Integrated topographic SEM imaging for software assisted fractography

make · explore · discover

point electronic

Outline

iFracto

Interpretation of fracture surfaces with Machine Learning based on SEM images and topography data

BAM

BAM – Federal Institute for Materials Research and Testing
Dirk Bettge, Lennart Schmies

GFAI

GFAI – Institute for Applied Informatics
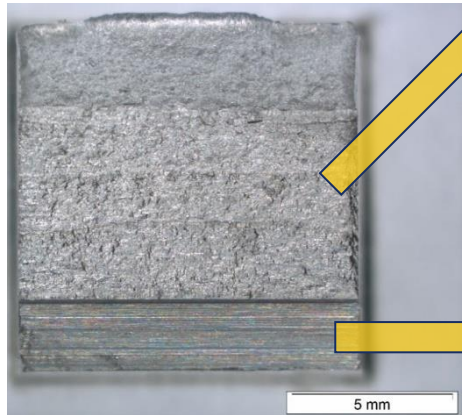*Ulrich Sonntag, Benny Botsch*

point electronic

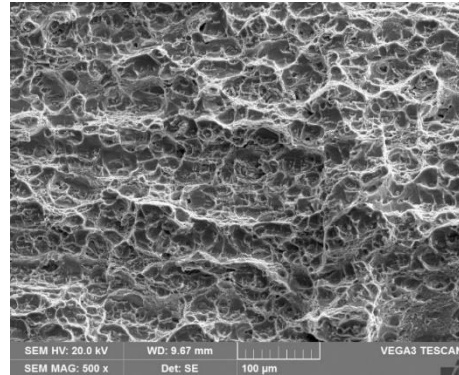point electronic GmbH

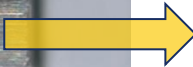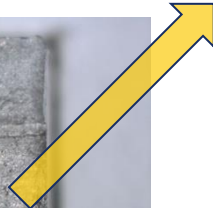make · explore · discover

point electronic
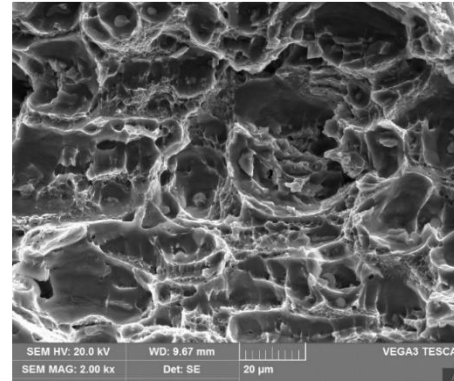
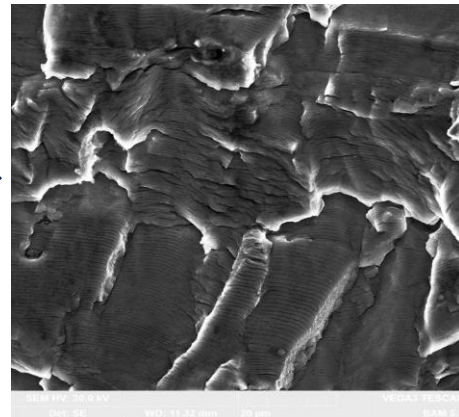# Fractography - Principles
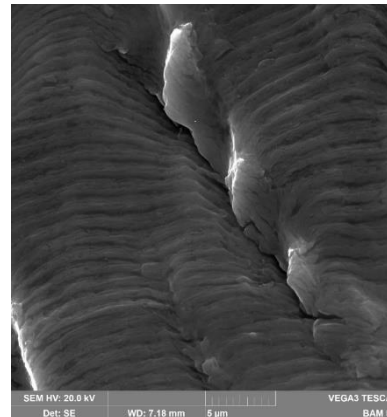

ISO compatible fracture test

Sample (ISO): AlZn4,5Mg1

Forced fracture

Dimpled surface (honeycombs)

Fatigue fracture

Oriented facets

// Evaluation and description of fracture surface characteristics

// Determination of the fracture mechanism

// Identify the cause of the failure

// Different crack types produce characteristic surface features

make · explore · discover

point electronic

Fractography – Typical applications

// Failure analysis

// Forensic investigations

// Material science, testing, research
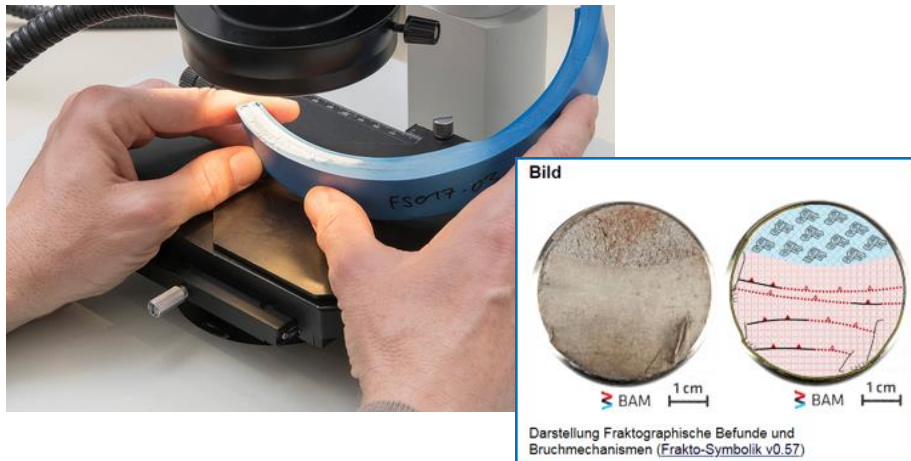
Wheel rim
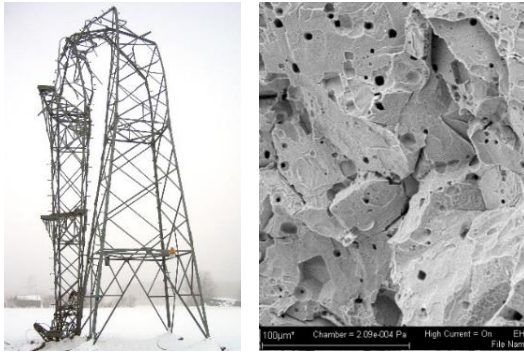(ICE accident Eschede 1998)
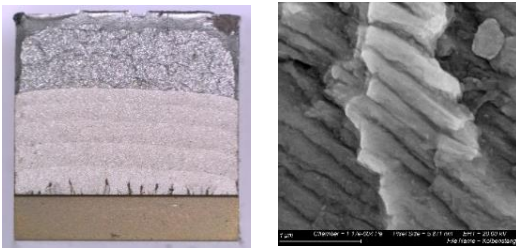

Power pole
(Snow storm, Northern Germany 2005)

make · explore · discover
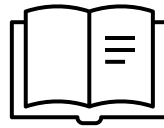
point electronic

# Fractography - Practices

Damage case: Samples

Lab experiments

Archived knowledge

// LM images for overview on macroscopic level

// SEM images for microscopic details

// Comparative mechanical testing and literature as evaluation base

// Very complex analysis requires considerable experience

// Time consuming work, heterogeneous skills required

make · explore · discover

Computer assisted fractography

Damage case: Samples
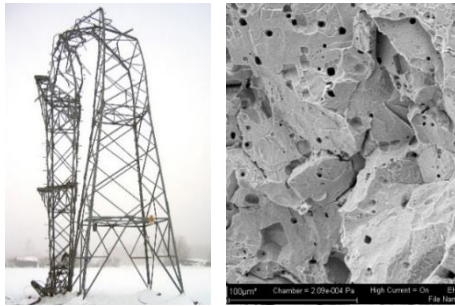
Lab experiments

Fracto DataBase

Machine Learning Tool
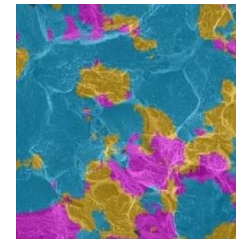
Proposed results
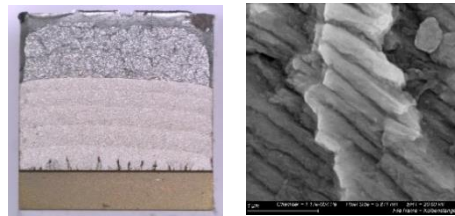
Verification

