Functional characterization of semiconductor devices by electron beam induced current microscopy

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Characterization techniques

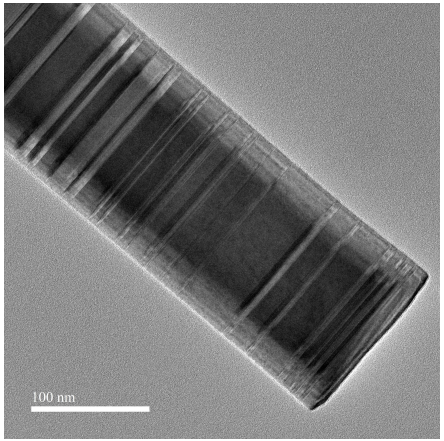
Structural characterization

- Microscopy: SEM, TEM, SPM
- PL, CL, X-ray spectroscopy
- Mass-spectrometry
- etc.

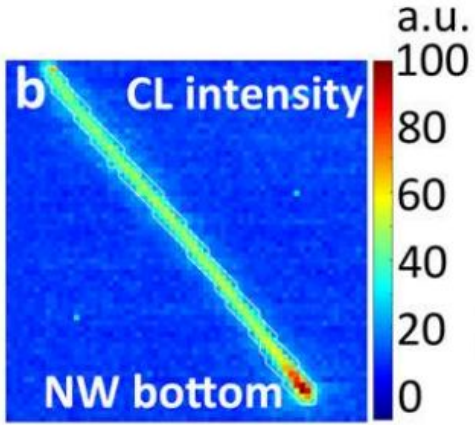
Functional characterization

- I-V, PC, EL, etc.
- LBIC and EBIC

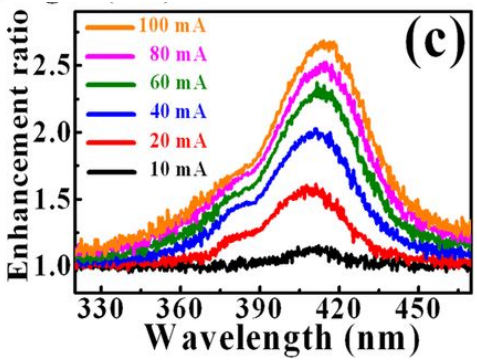
TEM image of GaP NW



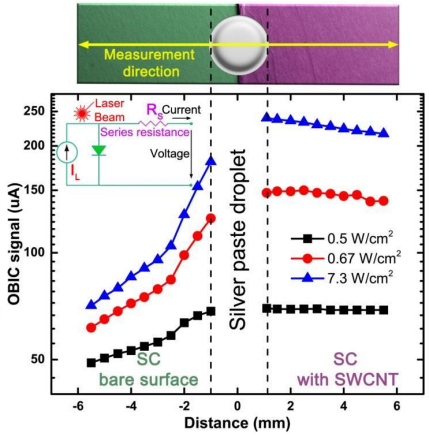
CL mapping of NWs



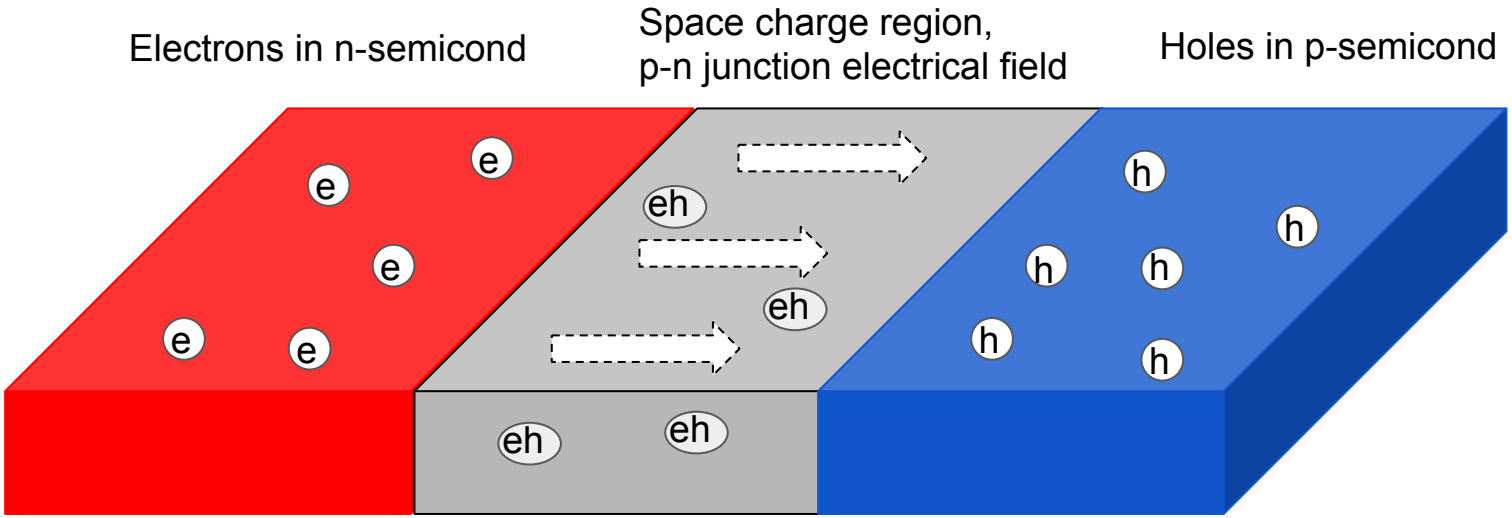
EL spectra of InGaN LED



LBIC for GaAs solar cell



Induced current (e. g. photocurrent)



Equilibrium

Diffusion current

Drift current

Induction by generation of e-h pairs in SCR

Diffusion current

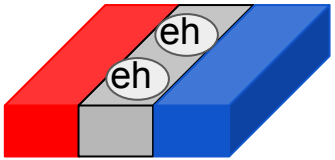
Drift current

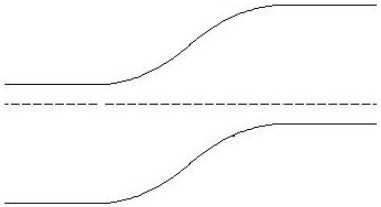
Electron beam induced current (EBIC) principle

