Development of a Non-Invasive Quality Control System for Semiconductor Wafer Inspection

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CÁTEDRA UV-VASIC DE MATERIALES AVANZADOS PARA LA INDUSTRIA DE MICROCHIPS Y SEMICONDUCTORES

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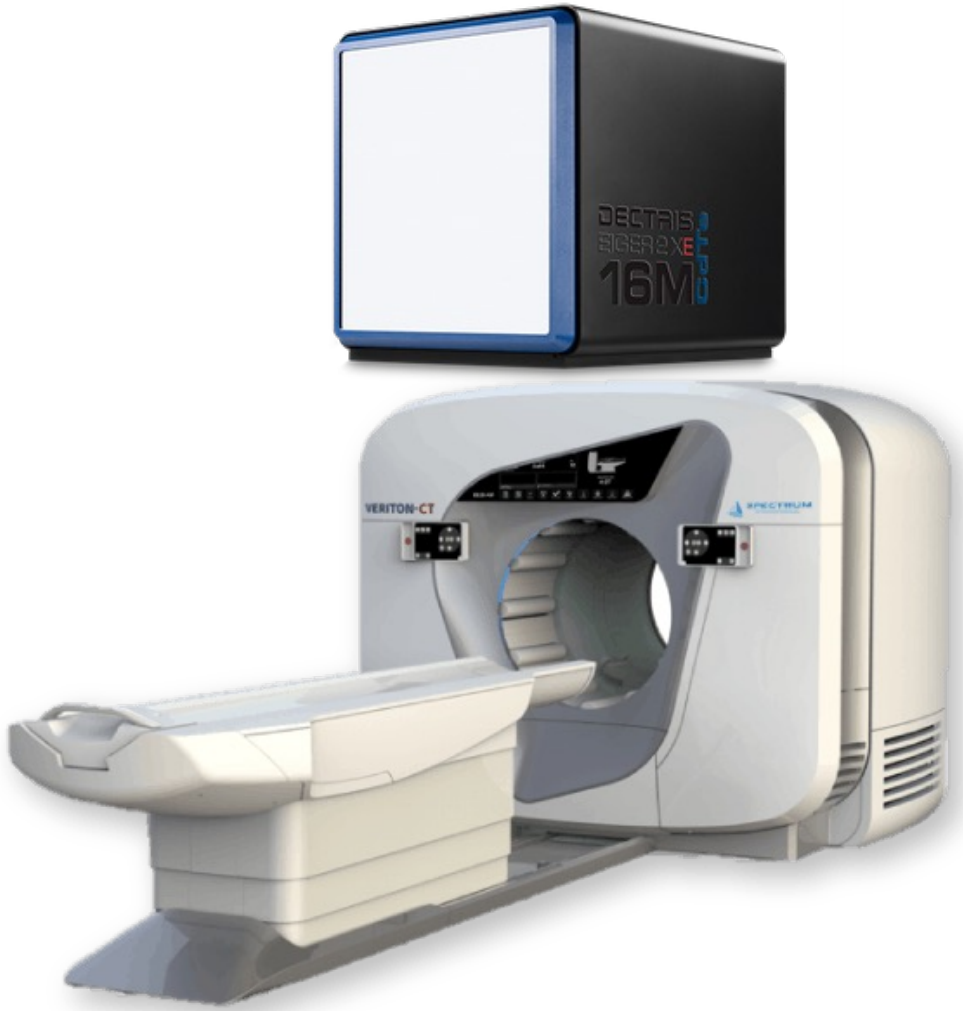
Introduction

- High-performance **X-ray and Gamma-ray detectors** are required for **medical imaging** (CT/SPECT), homeland security and X-ray diffraction techniques
- Traditional materials like **Silicon** (Si) or **Germanium** (Ge) have **limitations**: Si has low stopping power whereas Ge requires expensive cryogenic cooling
- Therefore, compound semiconductors such as **CdZnTe, CdTe** or **GaAs** have emerged as ideal candidates for these applications



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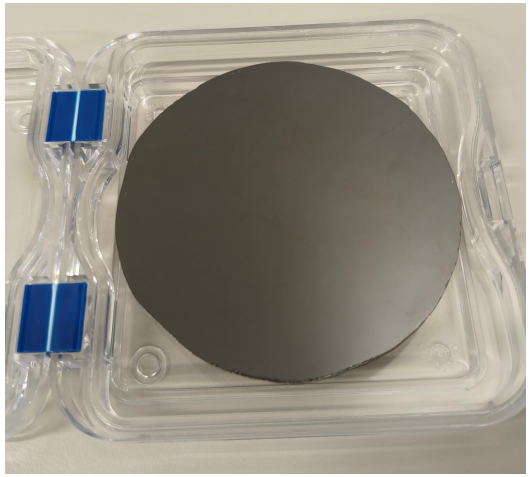
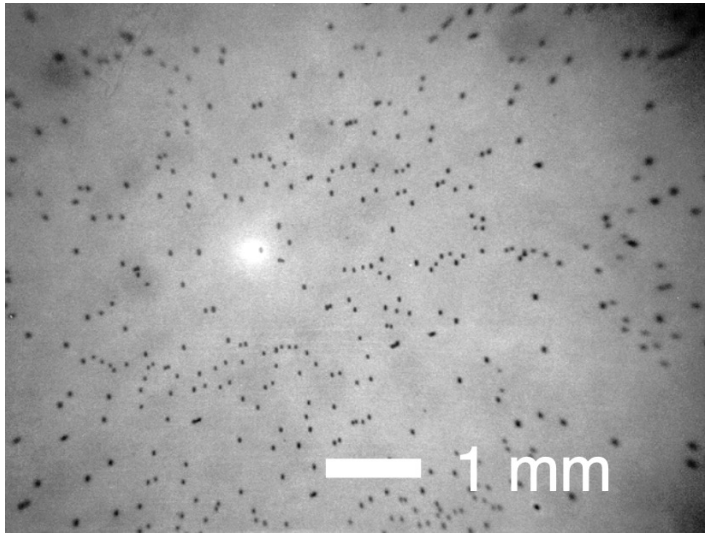
Cadmium Zinc Telluride (CZT)

- In particular, **CZT** is a semiconductor of interest for gamma and X-ray imaging due to:
  - **High atomic number** (**Z**)
  - **Wide band gap** (1.4 - 2.2 eV)
  - Suitability for **room temperature** operation
- However, it presents some **challenges**:
  - Development of **high-quality raw material** (homogeneous single crystals)
  - **Higher density of defects** (e.g., **Te inclusions, grain boundaries**) compared to Silicon
- Our objective is to develop a **complete system** for **wafer quality control**, while **studying the properties** of these defects



Szeles et al. (2002)