// Artificial Intelligence: Machine Learning and dedicated Knowledge Base

// Automated imaging (stage, different magnifications)

// Additional information: Multi-channel signals (SE, 4Q-BSE), Topography, Metadata

// Intuitive user interface (pre-analysis, report generation, database connection)

make · explore · discover

point electronic

Project iFracto

≥ BAM

// SEM Operator
// Expert Knowledge
// Fractographic Database

iFracto

GFa

// End-User Application
// Machine Learning Engine

**point electronic**

// SEM Data Workflow
Topography Acquisition

// Software development: quantitative determination of fracture characteristics and fracture mechanisms

// Applies machine learning algorithms and image segmentation

// Provide classifier from training network based on expert knowledge

// Workflow for multichannel data acquisition and processing

// Including automated acquisition of surface topography

make · explore · discover

point electronic

Machine Learning

Knowledge base / Round robin tests
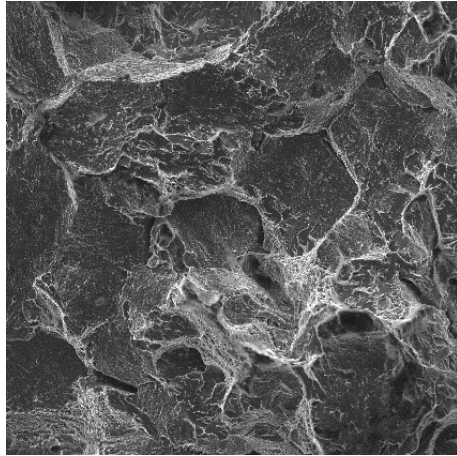
Sample #16 34CrNiMo6
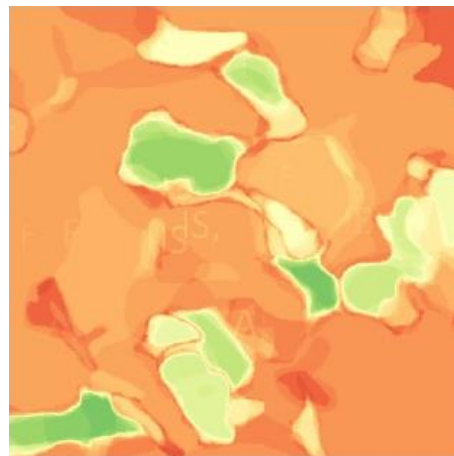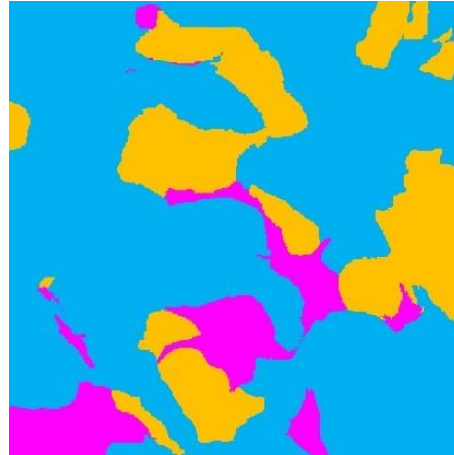
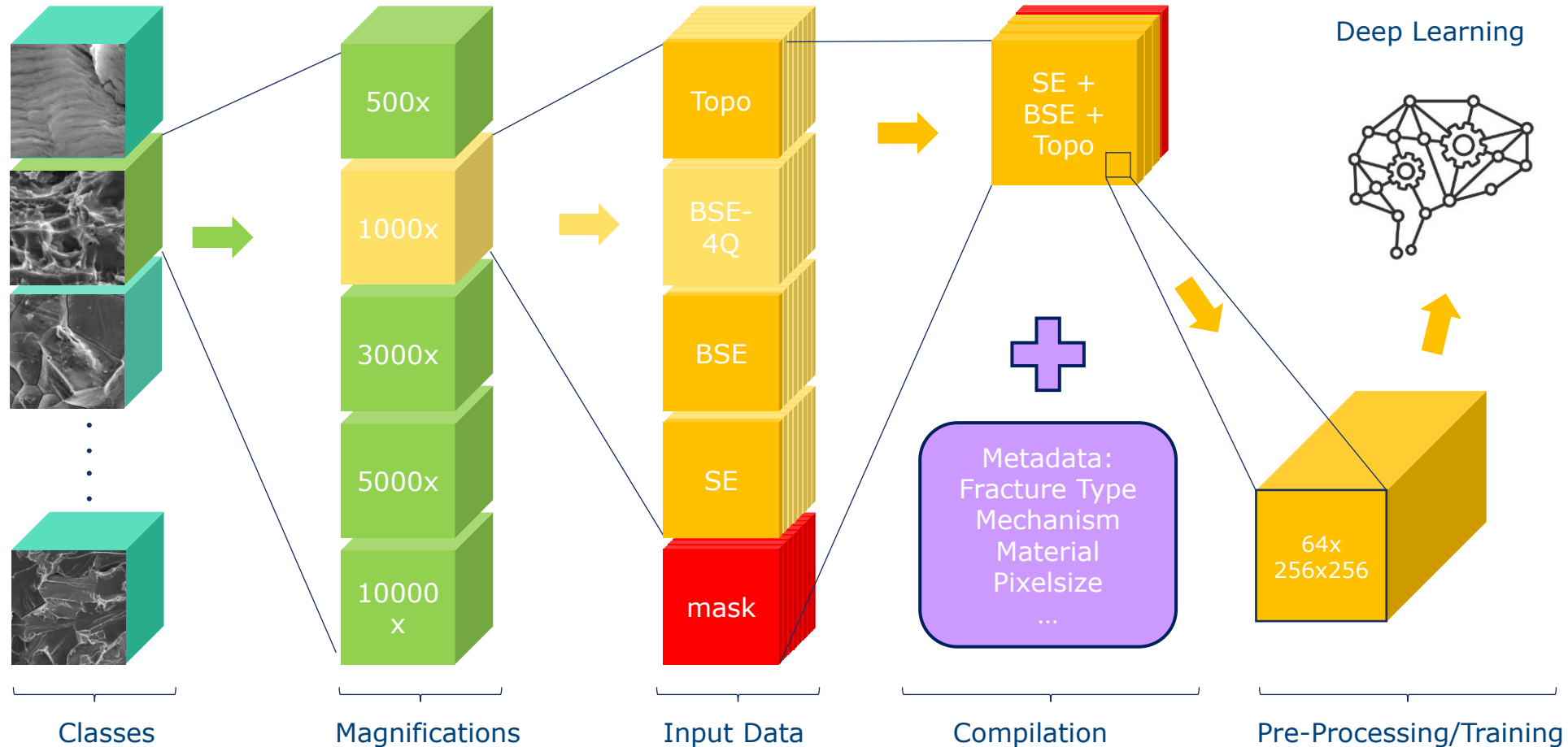| Kürzel	Vorgegebene Merkmalsbezeichnungen:	Übersetzung von	zu	Farbcode neu	Bemerkung
A	A: Waben	255 0 255			
B	B: Scherwaben	204 153 255			
C	C: Mikrowaben	255 204 255	A	255 0 255	
D	D: Schwingstreifen	0 255 0			Inkl. V, OS, ZI
E	E: Spaltflächen	255 192 0			Inkl. Q, Q1-Q4, TS
F	F: Offen liegende Korngrenzen	0 176 240			Inkl. IS, IB, IF
G	G: Kristallographisch orientierter Bruch	0 112 255			
H	H: Lamellenartiges Gefüge, z.B. Perlit	64 192 0			

