E3 Electrical Microanalysis System

Mapping electrical activity by scanning electron microscopy

False colour EBIC map showing individual dislocations, stacking faults, and grain boundaries in mc-Silicon material for solar cells

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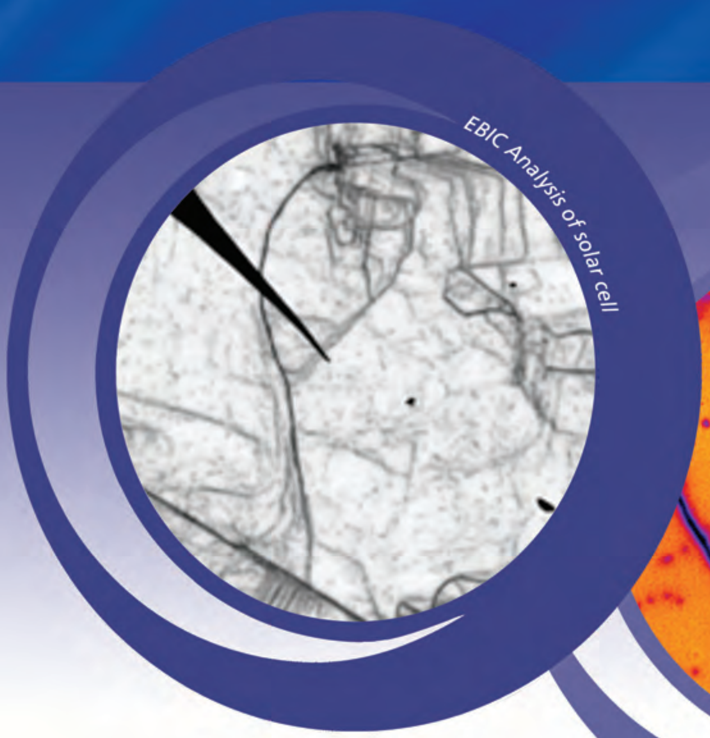
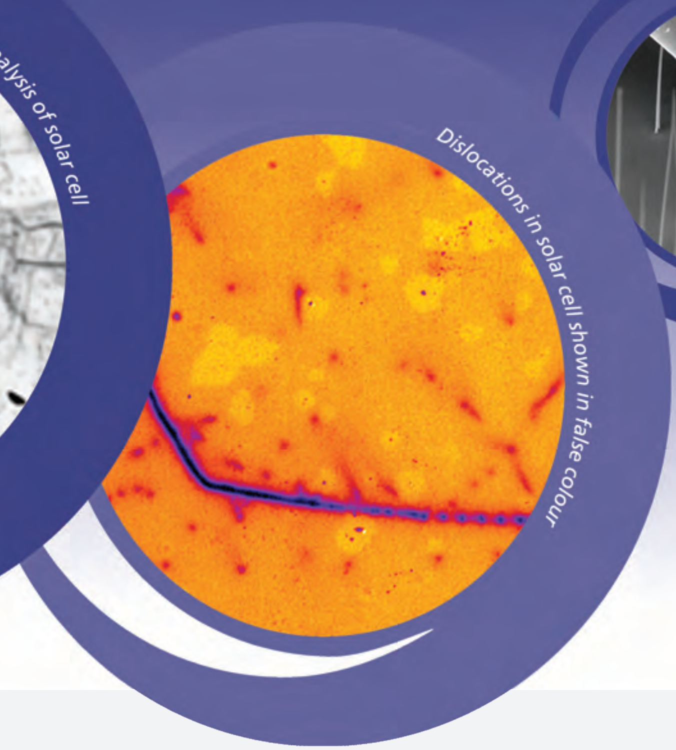
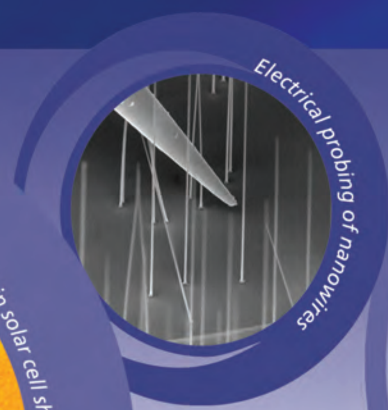
E3 Electrical Microanalysis System

