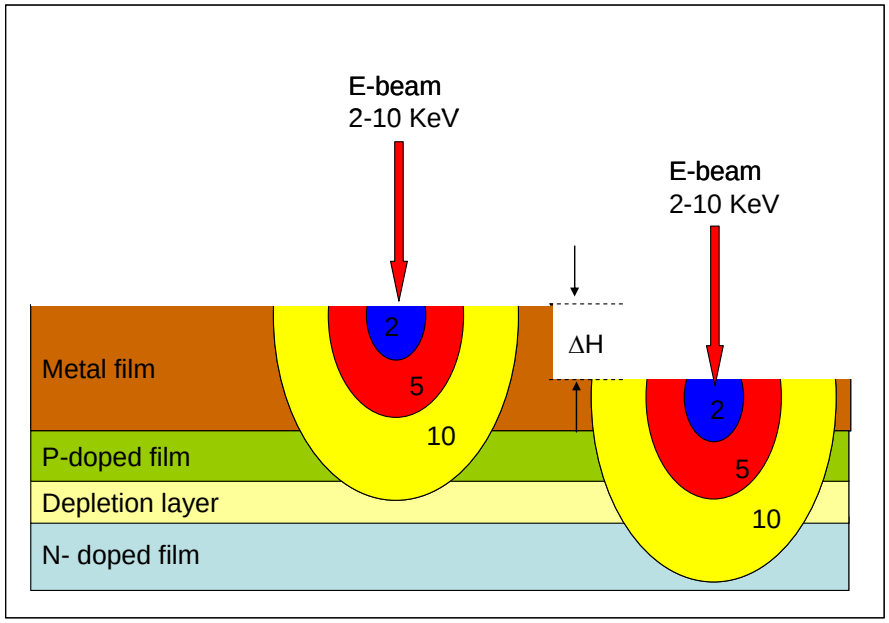
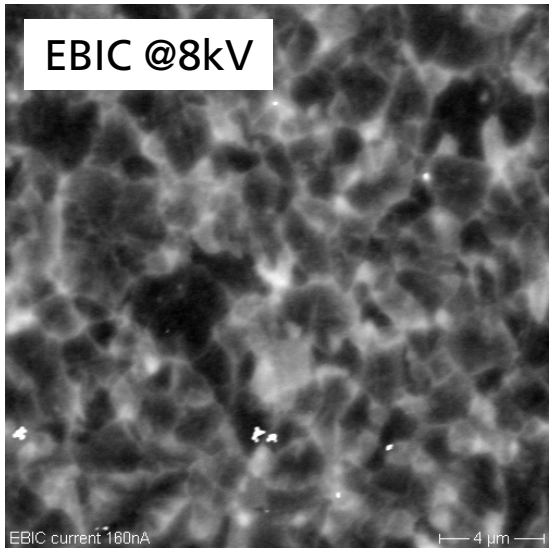
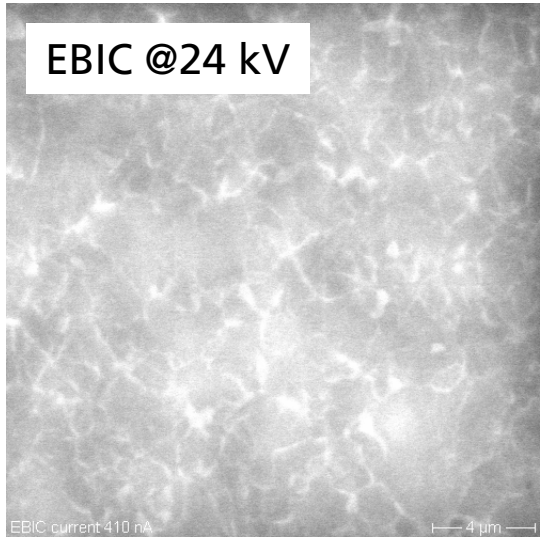
Top down EBIC







- Primary electron beam perpendicular to p/n junction
- Electron interaction volume has to extend to p/n junction to get EBIC signal
- Influence of topography and layer above p/n junction

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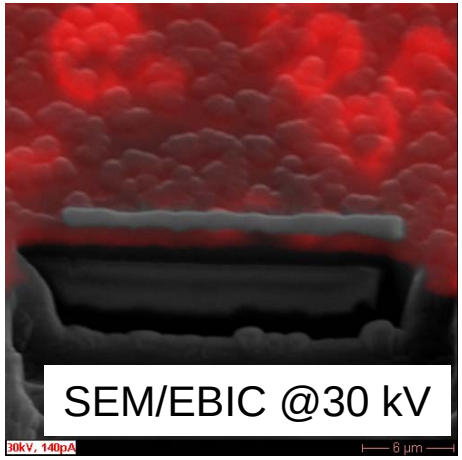
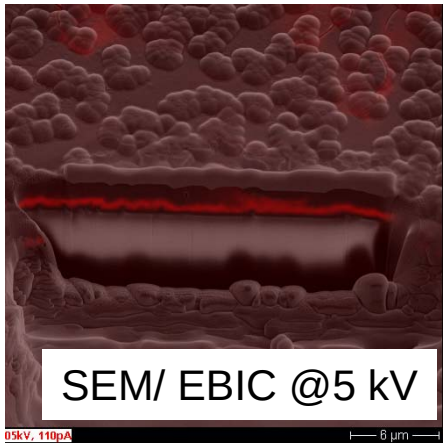
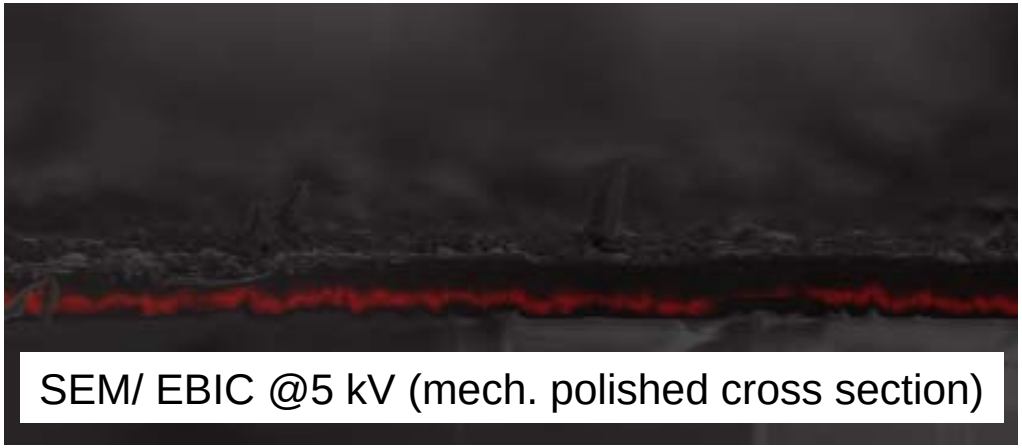
EBIC at FIB cross sections



- EBIC at FIB cross section, sample tilt 52°
- High acc. voltage to allocate subsurface defects
- Low acc. voltage to reduce electron beam interaction volume for high res. EBIC imaging
- Ga interaction at cross section can distort EBIC imaging -> 2kV FIB finish, verification at mechanically polished cross sections