EBIC is very similar to photocurrent
with e-beam instead of photons

1. e-beam bombards sample material

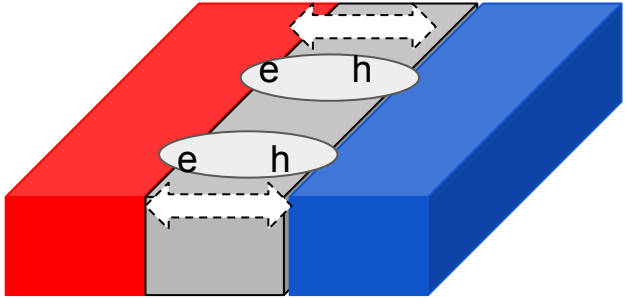
2. sample generates e-h pairs

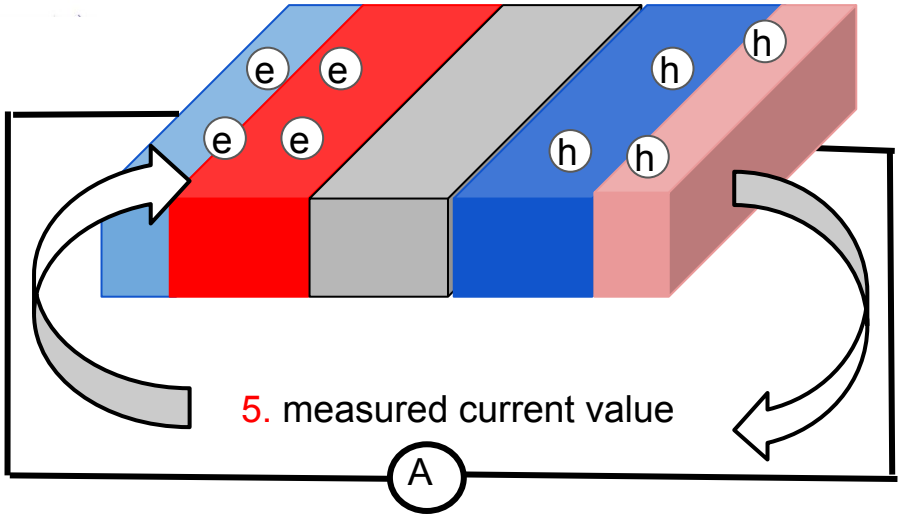




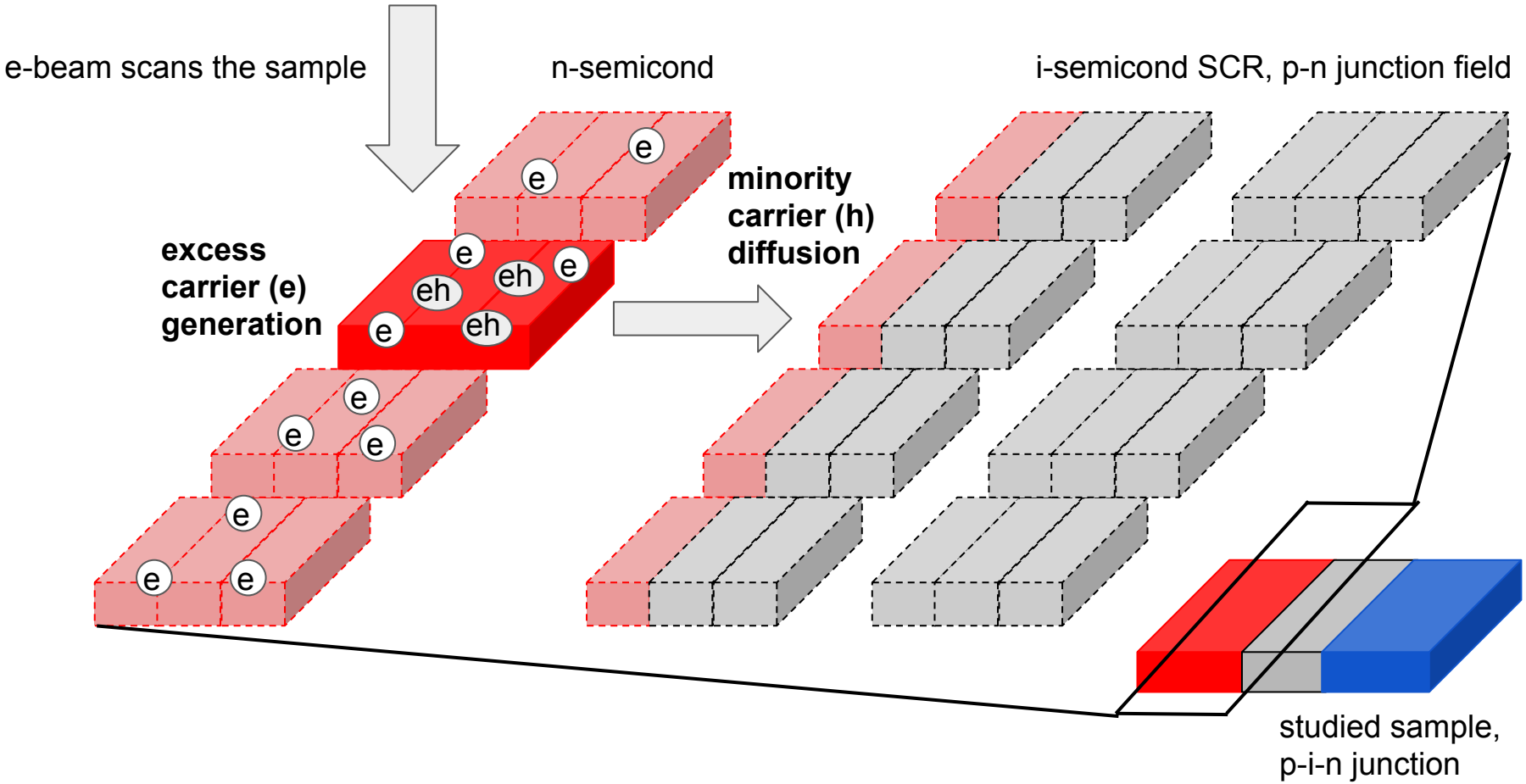
4. excess carriers are collected and measured with an external circuit

3. electric fields, e. g. p-n junction, separates carriers



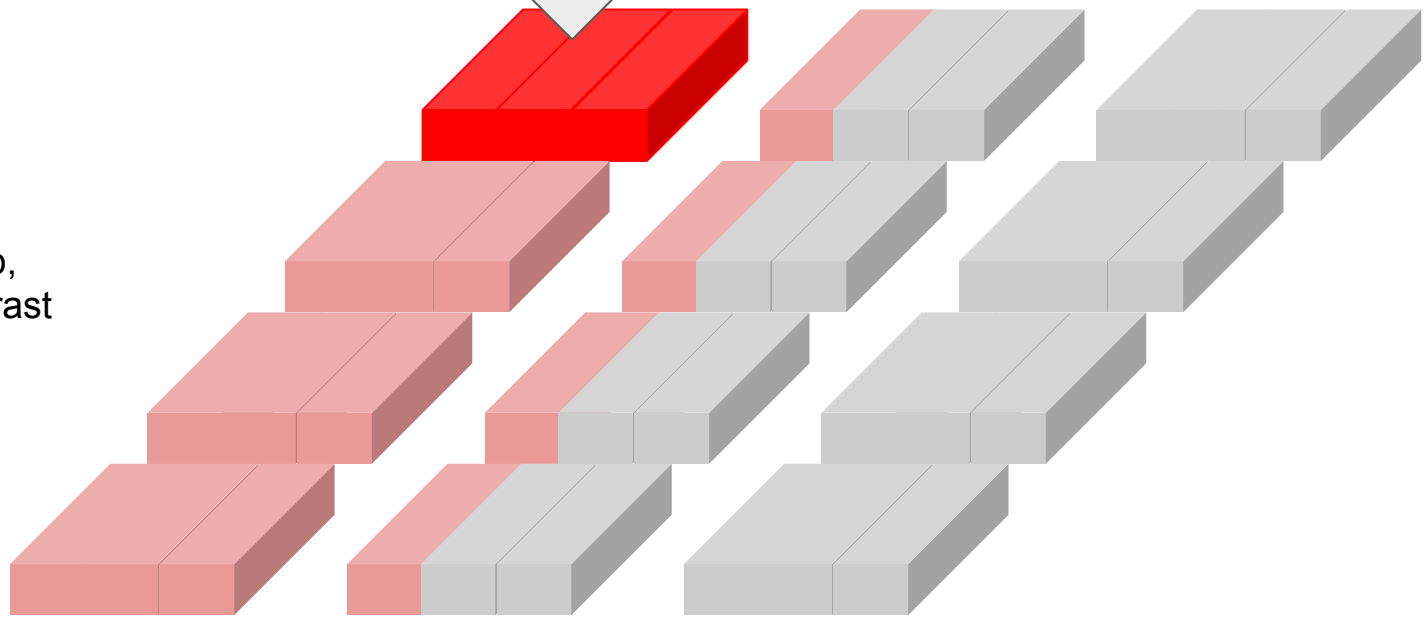


EBIC map construction

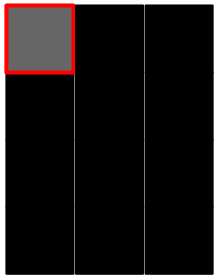


SEM e-beam

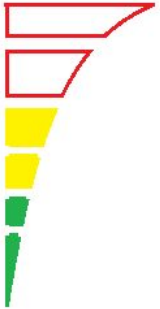
Measured current



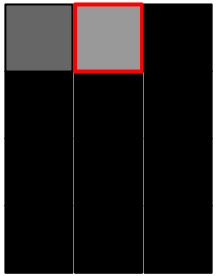
Constructed EBIC map,
grey scale, bright contrast



