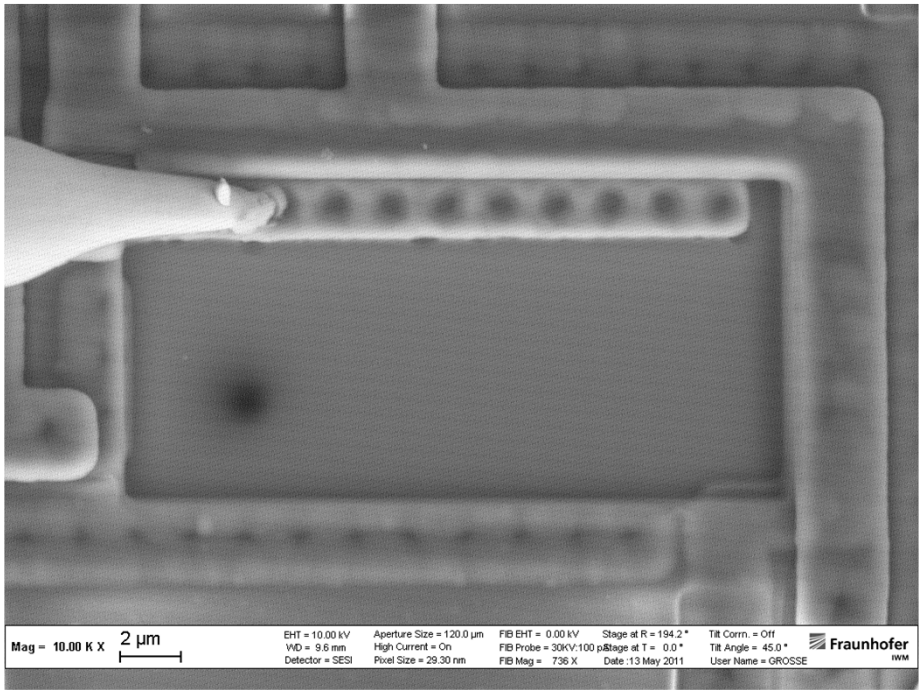
Combined FIB/EBAC Methods for Failure Analysis on Integrated Circuits

European CrossBeam® User Meeting Stuttgart, 15/16th May 2012



Frank Altmann
Michél Simon-Najasek
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Christian Große

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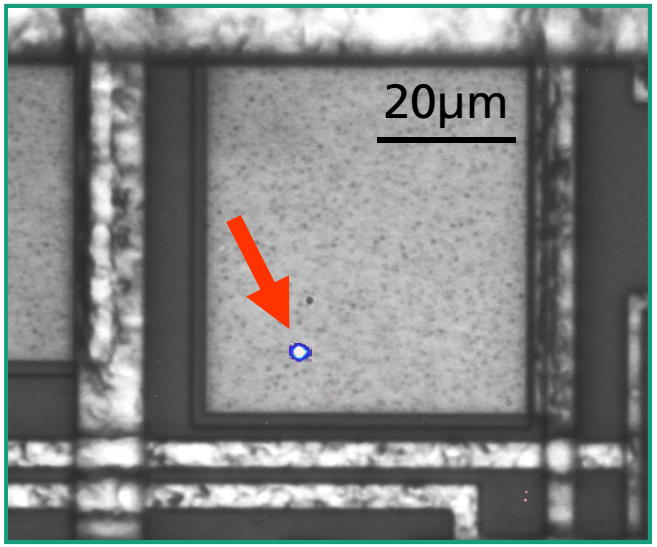
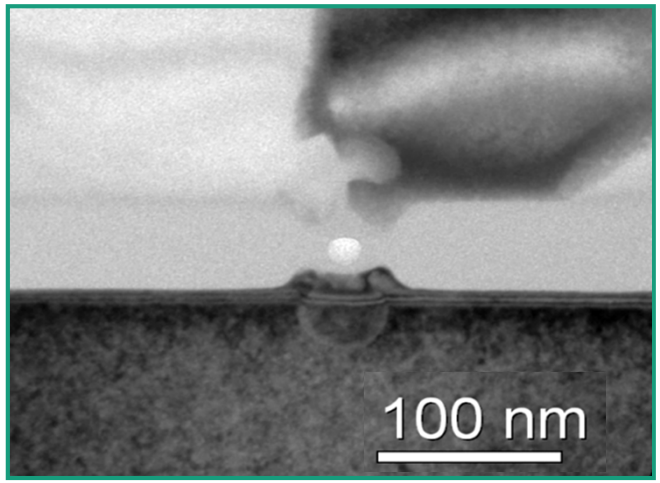
Failure analysis on IC structures





Challenges

- Typical nm sized defects
- Original defect signature could be modified by electrical treatment during operation, testing and localization
- Large area structures: insufficient alignment of OBIRCH/PEM image to IC structure for further physical FIB/TEM analysis
- Localisation of opens in metal networks (no signal from defect site)

New approach :

- EBAC localization within a SEM/FIB system
- Minimal electrical treatment during localization

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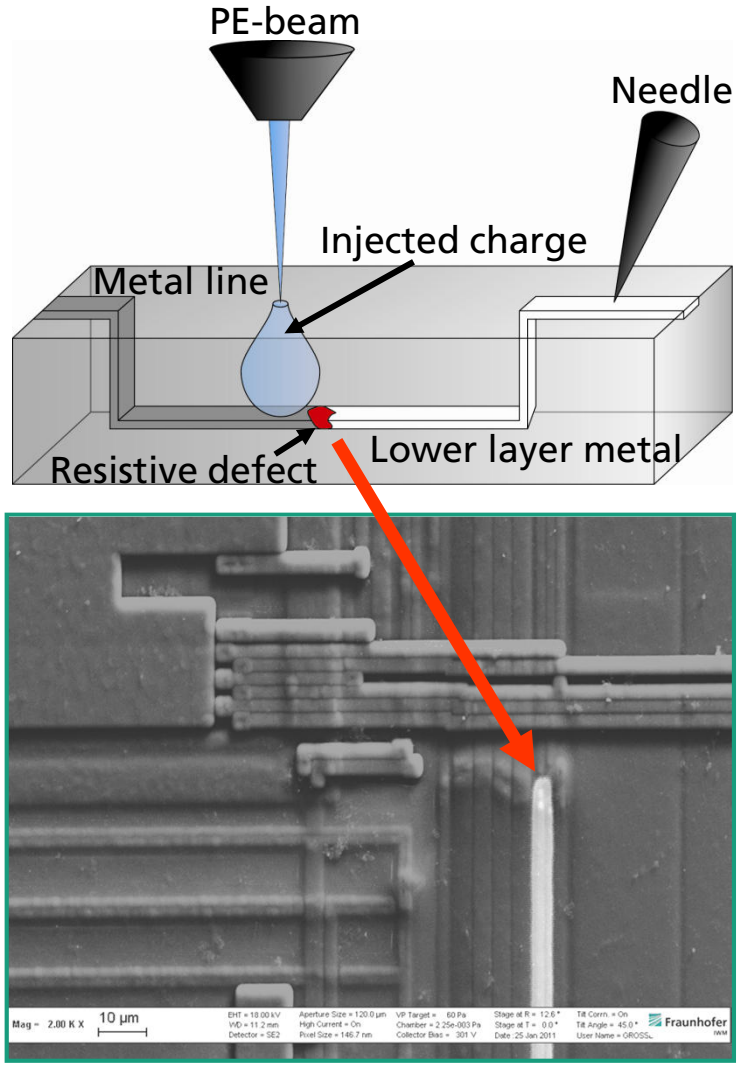
EBAC principle (electron beam absorbed current)



- Primary electron beam of SEM generates a local current source
- Absorbed beam current in the IC network is detected by probe needle
- Current image is constructed from the amplified current signal and superposed to the SE image
- Penetration depth can be aligned by acc. voltage of the primary beam –> buried metal lines can be analysed
- Direct localisation of metal line opens
- Short localisation in metal lines by comparison to layout / reference device

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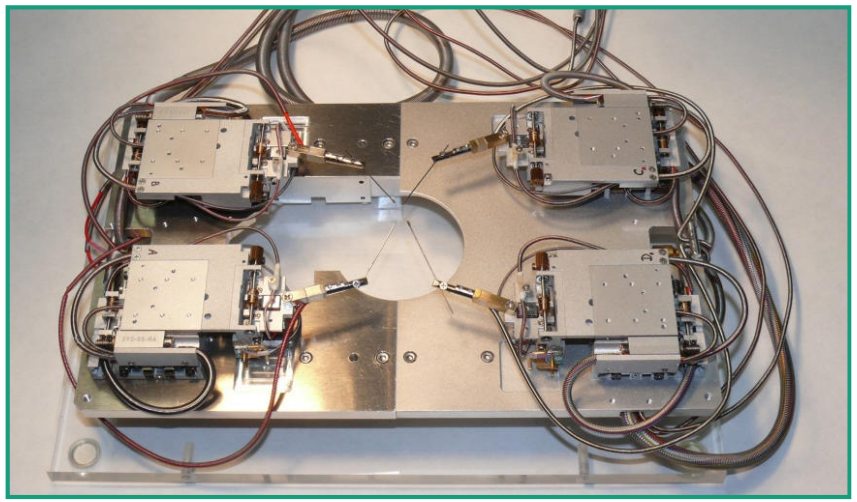
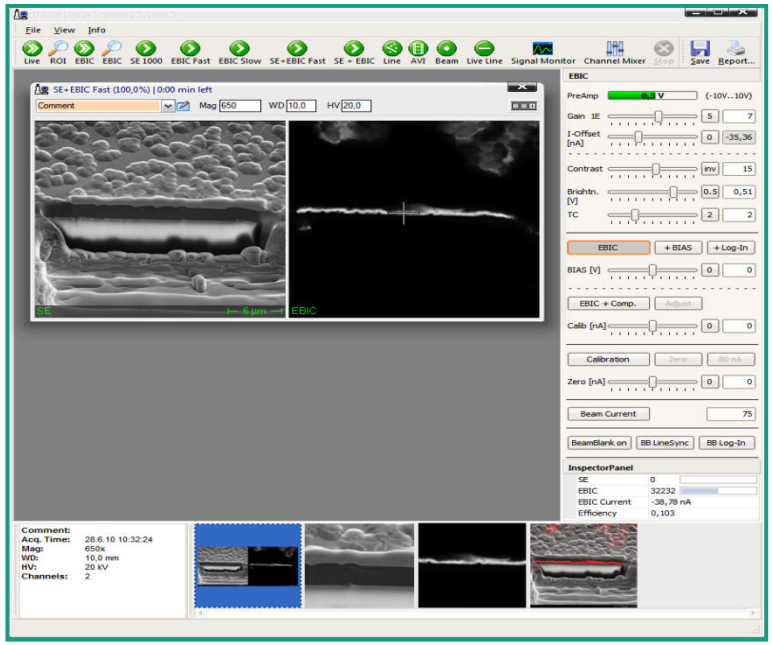
Equipment

- Zeiss Crossbeam ESB
- Zeiss Supra 55 VP SEM
- Kammrath&Weiss in-situ prober
- Point Electronics DISS 5 EBIC system