// 26 participants in industry and research institutes

// 46 images from lab generated fracture surfaces

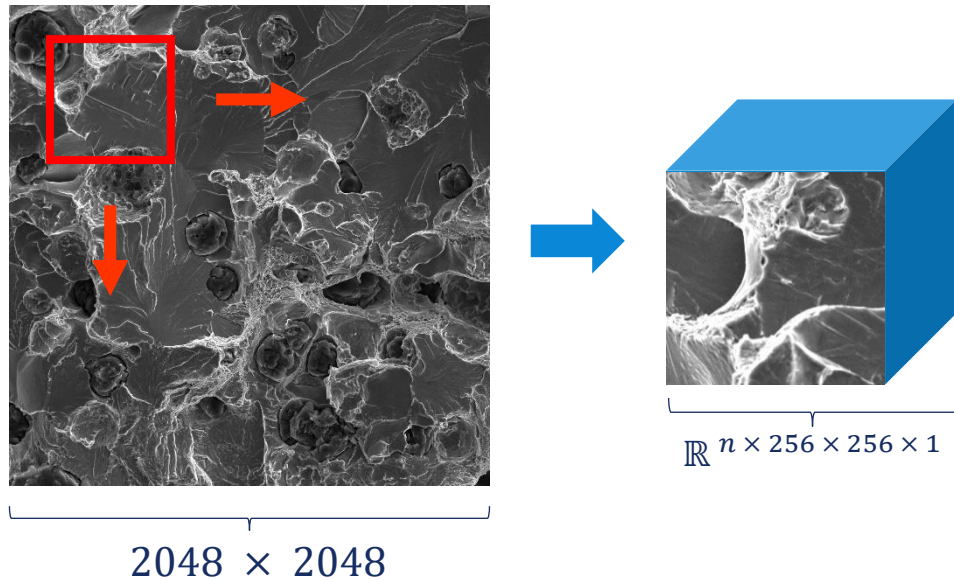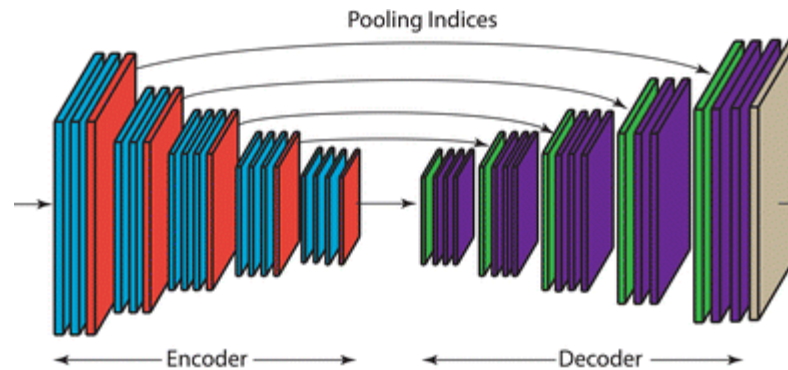// Results: Highlighted image areas for fracture mechanisms and surface characteristics

make · explore · discover

point electronic

Machine Learning

Training data management

Classes → Magnifications → Input Data → Compilation → Pre-Processing/Training

Classes: (SEM images)

Magnifications: 500x, 1000x, 3000x, 5000x, 10000x

Input Data: Topo, BSE-4Q, BSE, SE, mask

Compilation: SE + BSE + Topo **+** Metadata: Fracture Type, Mechanism, Material, Pixelsize ...

Pre-Processing/Training: 64x 256x256 → Deep Learning

make · explore · discover

point electronic

Machine Learning

Training network / Classifier (SE images)

Training Data

SegNet

$$\mathbb{R}^{n \times 256 \times 256 \times 1}$$

2048×2048

Pooling Indices

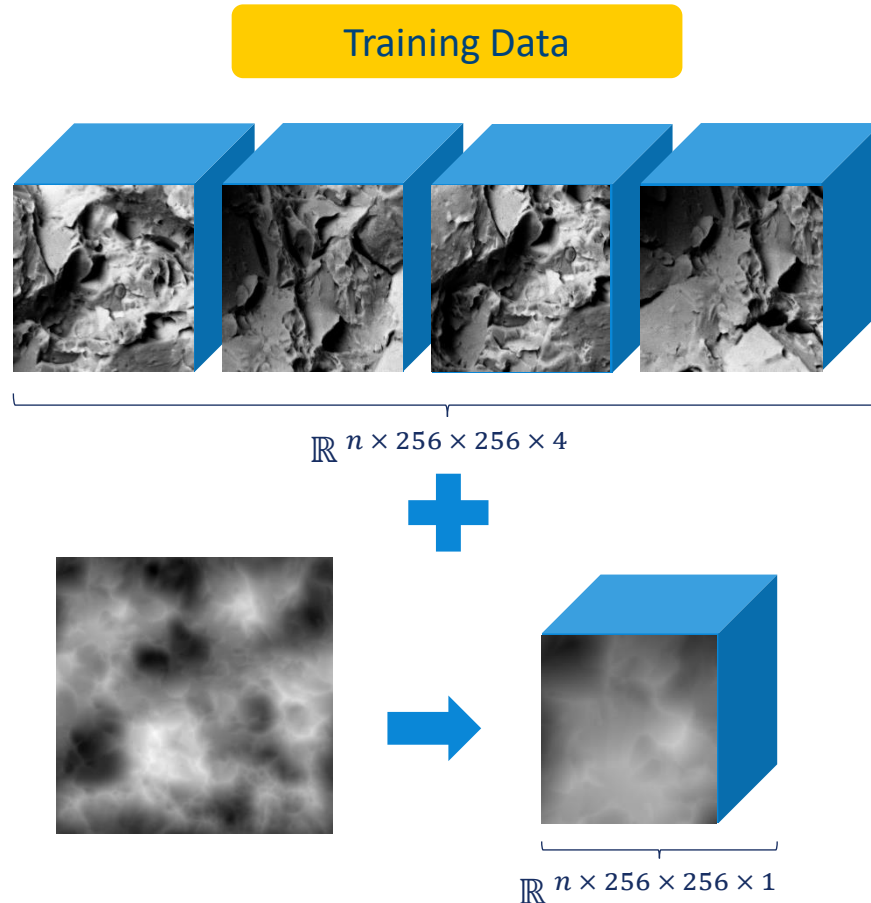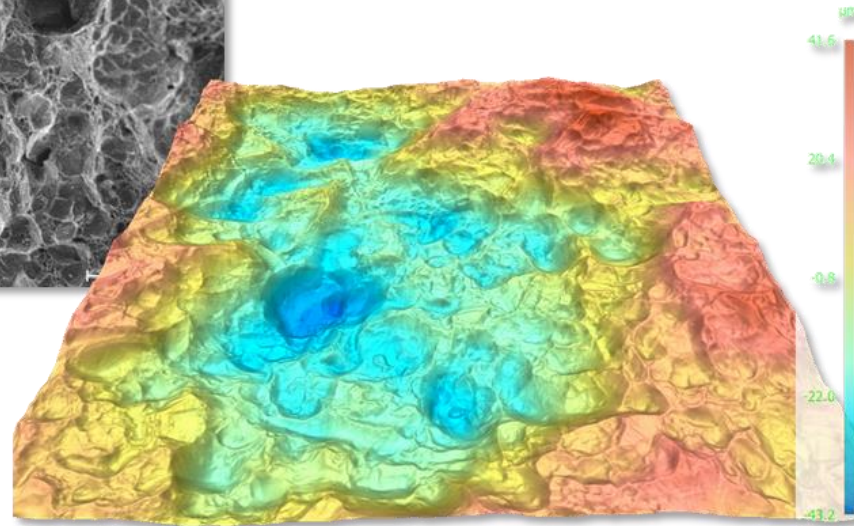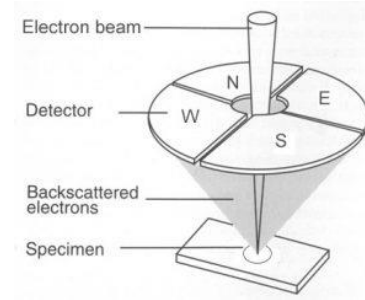Encoder