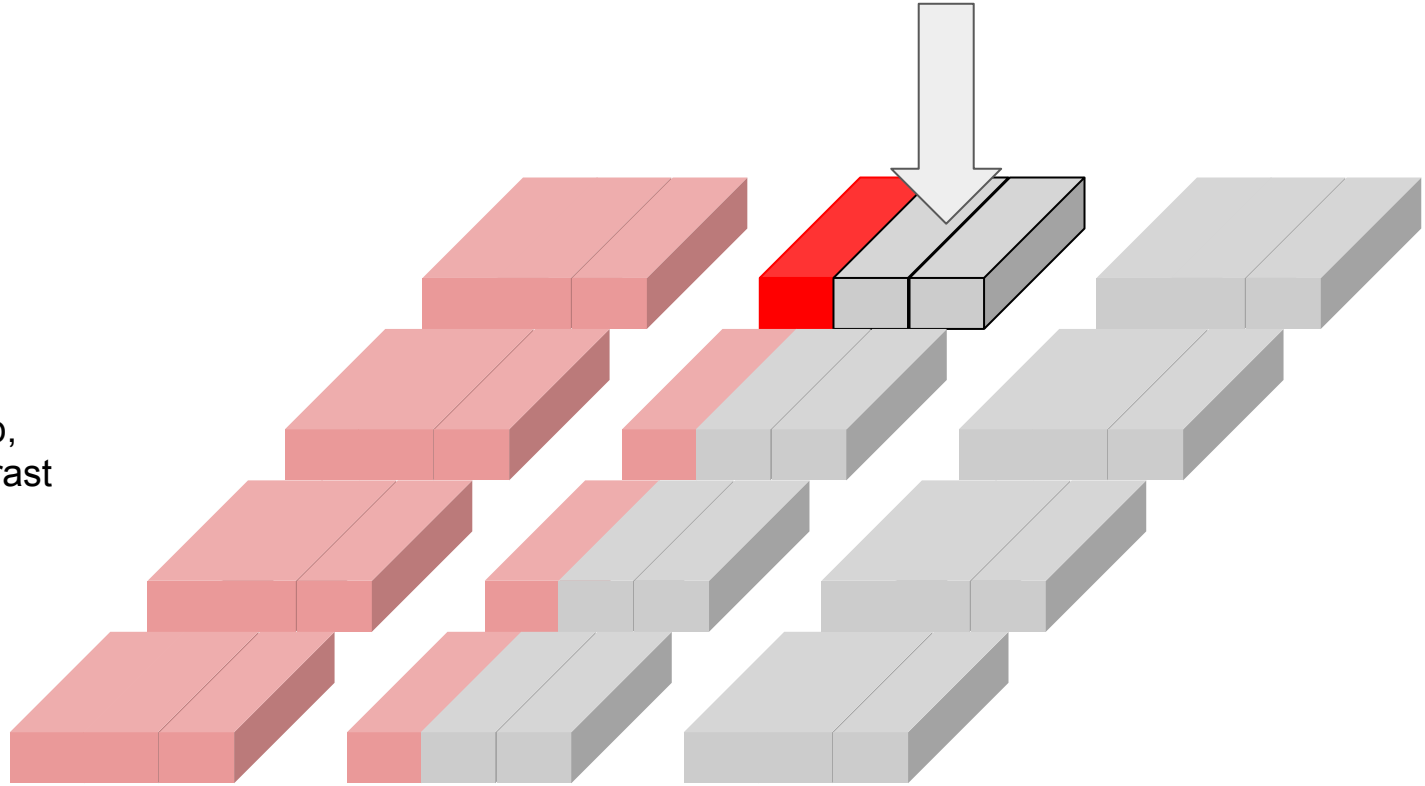
Measured current



Constructed EBIC map,
grey scale, bright contrast

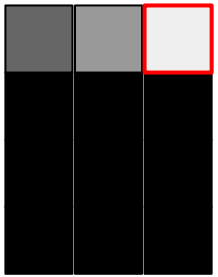


SEM e-beam

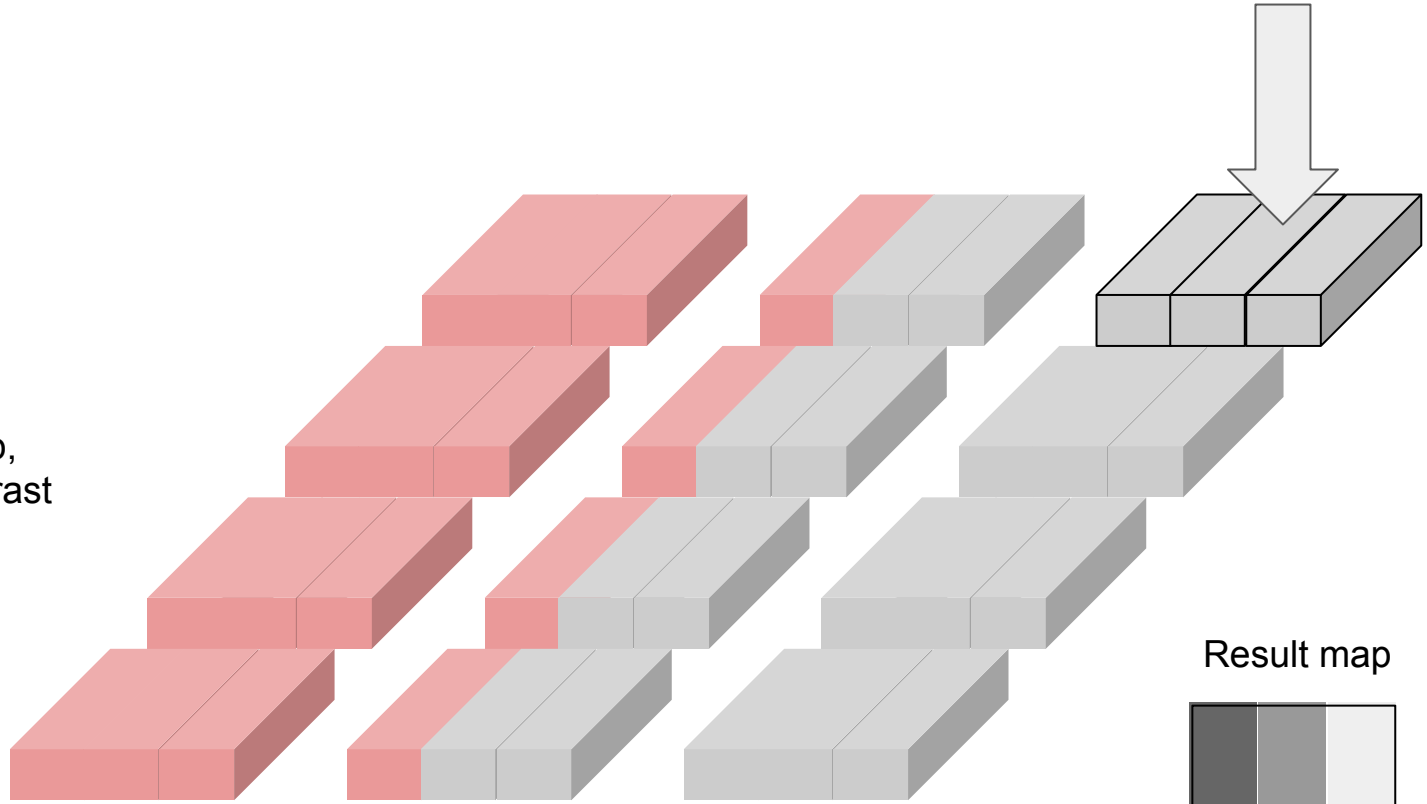


Measured current

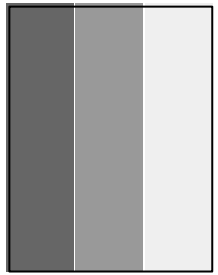
Constructed EBIC map,
grey scale, bright contrast