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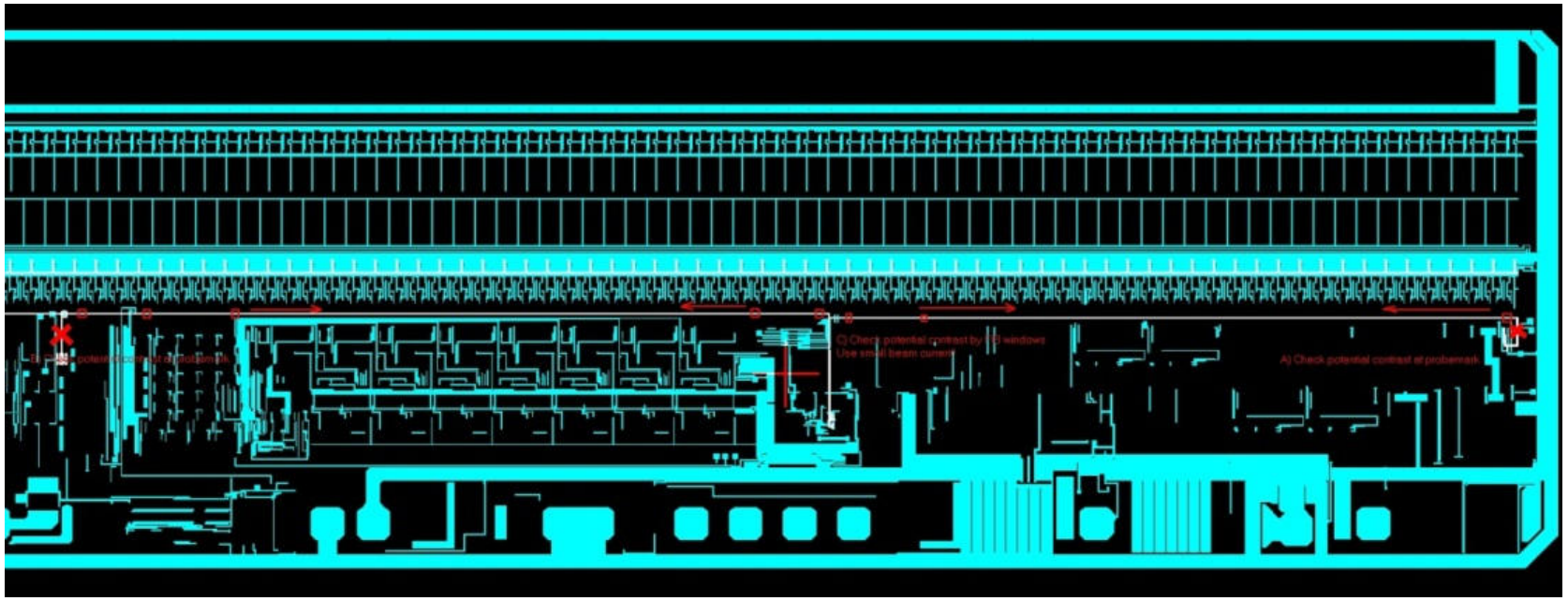
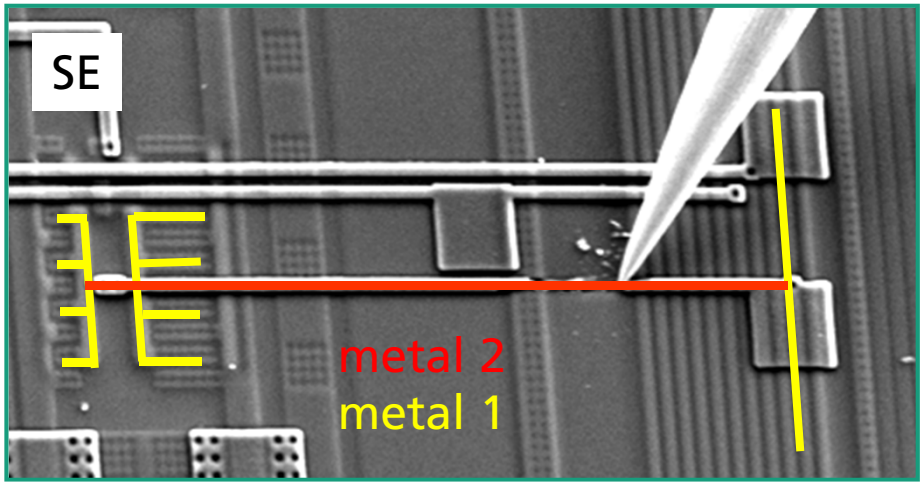
EBAC localisation of resistive defects in metal network

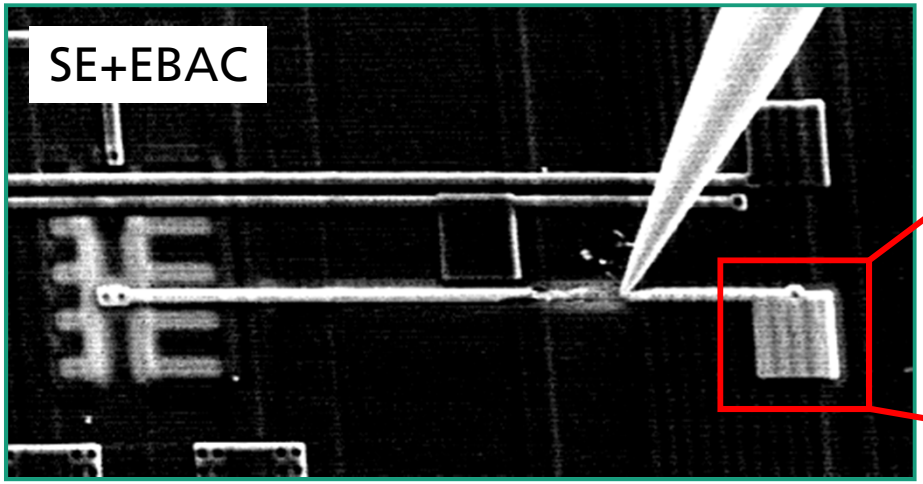


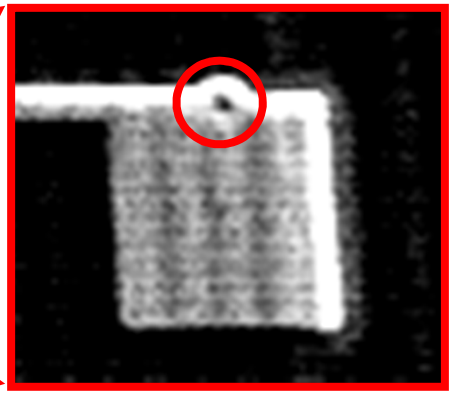
- Long metallisation network with high ohmic resistance
- Defect healing during PEM and OBIRCH analysis -> defect could not be localised
- EBAC at very low dissipation power (nW range) to avoid defect healing

EBAC localisation of resistive defects in metal network

EBAC imaging







- Primary electron energy of 15 kV to reach both metal levels
- Missing metal 1 (yellow) on right side

-> open via to metal 1

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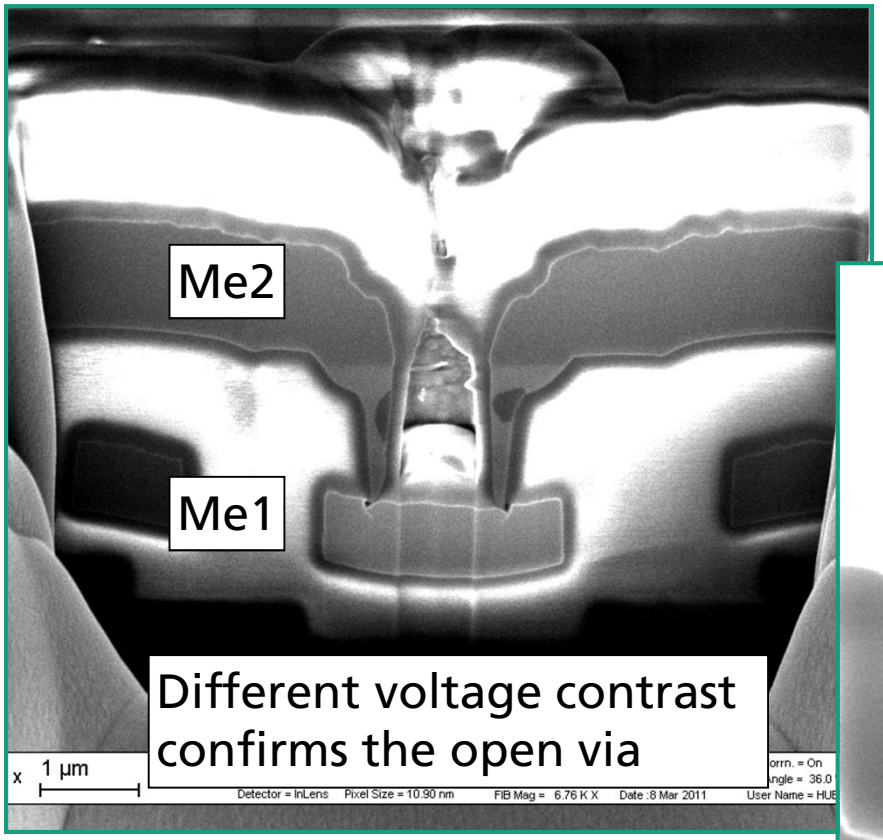
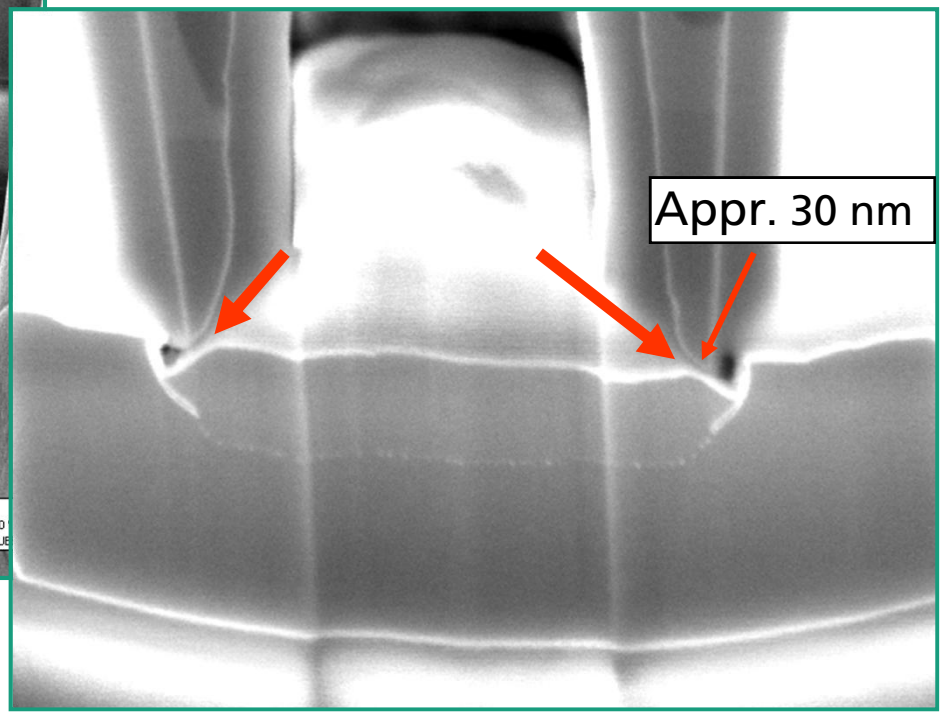
EBAC localisation of resistive defects in metal network

FIB + SEM analysis



- Only thin spikes in contact with metal 1 -> local high resistance
- Low dissipation power (nW range) preserved original defect