CZT Characterization Techniques

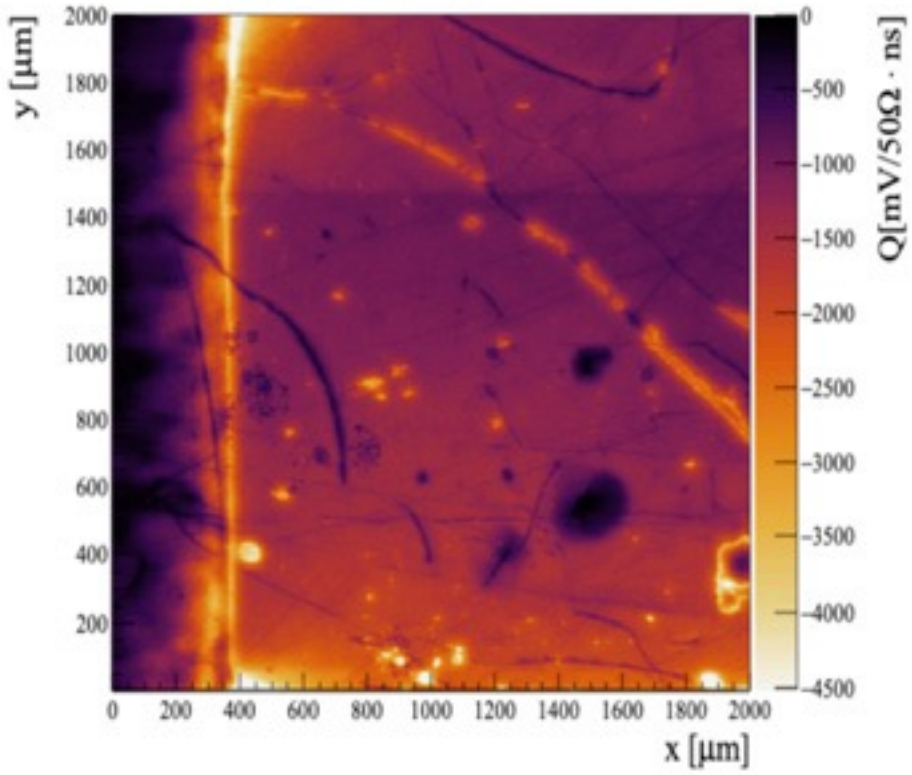
Surface Characterization:

- **Scanning Electron Microscope (SEM)**
  - Allows detailed inspection of the semiconductor wafer surface
  - Provides information on the **surface morphology** and its **composition**

Bulk Characterization:

- **IR Transmission Microscopy**
  - CZT is **transparent** to IR light **above 850 nm**, whereas some defects remain opaque
  - Enables the reconstruction of **3D defect maps**
- **Transient Current Technique (TCT)**
  - Quantifies **charge trapping** and **carrier mobility** (electrons and holes)
  - **Single Photon Absorption (SPA-TCT):** Targets near-surface defects
  - **Two Photon Absorption (TPA-TCT):** Probes deep bulk defects

M. Bezak et al. (2023)



Scanning Electron Microscopy (SEM)

Experimental Setup:

- JEOL JSM-IT800 Schottky Field Emission Scanning Electron Microscope (at the **Nanophotonics Technology Center -** NTC)

Detectors employed for image acquisition:

- **Secondary Electron Detector (SED)**: Reveals surface morphology and topography
- **Backscattered Electron Detector (VBED)**: Provides compositional (Z-contrast) and density contrast

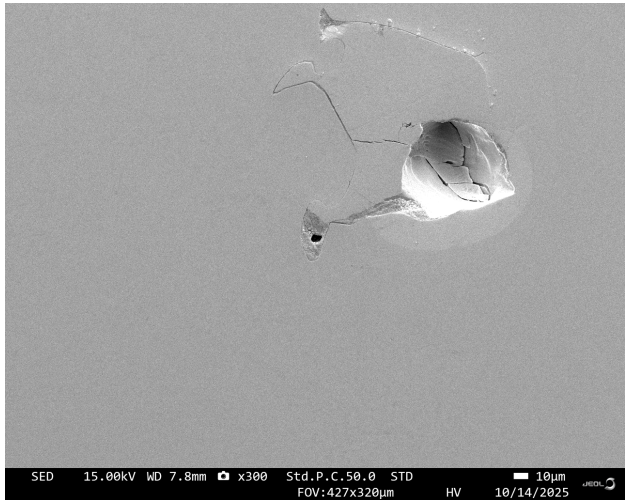
Capabilities:

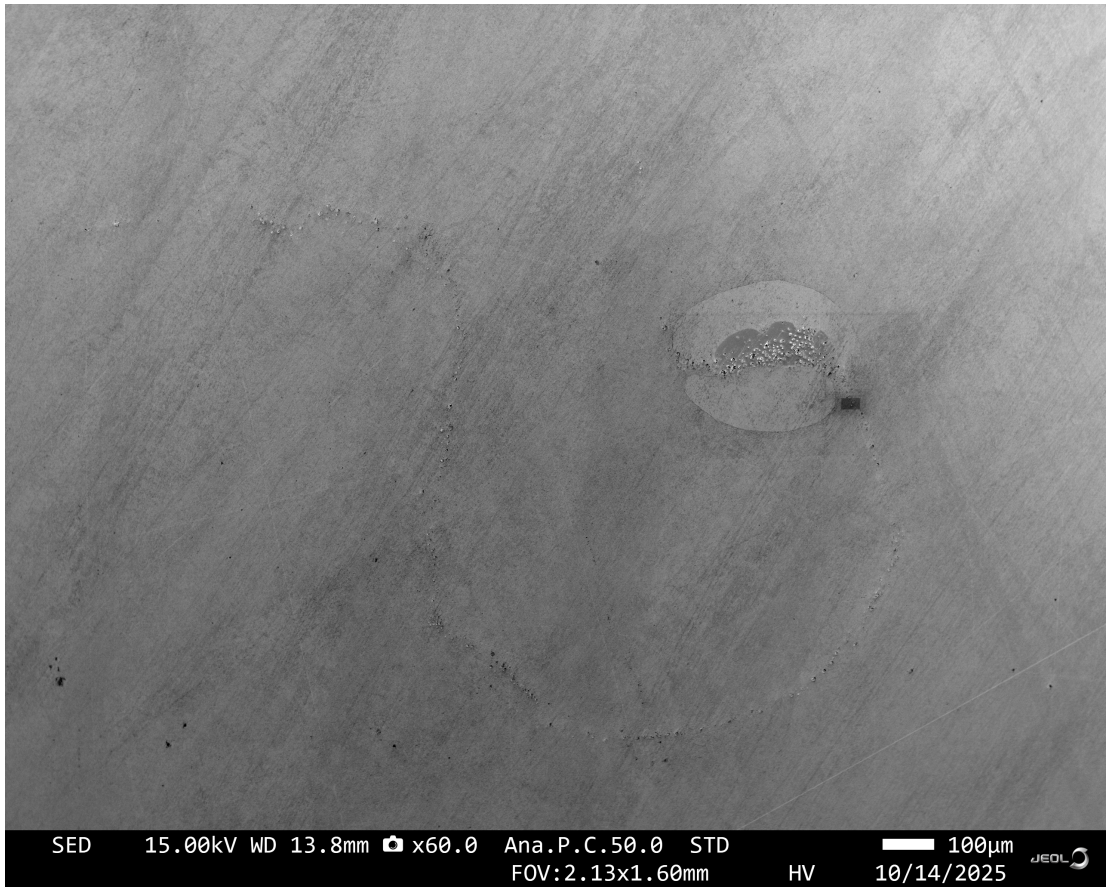
- These detectors allow us to determine if defects are caused by the polishing process, Te inclusions or other sources

Scanning Electron Microscopy (SEM)

Experimental findings:

- **Polishing artifacts:** Distinct linear scratches observed across the entire wafer surface
- **Mechanical damage**: Presence of **surface cracks**
- **Intrinsic defects:**
  - Visible **Te inclusions**
  - Identification of **grain boundaries**