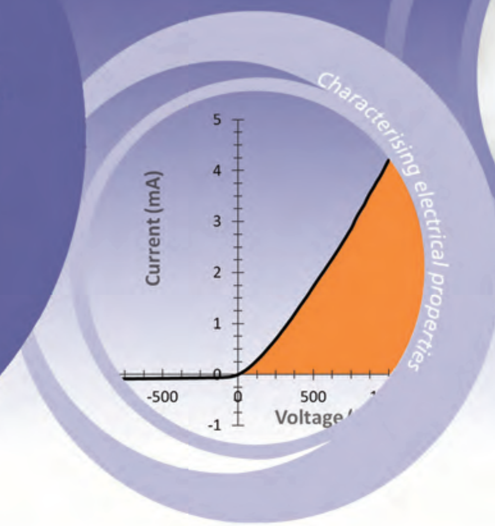
EBIC, EBAC and Electrical probing in the SEM / FIB...

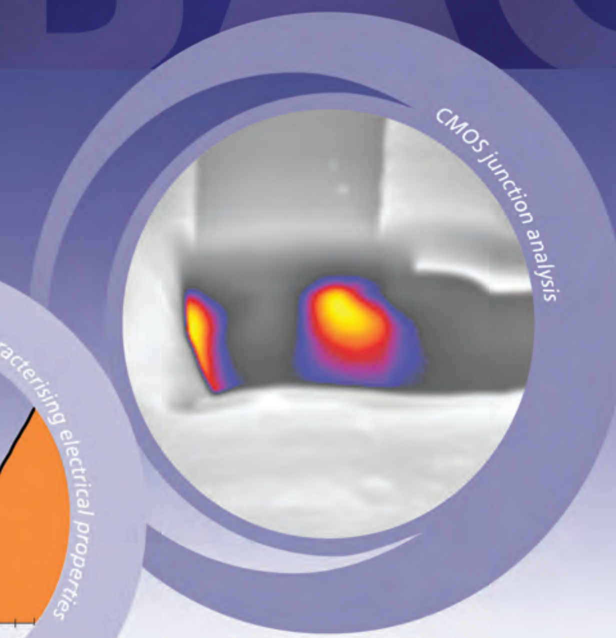
...is not just possible, but easy with the E3 system











Electrical microanalysis...

The **E3** quantitative nanoprobing microanalysis system enables the electrical characterisation of devices and materials in the SEM & FIB. Typical applications include:

- Nanodevice and nanomaterials research - from basic I-V device characterisation to the statistical analysis of failures
- Localising and characterising opens, shorts and high resistivity in interconnects, CMOS, optoelectronics and high-power devices
- Inspecting the statistical distributions of dislocation contrast to reveal trends in samples
- Identifying recombination centres, such as single dislocations, grain boundaries or inclusions
- Measuring minority-carrier diffusion lengths in thin films

...three methods enabled by E3

- **Electron Beam Induced Current (EBIC)**

EBIC is a method used for the imaging and characterisation of p-n junctions, the recombination strength of defects, and the diffusion length and surface recombination velocity of minority charge carriers in semiconducting materials and devices.

It is most effective when employed alongside EDS or EBSD as part of a wider workflow, for example, nanofabrication in the FIB, or sample preparation for the TEM or atom probe.

- **Electron Beam Absorbed Current (EBAC)**

EBAC is a method employed for the identification and physical failure analysis of metal defects (opens and shorts), high resistivity areas and layer non-uniformities in CMOS devices. It is primarily used in combination with electrical nanoprobing.

- **Electrical probing**

Nanoprobing is a method used for the electrical characterisation of nanodevices and nanomaterials in the FIB & SEM by direct electrical probing and imaging. It is used primarily for nanoscience and CMOS failure analysis.

Locating microscale faults in semiconductors just got easier, faster!