SEM e-beam

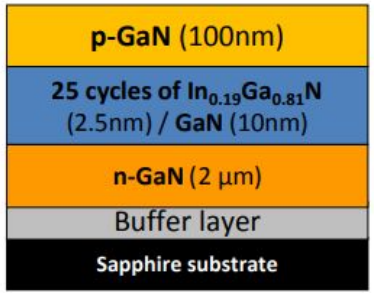


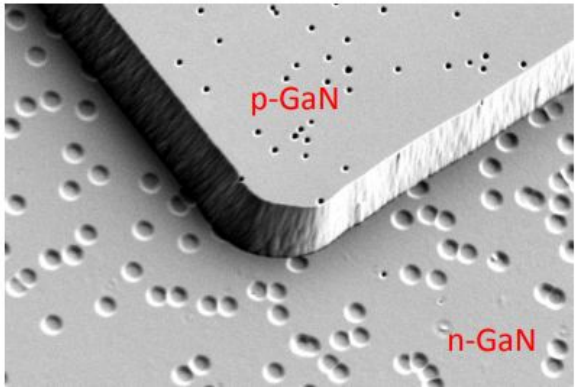
Result map



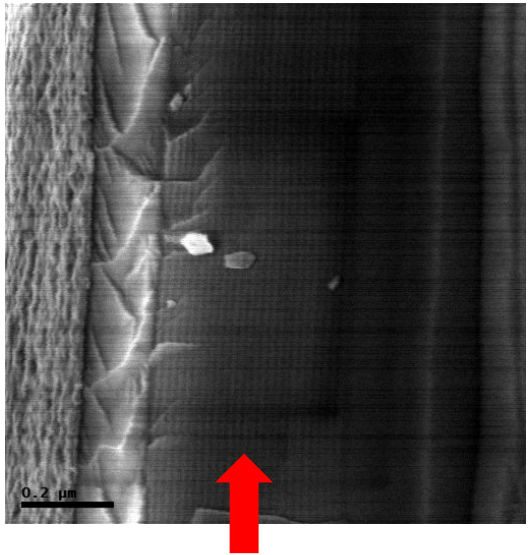
EBIC example. Thin film InGaN/GaN solar cell

$In_{0.19}Ga_{0.81}N$/GaN MQWs solar cell



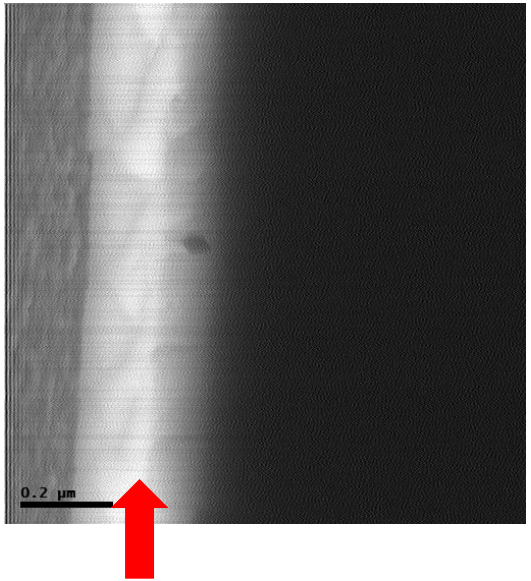


SEM image



MQW region

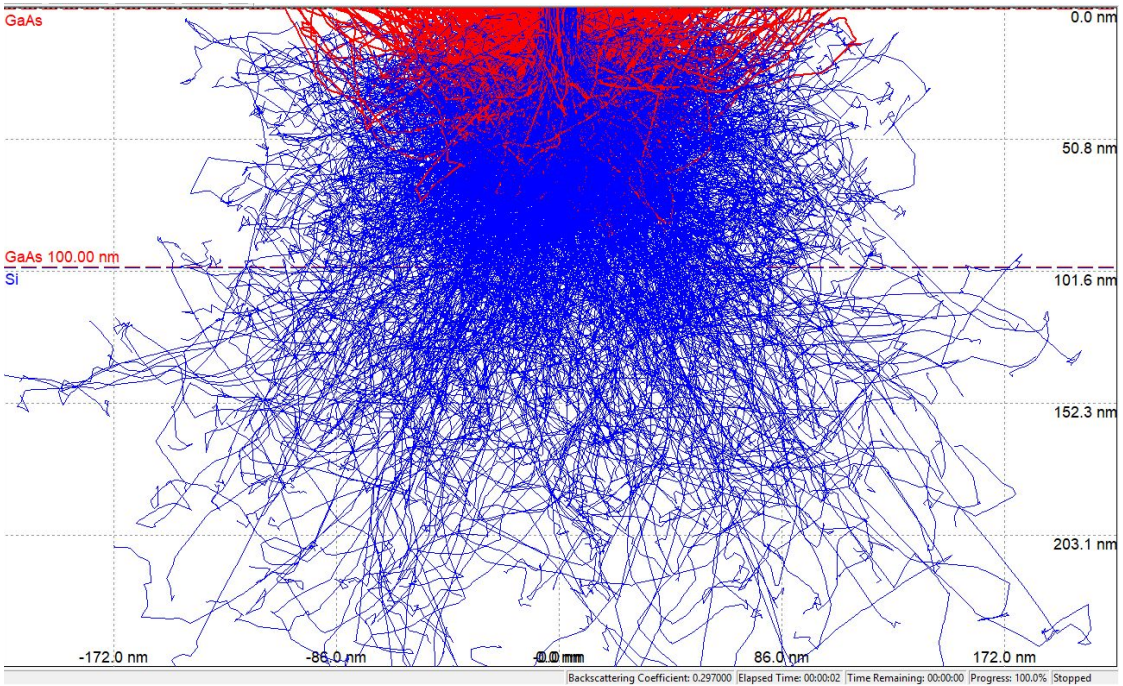
EBIC map of the same area



Current is generated in contact area instead of active region

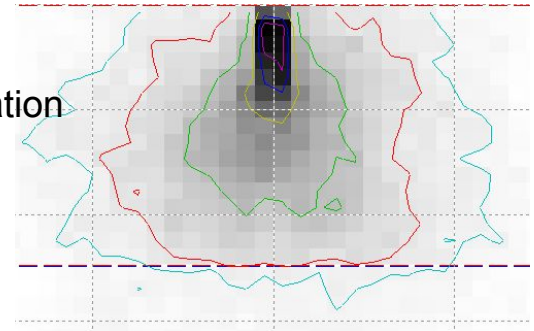
E-beam interaction with sample material

Monte Carlo simulation of 5 kV e-beam trajectories inside GaAs on Si, 2000 tracks



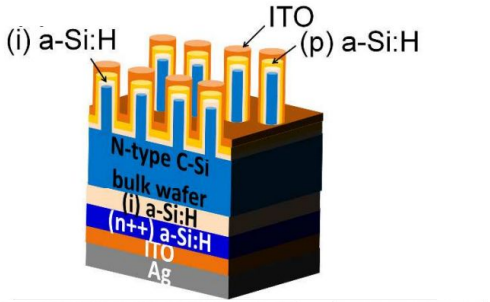
penetration depth

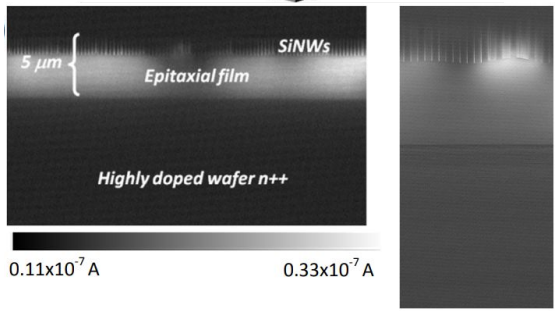
Energy dissipation

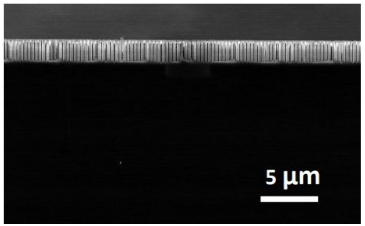


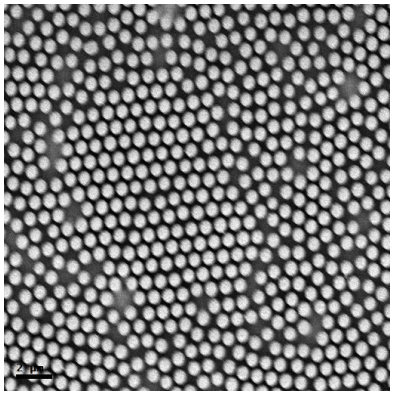
E-beam generates e-h pairs in the excitation volume, until electron kinetic energy is spent

