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Etch pits in CdZnTe and other CdTe-based Crystals

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Etch pits in CdZnTe and other CdTe-based crystals

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Introduction

- **Defects in high-quality CdZnTe detectors are much less common, but the growth process for perfect CdZnTe materials is still not understood or reproducible;**
- **Some defects, e.g. Te inclusions, sub-grain boundaries and dislocations, are found in commercial-grade CdZnTe crystals;**
- **Big Te inclusions (> ~2 μm) can be seen by IR transmission microscopes; but small Te inclusions, sub-grain boundaries and dislocations are not traceable by conventional IR inspection techniques, so they are often overlooked.**
- **Such defects in crystals degrade the detector's performance.**

To reveal such crystallographic defects effectively, we employed more advanced techniques, like X-ray reflection topography (XRT), chemical etching, and scanning electron microscopy (SEM).

Sample Preparation and Etching Process

➢ Samples: Method for growth

CdZnTe: THM, HPB and Floating Zone (FZ)
CdMnTe: Vertical Bridgman (VB) and Floating Zone

➢ Crystal processing

- **Al_2O_3 abrasive papers and alumina powder with decreasing grit size, and a final polishing with 0.1-µm alumina powder against multitex soft pad;**
- **Chemo-mechanical polishing with bromine-methanol solution and ethylene glycol.**

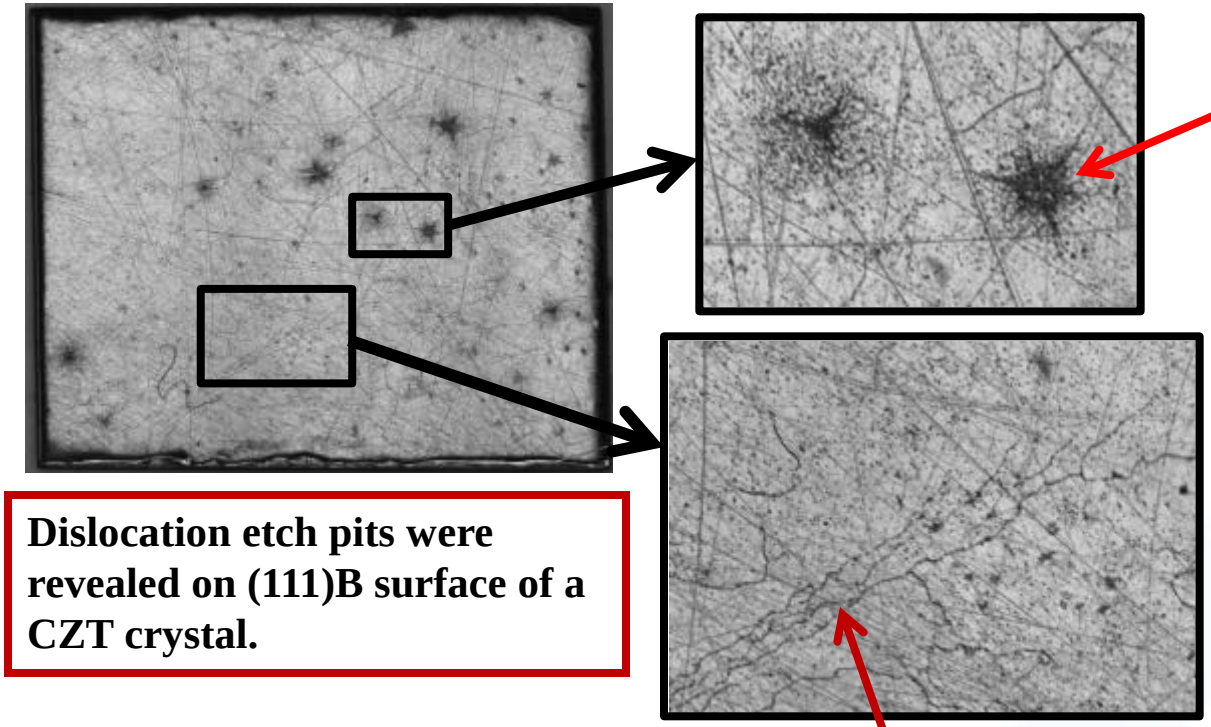
➢ Chemical etching for EPD

HF-based solutions were used to produce dislocation-related etch pits.