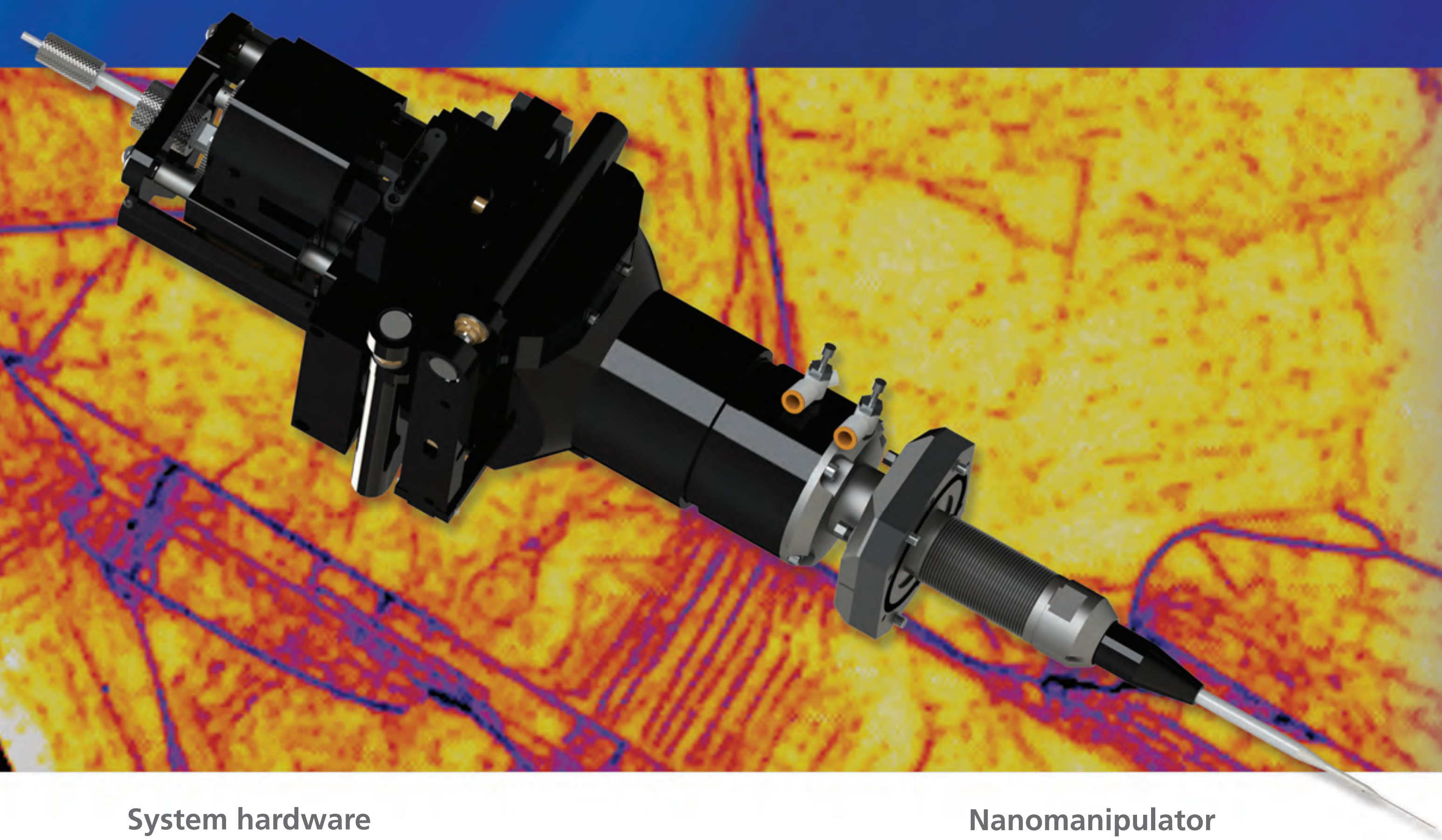
E3 System at a glance

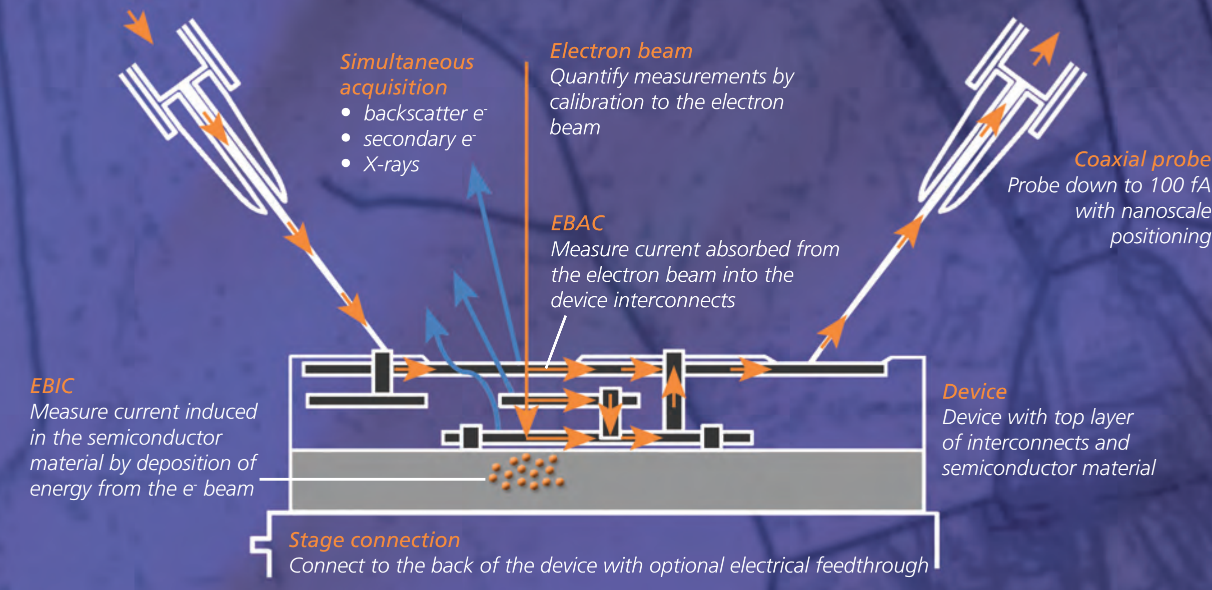
- A complete and fully integrated system using port-mounted **OmniProbe** nanomanipulators
- Nanometre scale positioning and fast amplifier for picoammeter-scale sensitivity
- Quantitative low-noise EBIC/EBAC imaging in seconds, with simultaneous SE and software amplifier control
- Retrofits in minutes to most microscopes, no modification or customisation required
- **E3** makes electrical microanalysis as easy and as routine to perform as other established microcharacterisation techniques, such as EDS

INTEGRATED

E3 System

Integrated, sensitive, accurate - as standard





Schematic showing EBIC/EBAC principle.

System hardware

Complete quantitative electrical probing system from Oxford Instruments:

- Integrated for simultaneous SE and EBIC/EBAC acquisition
- Standard port-mounted probes, ready for sequential measurements of nanoscale features, manipulation, and site-specific lift-out
- High-speed low-noise amplifier for fast image acquisition and streak-free images
- Integrated amplifier
  - 10^3 to 10^{10} V/A gain
  - ±1 V offset
  - ±10 V bias
  - Full amplifier calibration
  - 0.5 MHz bandwidth at 109 V/A gain
  - 200 ns - 6 ms dwell time

Retrofits to most SEMs and FIBs

Nanomanipulator