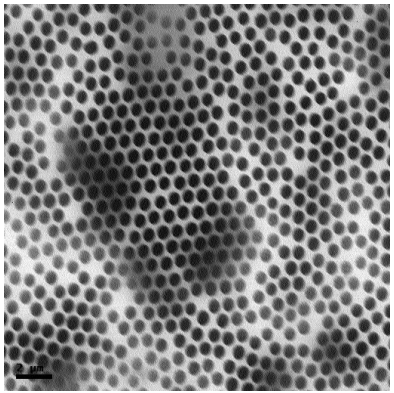
EBIC example. Top-bottom Si NW solar cell

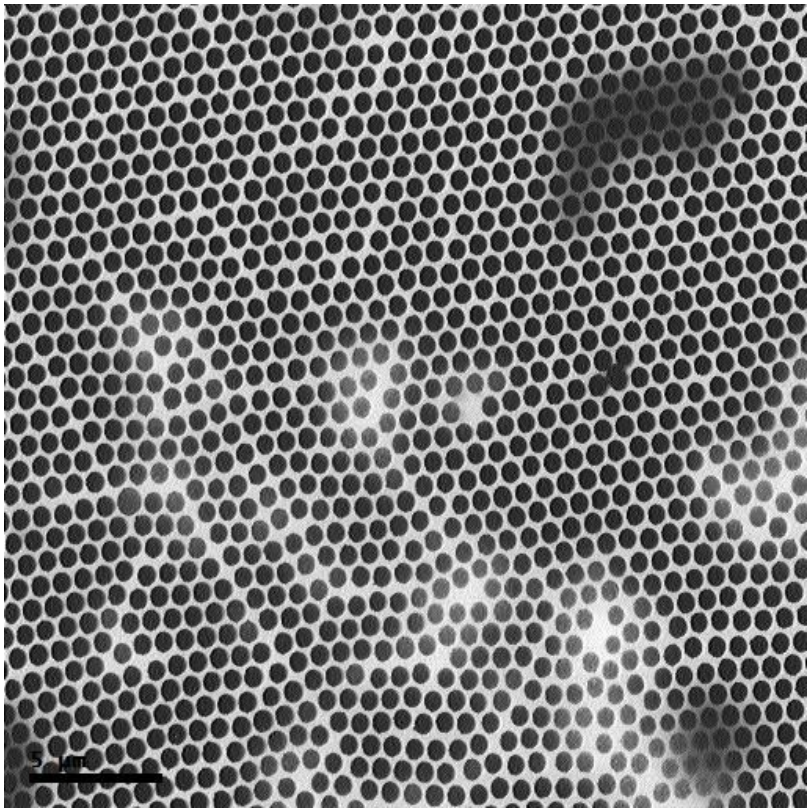




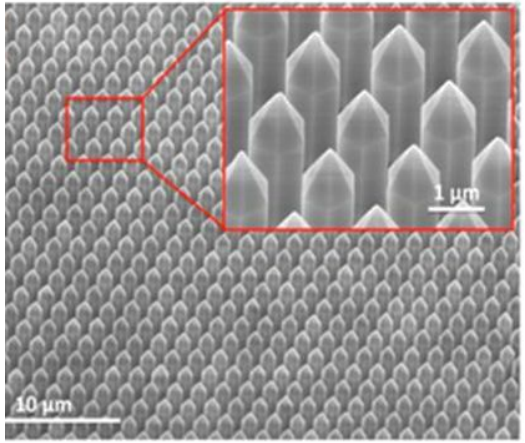






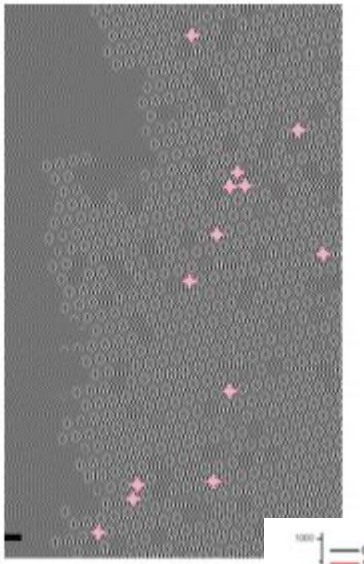


EBIC example. InGaN/GaN NW LED

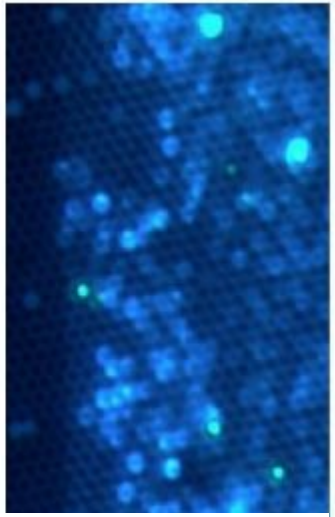


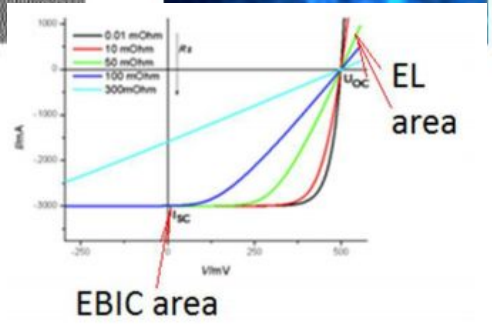
SEM

EBIC



EL

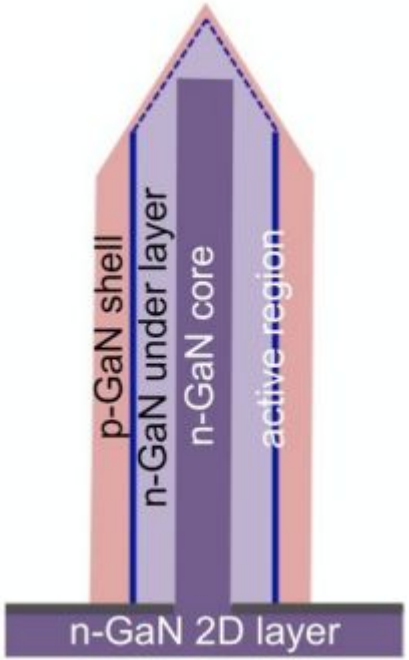


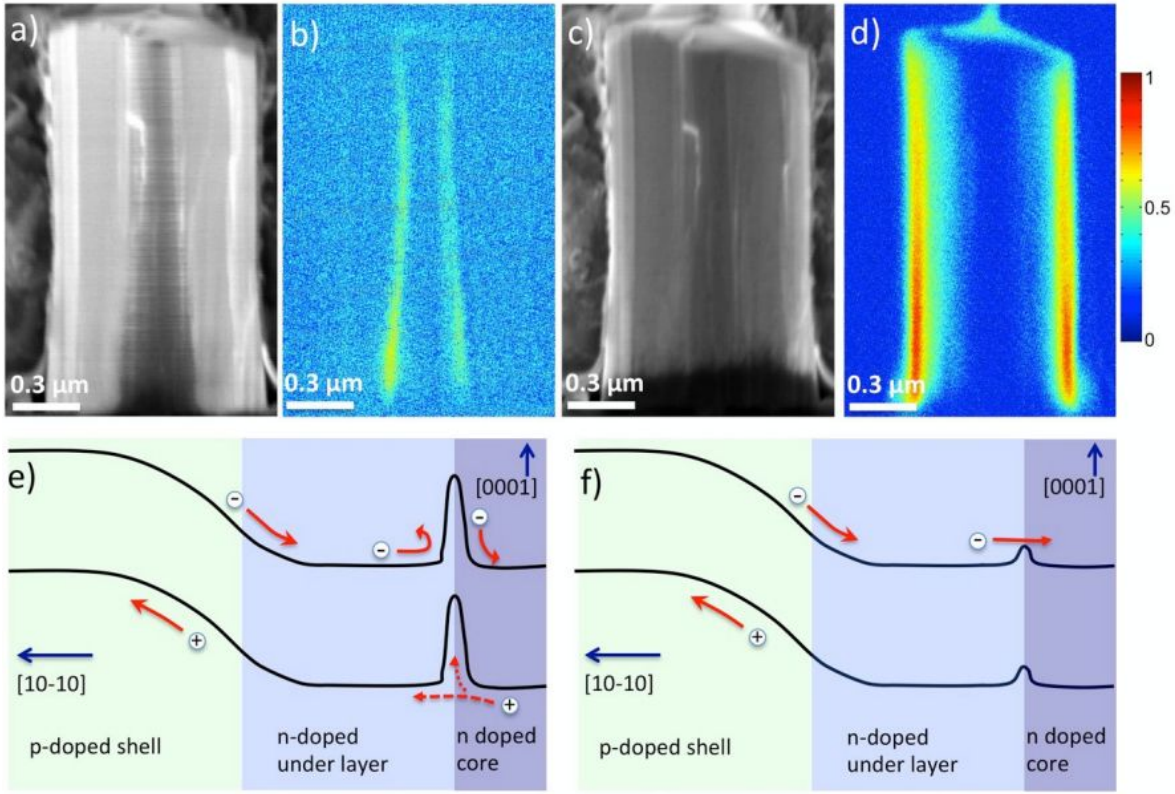


Comparison of electrical and optical signals allows to explain device functioning

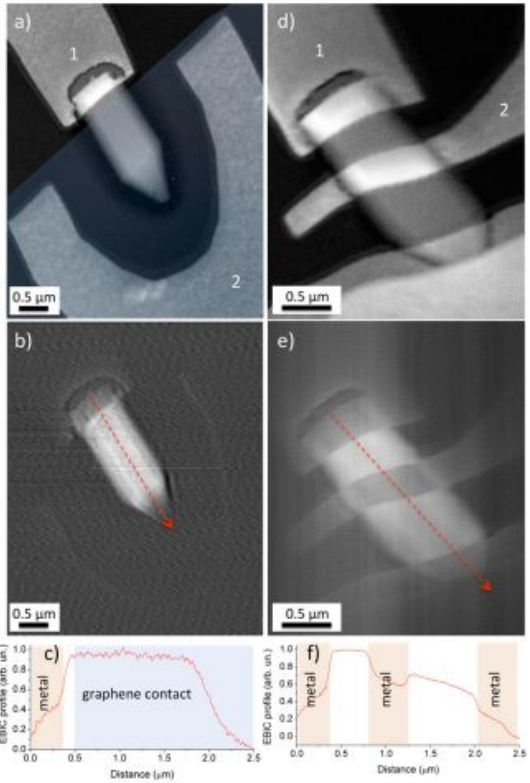
Carrier trapping and traps (dis)charging