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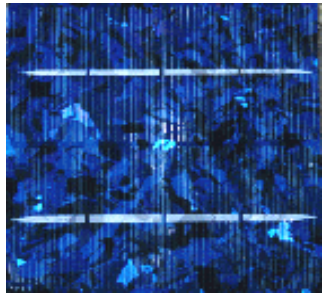
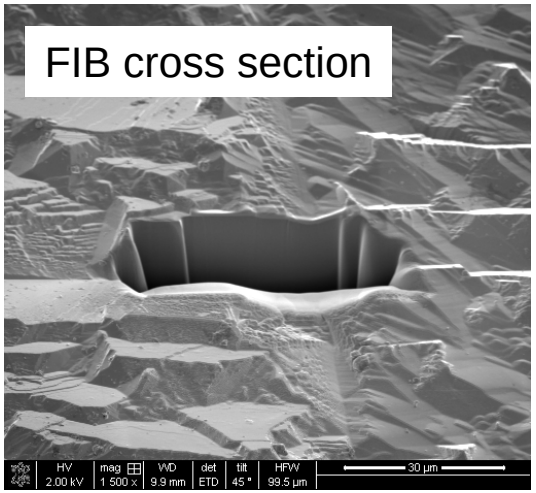
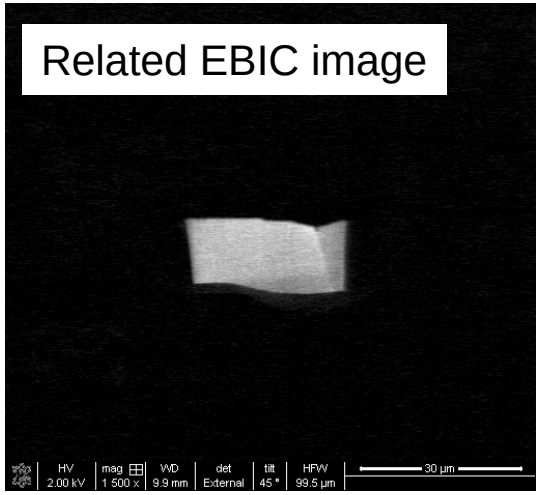
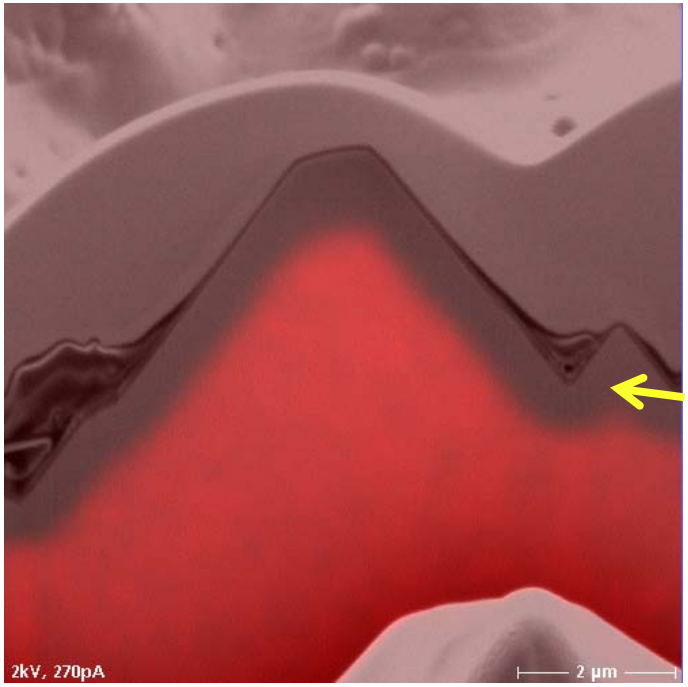
Characterization of p/n-junction









FIB-Pt to enhance cross section quality

n doped Si-layer

SEM/EBIC overlay, EBIC signal was colorized

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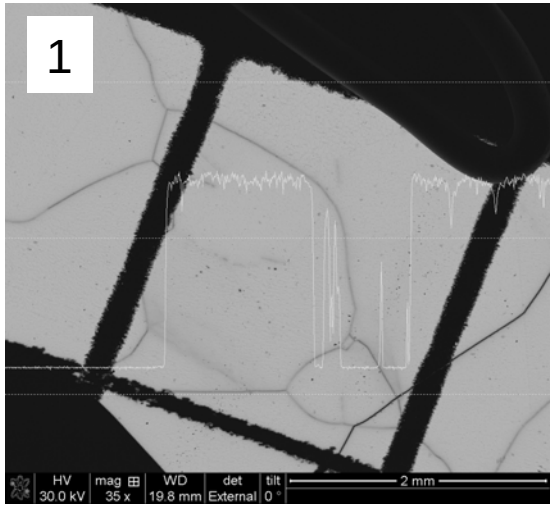
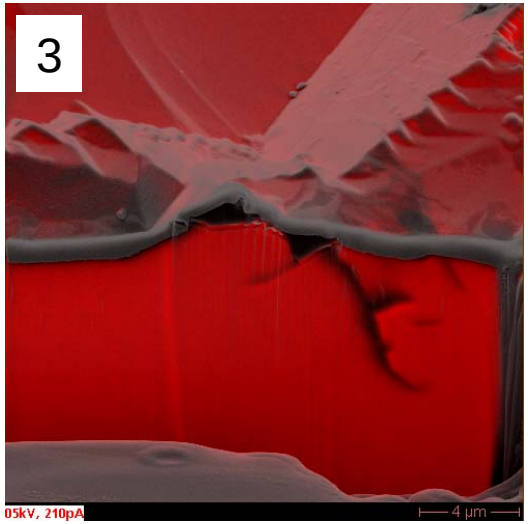
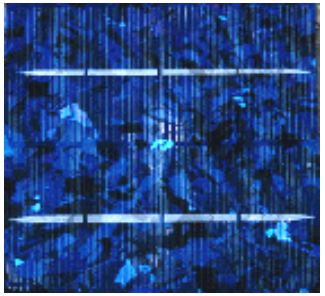
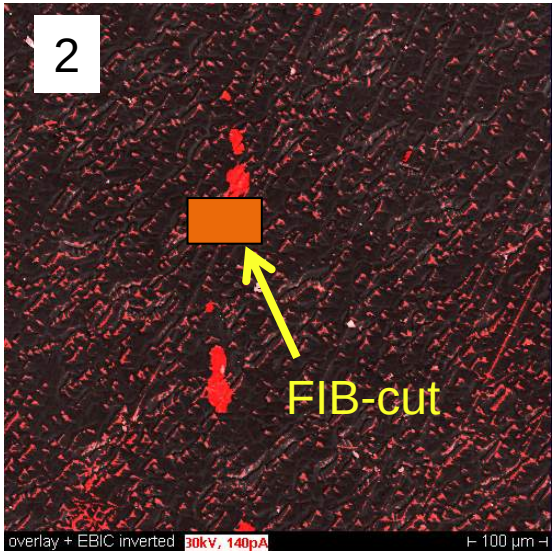
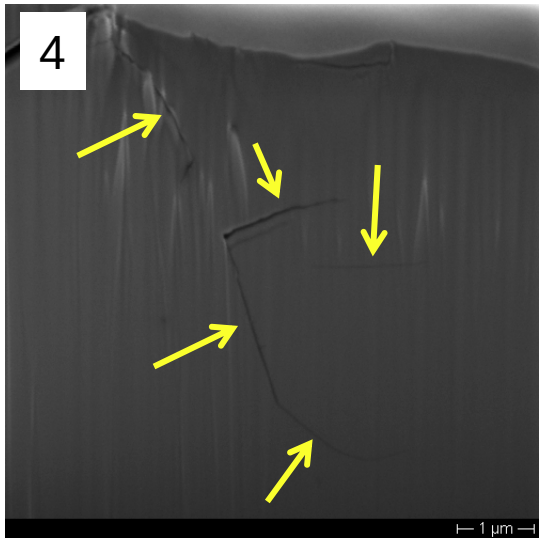
Defect localization and root cause analysis