Decoder

make · explore · discover

point electronic

Machine Learning

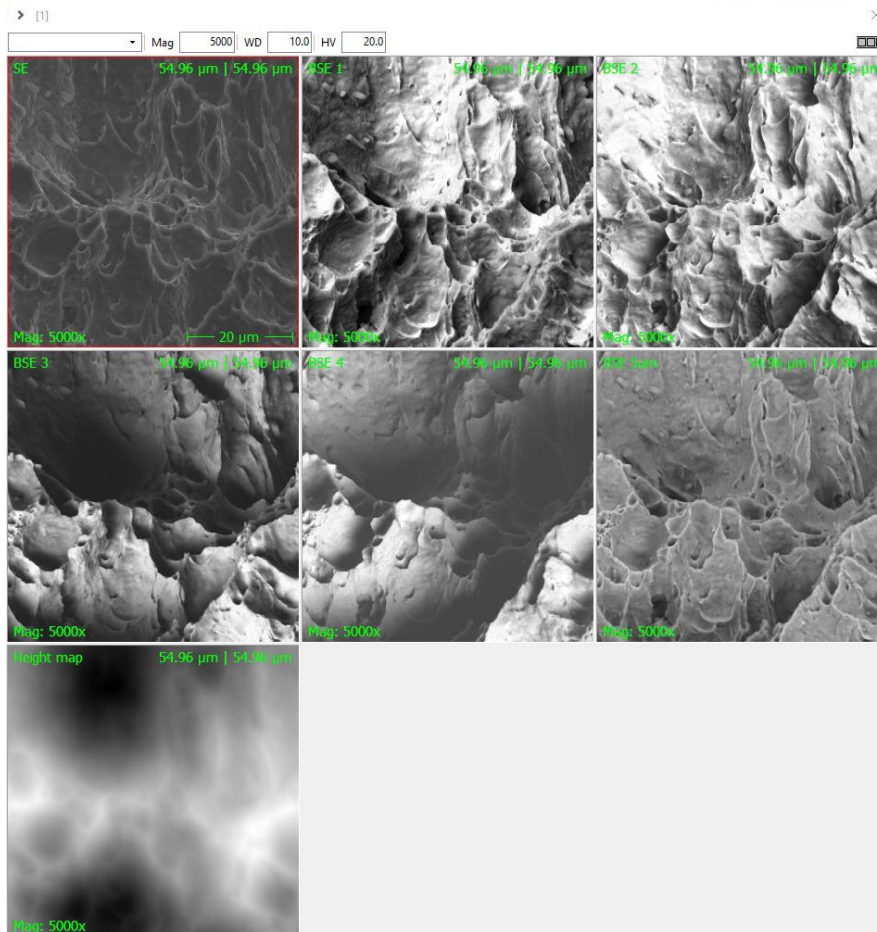## Training network / Classifier with additional height maps