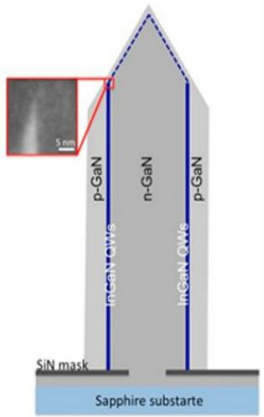
Gan/InGaN blue LED

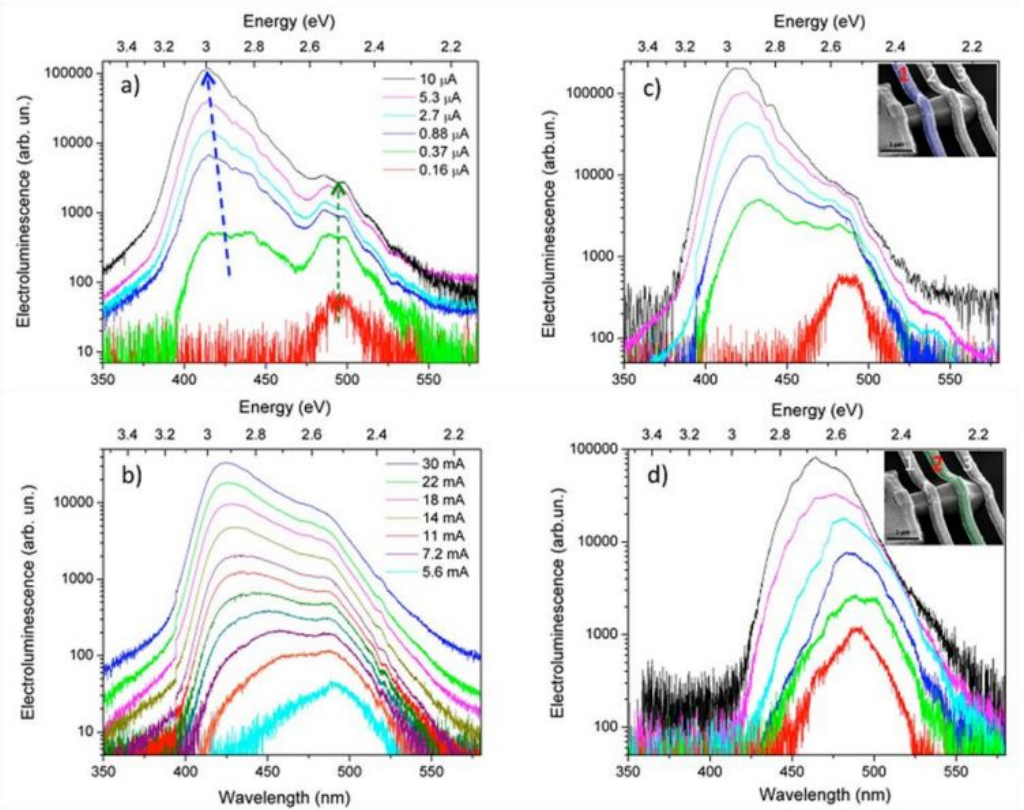




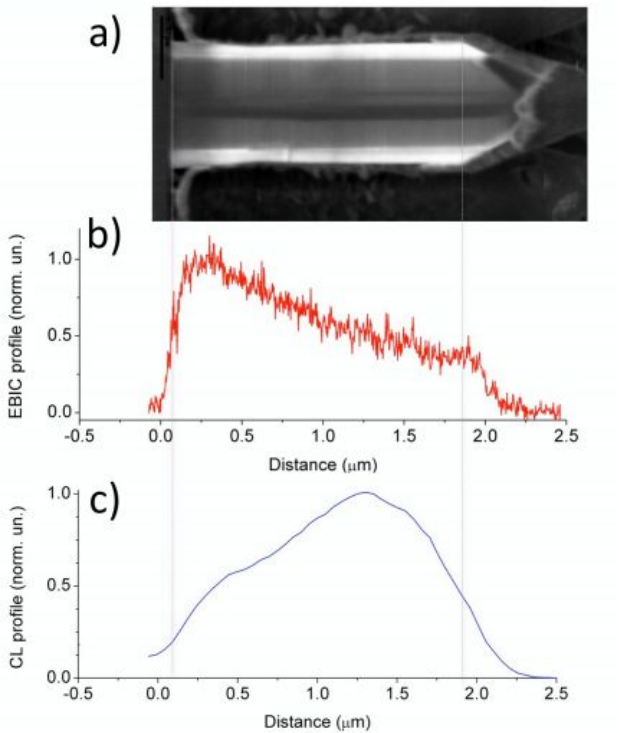
Examples of EBIC characterization

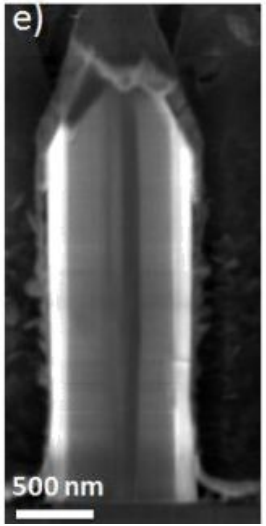


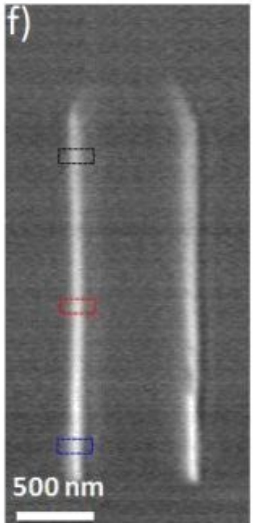




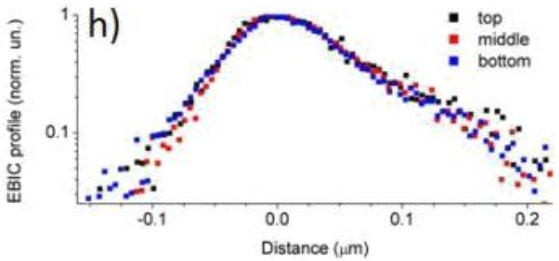
Examples of EBIC characterization







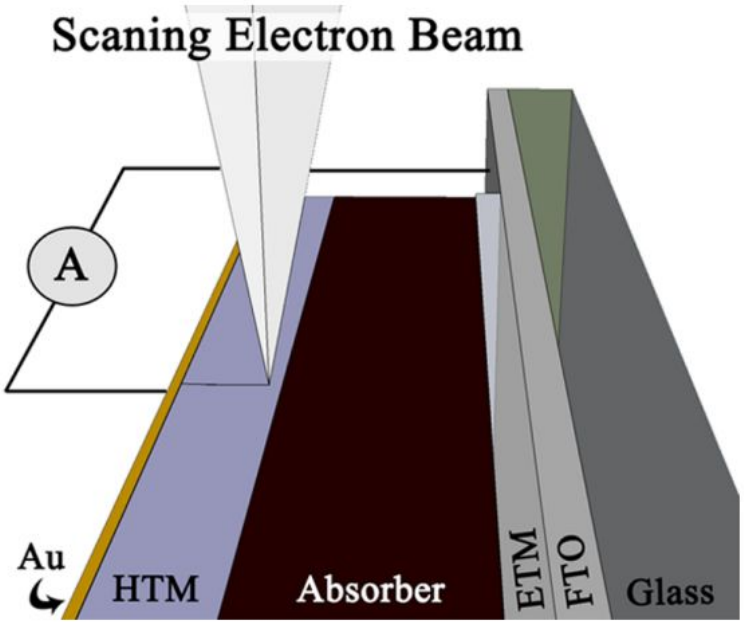
Horizontal EBIC profiles



refer papers
doi: 10.1039/C5NR00623F
doi: 10.1016/j.mssp.2016.03.002