1. EBIC overview linear recombination centers correlate mostly with grain boundaries

2. inner grain defect localized by EBIC (signal inverted)

3. EBIC at FIB cross section to visualize subsurface defect formation

4. SEM detail shows cracking in Si

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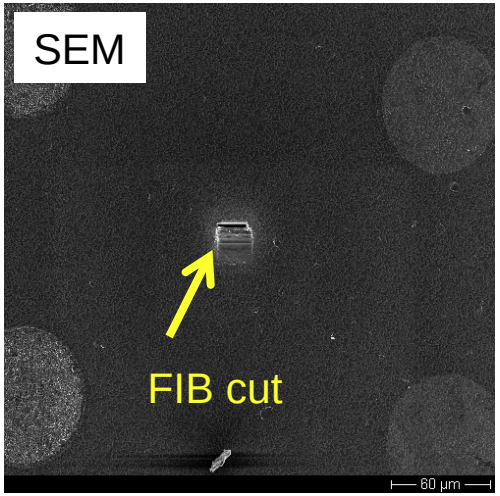
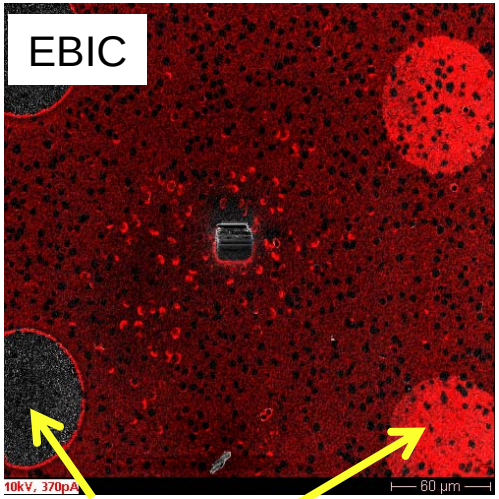
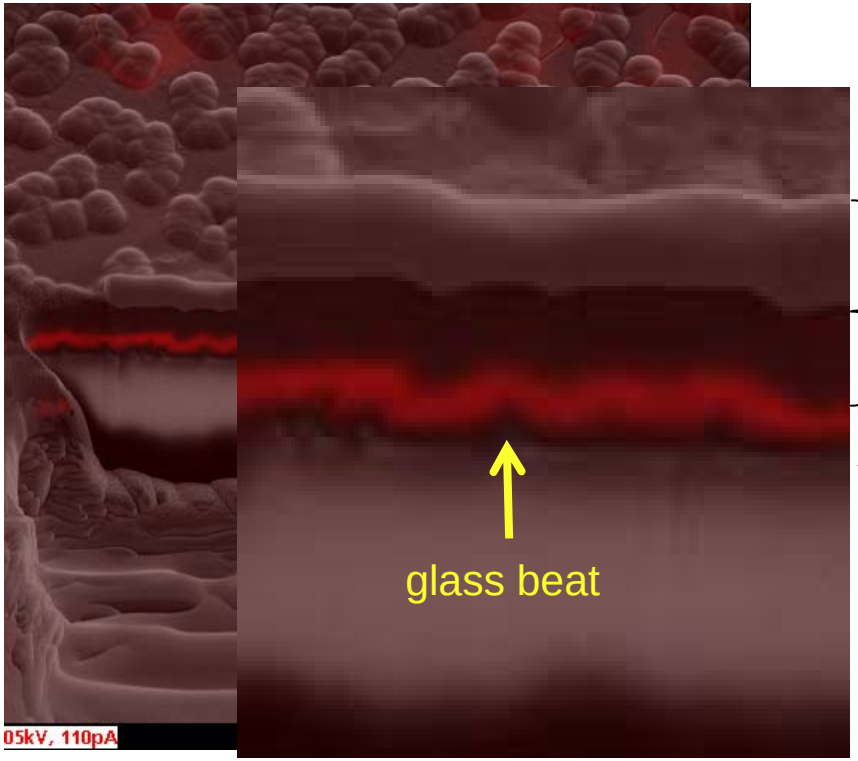
Characterization of p/n-junction





p and n contacts



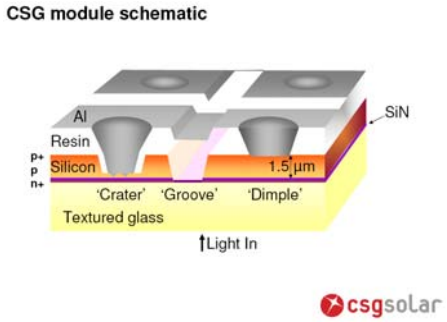
FIB Pt

p- layer

n+ layer

ARC and glass substrate

SEM/EBIC overlay at FIB cross section, EBIC signal in red



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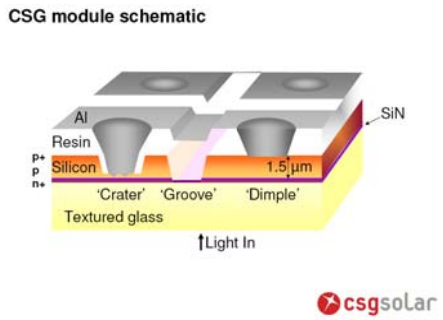
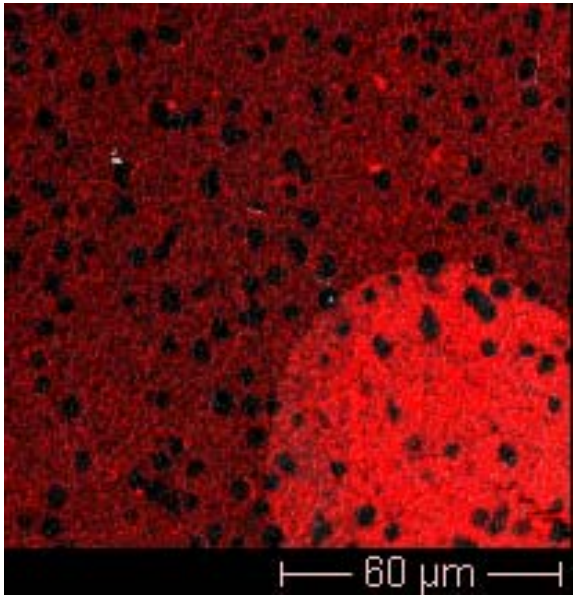
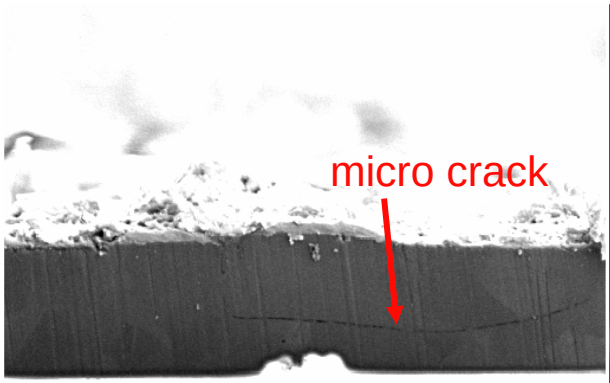
Defect localization and root cause analysis