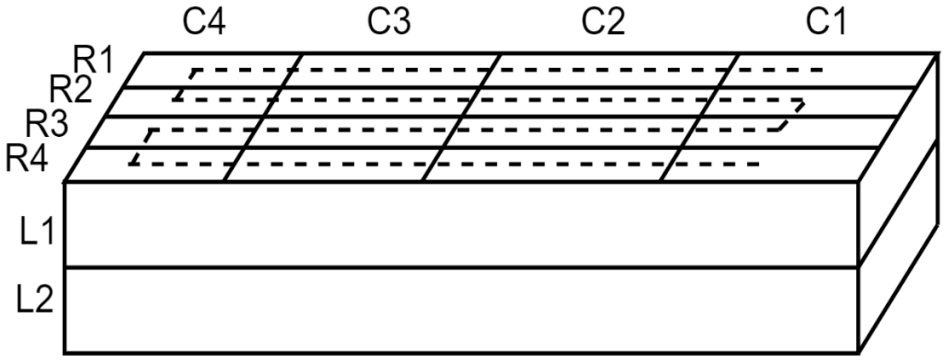


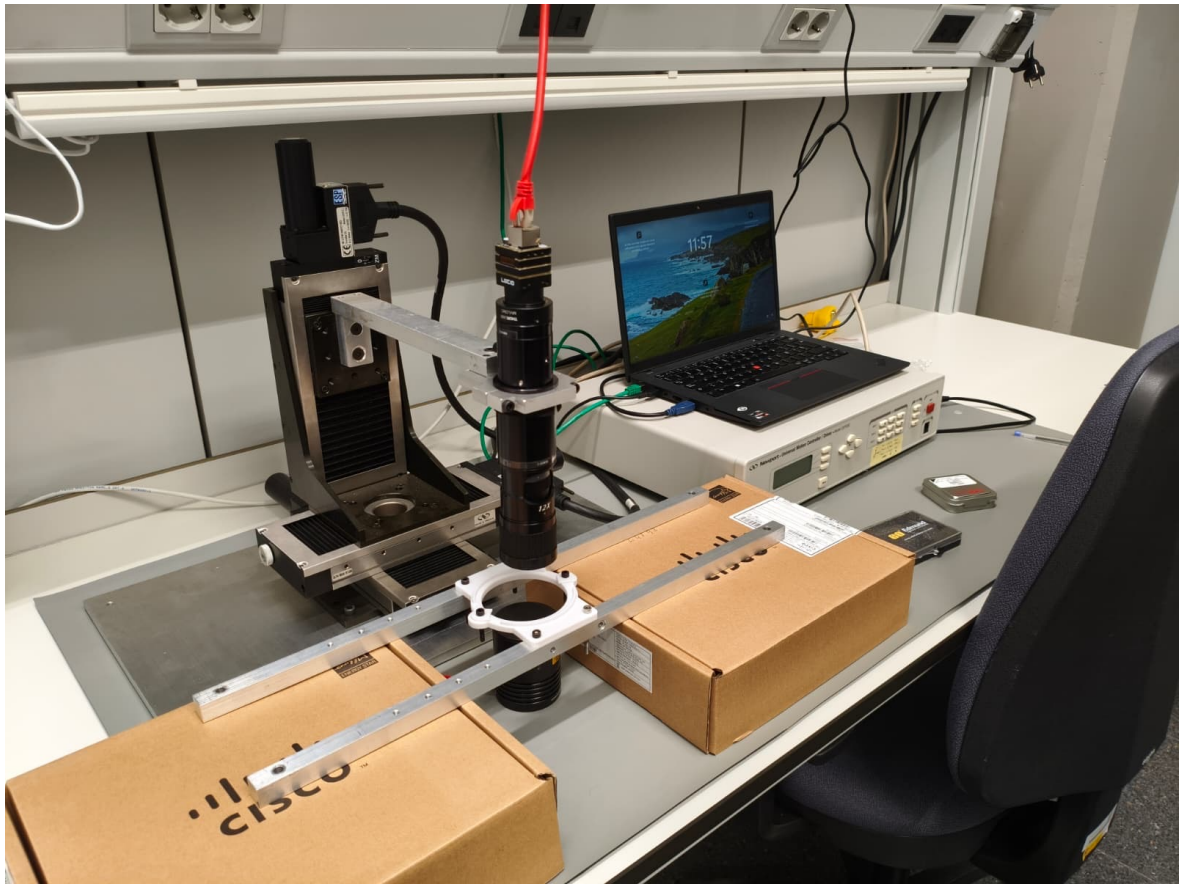


IR Transmission Microscopy

Experimental IR Microscopy Setup Components:

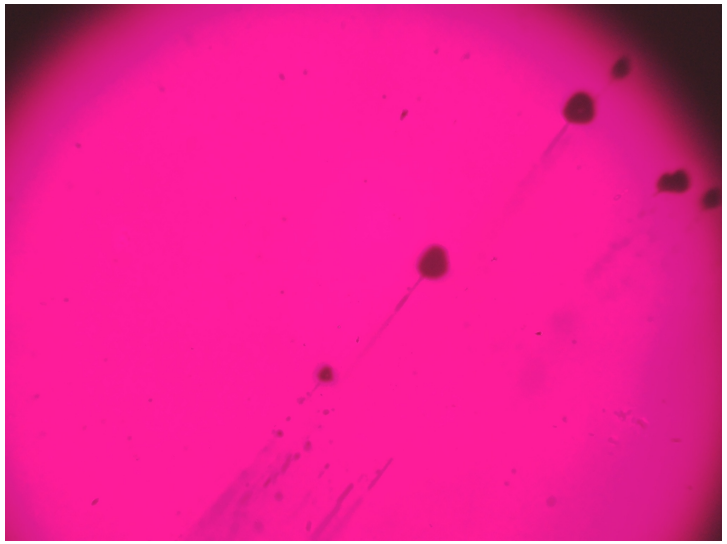
- Micrometric **XYZ stage**
- **Lens system** with 14x optical zoom
- **Monochrome camera** with near-IR sensitivity (<1100 nm)
- **Broadband emission lamp**
- Set of **near-IR filters**
- **Wafer holder** adaptable to various sample sizes