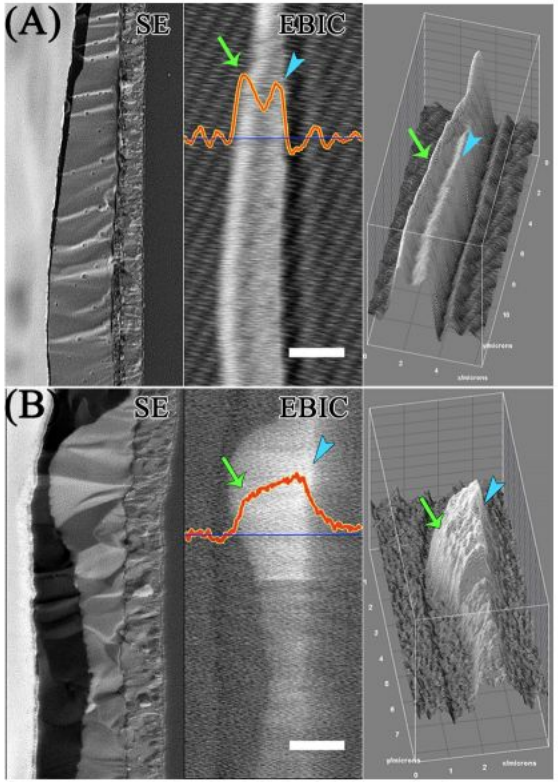
Examples of EBIC characterization

Perovskite solar cell



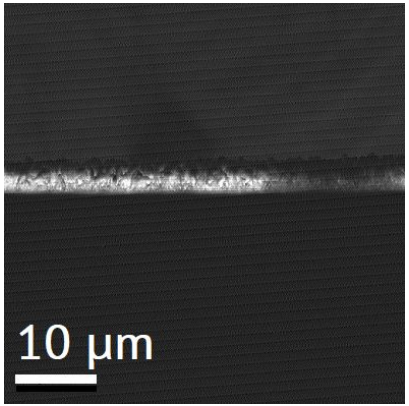
MAPbI3-xClx

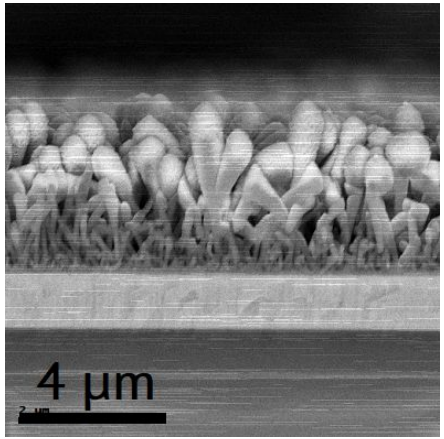
MAPbI3

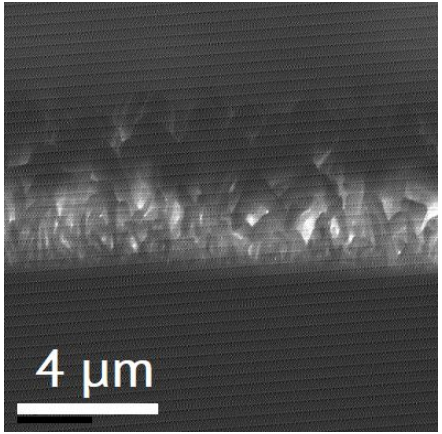


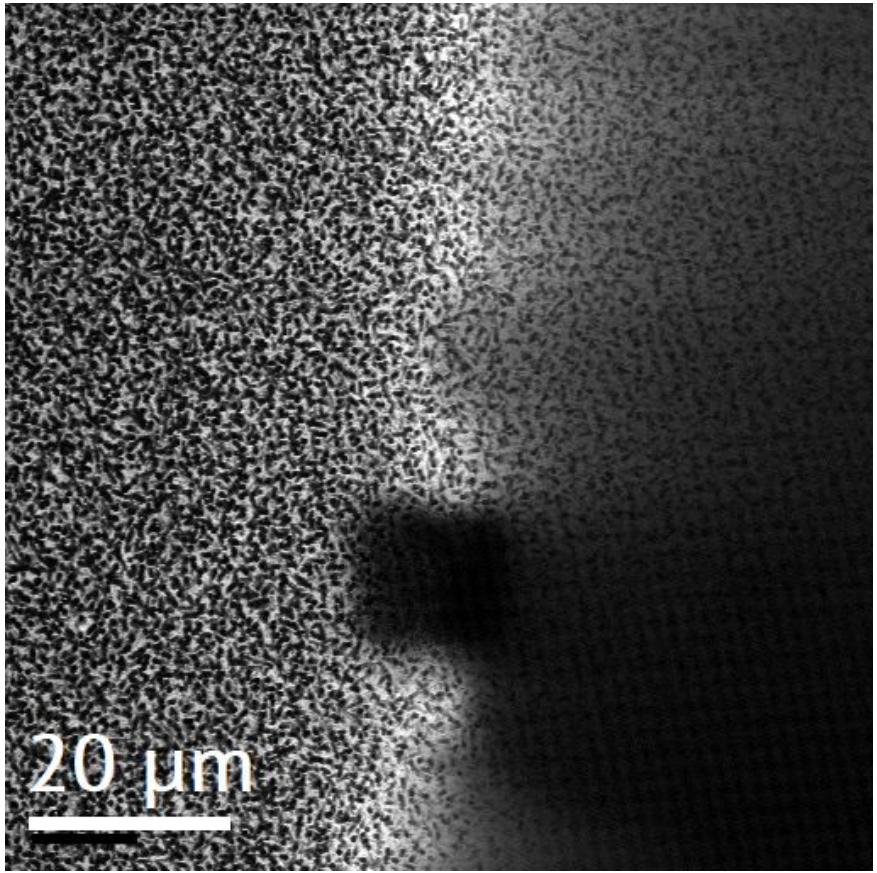
doi: 10.1021/nl404454h
Why Lead Methylammonium Tri-Iodide Perovskite-Based Solar Cells Require a Mesoporous Electron Transporting Scaffold (but Not Necessarily a Hole Conductor)