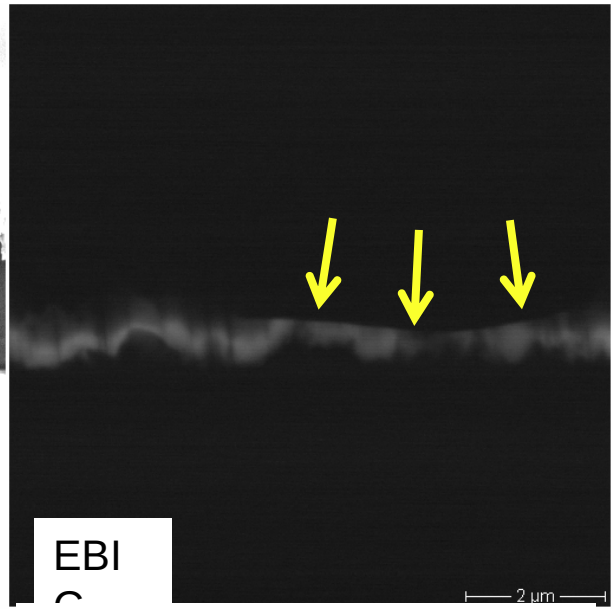
EBIC/SEM overview shows high density of defects (dark dots)



BSG is overexposed

SEM

FIB cross section analysis at defect site shows microcracks in Si absorber



EBI

depletion zone is cut by the crack

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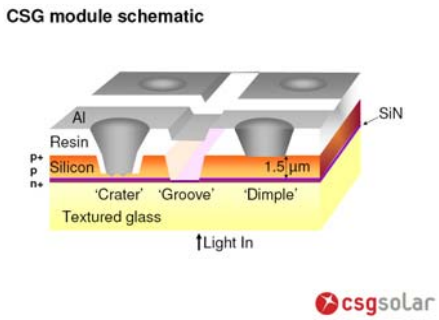
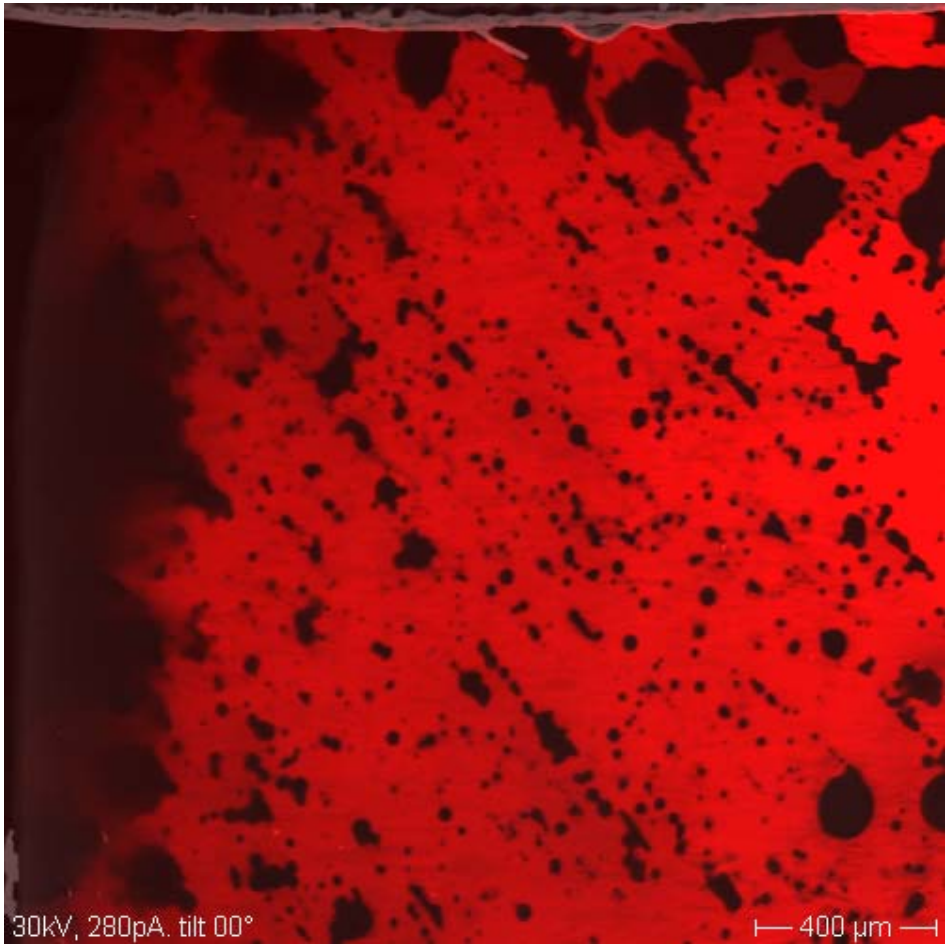
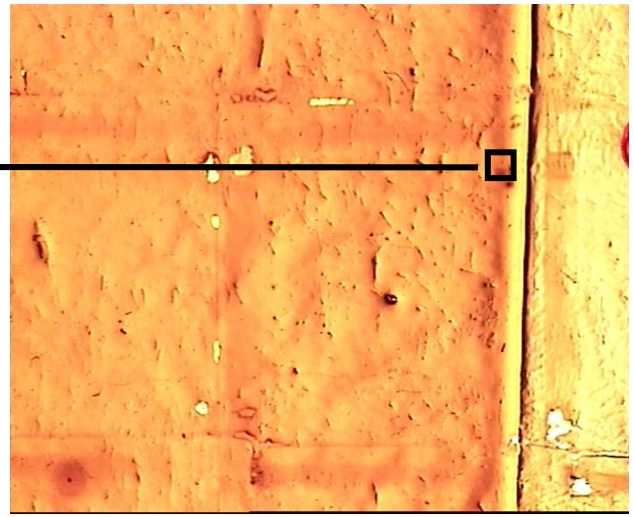
Defect localization and root cause analysis



