CENTER OF EXPERTISE

ADVANCED X-RAY TOPOGRAPHY

INDUSTRY READY DETECTION OF TSDs AND BPDs IN SIC WAFERS

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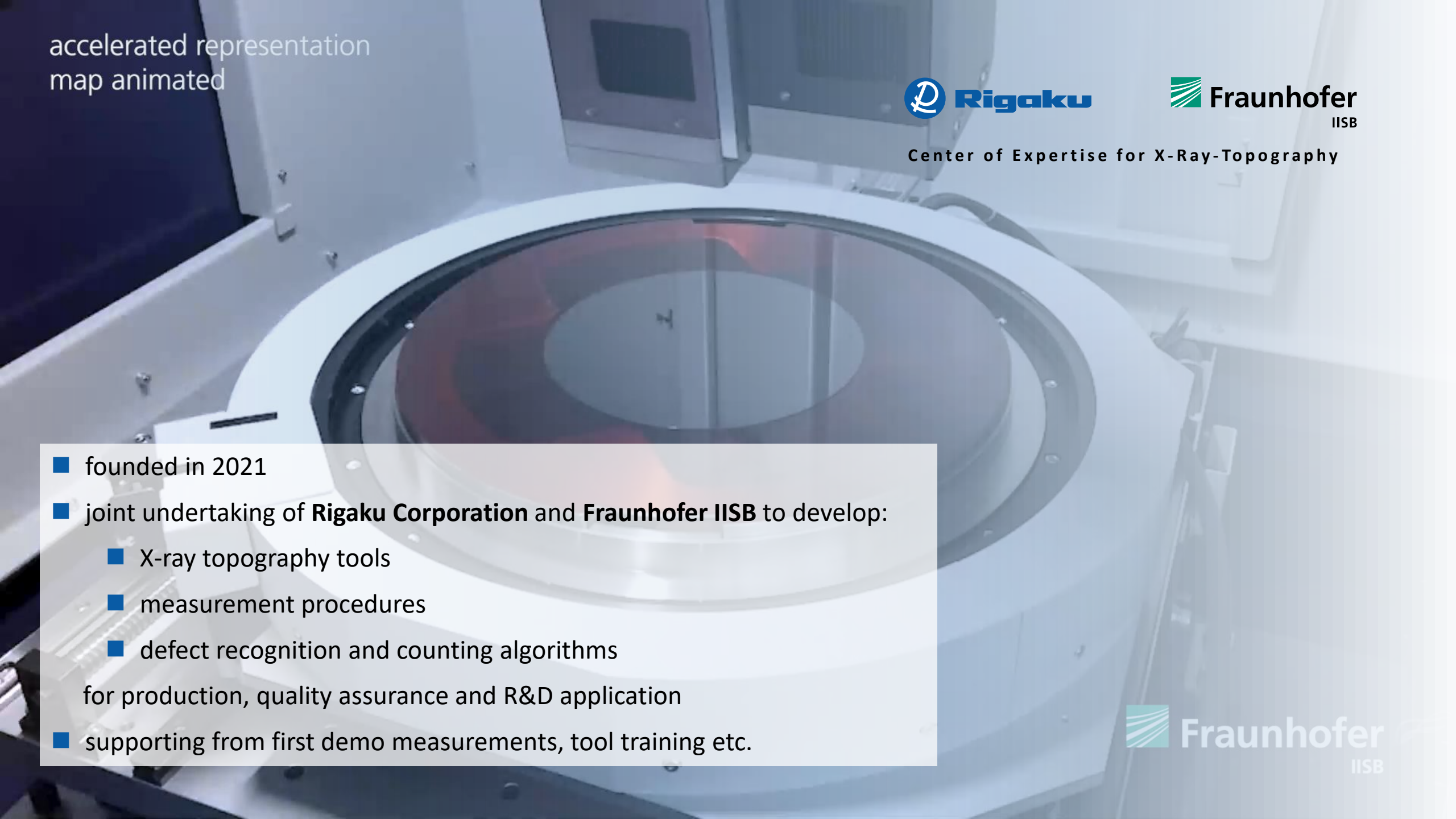

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Center of Expertise for X-Ray-Topography

- founded in 2021
- joint undertaking of **Rigaku Corporation** and **Fraunhofer IISB** to develop:
  - X-ray topography tools
  - measurement procedures
  - defect recognition and counting algorithms

  for production, quality assurance and R&D application
- supporting from first demo measurements, tool training etc.