Root cause:
deep + under etch in metal 1

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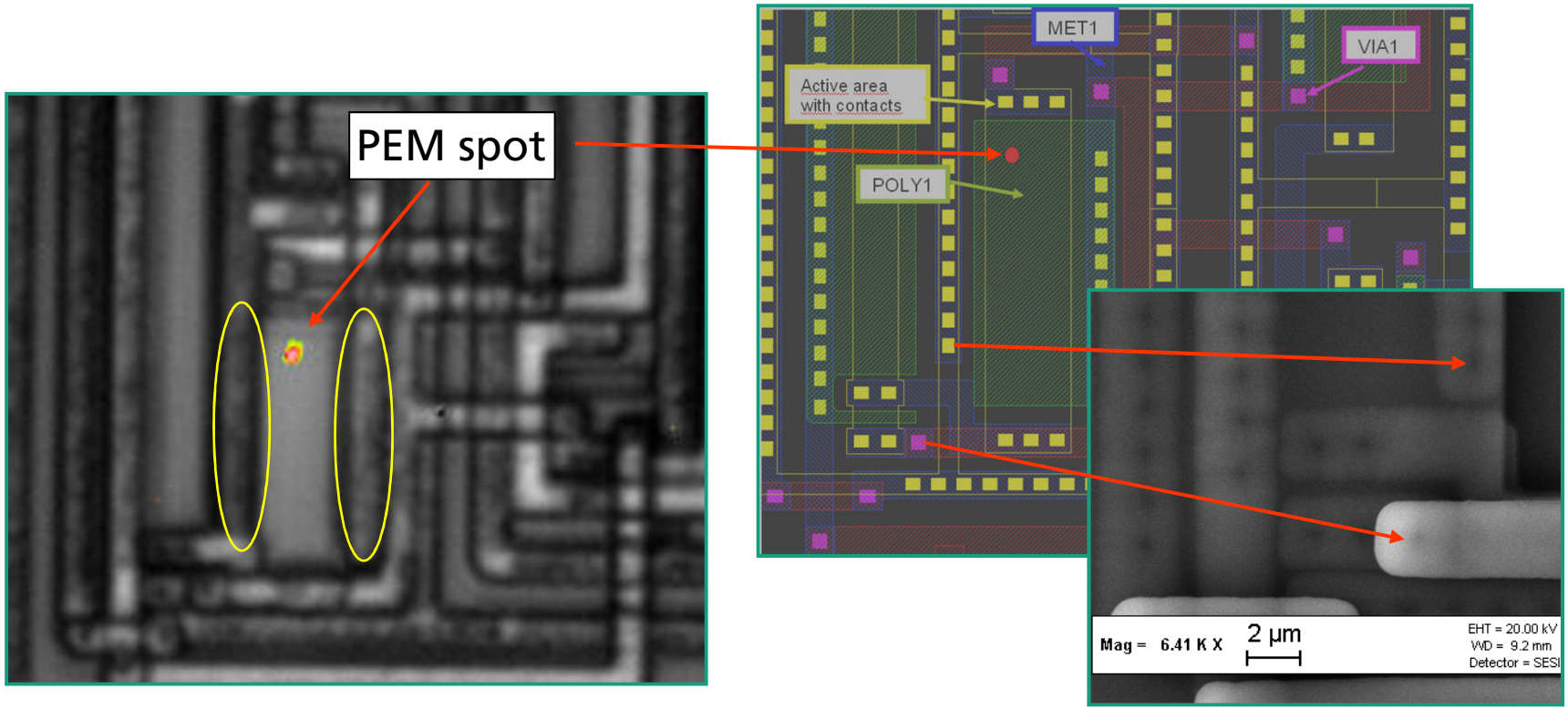
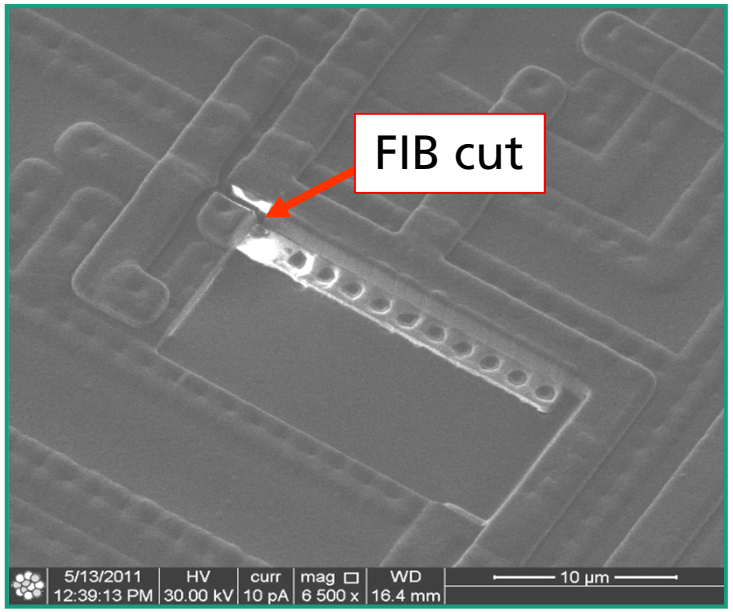
EBAC localisation of gate oxide breakdown

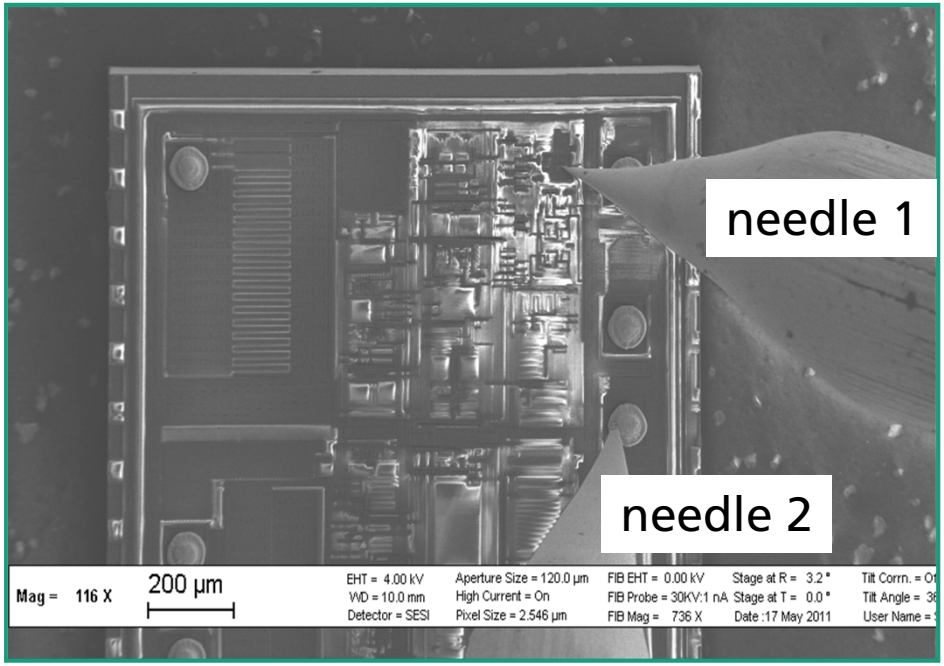


- Transistor gate shorted to substrate
- Short localisation by PEM, but alignment to IC structure was insufficient for further TEM analysis

  -> EBAC localisation

EBAC localisation of gate oxide breakdown





Preparation for EBAC :

- Electrical separation of gate structure by FIB cut
- Delayering by XeF2 FIB etch to metal 1 contacting poly Si plate
- Probing of metal 1 for EBAC detection (needle 1)
- Probing of substrate (needle 2 on ground pad)

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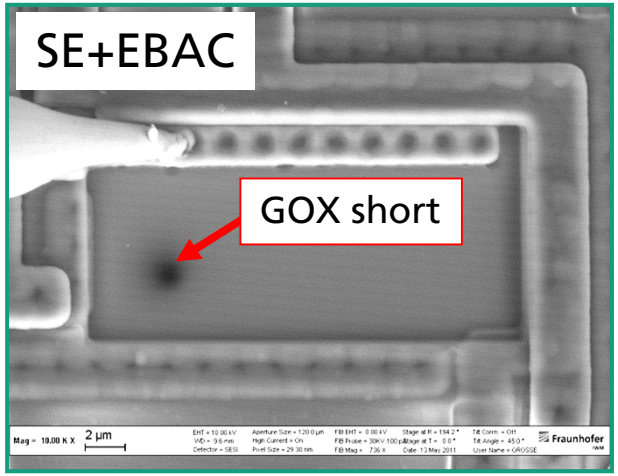
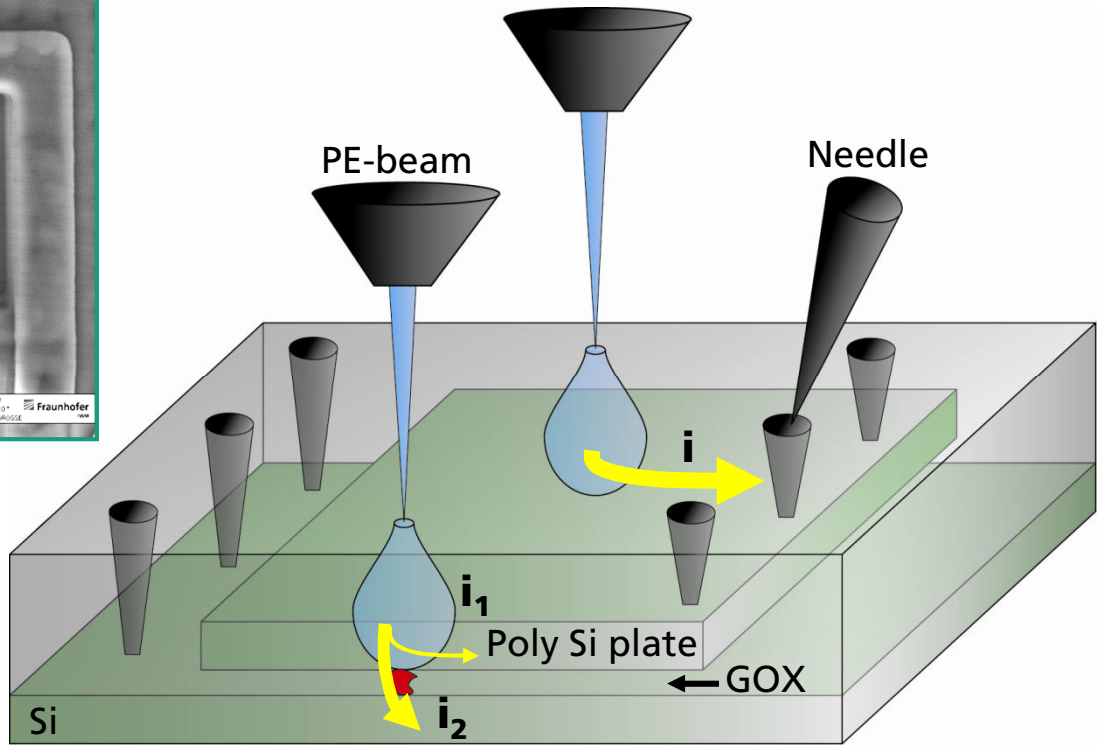
EBAC localisation of gate oxide breakdown





- Primary electrons reach the poly Si plate at suitable primary energy
- Current divider is active at GOX short, EBAC current flows to substrate
  -> locally reduced EBAC current at defect site measured by needle