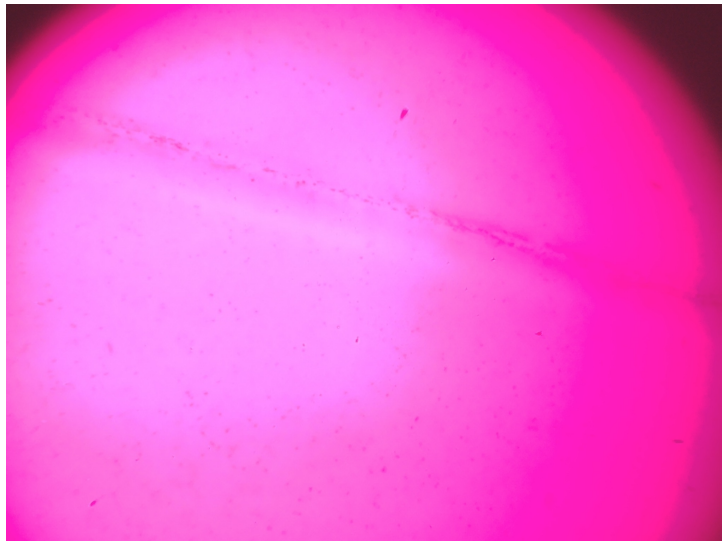




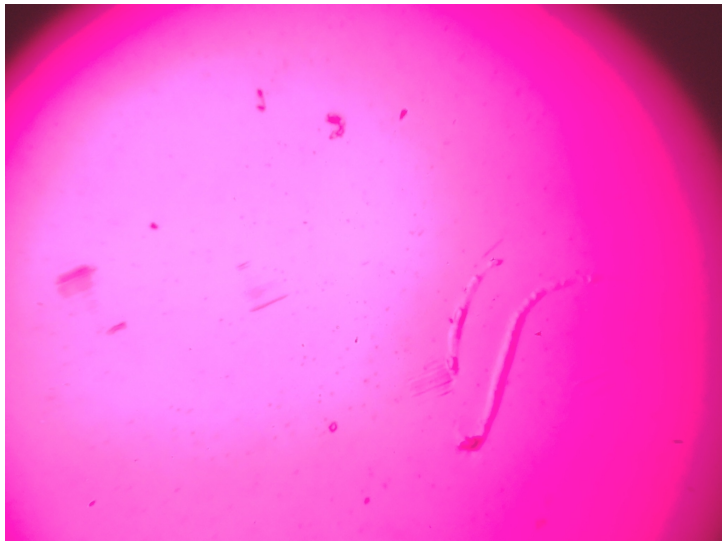
IR Transmission Microscopy

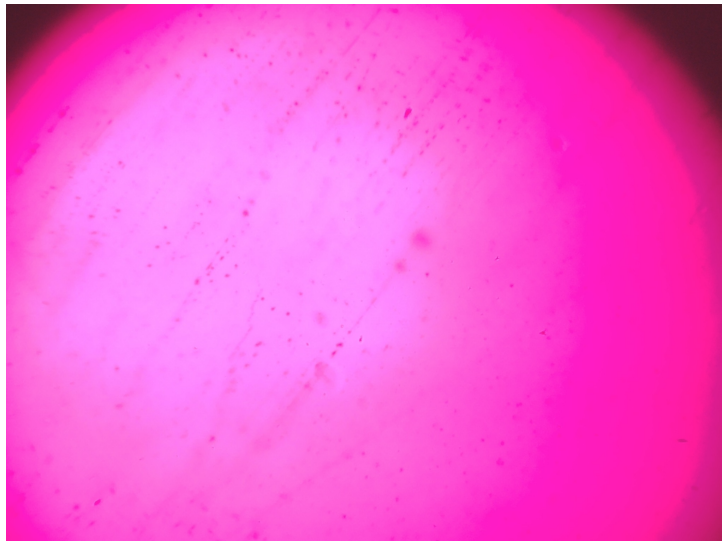
Surface Defects, likely induced by **polishing**





Grain boundary decorated with **Te inclusions**

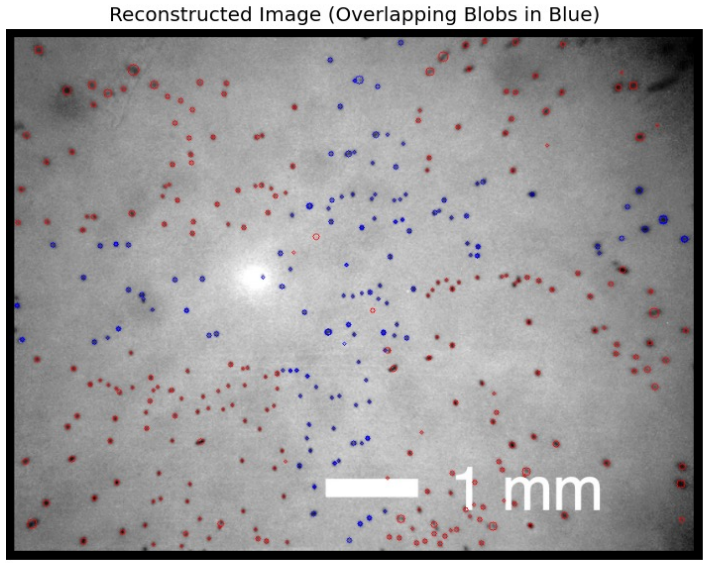


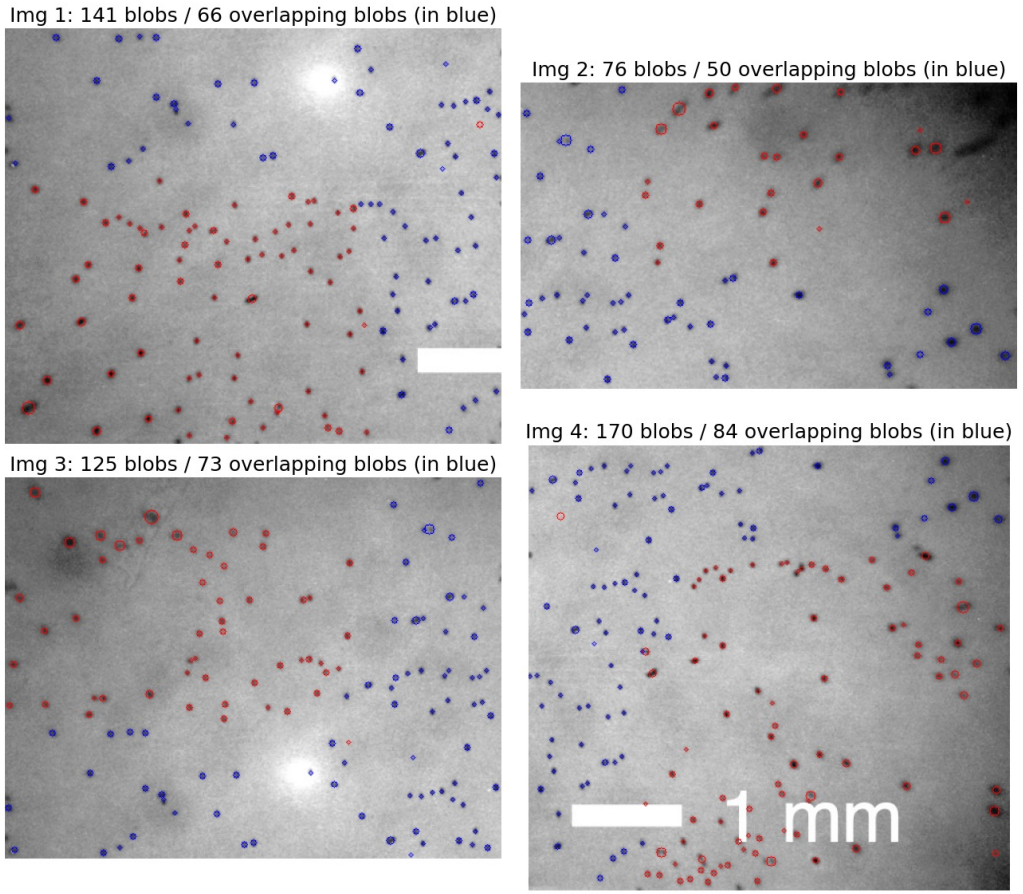


Te inclusions

Image Processing and Reconstruction

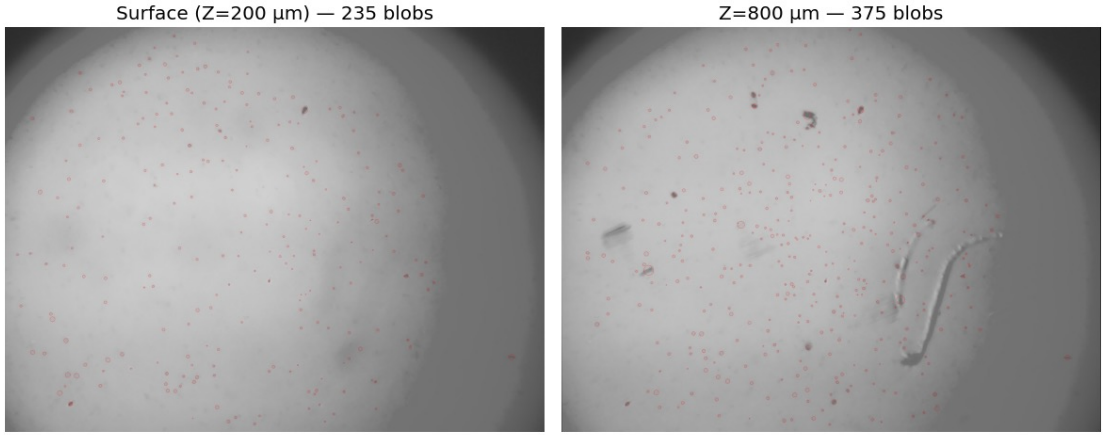
- **Defect Localization:** Implementation of **blob detection algorithms** to identify **Te inclusions** in individual frames
- **Feature Matching:** Comparison of blobs across adjacent images to determine **spatial overlaps**
- **Reconstruction:** Merging of overlapping frames to generate the final **high-resolution composite image**