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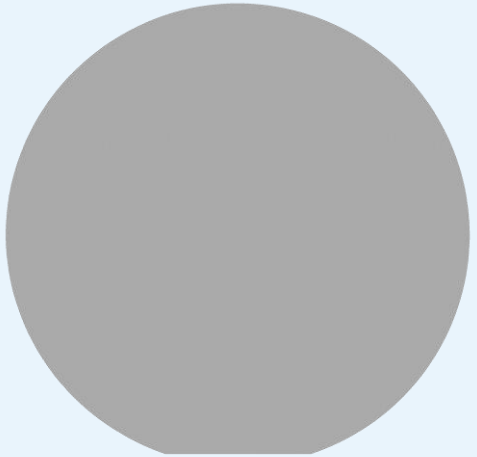
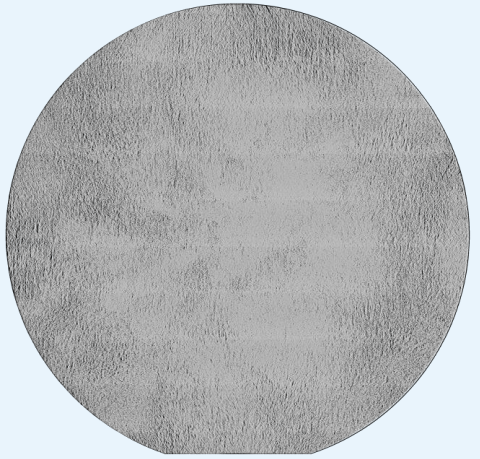
Taking away the power from silicon…

- … means leaving behind dislocation-free material!
- Dislocations can have an impact on device yield and reliability
- Every substrate is different

Silicon



Silicon carbide



Industry requires semiconductor ready, reliable, high-throughput, non-destructive substrate characterization

Defects in silicon carbide

Threading Screw Dislocations (TSD)

- Increase leakage current of diodes
- Detrimental to gate oxide lifetime
- Can result in growth pits causing problems during device processing

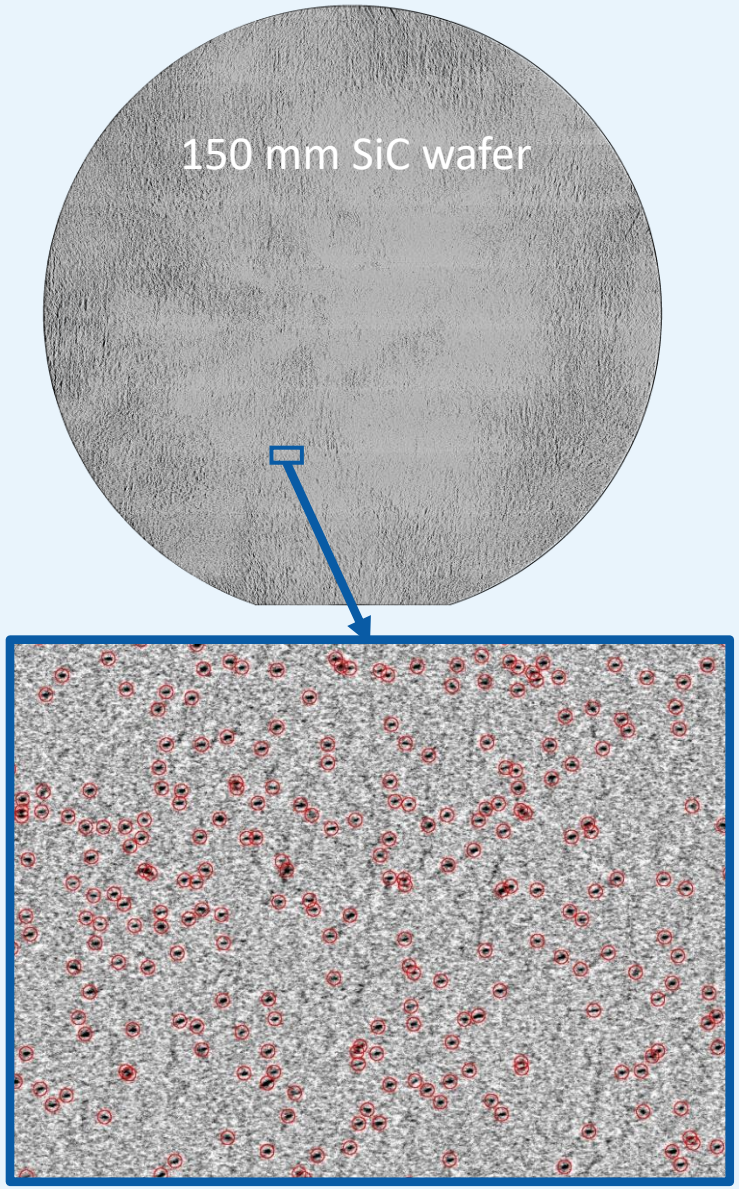
Basal Plane Dislocations (BPD)

- Result in stacking faults under stress
- Reduce lifetime of
  - MOSFETs
  - Bipolar devices