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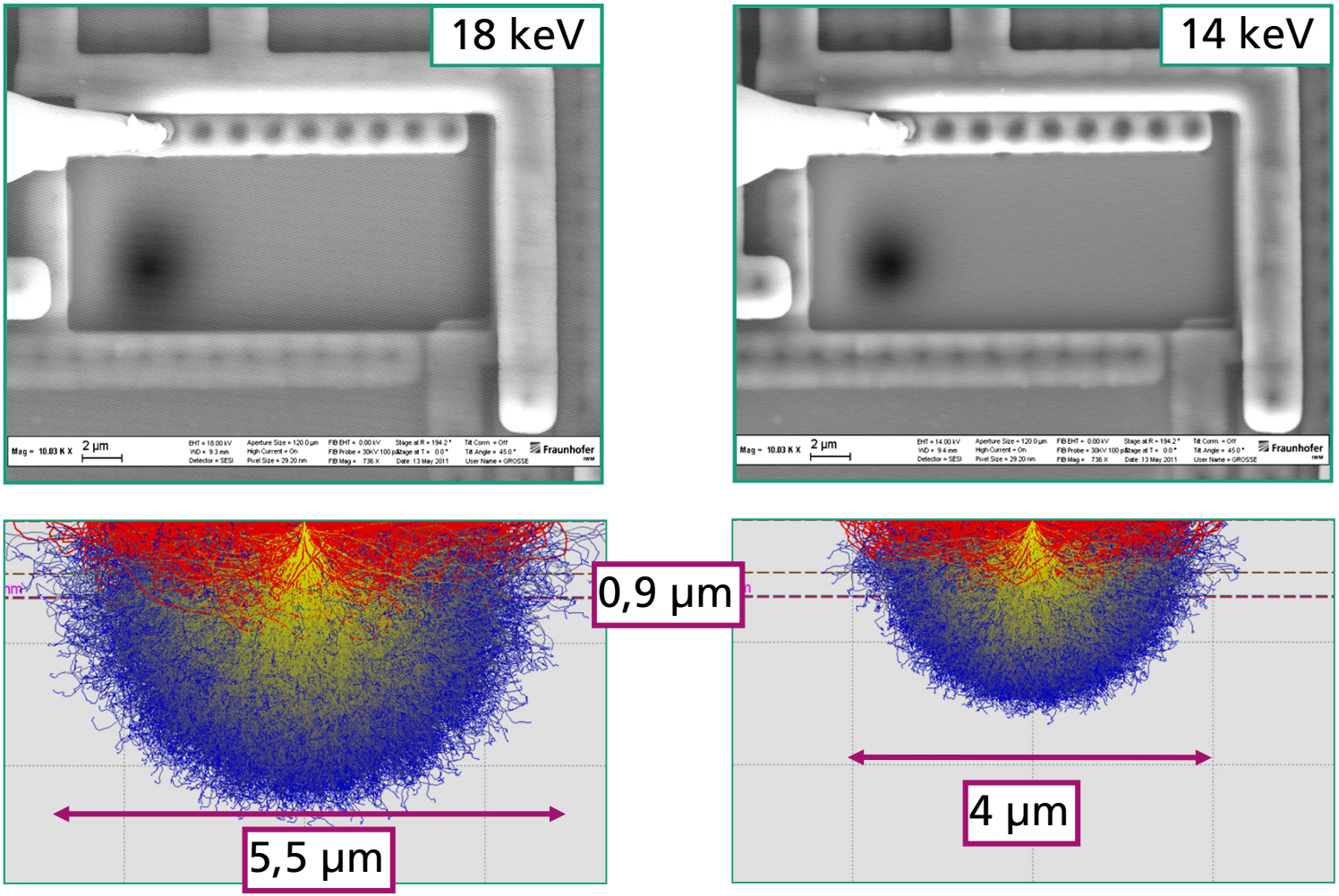
EBAC localisation of gate oxide breakdown

Stepwise reduction of primary energy to reduce interaction volume



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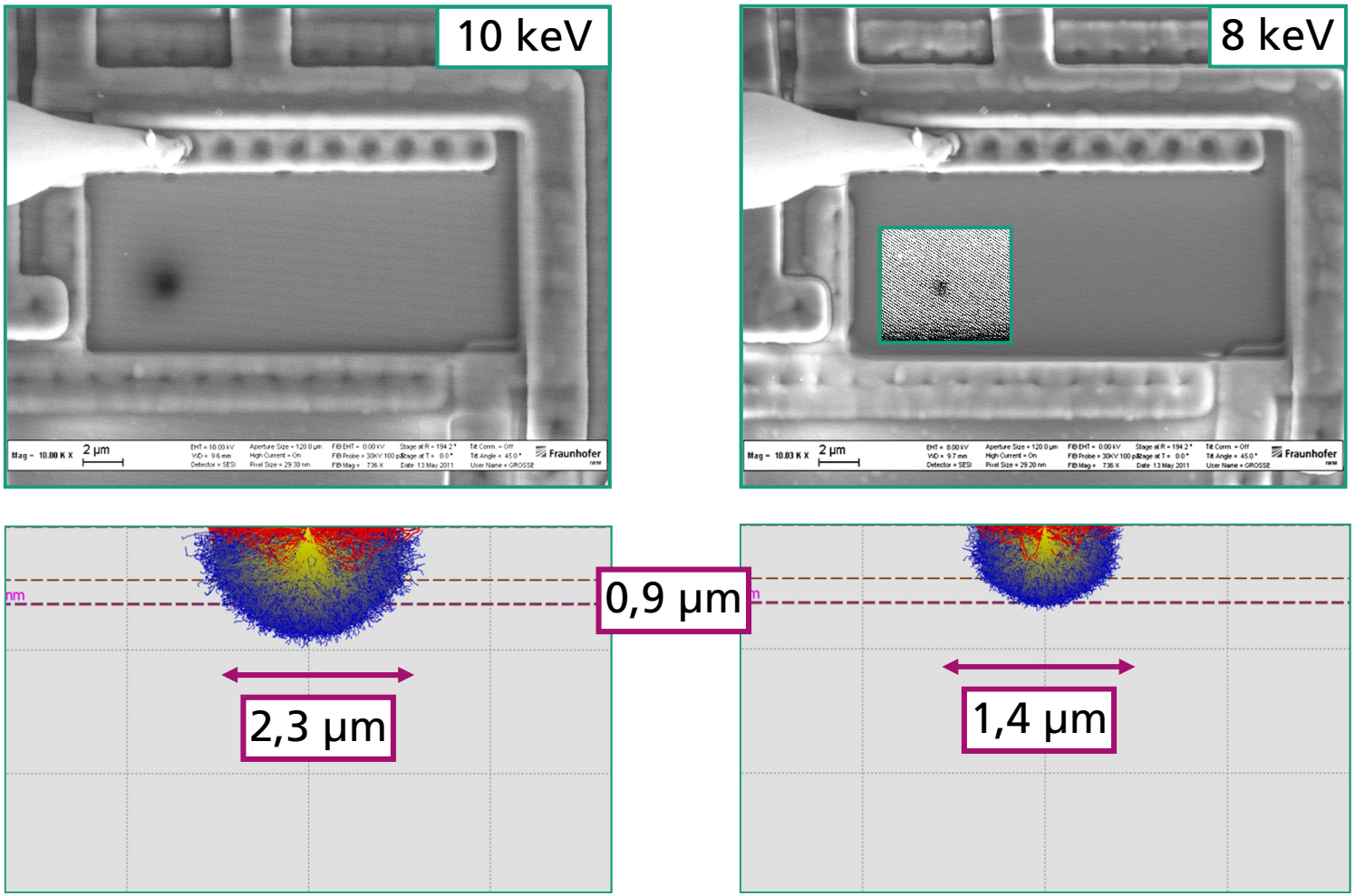
EBAC localisation of gate oxide breakdown

Stepwise reduction of primary energy to reduce interaction volume



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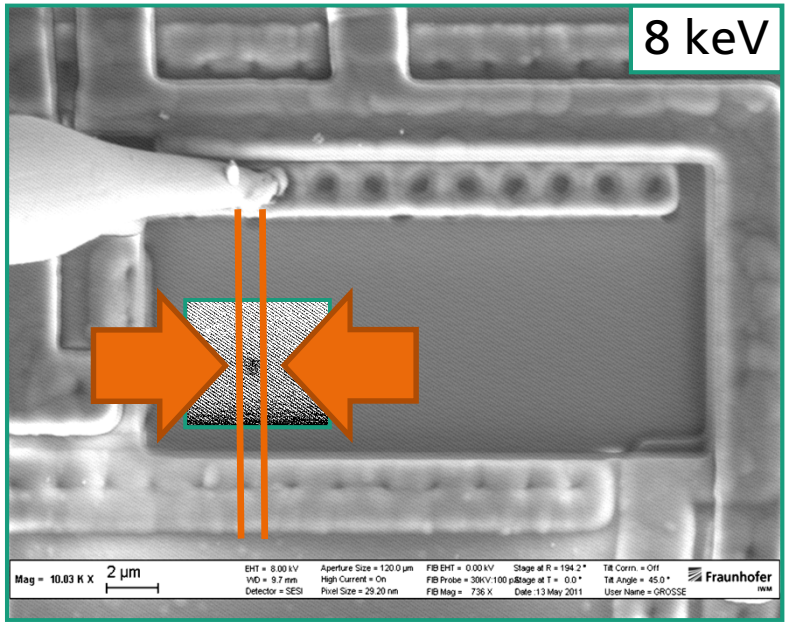
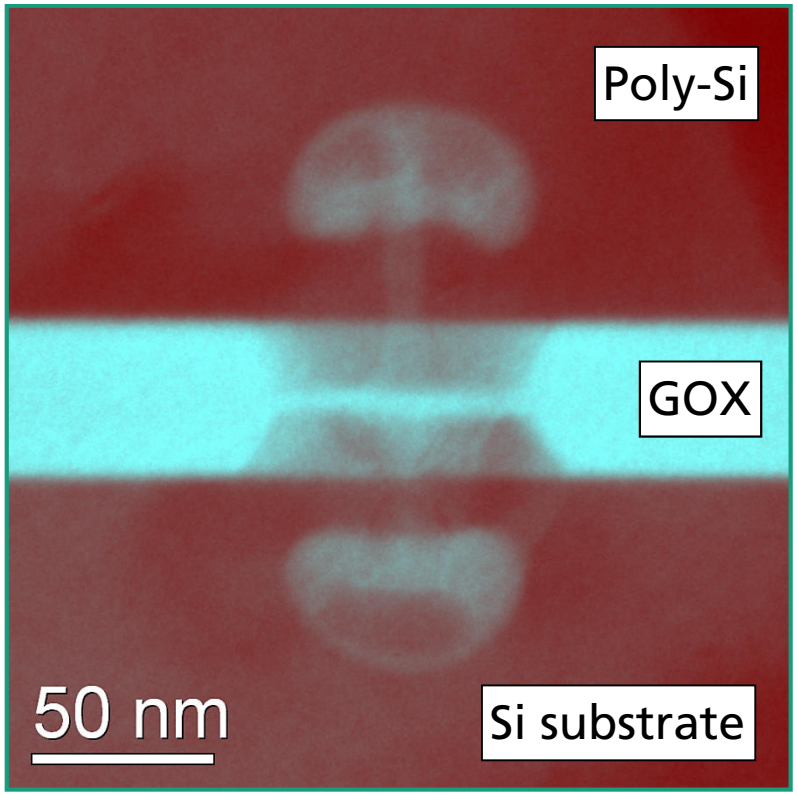
EBAC localisation of gate oxide breakdown