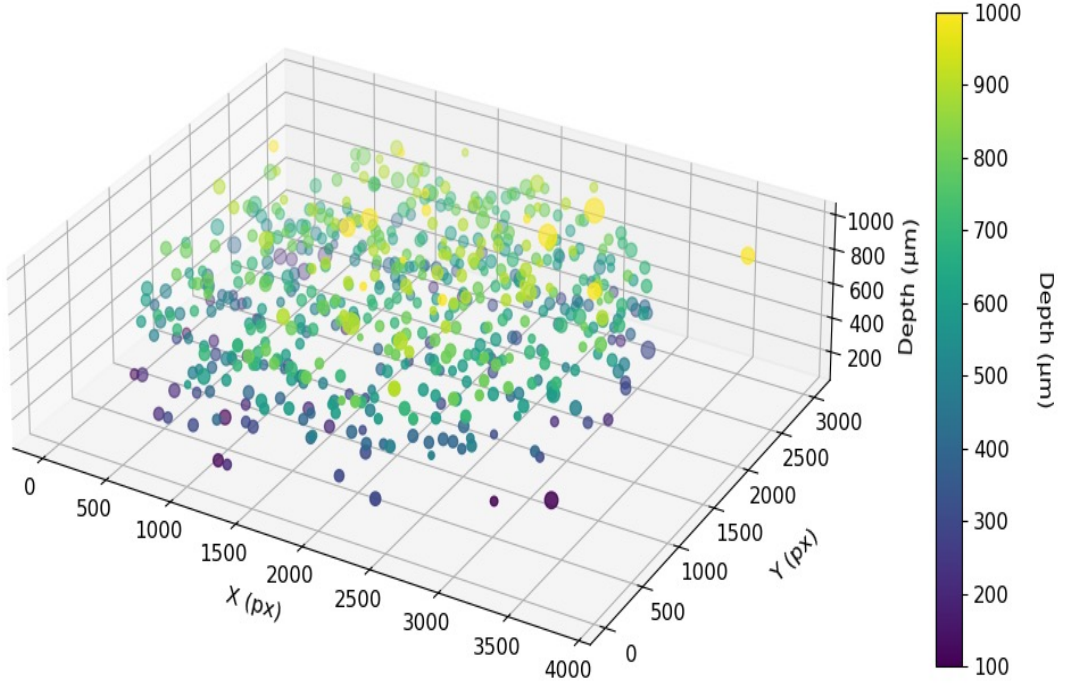




3D Defect Mapping Algorithm

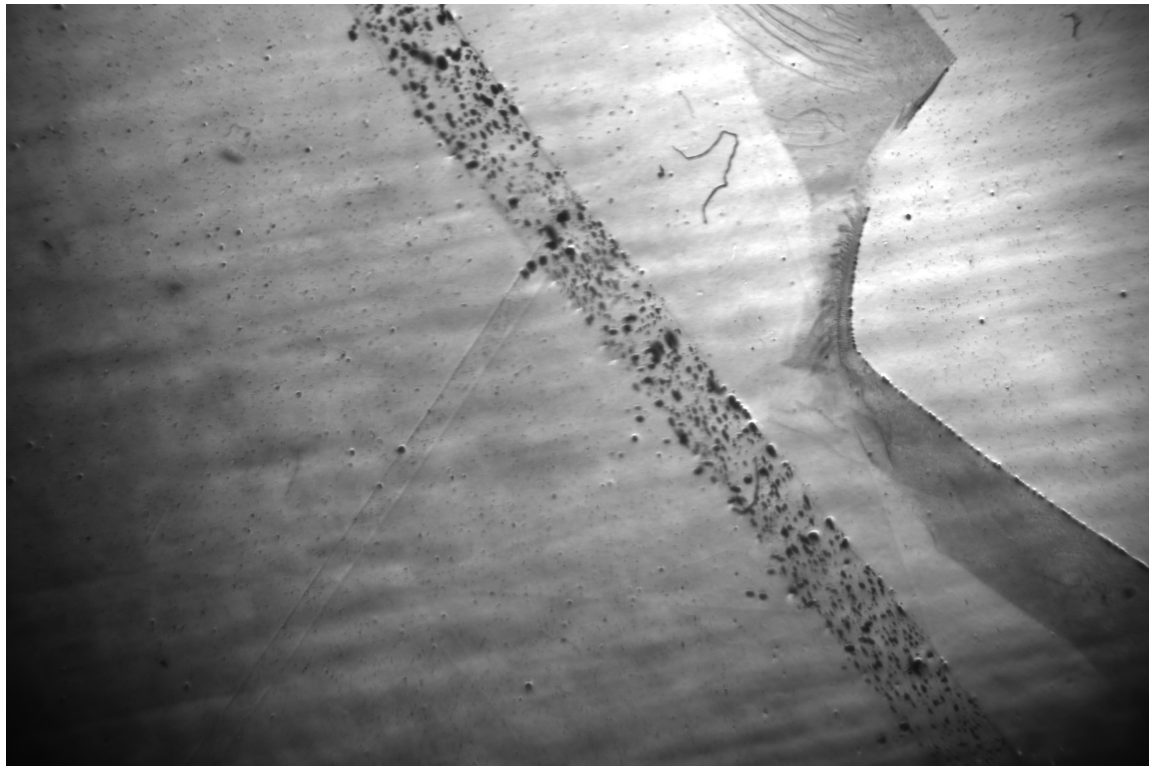
- **Z-Stack Acquisition:** Images captured at fixed XY coordinates across **varying focal planes** (focal depths)
- **Depth Estimation (Depth-from-focus):**
  - Analyzes blob **sharpness** across the Z-stack
  - Assigns the Z-coordinate based on the focal plane of **maximum sharpness**
- **Volumetric Mapping:** Generates a **3D distribution map** of Te inclusions





Summary

- **Development of a quality control system** for semiconductor wafers prior to hybridization
- Primary focus on **CdZnTe**, with methodologies adaptable to **other semiconductors**
- Successful validation using **SEM** and **IR inspection**, with plans to integrate complementary characterization techniques
- Implementation of custom **software** for **image stitching** and **3D defect mapping**
- Future work will focus on using **TCT** to understand how these defects impact the **detector's performance**