TSD Detection

TSD detection – „Old“ vs. „New“ language

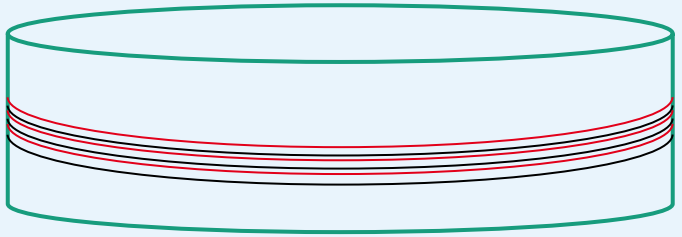
- TSD detection using chemical etching highly challenging
  - TED and TSD cannot be distinguished for standard KOH etching
  - Other alternative approaches come with different problems
- Use of (0008) reflex with XRTmicron
  - TSD/TMD appear as small, dark spots
  - Almost no other features visible (on today‘s production grade SiC)
  - Simple to classify and count → enables reliable and robust dislocation counting
    - **Measurement reproducibility: 3%**
    - **Tool2Tool: 5% (depending on samples could be 10%)**

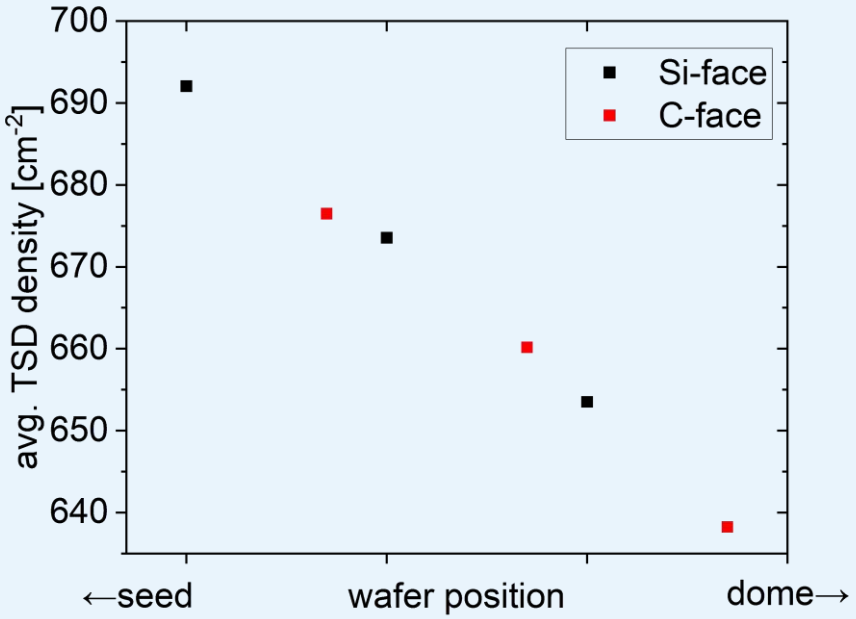


TSD detection

Reproducibility

- Measurement of **three neighboring wafers on both sides** (**Si-face** and **C-face**)
- Differences between individual wafers can be resolved
- Differences between front and back side of wafer can be resolved
- From trend between data points, the distance between wafers can be estimated!