FIB/SEM + TEM investigation



Localised defect size for FIB cross sectioning



GOX defect imaged by EFTEM

Root cause: ESD damage of GOX

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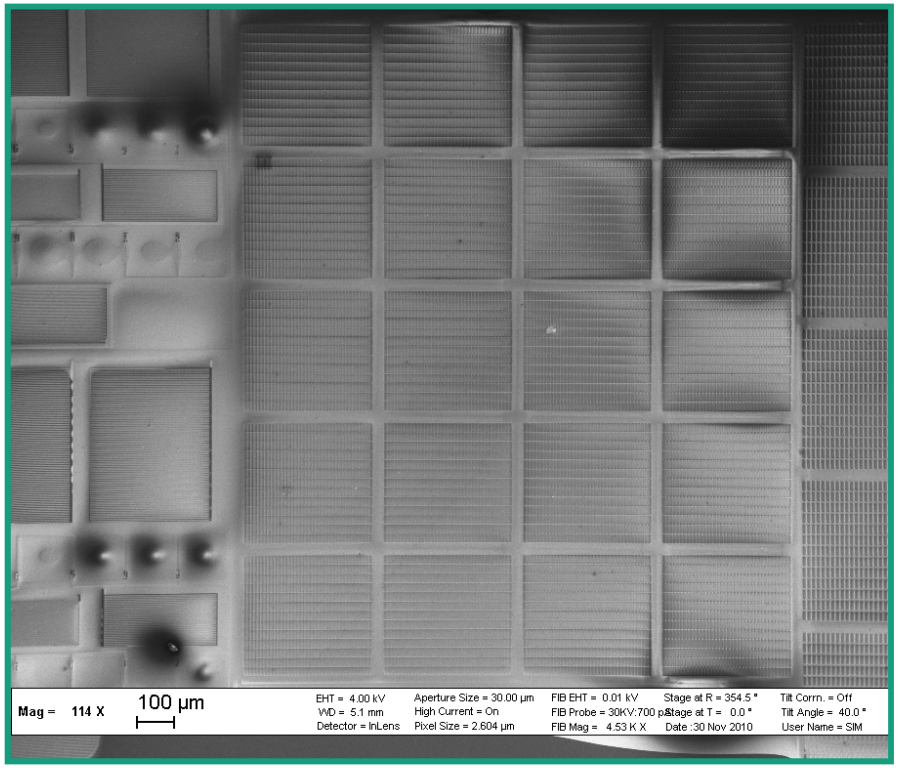
Voltage contrast and EBAC on a shorted CAP

Background



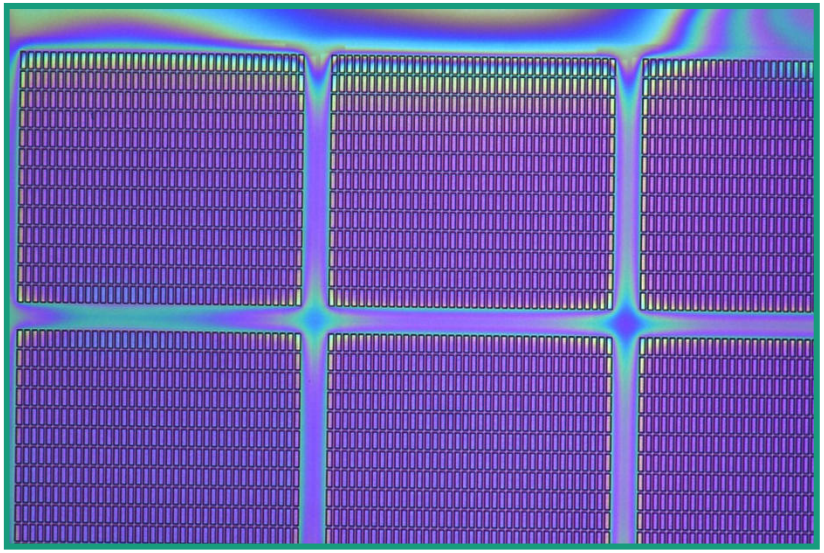
- The whole capacitor has a leakage to the substrate
- Capacitor consists of 20 modules with 13 columns and 38 rows each, makes 9880 overall single capacitors
- How to localize the defect?

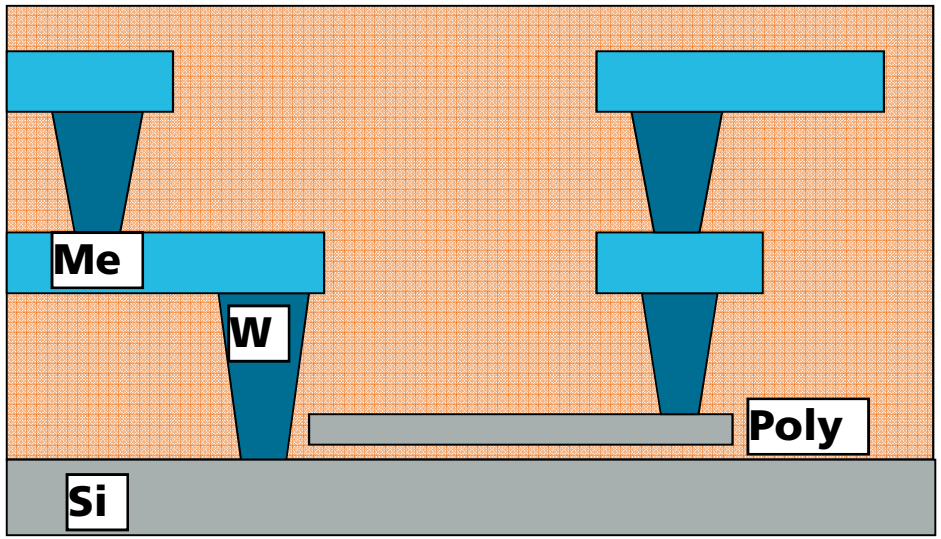
Basic idea:

1. Separation of all single capacitors
2. Pre localization of shorted capacitor by passive voltage contrast imaging
3. Precise localization by EBAC
4. Defect analysis by TEM

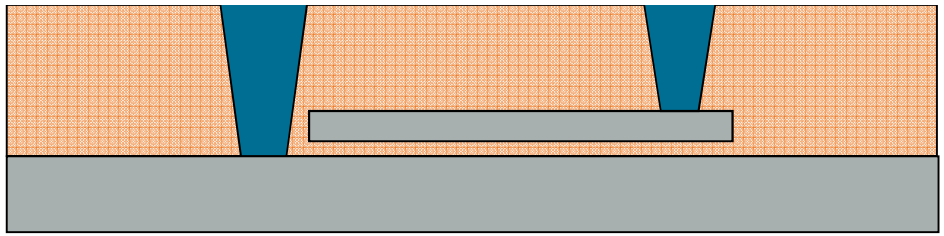
Voltage contrast and EBAC on a shorted CAP

Mechanical delayering





Mechanical delayering into the contact structure so that the capacitors are disconnected from each other



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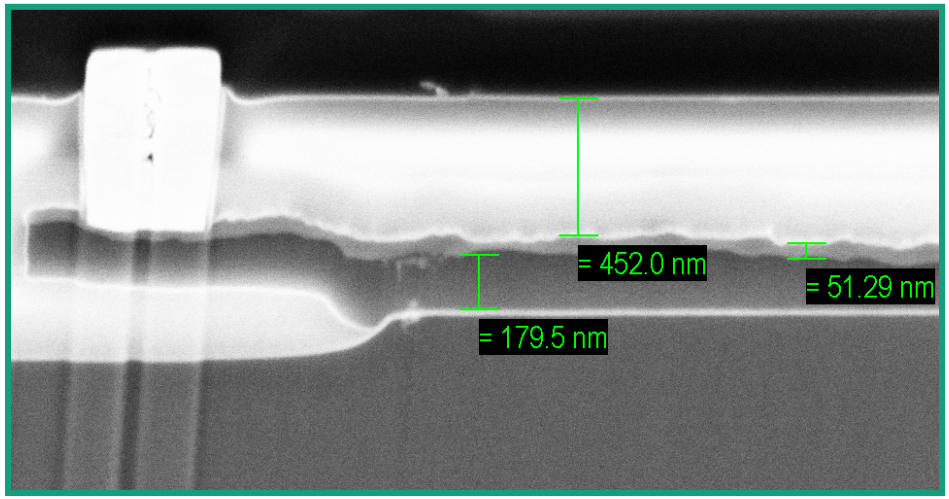
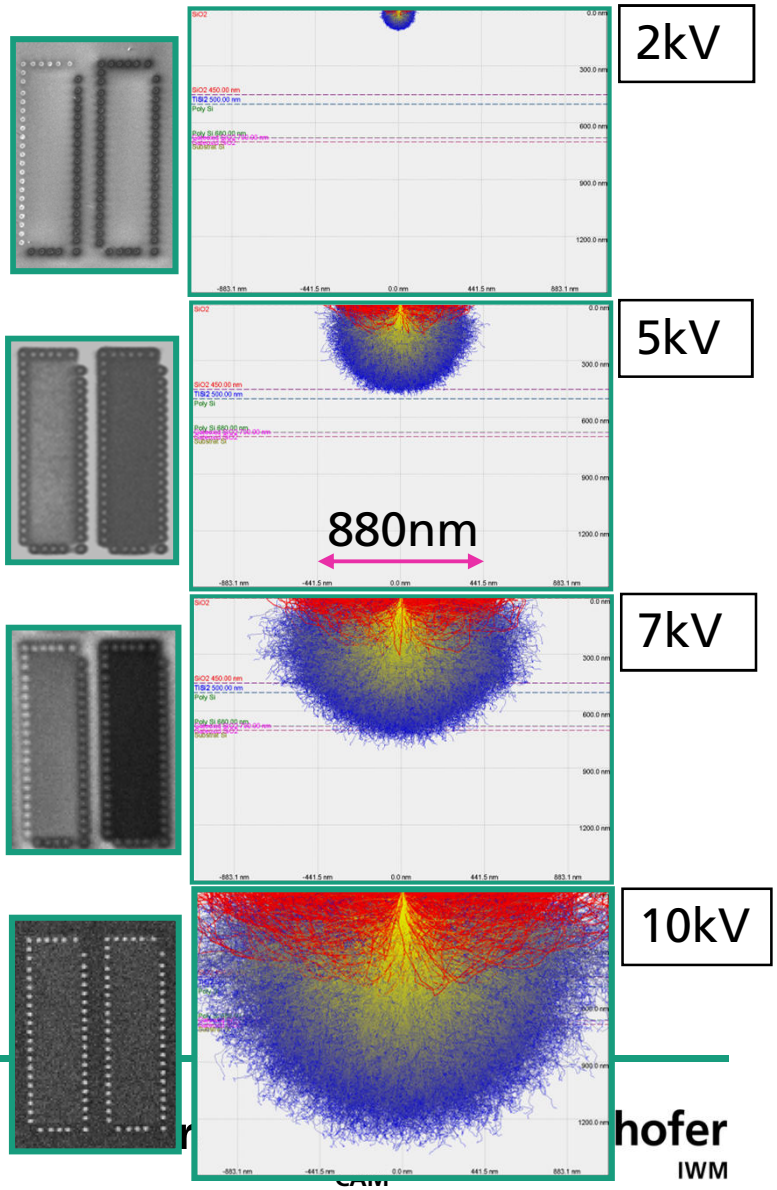
Voltage contrast and EBAC on a shorted CAP

Passive voltage contrast imaging



- SEM voltage contrast depends on primary energy
- @7kV electrons reaches the poly plate -> faultless capacitor is floating (appears bright), shorted capacitor appears dark)