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THANK YOU

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BACKUP

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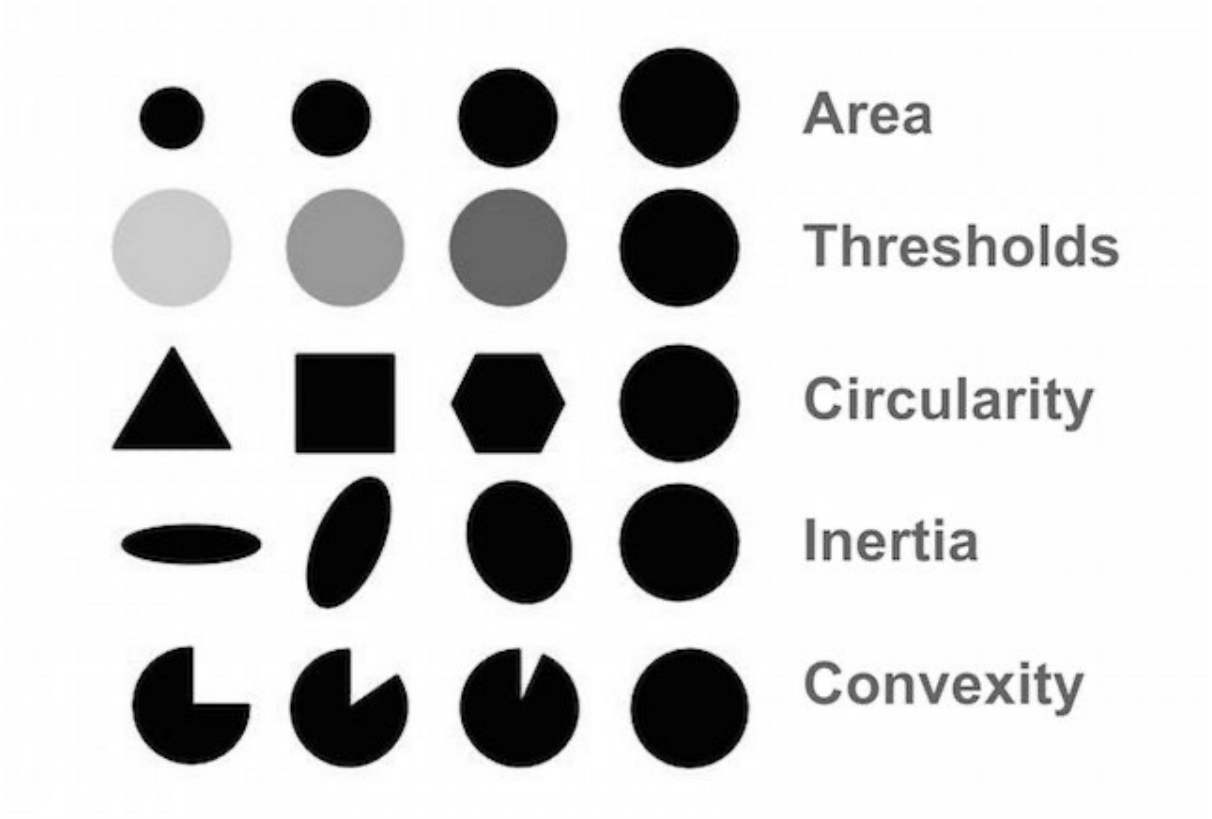
CÁTEDRA UV-VASIC DE MATERIALES AVANZADOS PARA LA INDUSTRIA DE MICROCHIPS Y SEMICONDUCTORES

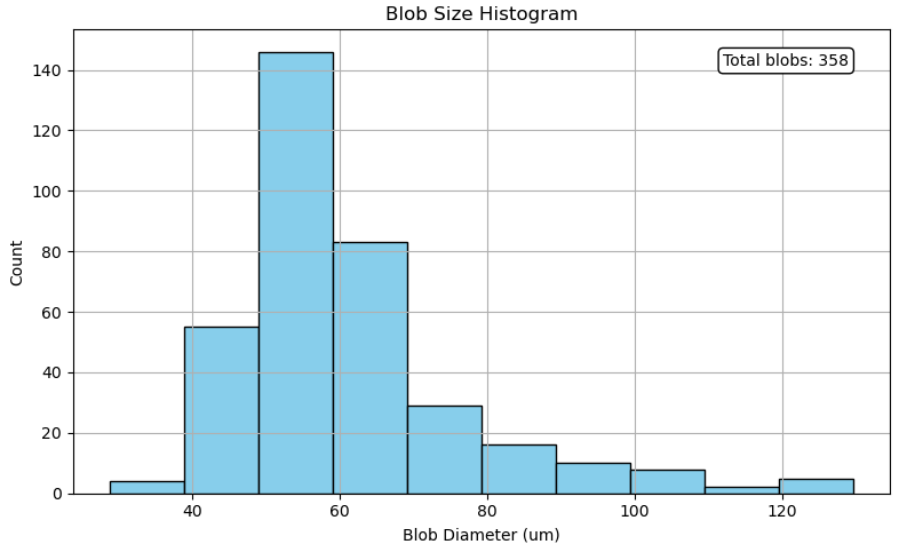
Software

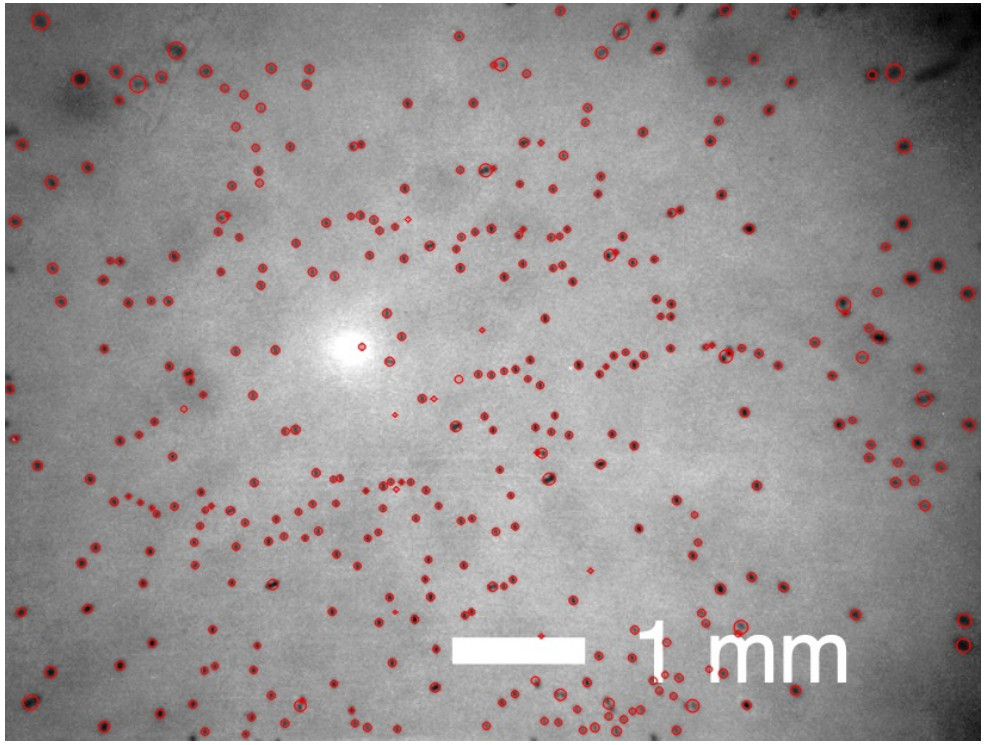
- The software used for blob detection is OpenCV, specifically, the SimpleBlobDetector class
- This tool allows us to filter detected blobs using various criteria, including::
  - **By size (to know how big is the inclusion)**
  - **By threshold (to infer the depth of the inclusion)**
  - By shape
    - Circularity
    - Inertia Ratio
    - Convexity



Software: Simple Blob Detection

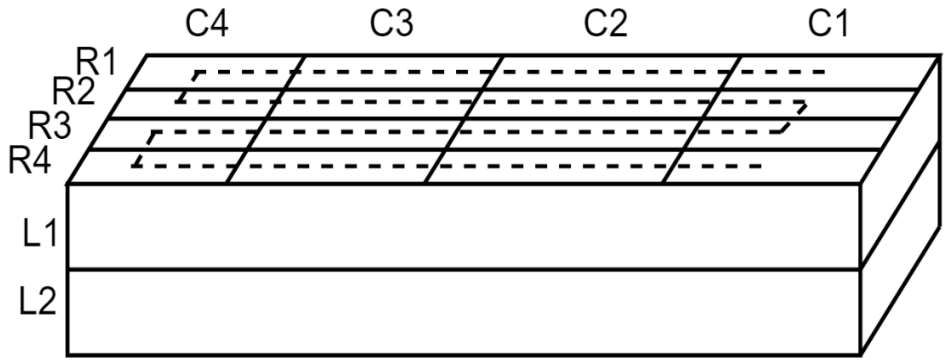
- Parameters used:
  - Threshold: Min=0, Max=200
  - ThresholdStep= 14, MinRepeatability=2
  - Area: Min=3 pixels
  - Circularity: Min=0.419