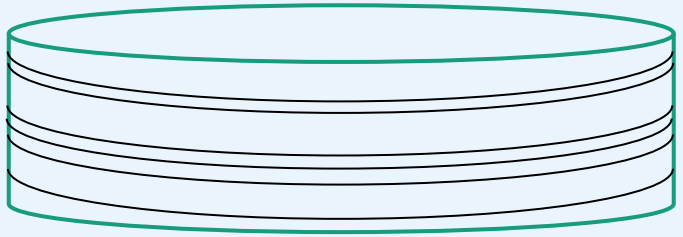


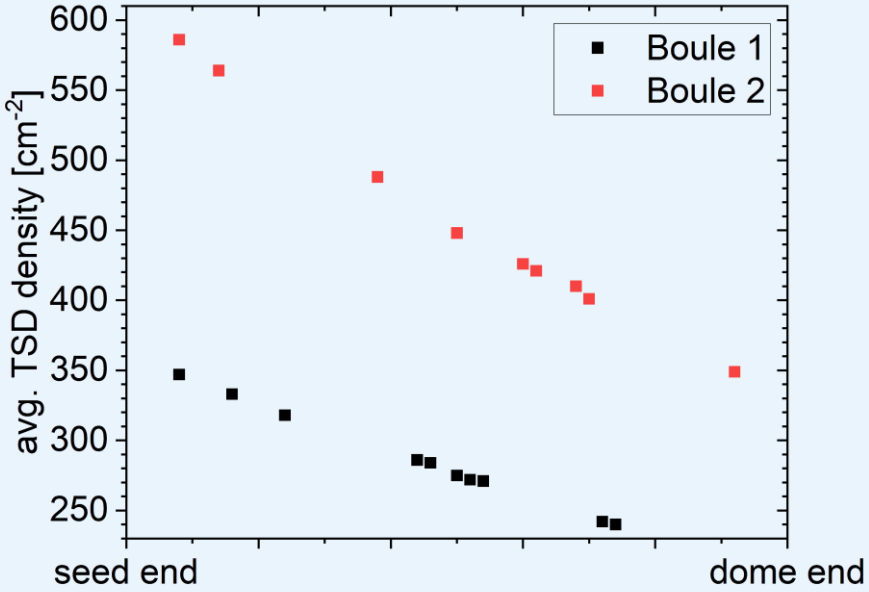


TSD detection

Reproducibility

- Full wafer measurement of **many wafers from two SiC crystals**
- Plot of TSD density over wafer number
- Monotonic TSD density variation is easily reproduced
- **Even small differences (1%) between wafers can be resolved**