Available with a choice of **OmniProbe** models - manual or automated control.

- Easily and rapidly land on nanostructures dimensioned in tens of nm, from graphene flakes to nanowires and vias
- Navigate smoothly and precisely over long distances
- Compatible with a wide range of electronics and source current measuring devices
- Industry-leading performance for nanomanipulation and lift-out

System software

The system software controls the image acquisition and operates the EBIC measurement amplifier for the adjustment of operation mode, gain, contrast, brightness, DC compensation and zero balance.

All parameters of the measurement amplifier are saved with the EBIC image for later *quantitative* analysis.

Additional functions include:

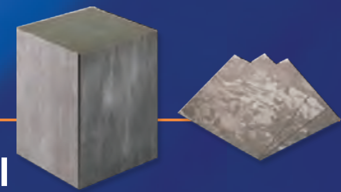
- Signal monitor
- Region scan
- Live SE + EBIC signal mixing
- Configurable scan functions
- Configurable control panel for the EBIC amplifier
- Data output for further processing, such as false colour mapping

Configured operation mode:

- EBIC measurement
  - with/without bias voltage
  - with DC compensation
- Recording sample I-V characteristic
- Beam current measurement (internal or via external measurement device)
- Zero balance with sample, electron beam turned off
- Measurement functions for distances, angles, radii, measurement on image