Development of new laser crystallization process

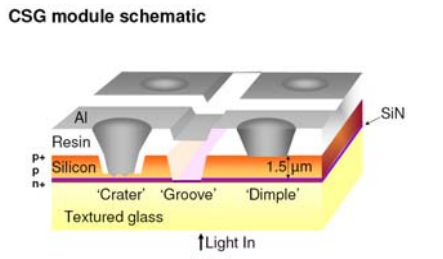


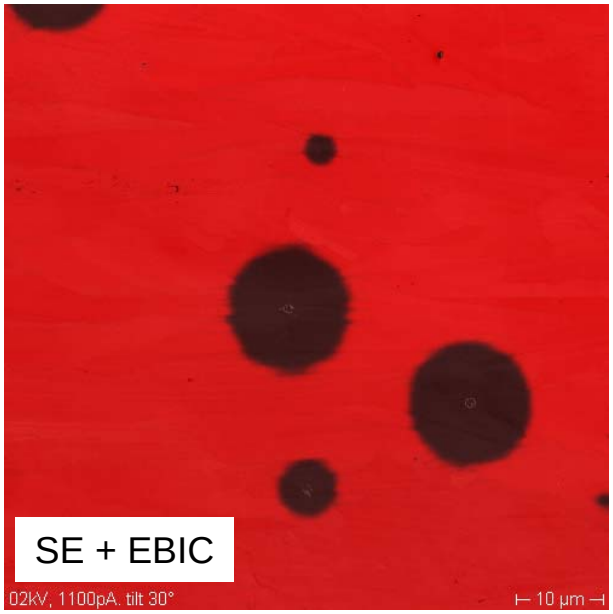
EBIC Overview shows high defect density

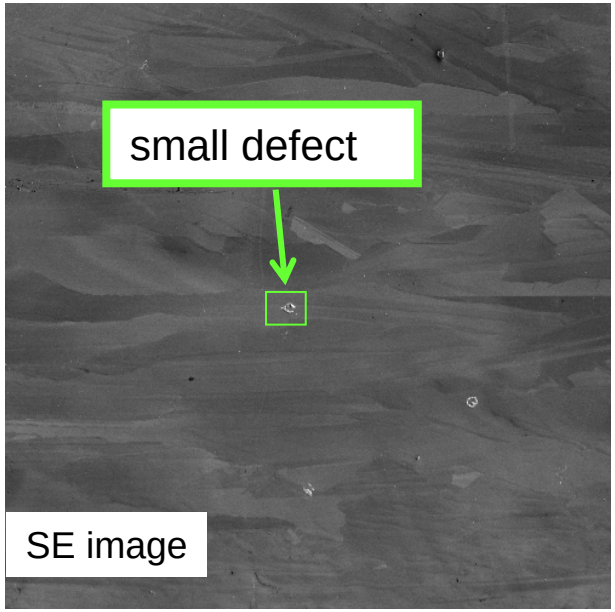


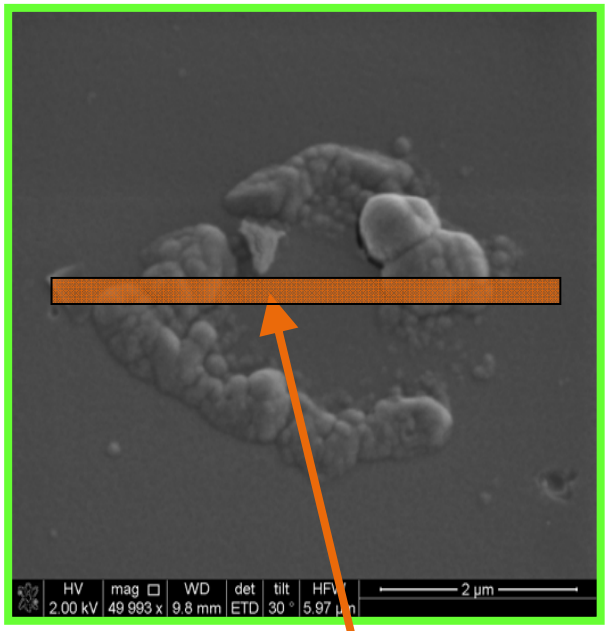
Light optical overview

Defect localization and root cause analysis





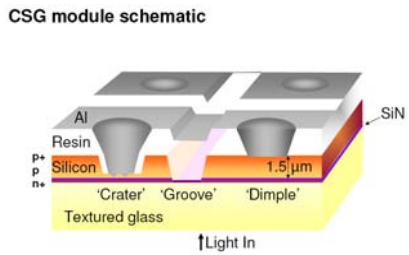




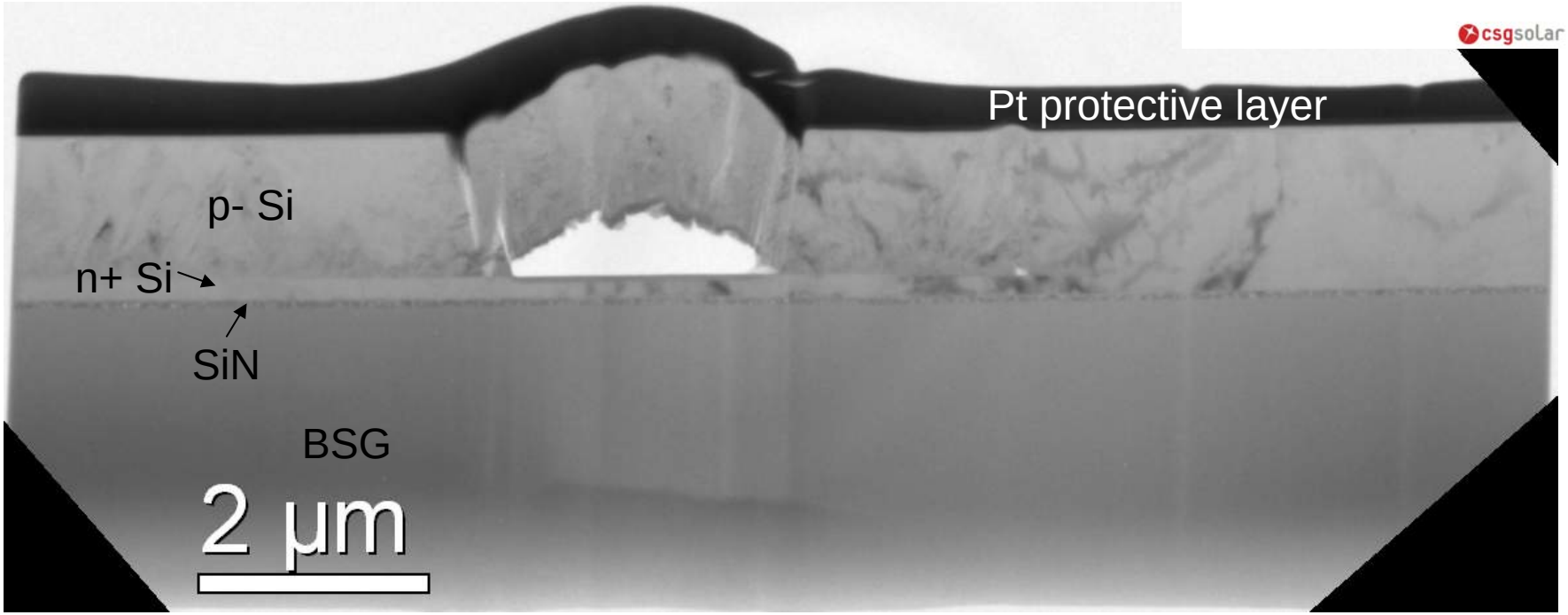
circular defect areas without EBIC signal
small defects at centre