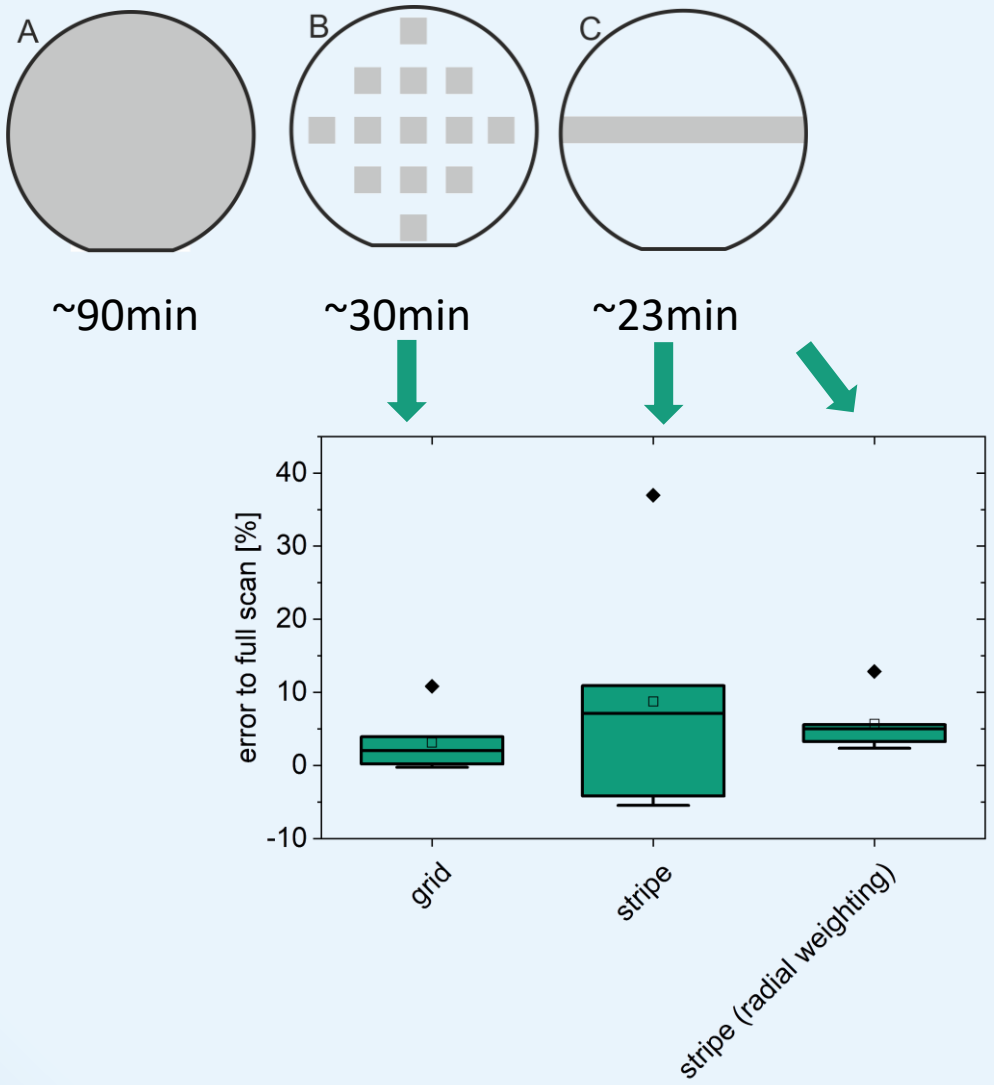




TSD detection

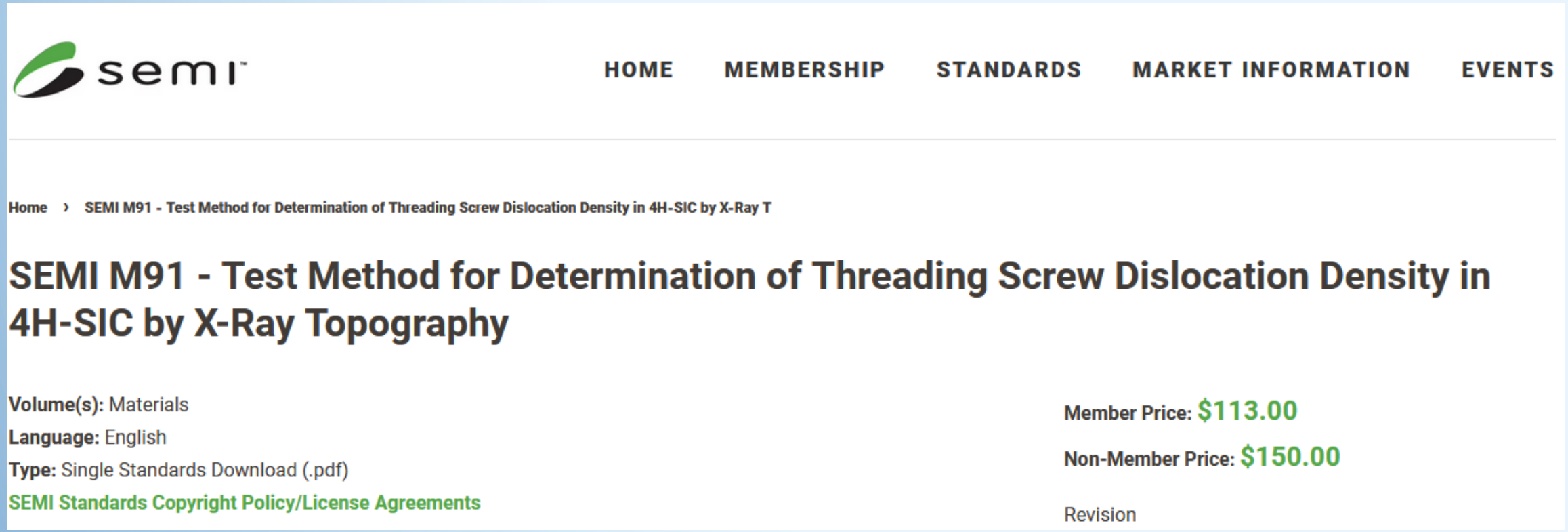
Measurement times

- Industrial application:
  - Perfect accuracy usually not required
  - **High throughput essential**
- TSD detection requires minimum image quality → Throughput on full wafer scale is limited (A)
- Use of local measurement to increase throughput
  - Grid measurement (B) → only very small error at 3x throughput
  - Stripe measurement (C) → critically increased error at 4x throughput
    - Use of radial weighted average reduces error and narrowness of the distribution



TSD detection

SEMI Standard M91



semi

HOME MEMBERSHIP STANDARDS MARKET INFORMATION EVENTS

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SEMI M91 - Test Method for Determination of Threading Screw Dislocation Density in 4H-SIC by X-Ray Topography

Volume(s): Materials
Language: English
Type: Single Standards Download (.pdf)
SEMI Standards Copyright Policy/License Agreements

Member Price: $113.00
Non-Member Price: $150.00
Revision

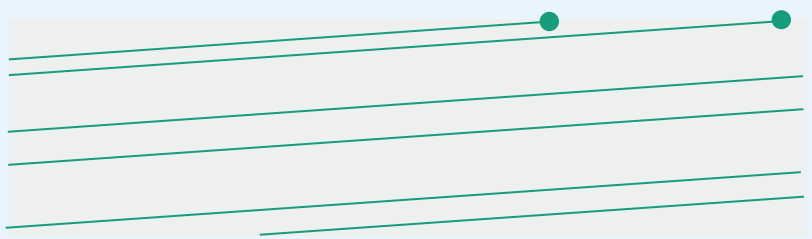
READY FOR INDUSTRY!