$$\mathbb{R}^{n \times 256 \times 256 \times 4}$$

$$\mathbb{R}^{n \times 256 \times 256 \times 1}$$

Training Data

SegNet

make · explore · discover

point electronic

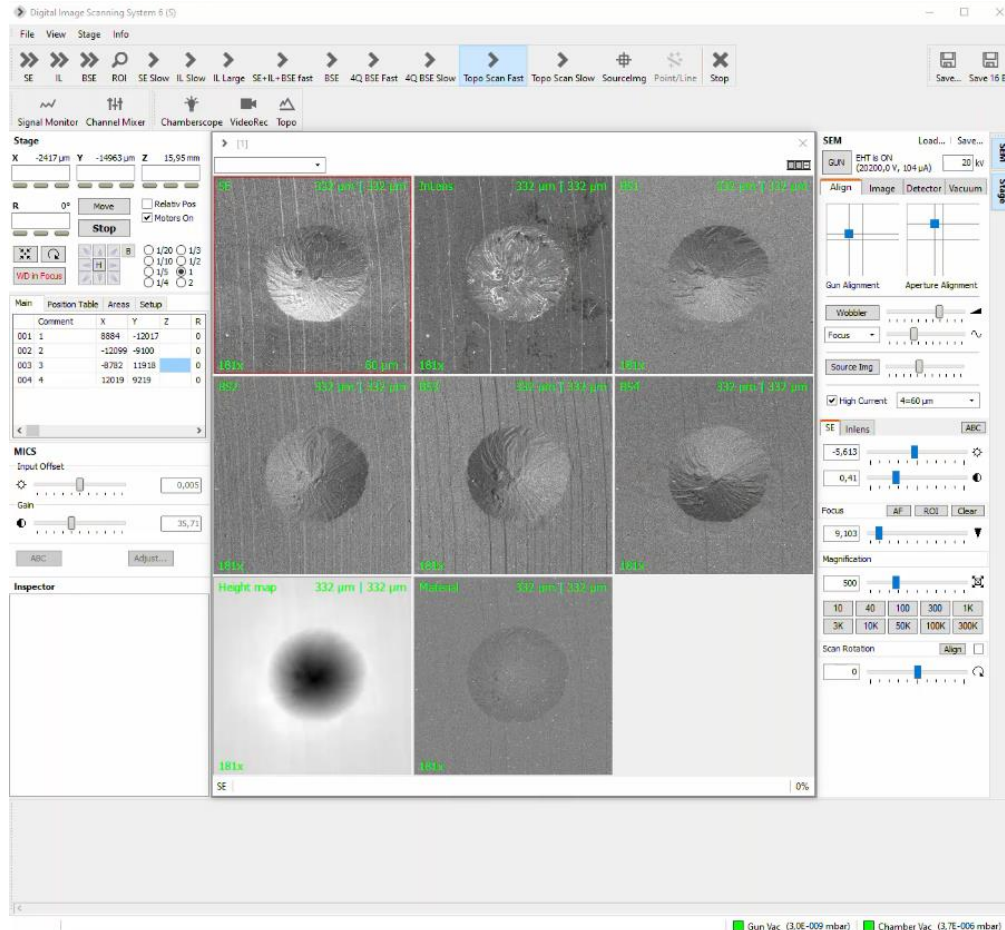# SEM Topography

Electron beam
Detector
Backscattered electrons
Specimen
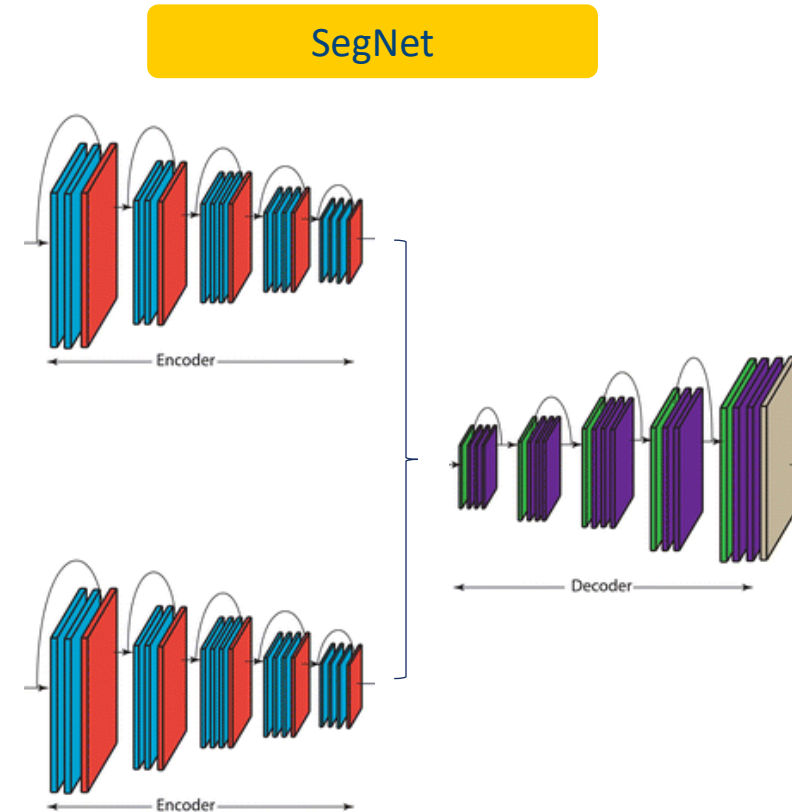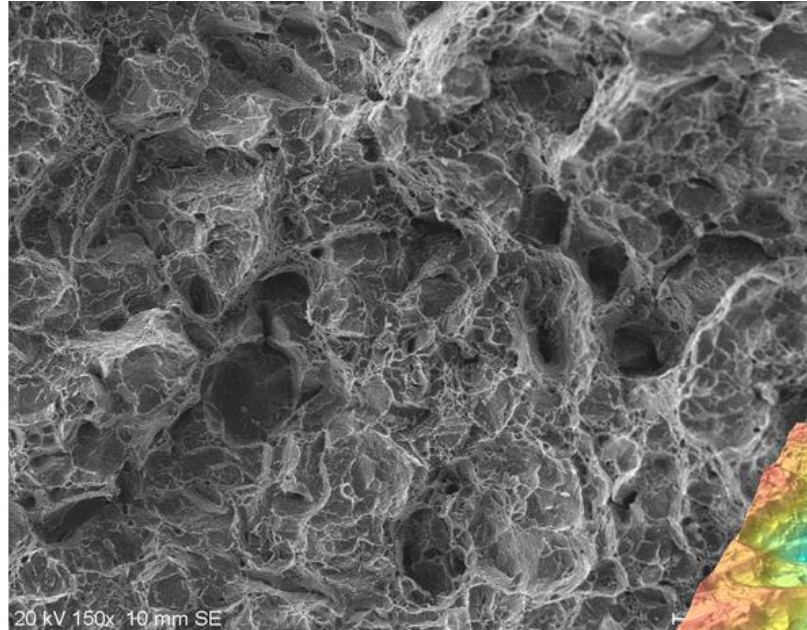
// BSE detector with 4 symmetric segments and calibrated signal acquisition

// Surface reconstruction with Shape-from-Shading, no sample tilting

// Integrated 3D calibration for quantitative height maps

make · explore · discover

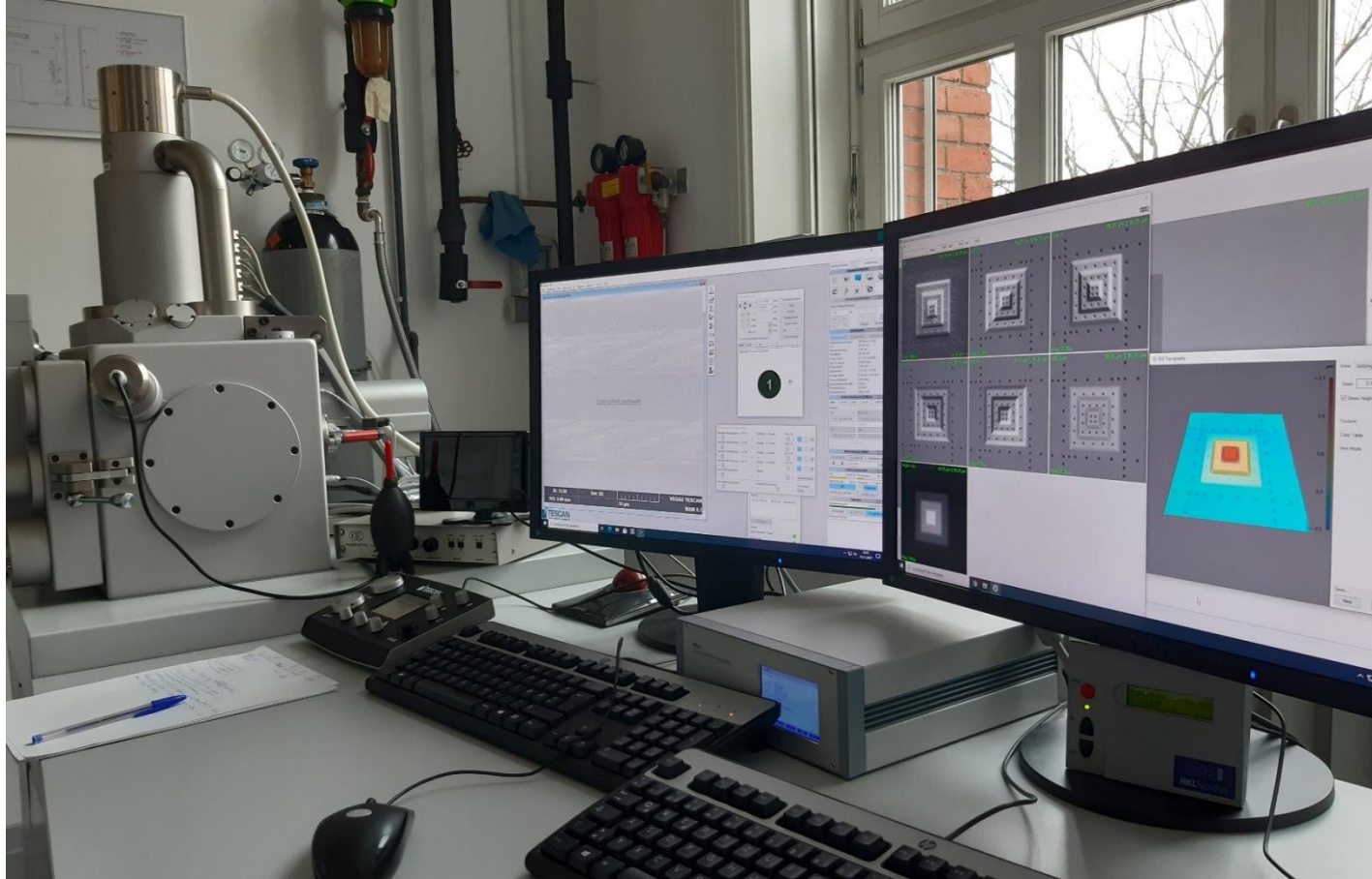point electronic

Automated multichannel data acquisition

// Scan control and multichannel signal acquisition

// Additional channels for height map and BSE compositions (material and topographic contrast) at the same time

// Remote control for image and height acquisition including data storage

// Apply your scripts for automated workflows with integrated JSON interface

make · explore · discover

Automated multichannel data acquisition

// Scan control and multichannel signal acquisition

// Additional channels for height map and BSE compositions (material and topographic contrast) at the same time