Exposure effect

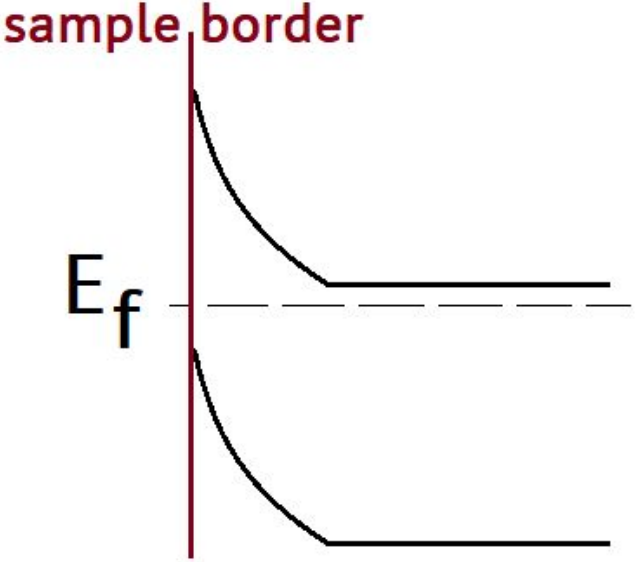


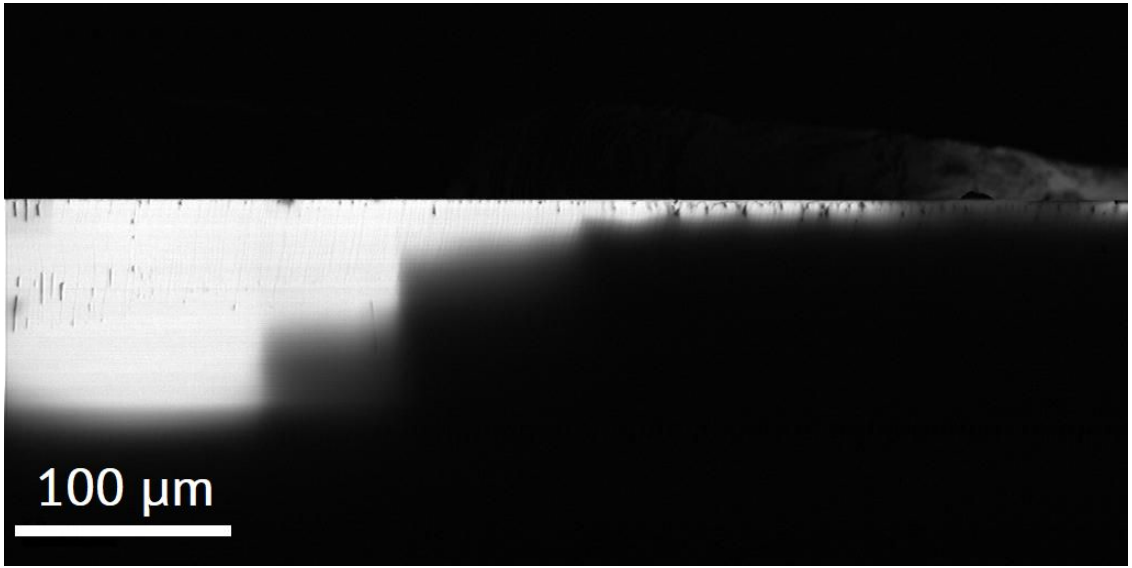




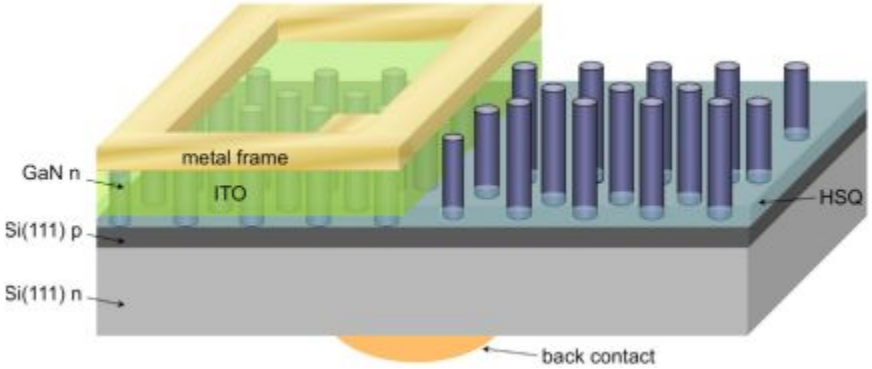


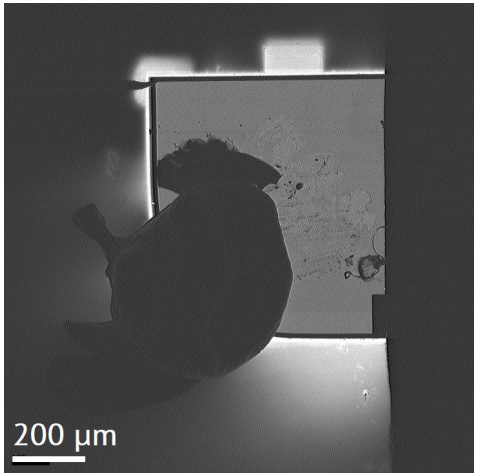
Positive exposure effect





Macroscopic in plane EBIC map





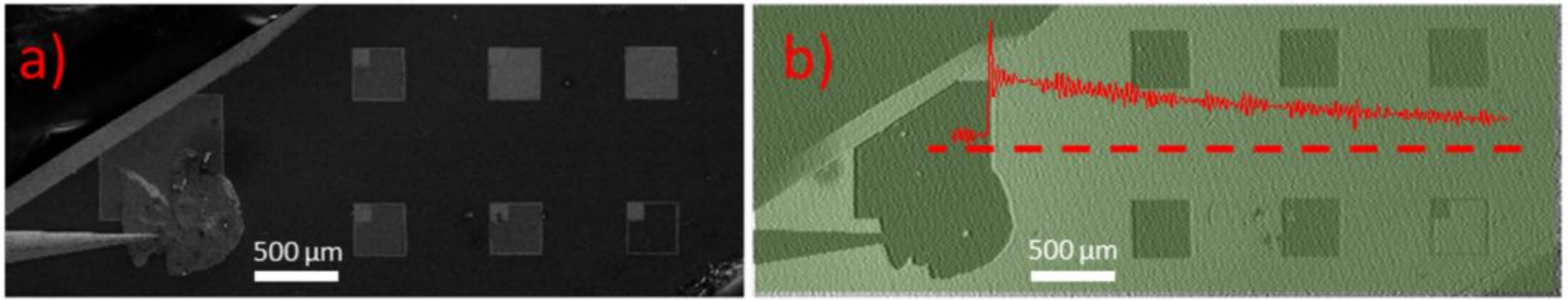


Fig. 7. SEM image (a) and EBIC map (b) of the as-processed sample collected under 3 kV acceleration voltage.

Acknowledgements

The author acknowledges support from the Ministry of Science and Higher Education of the Russian Federation (RFMEFI61619X0115)