Etch pits were revealed on the crystallographic surfaces (111)A and (111)B.

Etch Pits Revealed in CdZnTe THM-Grown Sample

THM-grown CdZnTe annealed sample



Dislocation etch pits were revealed on (111)B surface of a CZT crystal.

Six- or three-pointed dislocations are formed likely due to plastic deformation in the crystal.

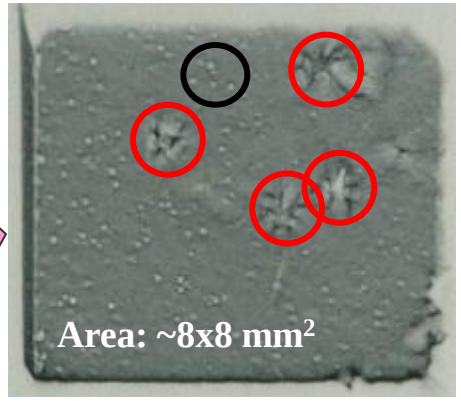
Origin of these features still unclear, but we think it may caused by build-up of high pressure inside inclusions after annealing; or, the reactions of Cd atoms with Te inclusions during annealing.

The core of these features is mostly found to be empty.

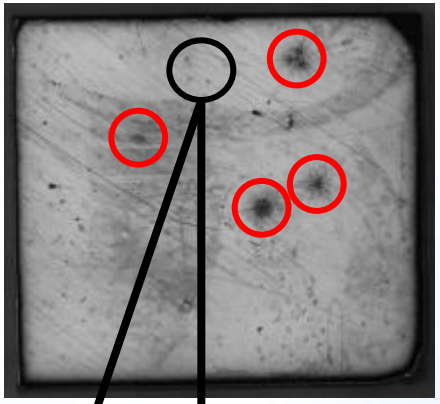
Etch pits are sometimes arranged in linear patterns, possibly along the direction of crystalline slip planes.

XRT and IR Images of Defects in CdZnTe Crystals

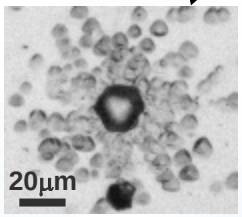
XRT image displays a random distribution of white spots on polished surface;
Spots appeared on surfaces that were damaged by polishing.
Chemical etching produced dislocation pits surrounding the spots.

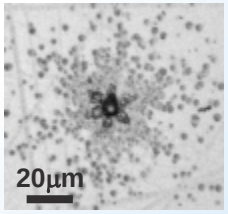


XRT image of polished surface



IR image of etched surface

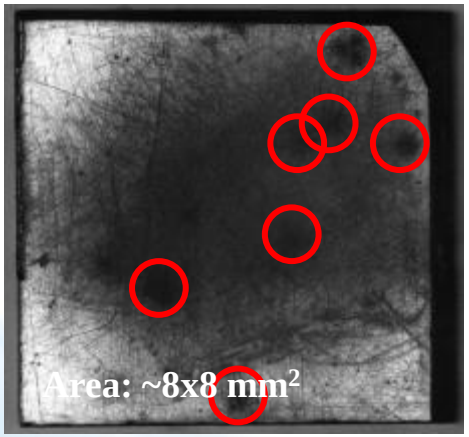




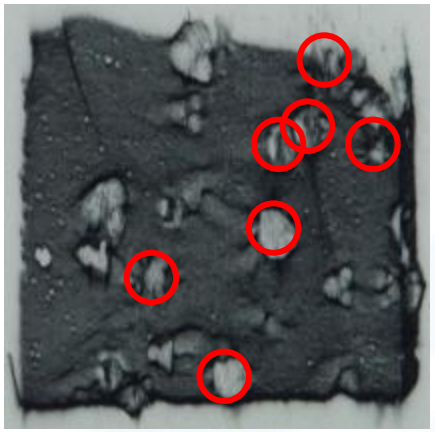
Dislocation etch pits observed around these empty pits.