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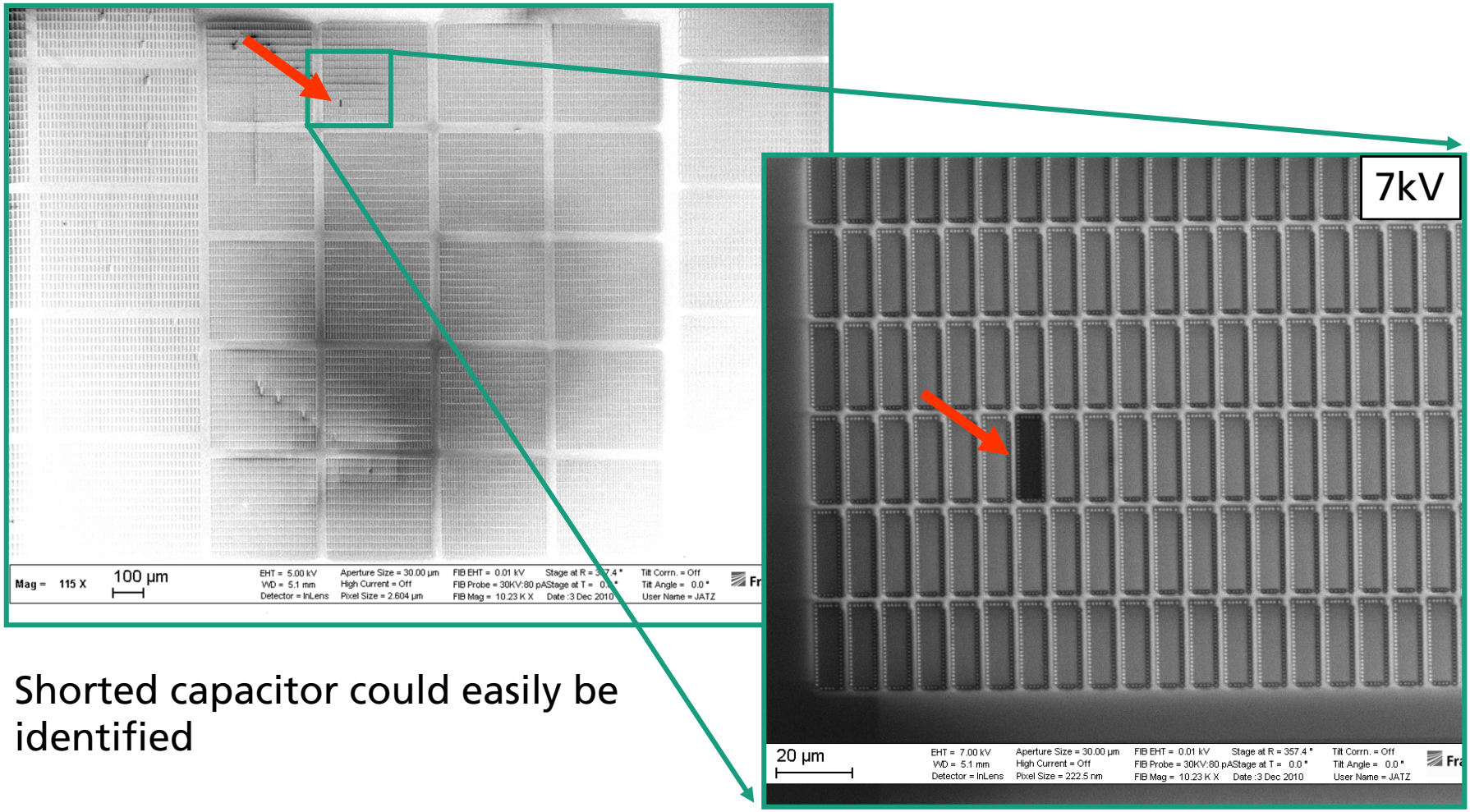
Voltage contrast and EBAC on a shorted CAP

Passive voltage contrast imaging



Shorted capacitor could easily be identified

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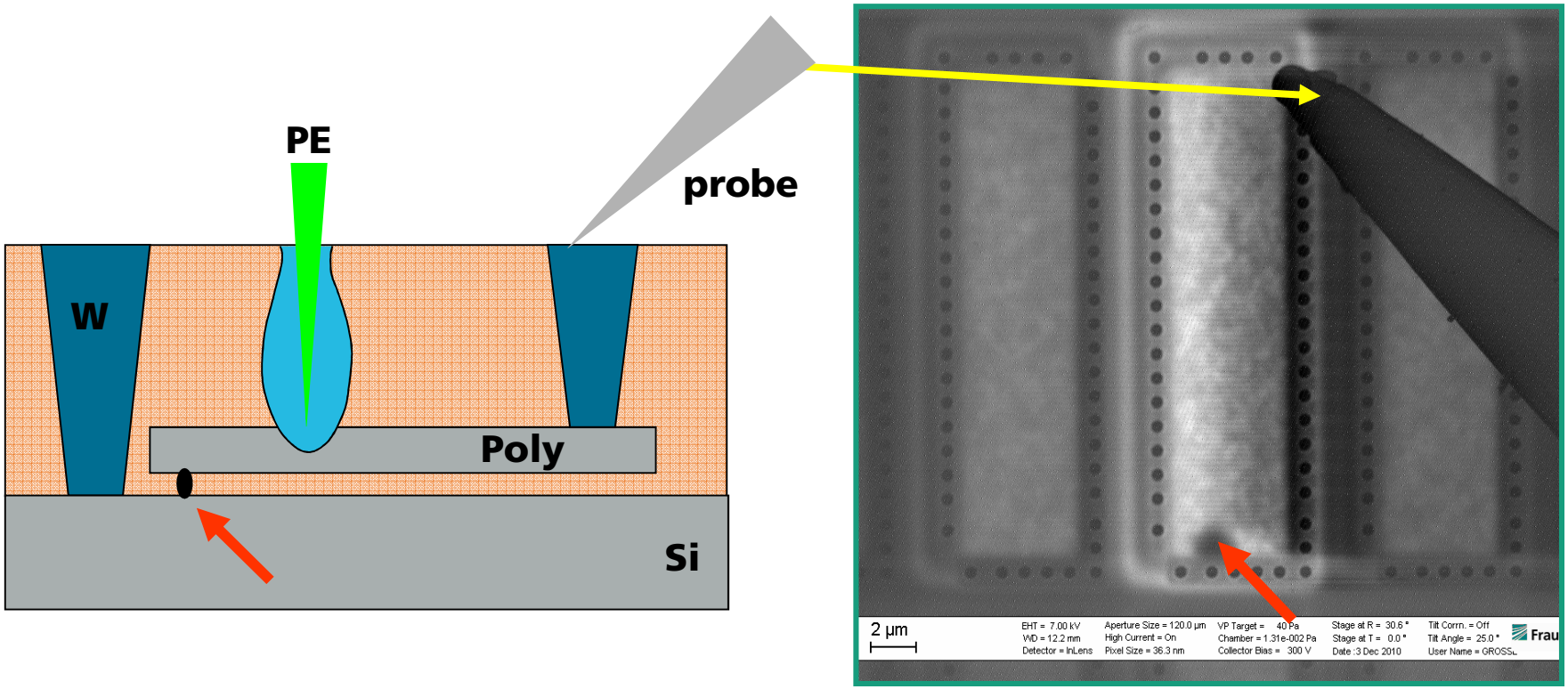
Voltage contrast and EBAC on a shorted CAP

EBAC - localisation



Short in capacitor oxide is localized with sub-µm precision

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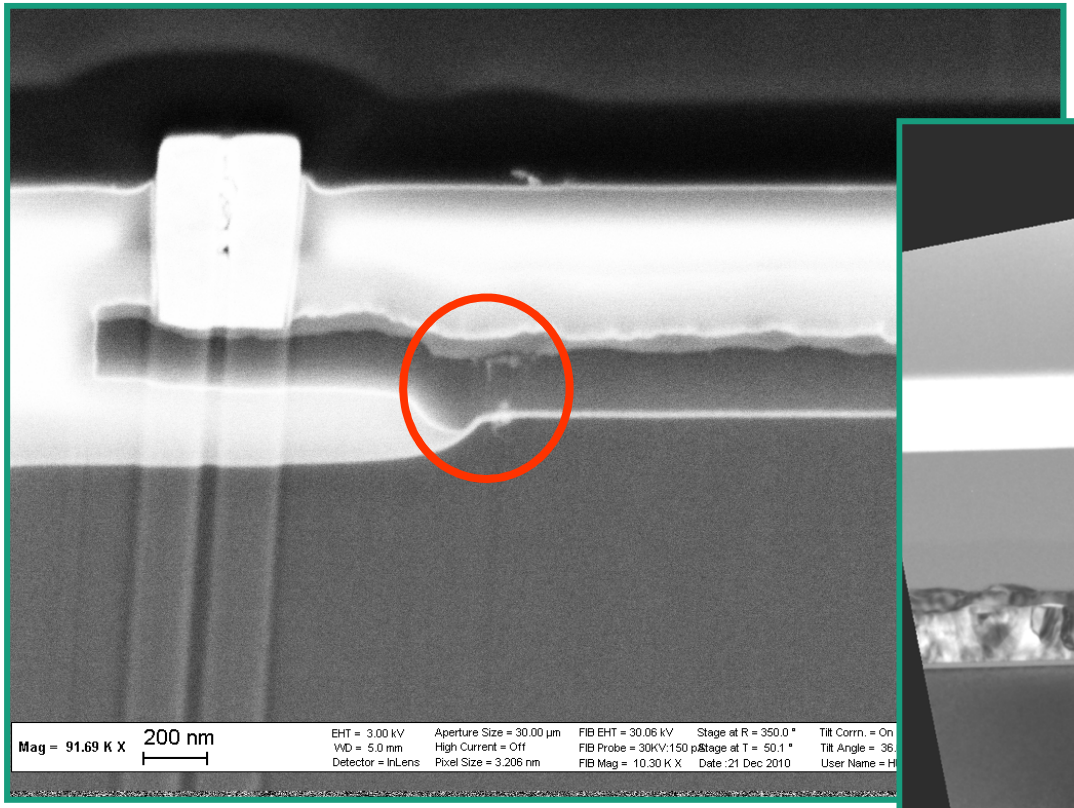
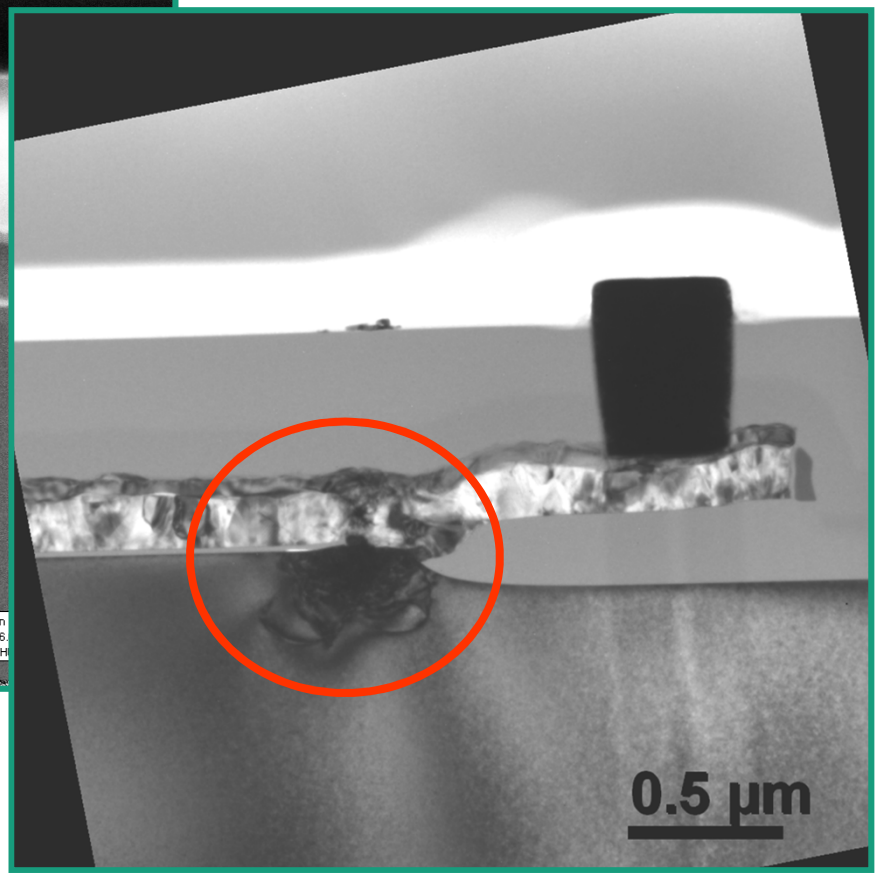
Voltage contrast and EBAC on a shorted CAP