FIB preparation of TEM lamella

Defect localization and root cause analysis

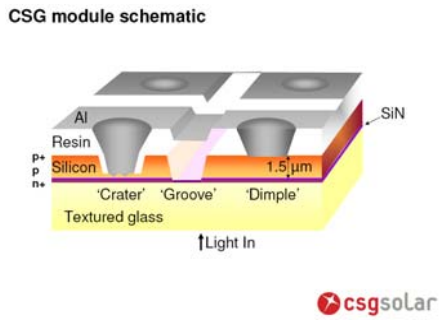


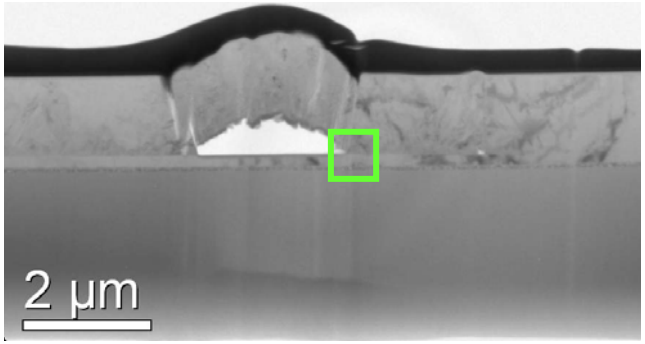
TEM-overview of defect

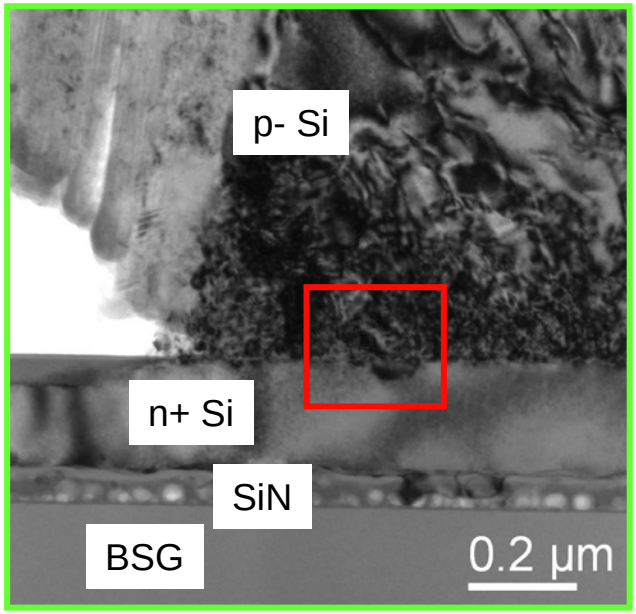


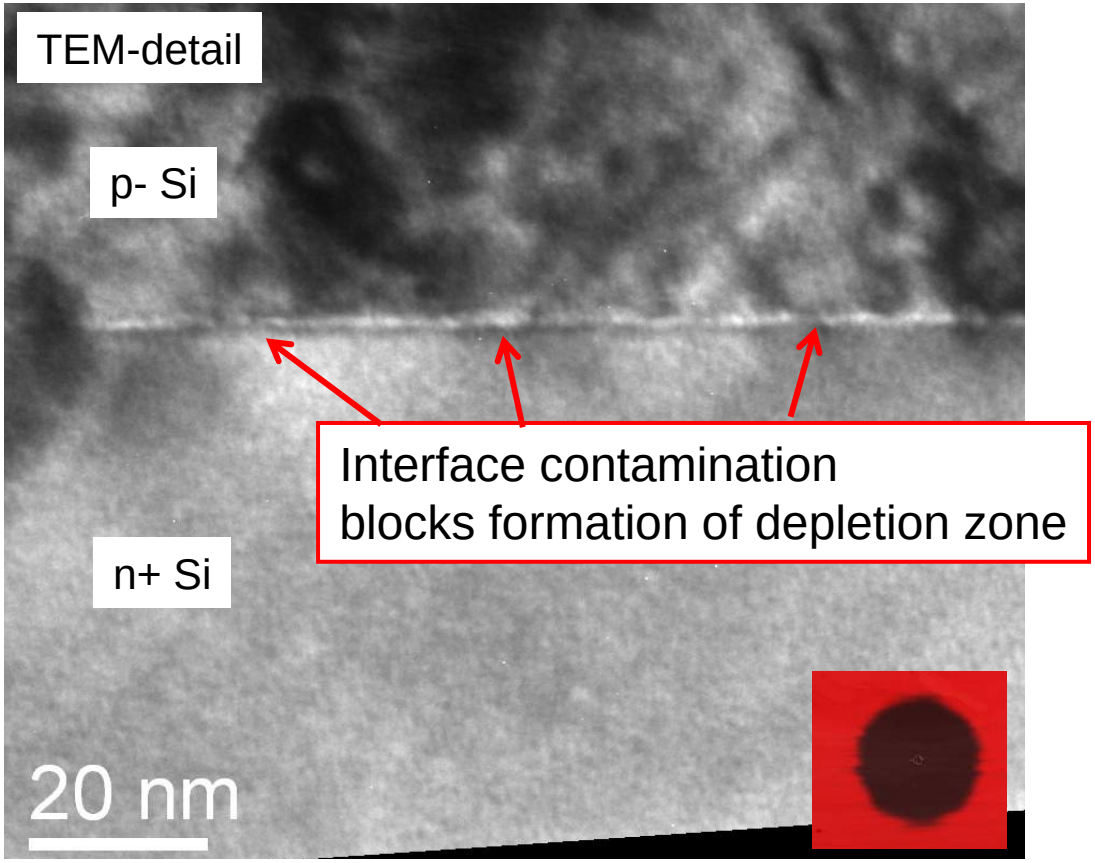
-> raised absorber layer at defect centre
-> disturbed epitaxial grown due to interface contamination between p- and n+ layer

Defect localization and root cause analysis









Interface contamination
blocks formation of depletion zone

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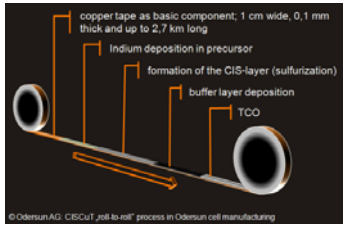
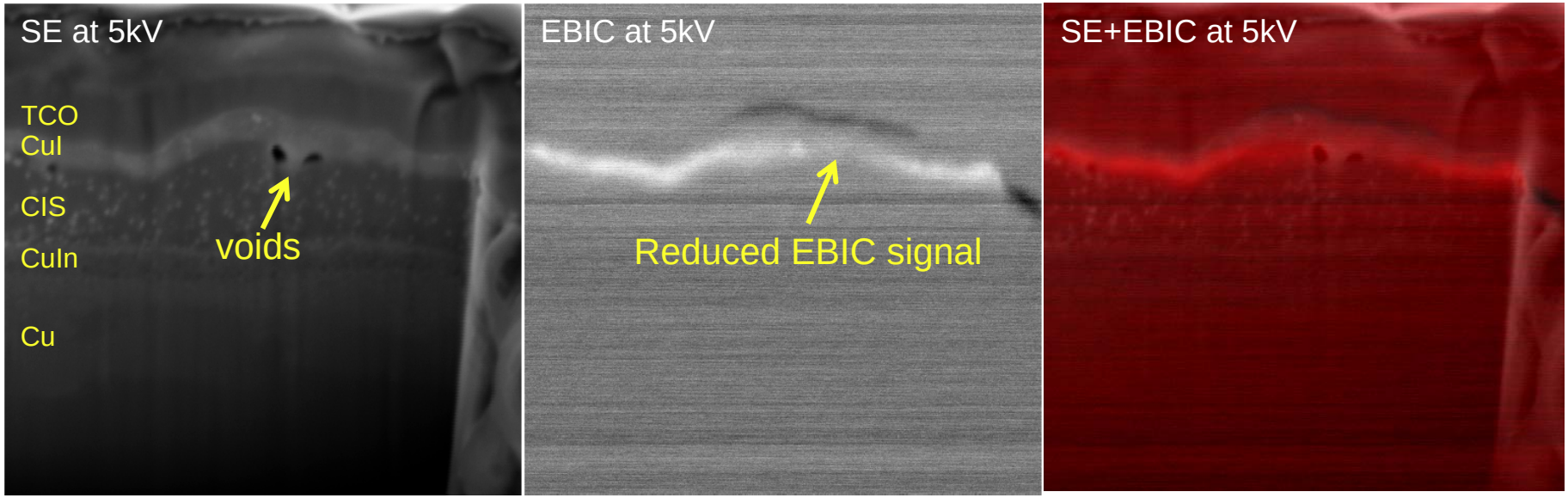
Characterization of p/n-junction





- Inhomogeneous EBIC-signal at the CuI/CIS interface
- Voids CIS layer correlate with reduced EBIC signal
- Inverted EBIC signal at CuI/TCO interface