BPD Quantification

BPD quantification

Principle

- BPDs give only weak contrast in reflection geometry due to in-plane Burgers vector
  → usually measured by XRT in transmission geometry
- Which properties to investigate?
  - BPD count?
  - BPD length?
- Volumetric density (cm/cm^3) differs strongly (factor of 14 at 4° offcut) from
  etch pit density (cm^{-2})

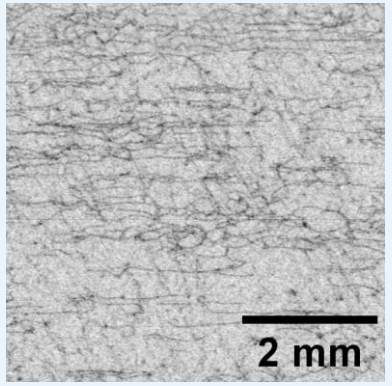


BPD quantification – „Noodle salad challenge“

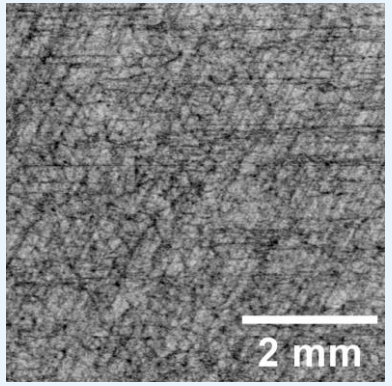
Principle

- Linear appearance of BPD pose challenges to counting
  - Detection of start and end of dislocation already challenging for low densities
  - At higher densities → strong overlapping hinders differentiation between dislocations
  - Discrete counting (as for TSD) not possible

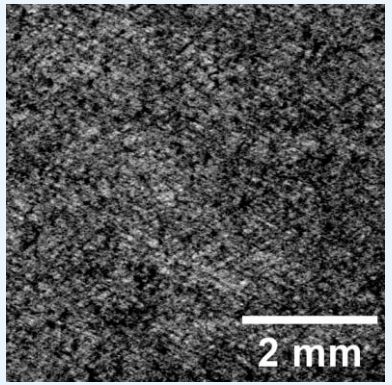
low density



medium density



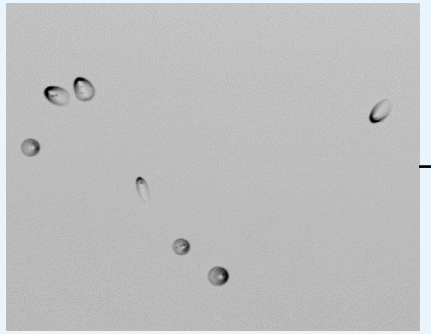
high density

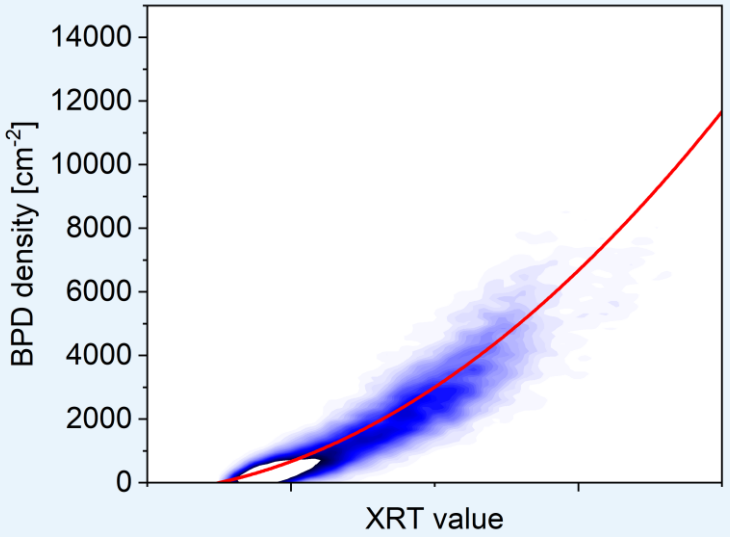


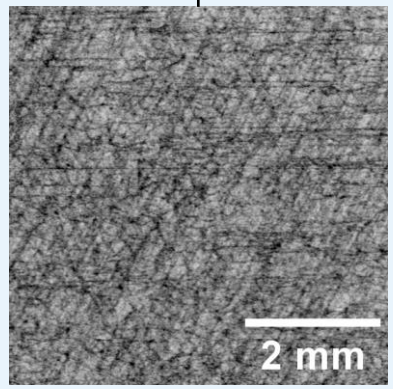
BPD quantification – „Noodle salad challenge“

Principle

- Use of a calibrated approach to obtain results consistent to KOH results
  - Divide topogram into tiles (typically 1x1mm²)
  - Analyze topogram to obtain a numeric value
  - Etch wafer by KOH and obtain etch pit density for the same tiles
  - Calibration curve obtained by correlating both data sets



