Evaluation of combined EBIC/FIB methods for solar cell characterization


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** FEI Company

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Fraunhofer-Center for Silicon Photovoltaics (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

Q-Cells, EverQ, CSG Solar, Calyxo, Brilliant 234., Solibro, SSF, City Solar, Solarion

Sovello, Schott Solar, SunWays, PV Silicon, Antec

Conergy, First Solar, Odersun
**Solar Cell technologies**

**Si-wafer cells**

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

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(CdTe, CIS/CIGS, a-Si, CSG …)


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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
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 efficiency
- saveable preamp settings
- preamp settings and calculations in the image
**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
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
Characterization of p/n-junction

FIB cross section

Related EBIC image

SEM/EBIC overlay, EBIC signal was colorized

FIB-Pt to enhance cross section quality

n doped Si-layer
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
Characterization of p/n-junction

SEM/EBIC overlay at FIB cross section, EBIC signal in red
Defect localization and root cause analysis

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

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

EBI C cross section shows depletion zone is cut by the crack
Defect localization and root cause analysis

EBIC Overview shows high defect density

Development of new laser crystallization process

Light optical overview
Defect localization and root cause analysis

- SE + EBIC
- SE image
- small defect
- 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

TEM-detail:
- Interface contamination blocks formation of depletion zone
- p-Si
- n+ Si
- SiN
- BSG

20 nm

2 µm

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Inhomogeneous EBIC-signal at the CuI/CIS interface
Voids CIS layer correlate with reduced EBIC signal
Inverted EBIC signal at CuI/TCO interface
Defect localization and root cause analysis

Bright dots in EBIC image corresponds to small voids in the TCO-layer
Characterization of p/n-junction

- Irregular formed depletion zone in thin film absorber
- EBIC signal correlates with grain structure
Defect localization and root cause analysis

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

EBIC signal was inverted to better visualize the shunted region

CdTe

50µm

SEM/EBIC detail @30kV

Hot spot

LIT amplitude image

EBIC overview
Defect localization and root cause analysis

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

3D FIB/EBIC @30kV

FIB/EBIC @2kV

CdTe
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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