Deformation dislocations formed surrounding the empty core.

XRT image reveals the star-shaped features as big white spots

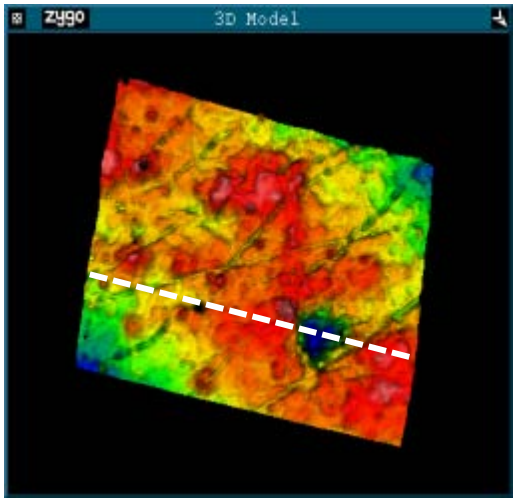


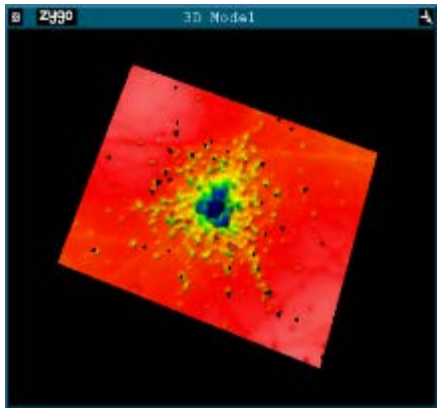
IR image of etched surface

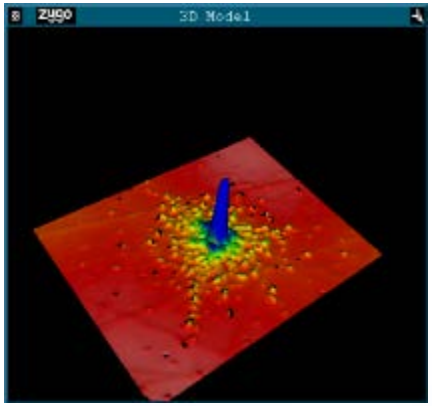


XRT image of etched surface

Topographic image of Etched Surface Obtained by Optical Profilometer

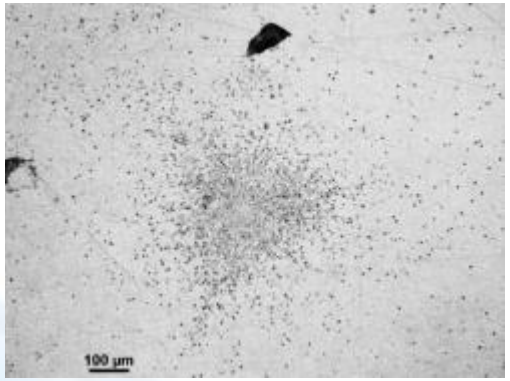




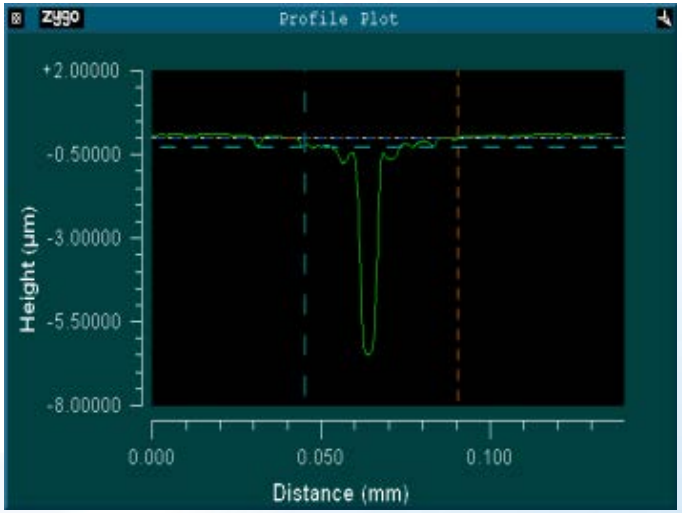


3D images of three-pointed feature.