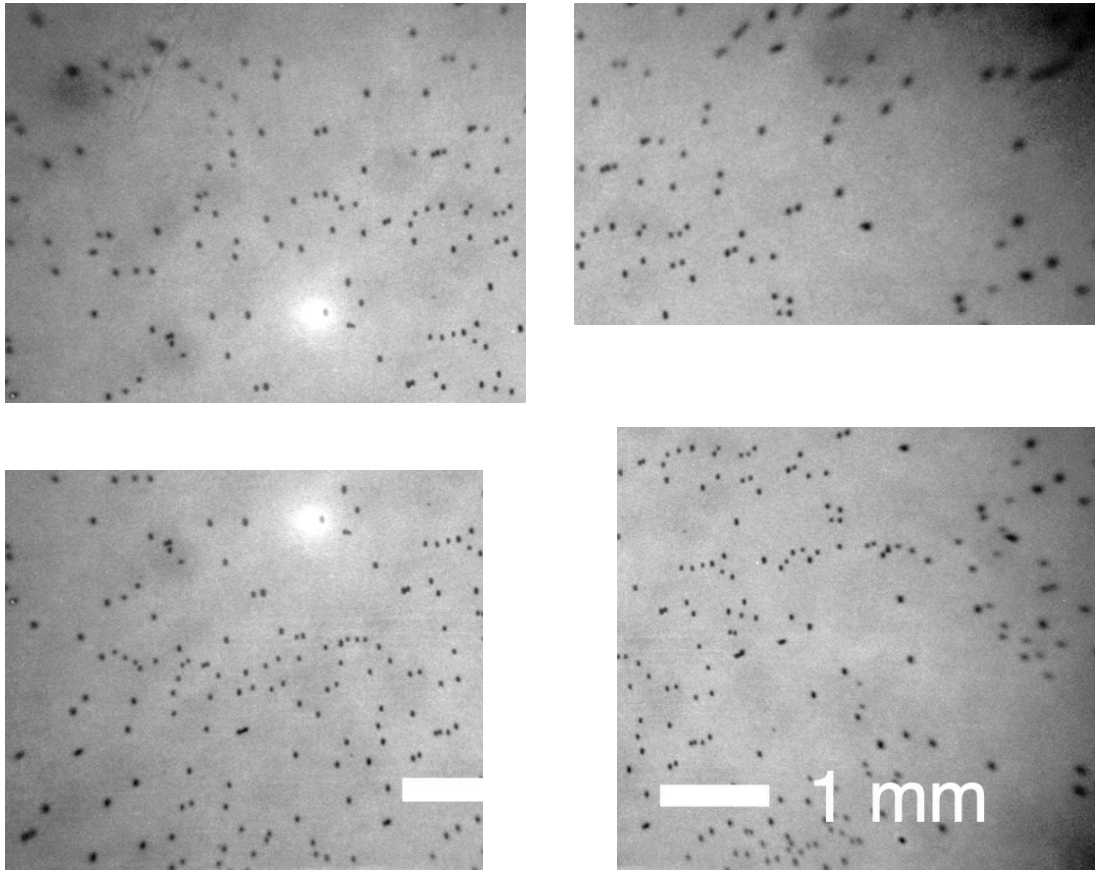




Software: Reconstruction of Images

- To scan the CZT wafer, we need to take multiple images with overlaps in order to cover the whole wafer
- We have developed an algorithm that reconstruct these overlapping images taken from different positions to create a complete 2D image of the sample

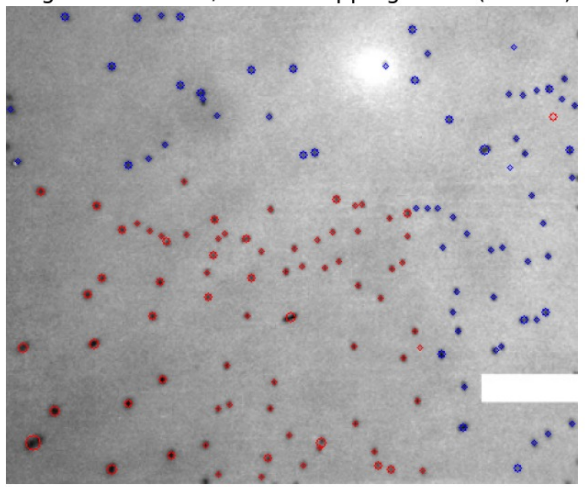




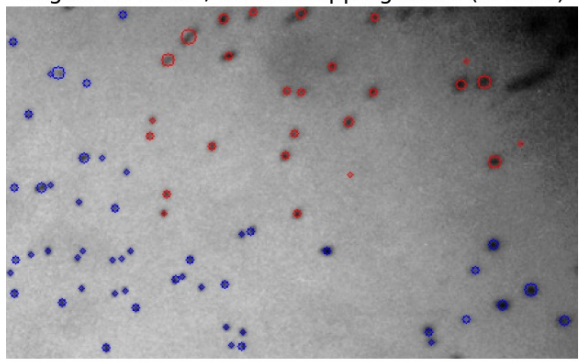
Software: Reconstruction of Images

- We use the blob detection software to localize the Te inclusions
- Then, we apply an algorithm that compares the blobs from different images to check for overlaps
- The software marks in red the blobs that are unique to that image, and in blue those that are also present in others images

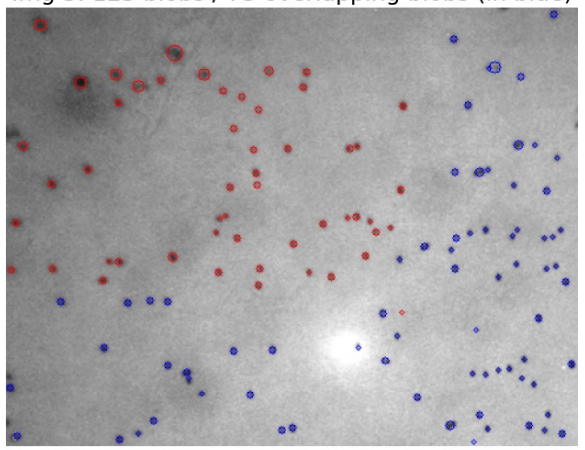
Img 1: 141 blobs / 66 overlapping blobs (in blue)



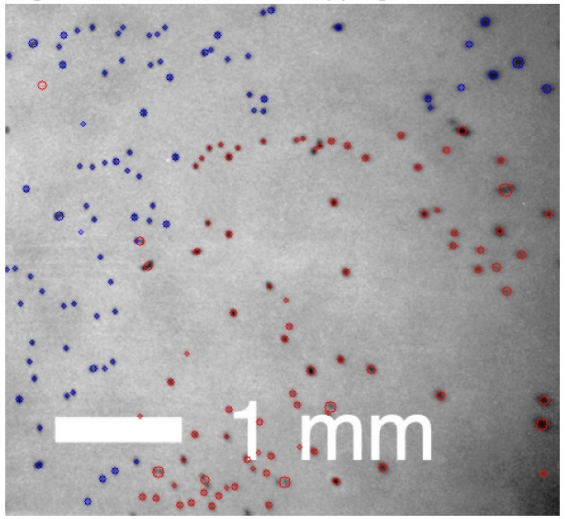
Img 2: 76 blobs / 50 overlapping blobs (in blue)



Img 3: 125 blobs / 73 overlapping blobs (in blue)