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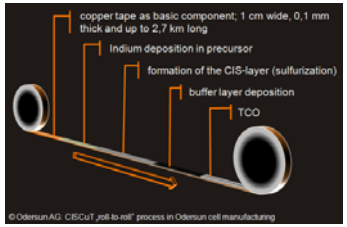
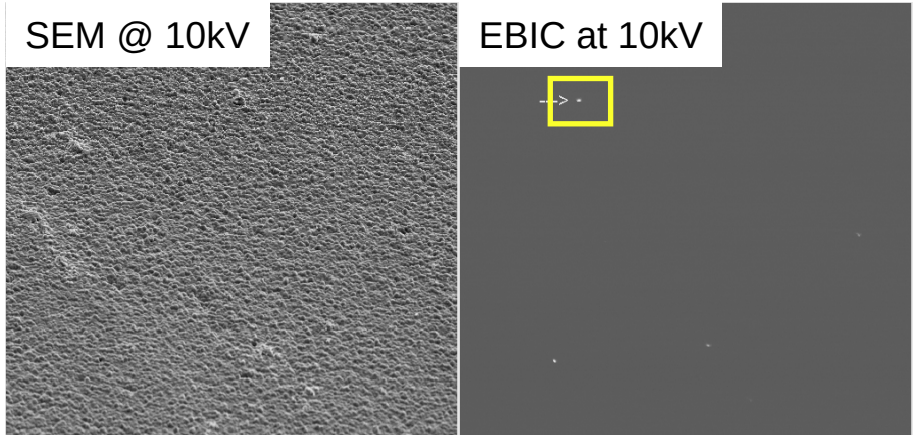
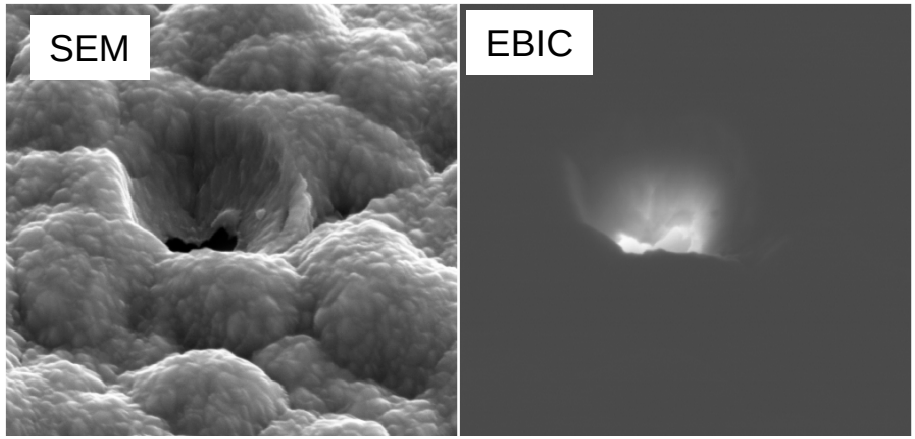
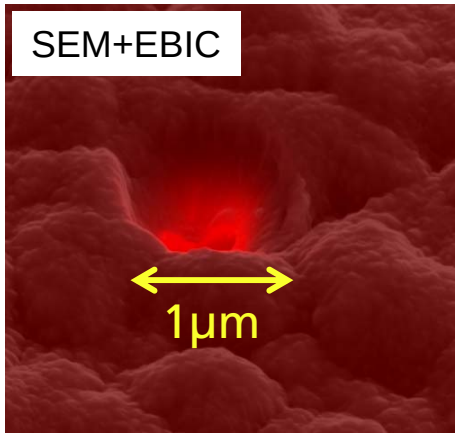
Defect localization and root cause analysis





Bright dots in EBIC image corresponds to small voids in the TCO-layer





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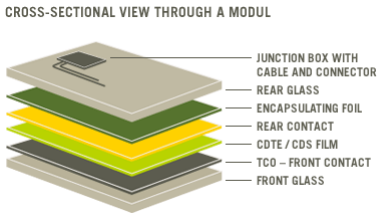
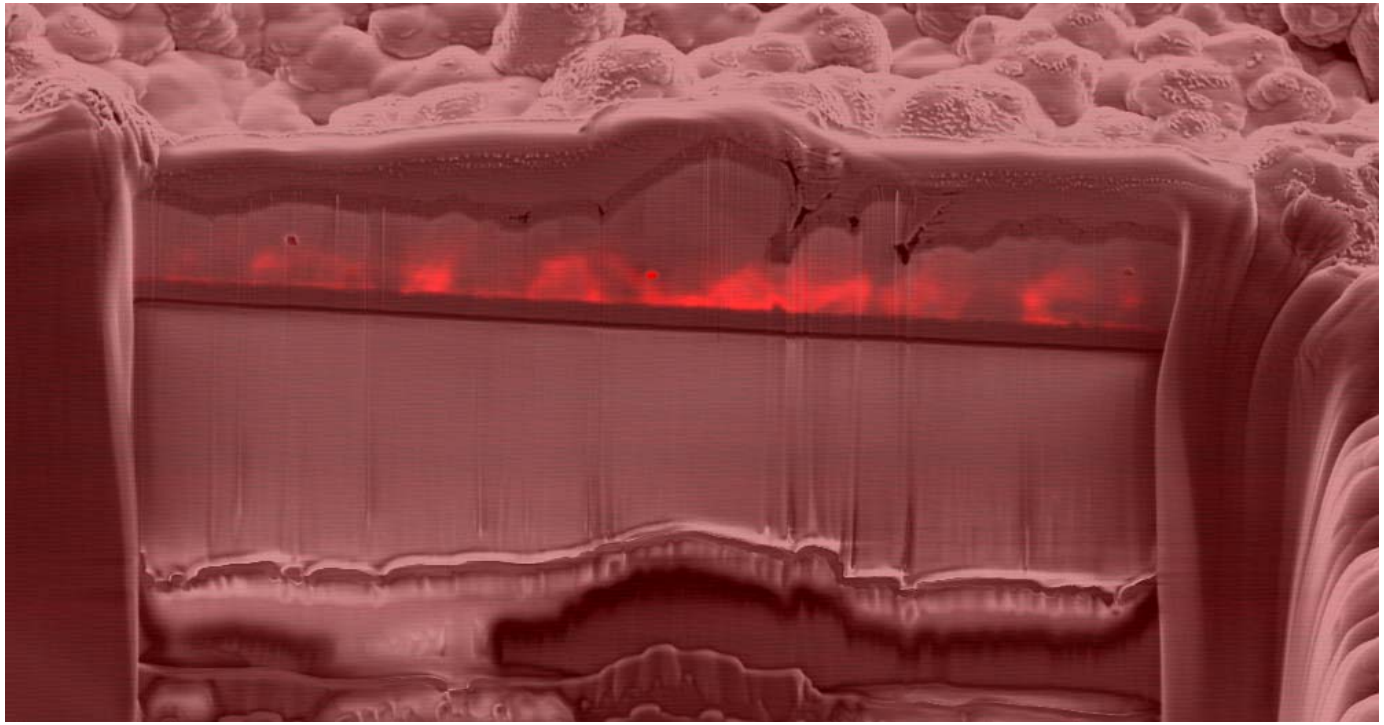
Characterization of p/n-junction



CdTe



- Irregular formed depletion zone in thin film absorber
- EBIC signal correlates with grain structure

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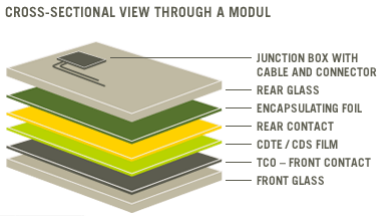
Defect localization and root cause analysis