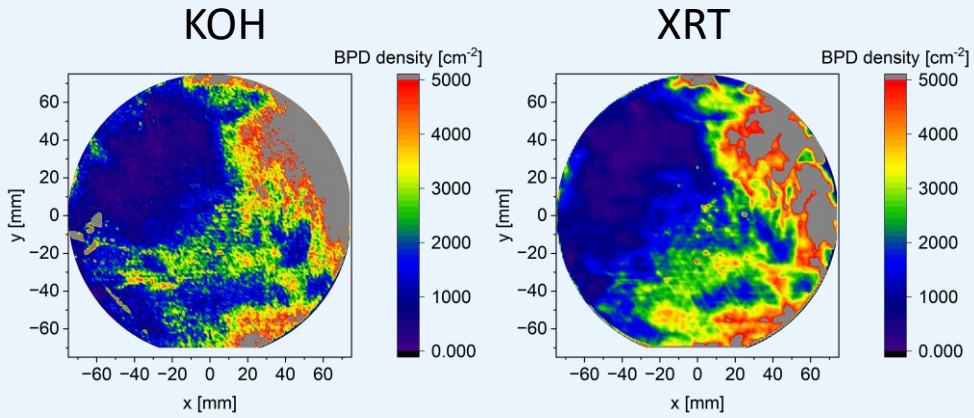




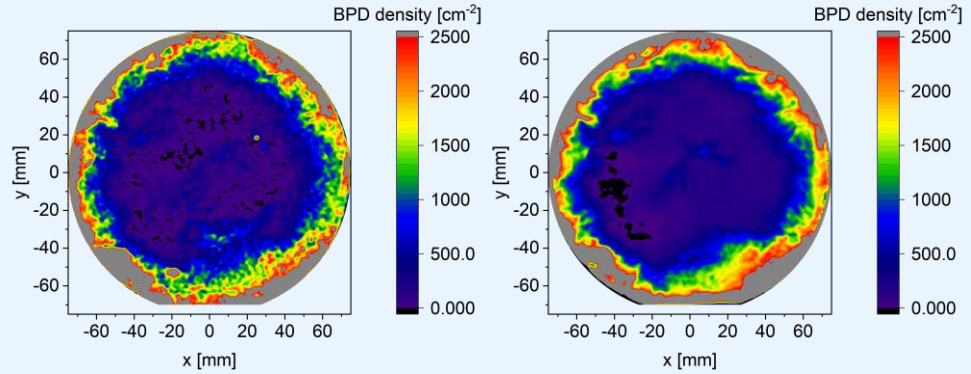
BPD quantification

Verification

- Calibration tests using wafers from 5+ leading manufacturers
- Very good agreement with the same set of calibration data for all manufacturers
  - Independent of material properties (except thickness and offcut angle)
  - Recalibration / system check can be done based on XRT measurements, i.e., without additional KOH etching



Kranert et al., poster presentation @ECSCRM 2021

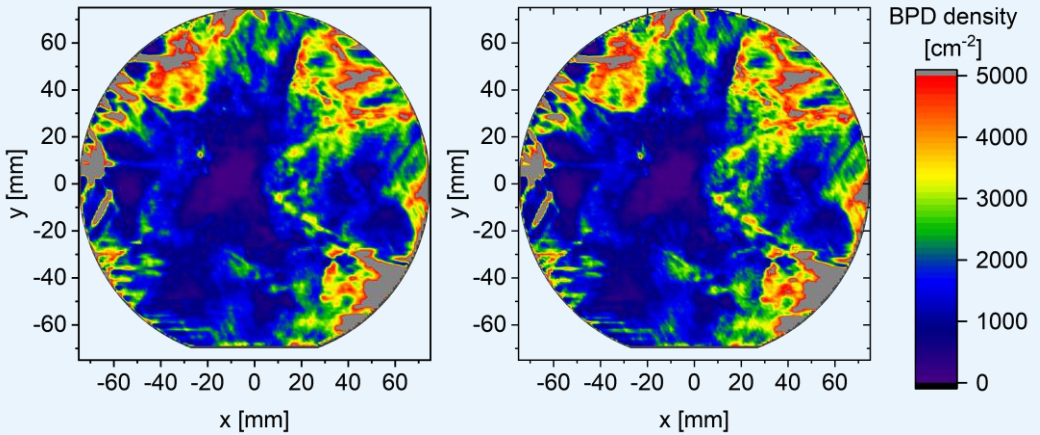


Kranert et al., poster presentation @ICSCRM 2022

BPD quantification – „The faster the better“

FastBPD approach using HyPix detector

- New version of XRTmicron available on request
  - Measurement times of **~5min per 150mm wafer**
  - Identical results as for standard measurement
  - Insensitive to lattice curvature → wafers that fail on standard system can be measured
  - Very simple and fast alignment
  - For sufficiently tight specs → no alignment at all
  - **Measurement reproducibility 5%**
  - **Tool2Tool: 5% or 50/cm²**



BPD detection

SEMI Standard M93

SEMI M93 - Test Method for Quantifying Basal Plane Dislocation Density in 4H-SiC by X-Ray Diffraction Topography/Imaging

Member Price: $138.00

Non-Member Price: $180.00

Volume(s): Materials

Language: English

Type: Single Standards Download (.pdf)

SEMI Standards Copyright Policy/License Agreements

READY FOR INDUSTRY!