Physical defect analysis by SEM/TEM at FIB cross section





Root cause: oxide weakness at capacitor edge causes electrical breakthrough during operation

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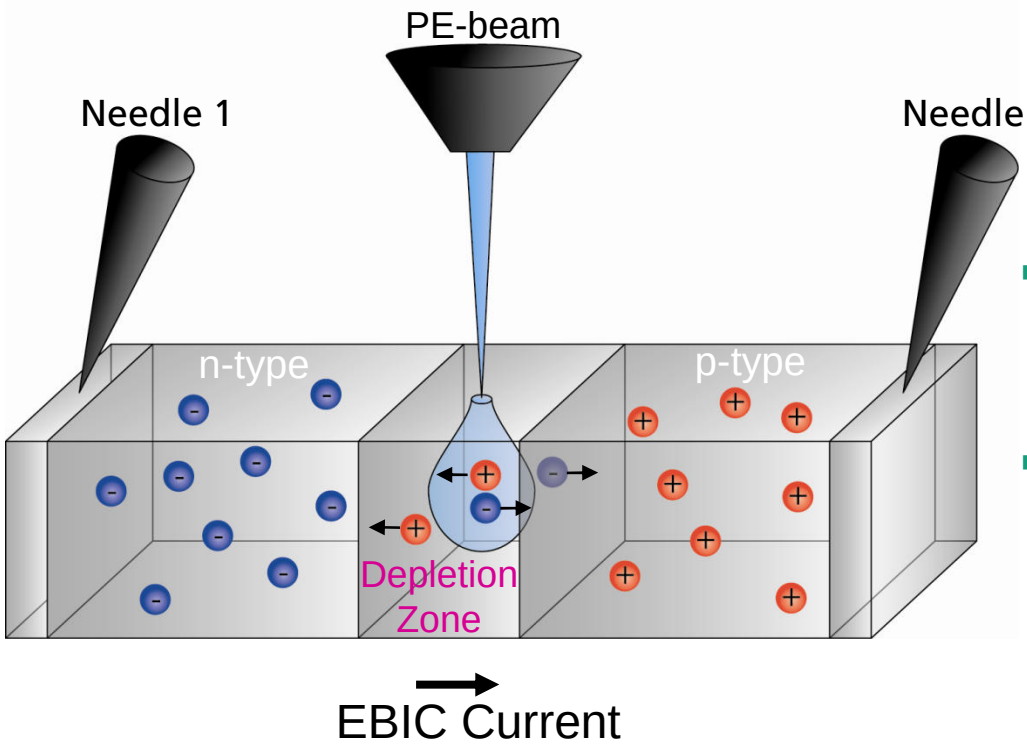
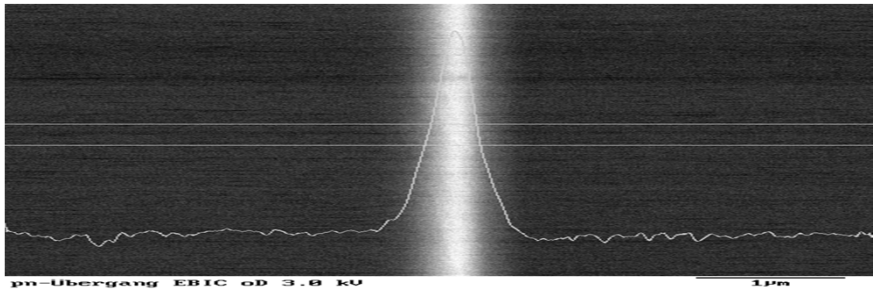
EBIC principle (electron beam induced current)





- 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
- Depletion zone is visualized by current image

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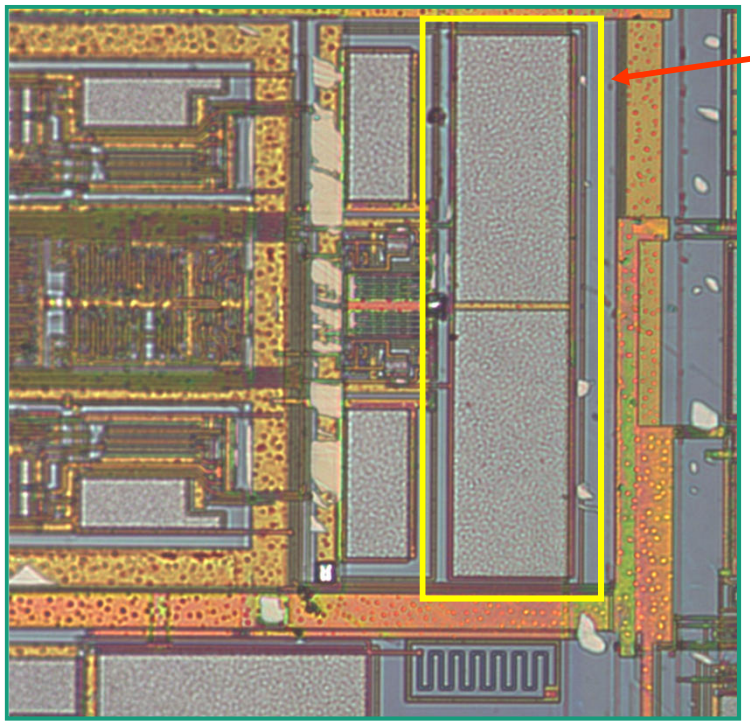
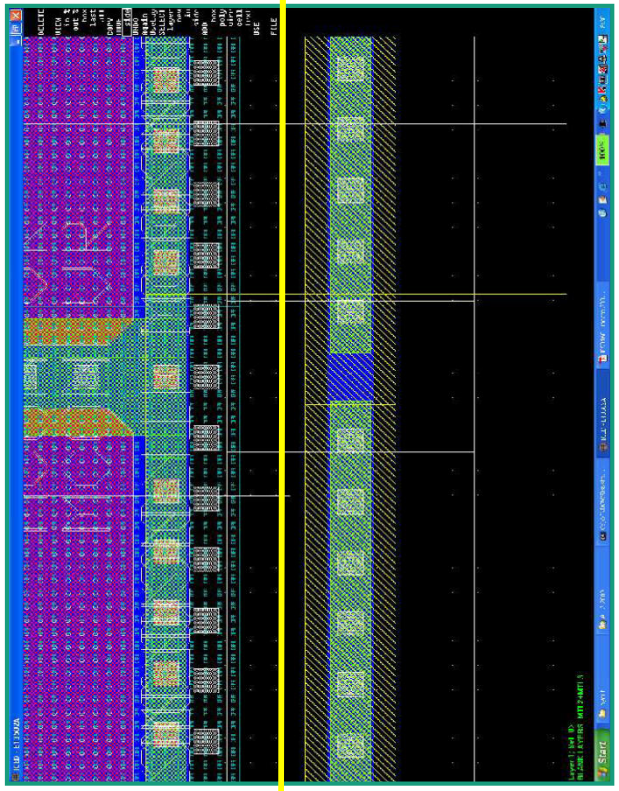
EBIC analysis of large area shorted capacitor



Position of the pn-junction surrounding the capacitor



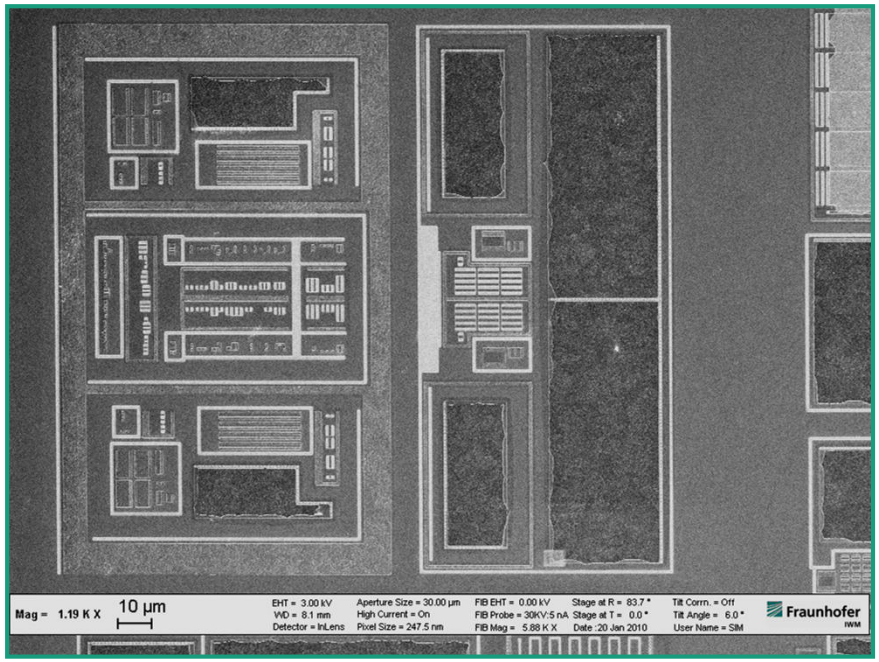
- Large area capacitor shorted to ground possibly caused by short to guard ring
- PEM, OBIRCH analysis not successful

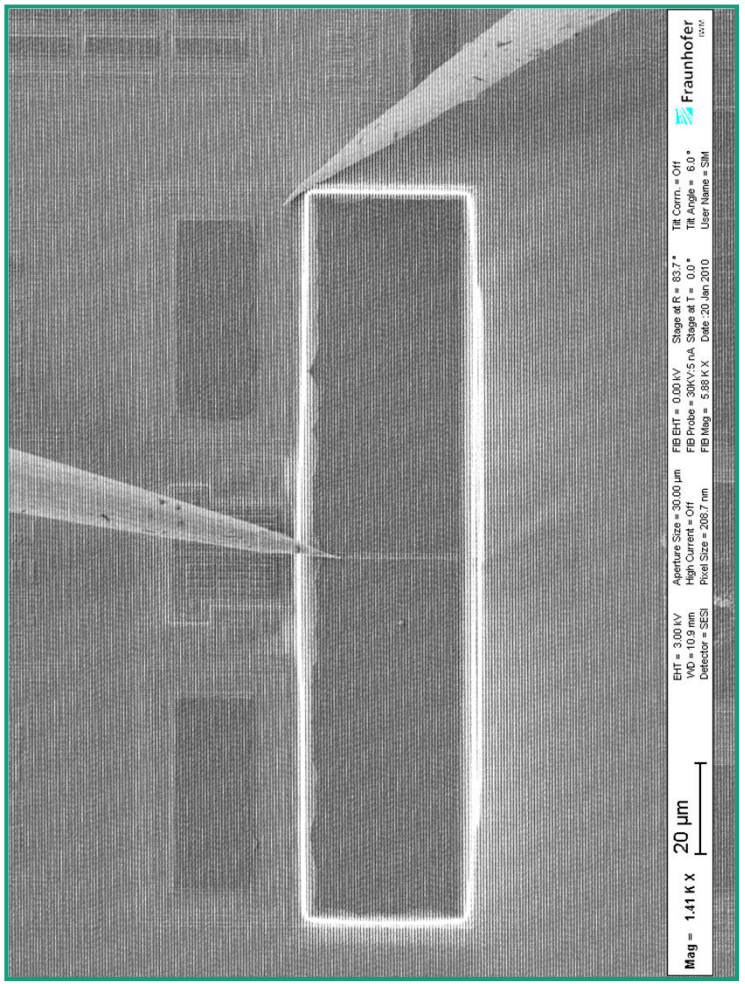
-> EBIC to visualise pn-junction

Grounded guard ring around the capacitor

EBIC analysis of large area shorted capacitor

Top down EBIC to visualise pn-junction frame around capacitor





- Chemical delayering of IC structure
- Probing of p/n Si
- Top down EBIC analysis to visualise pn-junction