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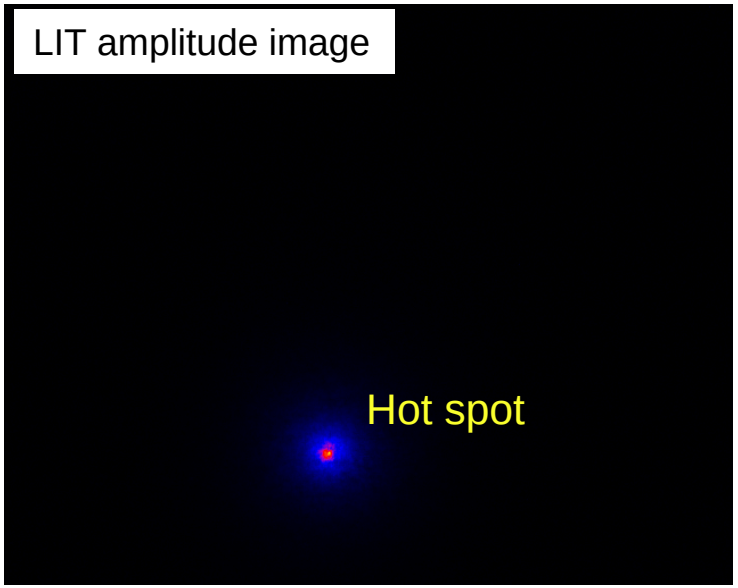

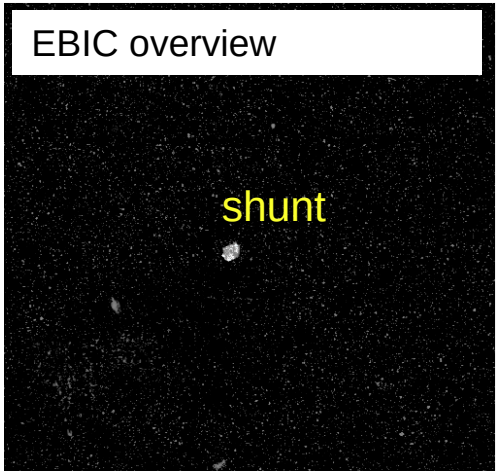

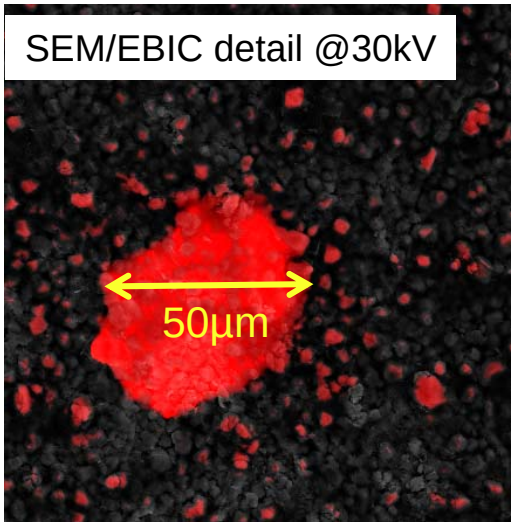

EBIC signal was inversed to better visualize the shunted region

- shunt localization on a large area by Lock-in-Thermography
- Top down EBIC to allocate shunts for further FIB cross section analysis

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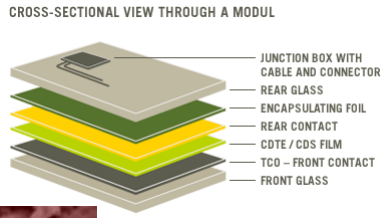
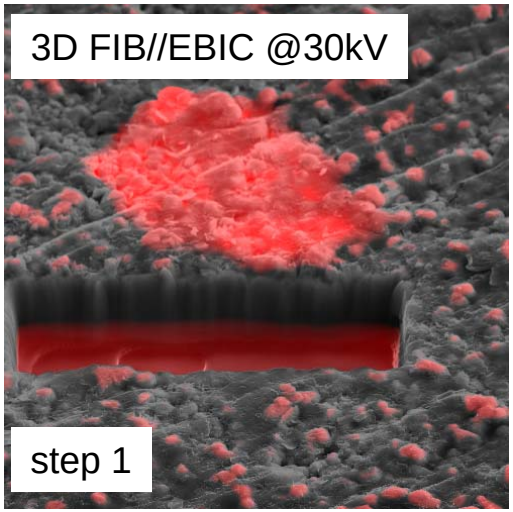
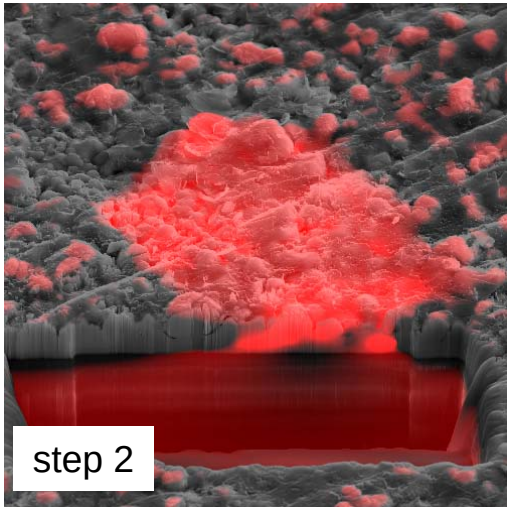
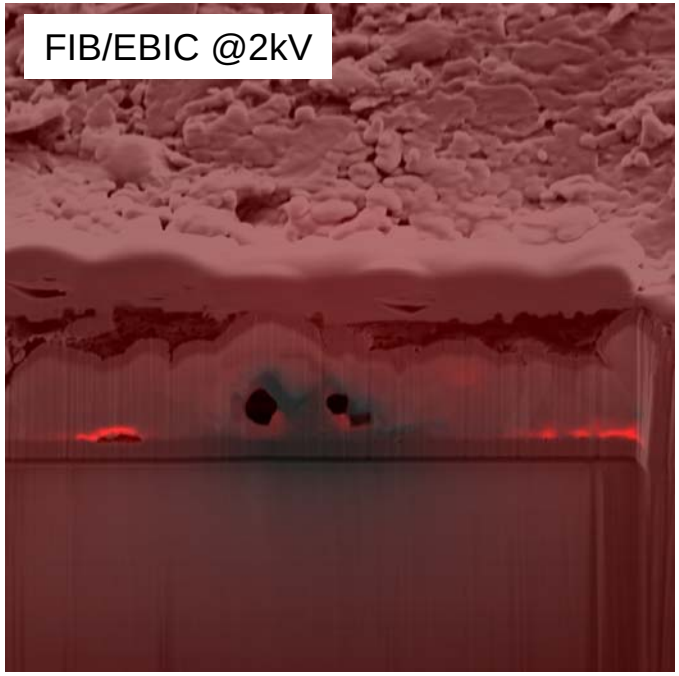
Defect localization and root cause analysis



CdTE







- Stepwise FIB milling and SEM/EBIC imaging to investigate 3D structure of shunt
- Inhomogeneous CdS/CdTe layer with voids could be found

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Summary and Conclusion

- FIB/EBIC was successfully applied to investigate varies solar cell samples
- Depletion zones could be visualize and correlated to the thin film layer stack at FIB cross sections
- Electrically active defects could be found and allocated by top down EBIC
- Following EBIC at FIB cross sections visualize the subsurface defect structure
- It could be demonstrated, that FIB/EBIC is an effective tool for solar cell characterization and failure analysis

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