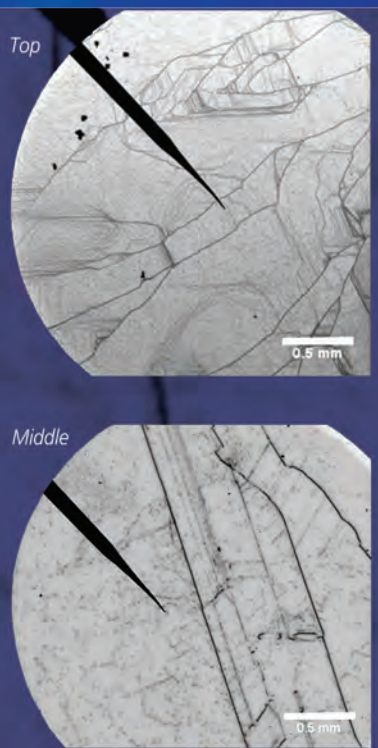
POWERFUL

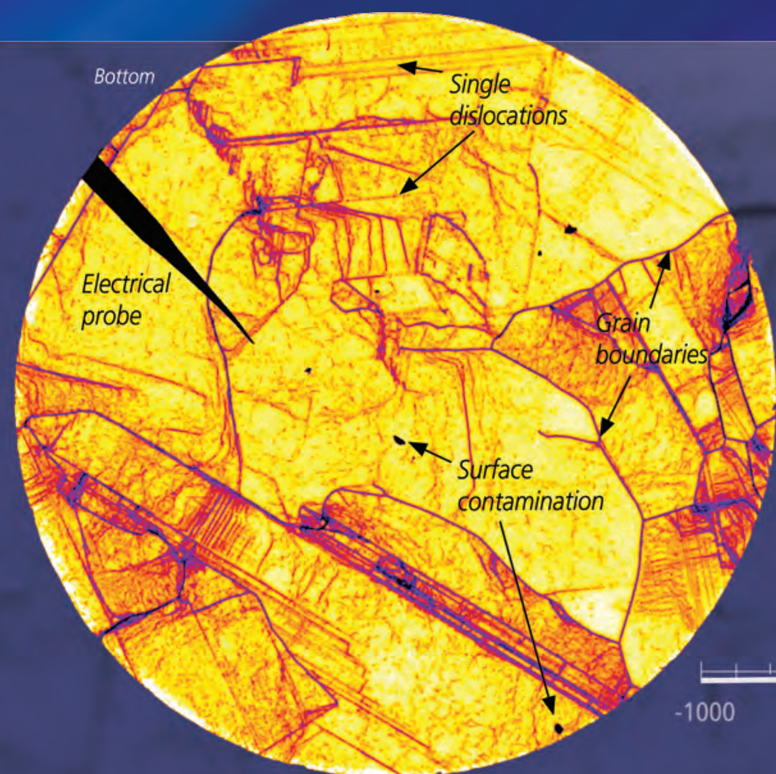
Application example

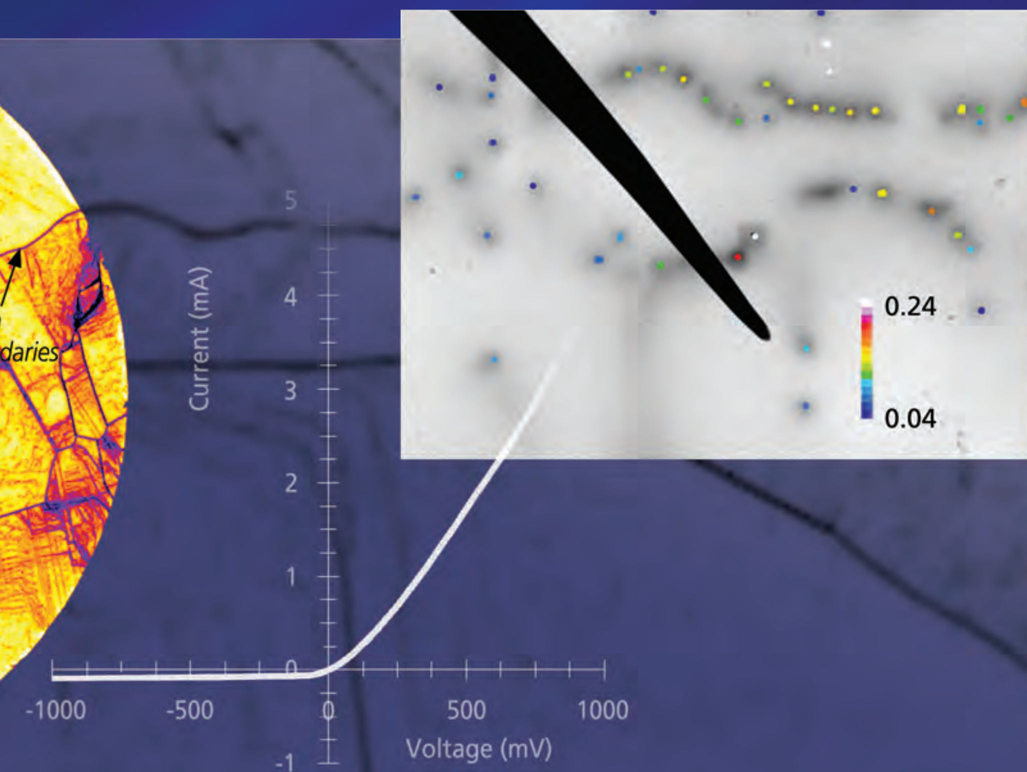


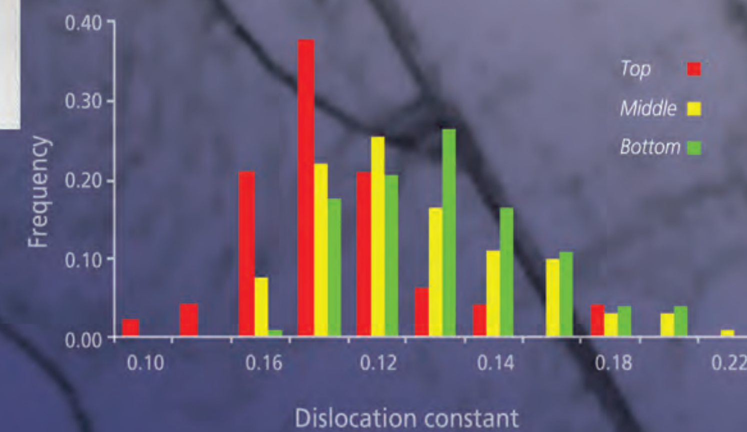
EBIC characterisation of a multi-crystalline Si solar cell

For the full note visit www.oxinst.com/E3









Background and experiment

Solar cell materials present a complex array of defects; the aim here is to identify and measure dislocation recombination activity in mc-Si solar cells to enable potential further analysis (atom probe, TEM lamella prep …).

Three wafers were cut from the top, middle and bottom of the same ingot with Al pads deposited on each to create Schottky contacts. A single probe configuration utilising an **OmniProbe** 100 manipulator with a coaxial shaft was used for electrical connection to the top contact and a stage connection at the bottom. The SEM accelerating voltage was 20 kV with typical dwell times of 16 µs for 2,048 x 2,048 pixel images and an EBIC amplification of 104 V/A.

I-V characteristics confirmed successful electrical probing and the diode behaviour of the solar cell device.

Interpretation of the EBIC image

The EBIC signal is collected only in the presence of the electric field of the circular Schottky contact, and the electrical probe produces a shadow (as shown above).

Subtle changes in EBIC intensity can be difficult to see in greyscale, but applying false colour* improves visualisation. This approach also enables overlay of the SE image allowing colocalization, e.g. for failure analysis.

Grain boundaries and single dislocations are immediately seen, where dark contrast corresponds to increased non-radiative recombination activity and therefore highlights active defects in the material. Here, a majority of dislocations are perpendicular to the wafer, and show as individual dark points, but some are at an angle or indeed parallel to the surface, and appear as elongated points or grey lines.

* Not included

Automated dislocation analysis

An automated procedure identified the location of dislocation sites and measured the dislocation intensity.

- Azimuthal intensity analysis found the capture radius within which the recombination activity increased
- Intensity at dislocation core and away from the capture radius was used to calculate dislocation contrast for each dislocation found in the image
- This provides a statistical measure of dislocation contrast for the sample, shown above. This particular device shows an average dislocation contrast of 40 x10^{-3}. Such analysis provides a means for the quantitative comparison between samples, as well as a quantitative relationship between device manufacture and recombination activity.

Conclusions

The application of EBIC analysis to typical mc-Si solar cell devices reveals grain boundaries, stacking faults and single dislocations. Quantitative acquisition and data export is used for automated identification and analysis of single dislocations, showing a statistical distribution of dislocation contrast. Analysis of devices from different heights of a single ingot reveals a shift in recombination activity from 0.12 at the bottom to 0.08 at the top. Changes in dislocation contrast are attributed to varying dislocation density, or the different times available for dislocation to collect impurities along the height of the ingot, and therefore the resultant variations in impurity concentration at dislocation cores.

We thank the Department of Materials, University of Oxford for their assistance in making this application note. For the full note visit www.oxinst.com/E3.

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