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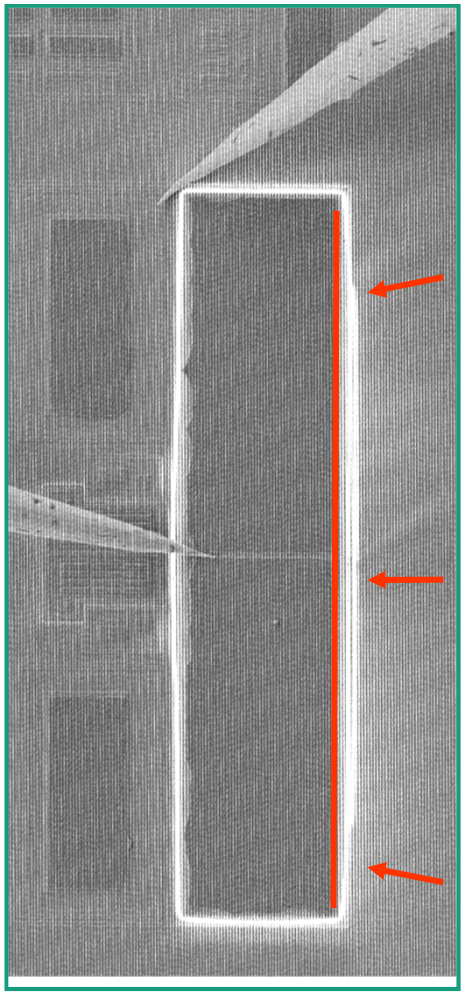
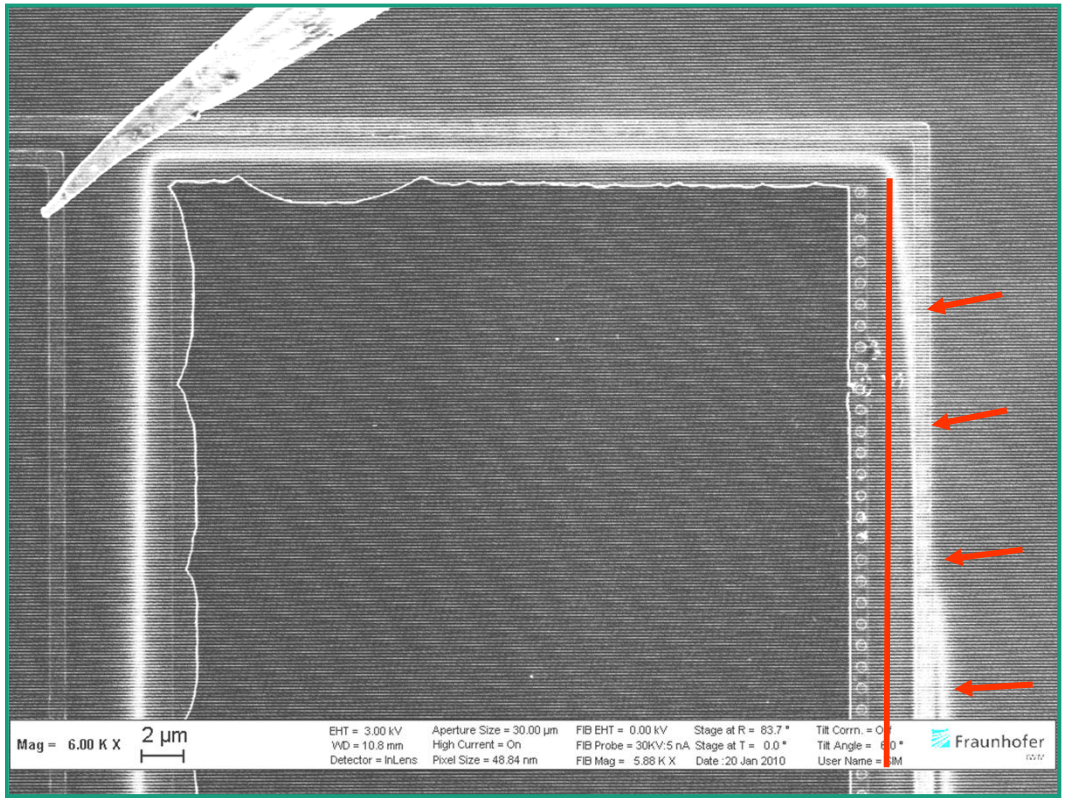
EBIC analysis of large area shorted capacitor

Top down EBIC





- Red line marks expected position of the pn-junction
- EBIC signal confirms shift of pn-junction to the guard ring structure

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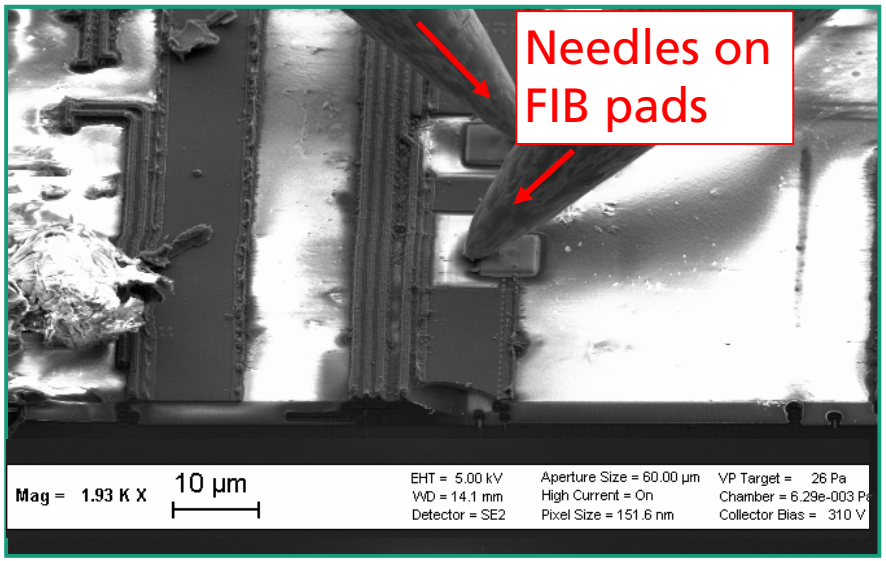
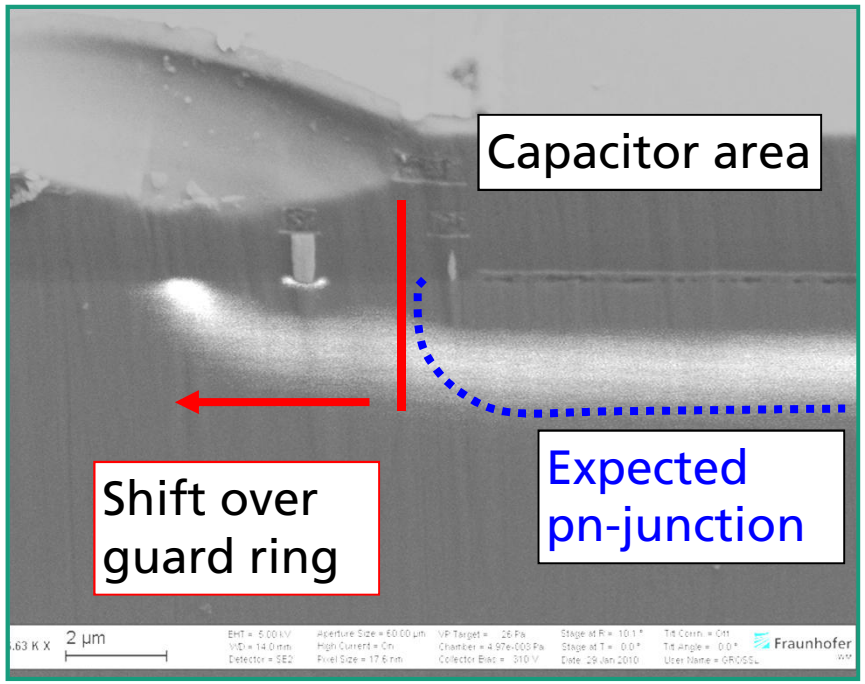
EBIC analysis of large area shorted capacitor

EBIC analysis at mechanical cross section

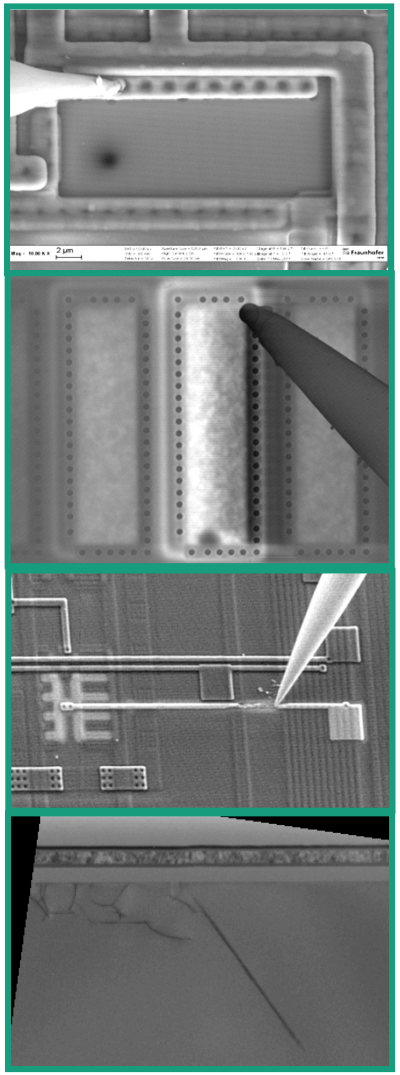




Root cause: shift of implantation mask is shortening n-doped guard ring with lower capacitor plate

- EBIC at mechanical cross section to verify pn-profile (second sample)
- FIB pads to probe doped areas of capacitor
- Results confirm shift of pn-junction over the guard ring

Summary



- It could be shown that EBAC and combined SEM/FIB is suitable to localise
  - metal opens
  - thin oxide defects
  - substrate dislocations
- Defect localisation can be done with sub µm resolution
- EBAC method utilizes very low currents in the pA / nA range generated by SEM for defect localization
- The defect is less affected than for comparable methods (PEM, OBIRCH and LIT)
- opportunity to analyse the original defect structure by further FIB target preparation and TEM analysis