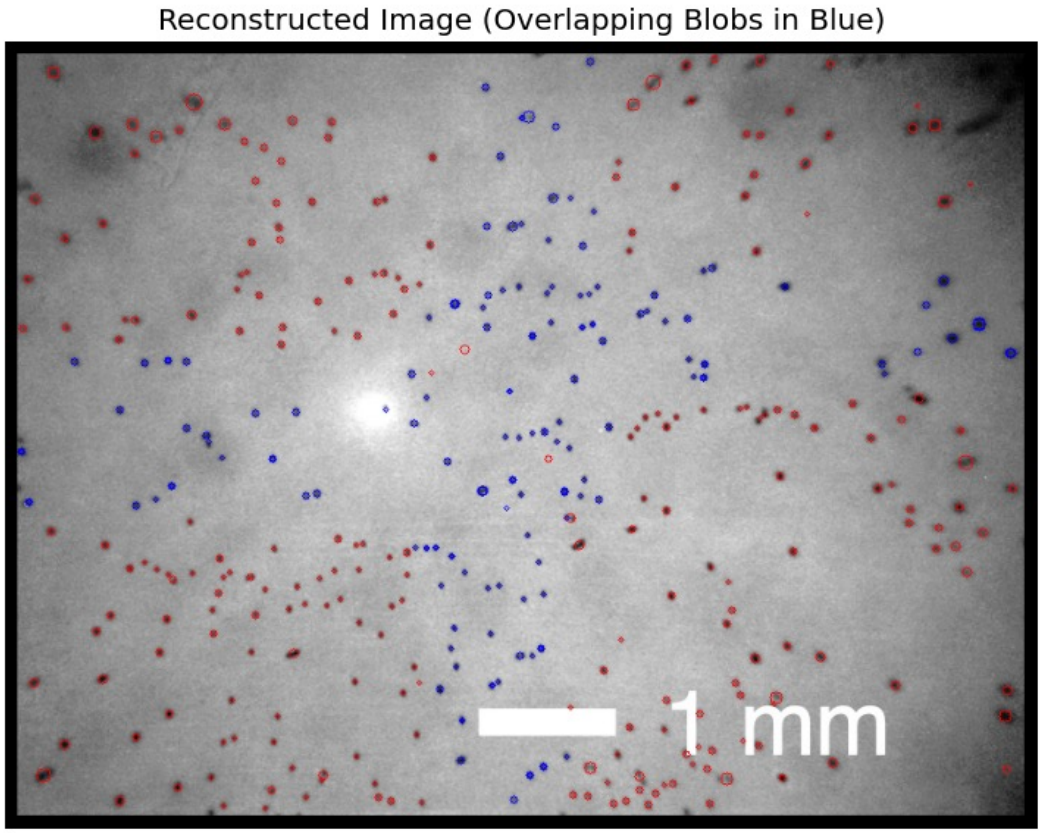
Img 4: 170 blobs / 84 overlapping blobs (in blue)



Software: Reconstruction of Images

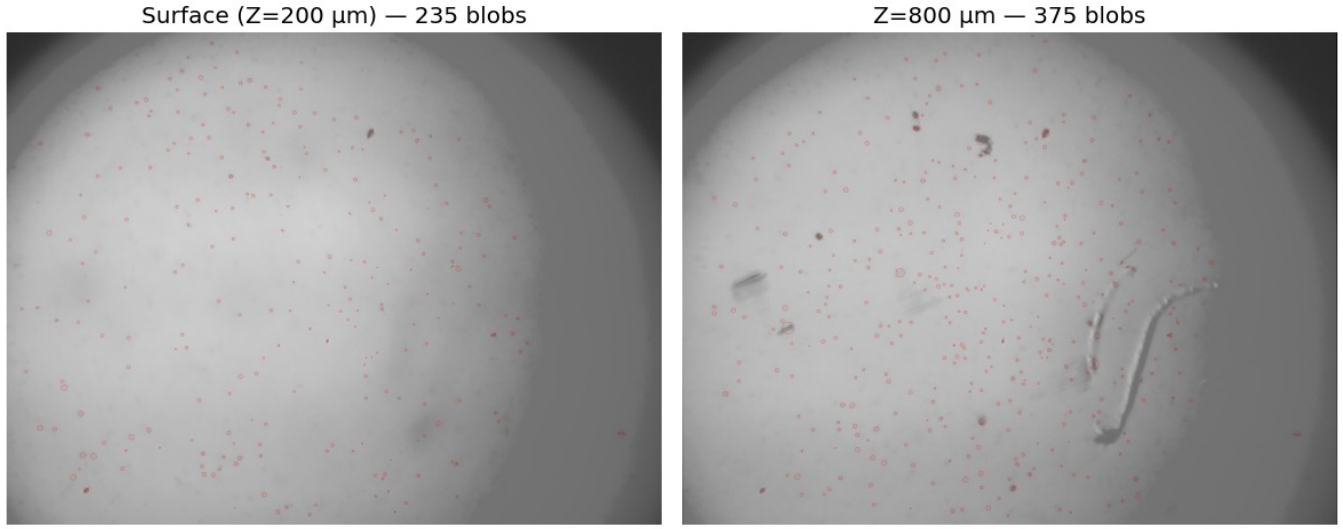
- Finally, the algorithm overlaps these images to form the complete image we were aiming for
- This reconstructed image can then be further processed to obtain the 3D positions of the inclusions

```
Found 4 images.
Image 0: 141 blobs detected
Image 1: 76 blobs detected
Image 2: 125 blobs detected
Image 3: 170 blobs detected
Pair (0,1): REJECTED
Pair (0,2): dx=0.00, dy=-242.00, count=37, std=0.059 -> ACCEPT
Pair (0,3): dx=330.99, dy=-74.00, count=42, std=0.065 -> ACCEPT
Pair (1,2): dx=-375.01, dy=0.01, count=30, std=0.079 -> ACCEPT
Pair (1,3): dx=-44.00, dy=168.01, count=35, std=0.138 -> ACCEPT
Pair (2,3): dx=331.00, dy=167.99, count=35, std=0.157 -> ACCEPT
Connected components: [[0, 1, 2, 3]]
Reconstruction component 0: images = [0, 1, 2, 3]
```



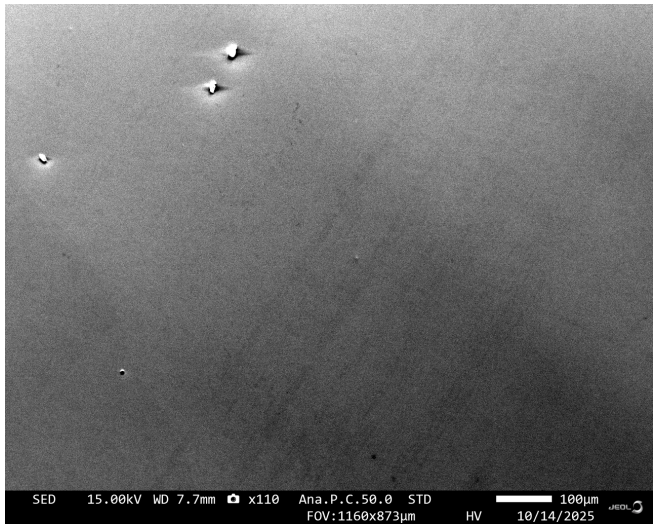
Software: 3D Defect Mapping

- **Multi-Focal Comparison:**
  - Images capture the same Region of Interest (ROI) at **varying focal depths**.
  - Defects appear **sharp** (in focus) only at their specific Z-plane.
- **Algorithmic Alignment:**
  - **Blob detection** combined with an **alignment routine** matches features across the image stack.
- **3D Reconstruction:**
  - Depth is assigned based on **maximum sharpness** (or single-plane occurrence).
  - Generates a precise **3D volumetric map** of inclusion positions.



SEM: Te Inclusions

Secondary Electron Detector (SED)



Backscattered Electron Detector (VBED)