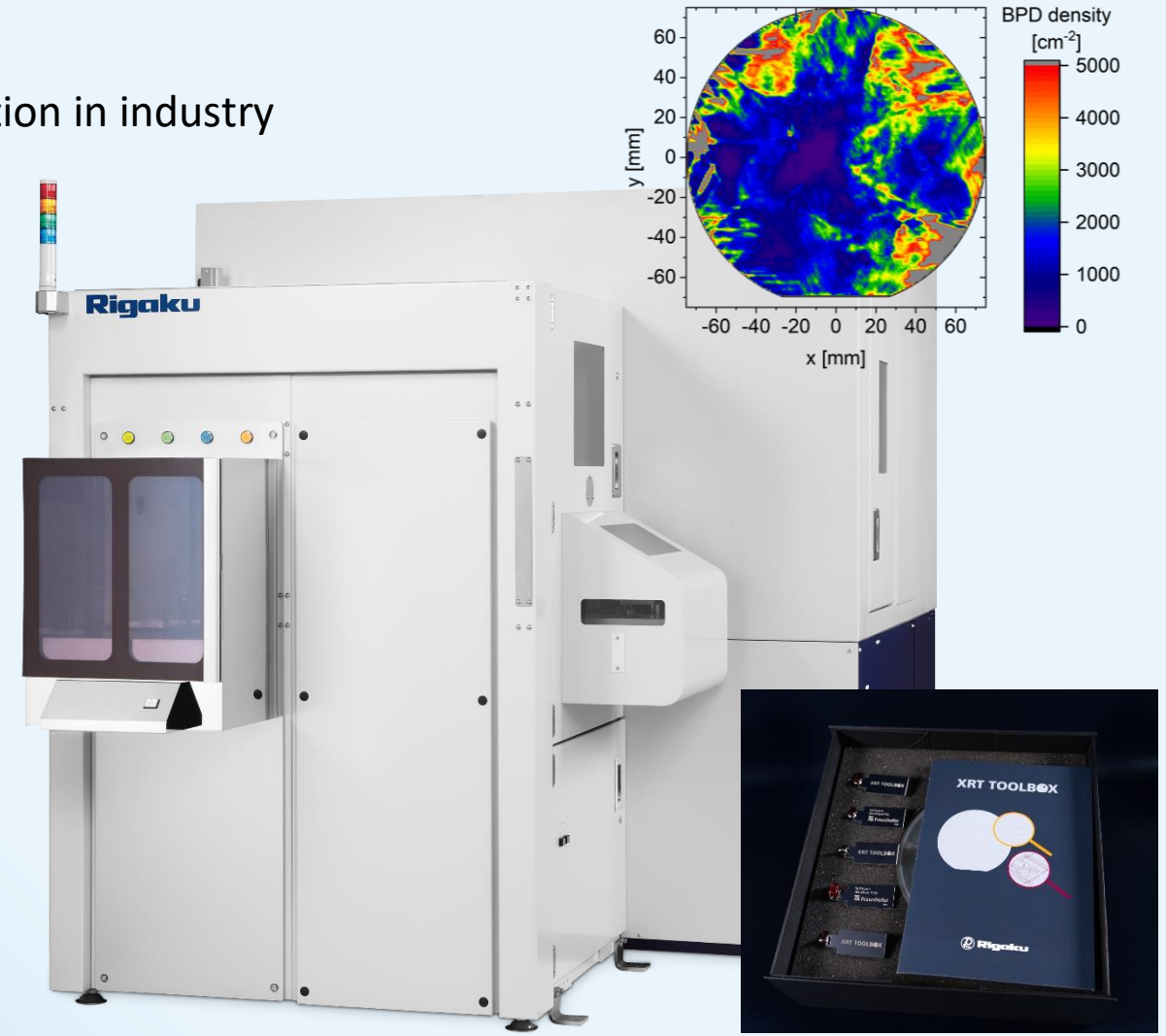
XRT Toolbox - Defect analytics software

- Experience from defect analysis condensed into XRT Toolbox
- Very fast defect analysis
  (<5 min for a full 150mm wafer scan)
- Currently built for analysis of SiC wafers
- Can be adapted also for an analysis of defects in other materials
- **Implemented evaluation routines fully compatible to SEMI Standards**

READY FOR INDUSTRY!

Summary

- XRT has become a mature technique ready for application in industry
  - **High accuracy, high reproducibility**
  - **SEMI-standardized procedures**
  - **High throughput**
  - **Further developments under progress!**
  - **Please be invited for further discussion!**



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ご清聴ありがとうございました。

Thank you for your kind attention!

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