// Remote control for image and height acquisition including data storage

// Apply your scripts for automated workflows with integrated JSON interface

make · explore · discover

Multichannel data exchange
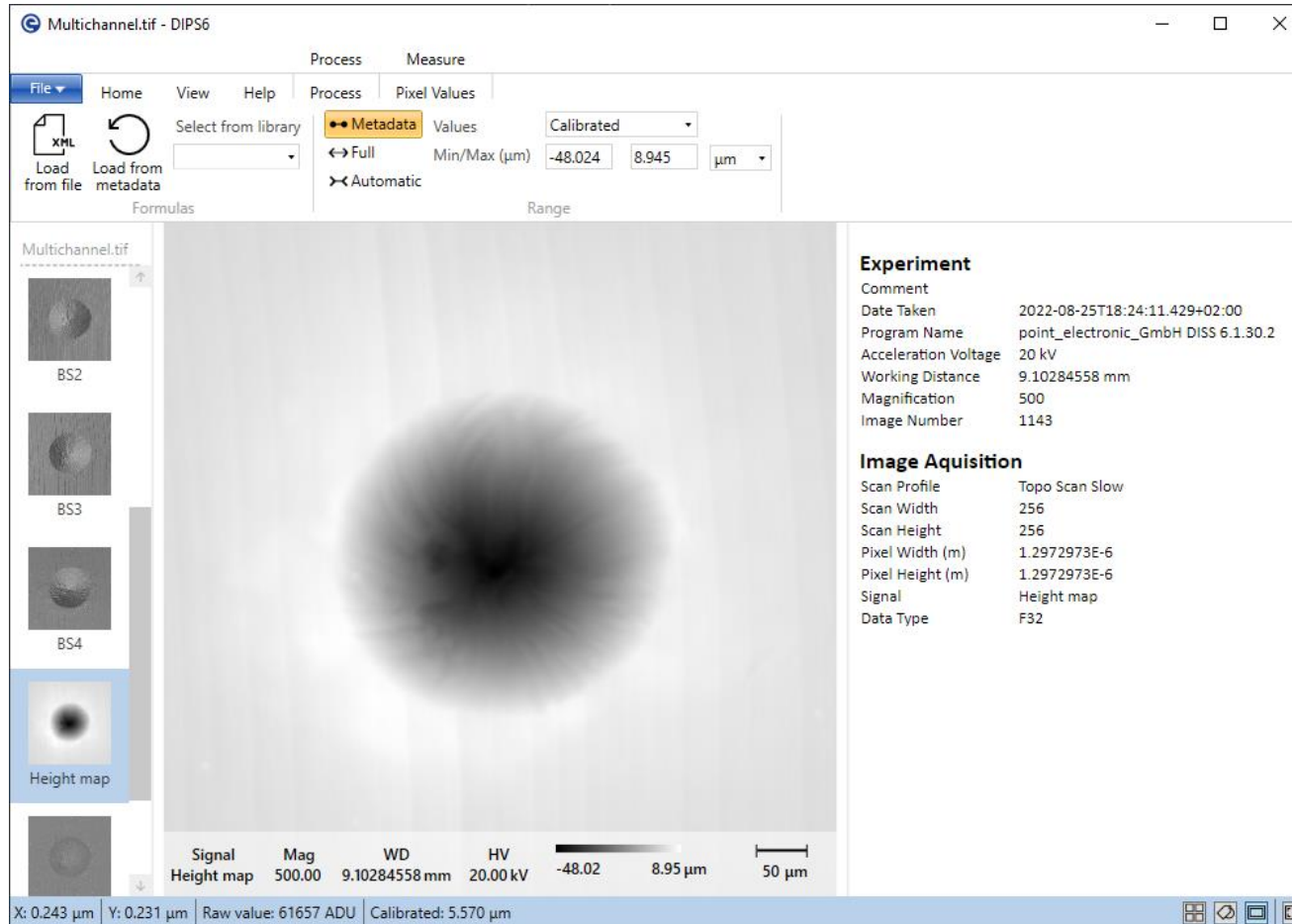
// Standard data formats: Multipage-TIFF including all metadata

// 8 or 16 bit data with calibration information

// Additional formulas for quantitative calculations

// Open access to metadata (XMP)

// DIPS6 viewer (point electronic)

make · explore · discover

Applied system for iFracto project

// Tescan Vega3 at Federal Institute for Materials Research and Testing (BAM, Berlin)

// 4Q-BSE Detector with DISS6-Topography (point electronic)

// Calibration with 3D reference sample (MMC-80-4BSD)

// Fracture samples

// Image data, height data

make · explore · discover

point electronic

Results

Software prototype
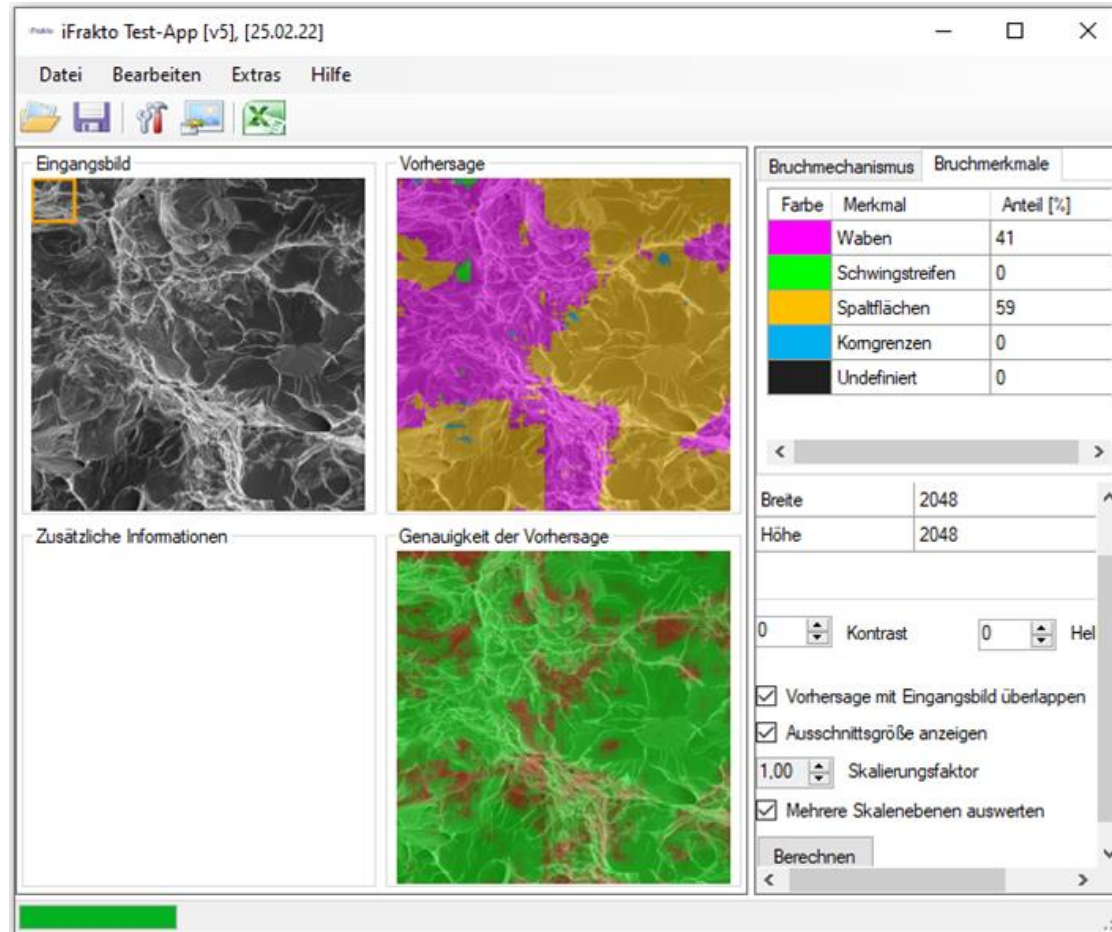
- // Predicted fracture surface characteristics
- // Predicted fracture mechanism
- // Accuracy of the prediction
- // Color editor and data overlay
- // Data report (Excel)

make · explore · discover

Results

Software prototype
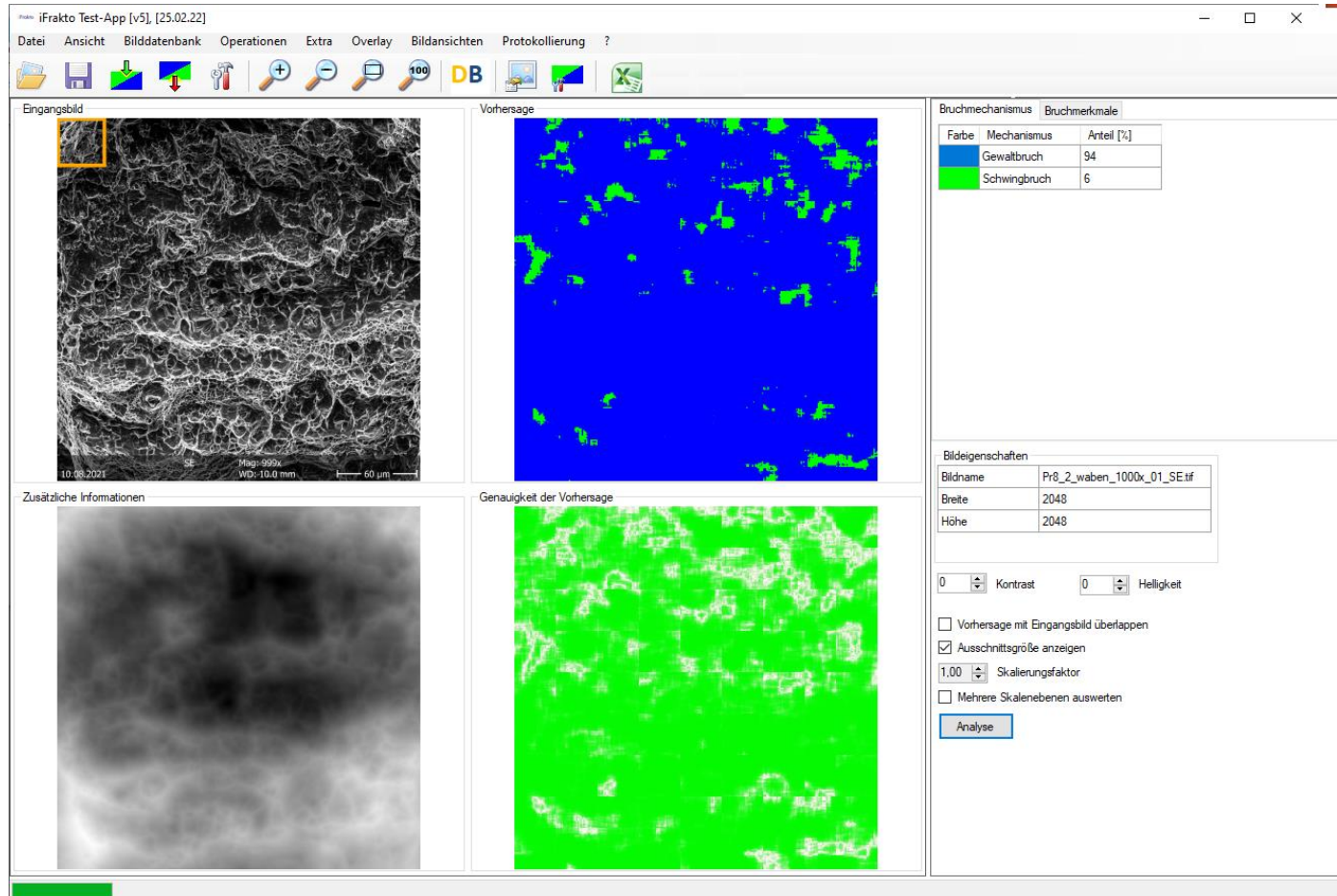
// Topography data (height map) as additional input

make · explore · discover

Results

Improved results with topographic data
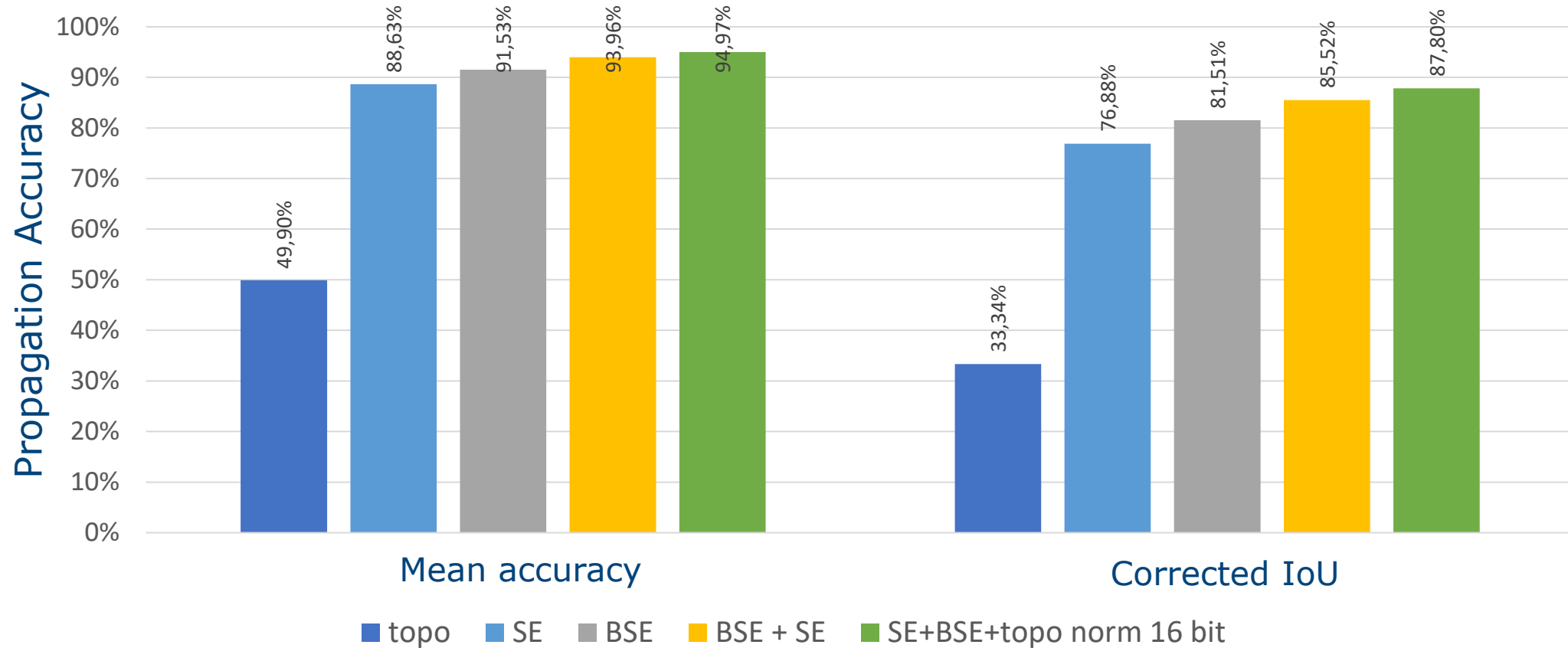
Comparison of fracture surface characteristics (IoU = Intersection over Union)

make · explore · discover

Results

Improved results with topographic data
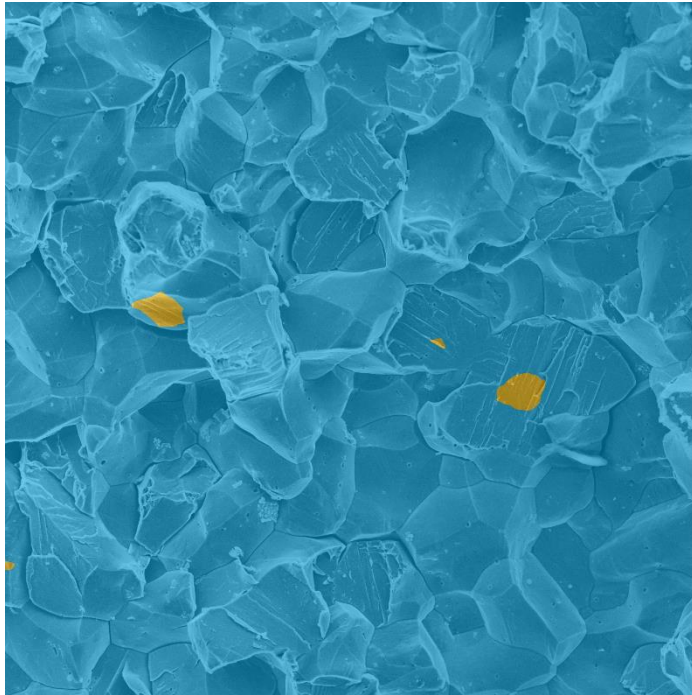
Predicted surface characteristics with SE images
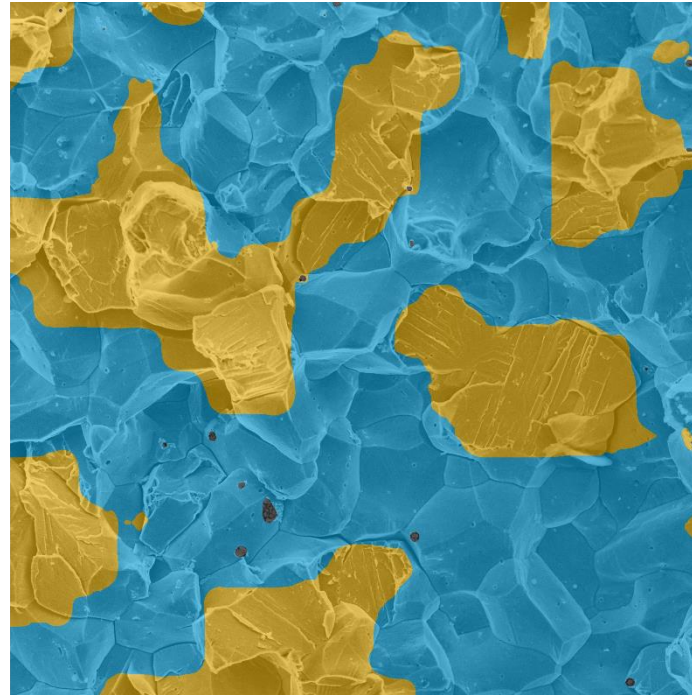
Improved results with additional topographic data

■ (magenta)	Dimple surface (honeycombs)
■ (orange)	Cleavage areas
■ (blue)	Grain boundaries
■ (green)	Facets
■ (black)	Not allocated

make · explore · discover

point electronic

Results

Further results

![magenta]	Dimple surface (honeycombs)
![orange]	Cleavage areas
![blue]	Grain boundaries
![green]	Facets
![black]	Not allocated

make · explore · discover

Results

Further results

█	Dimple surface (honeycombs)
█	Cleavage areas
█	Grain boundaries
█	Facets
█	Not allocated

make · explore · discover

point electronic

Fractographic Database (free access)

Contents (9/2022):
> 380 data sets
> 4.200 images
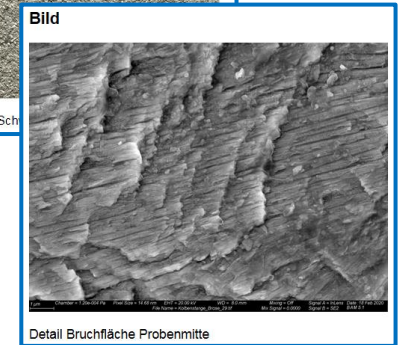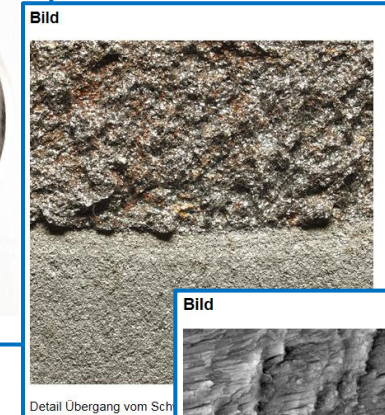
www.fraktographie.bam.de

request password: please email

fraktographie@bam.de

make · explore · discover

point electronic

Summary

// Software prototype ready for quantitative fractography

// 1st round robin test for generation of training data set

// Classifier and training data enhanced with topographic data

// 2nd round robin test with software prototype

// Promising results for SE images in combination with BSE data and height maps

// Enhanced fractography database

make · explore · discover

point
electronic
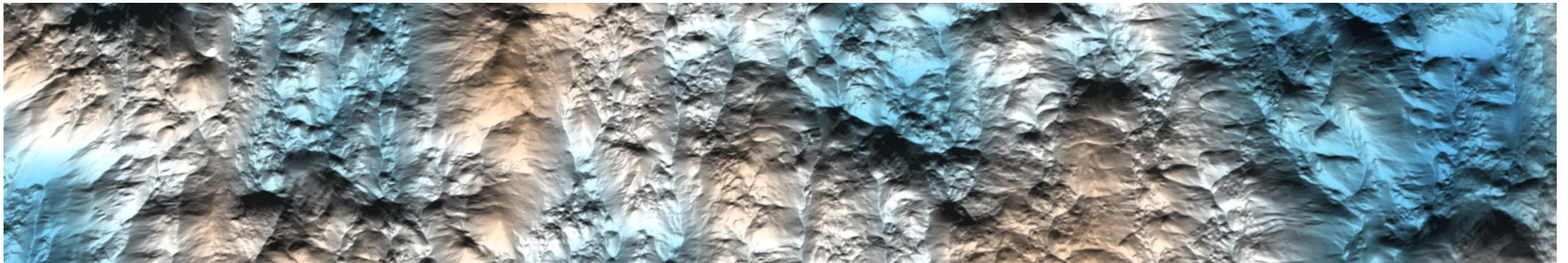
Outlook

// Integration of prediction in SEM software (live pre-classification)

// Interface to fractography database

// Enhanced training data management (growing knowledge)

// Further development of fractography software (market release)

make · explore · discover
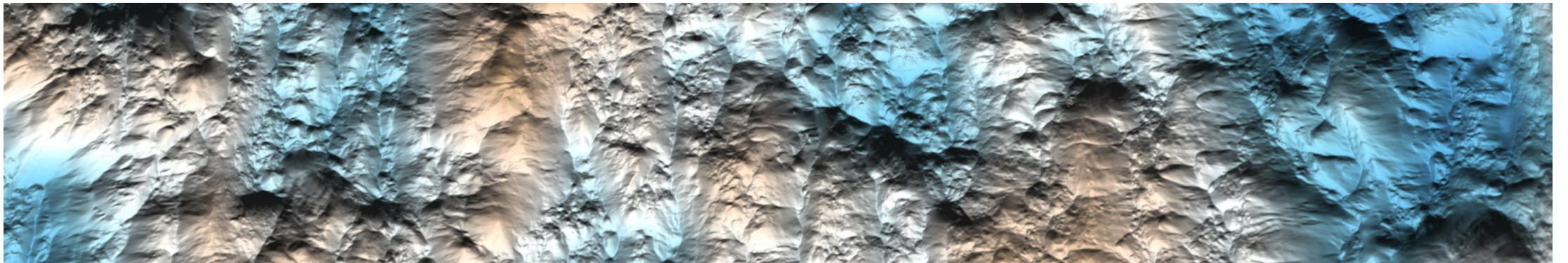
point electronic

Thank you!

Dr. Matthias Hemmleb

Senior developer / scientist, point electronic GmbH

📞 +49 345 – 472256-21

✉ mh@pointelectronic.de

www.pointelectronic.de

point electronic