3D topography image of an etched surface. Dislocation etch pits align linearly.

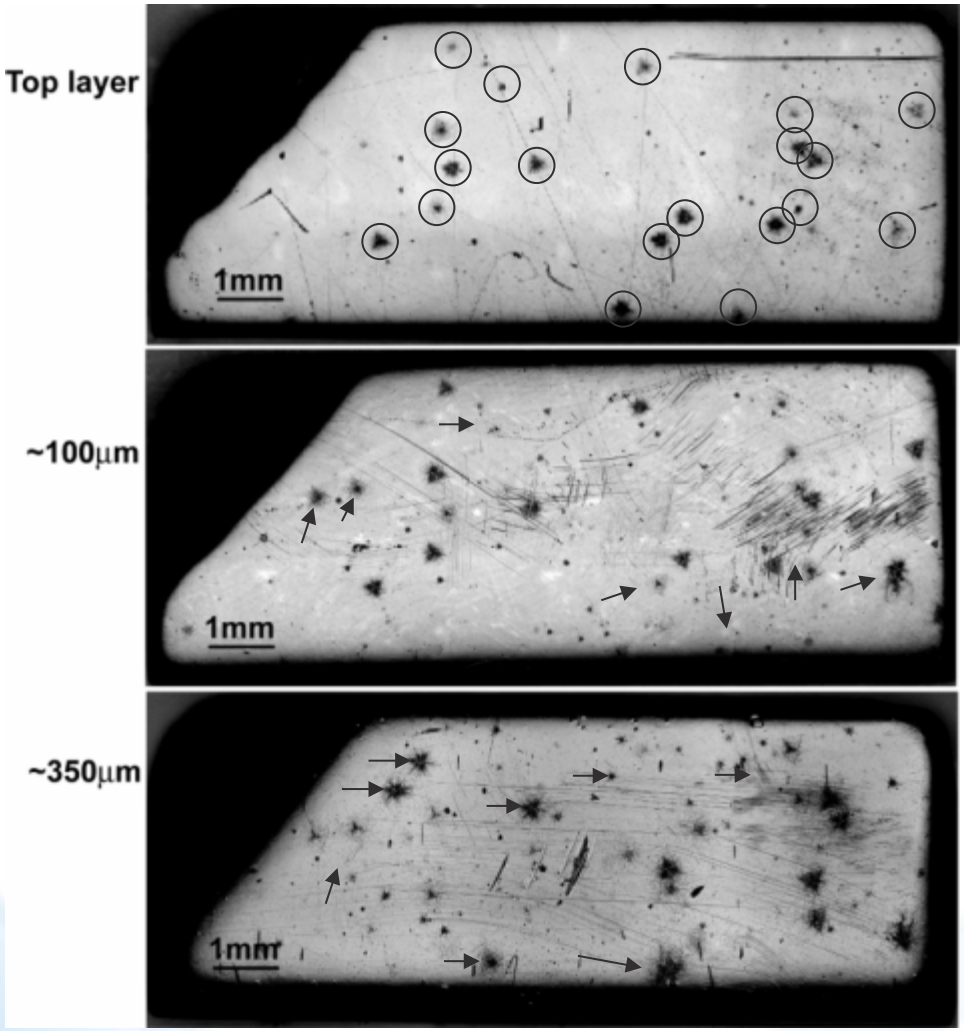


IR image of a three-pointed feature.



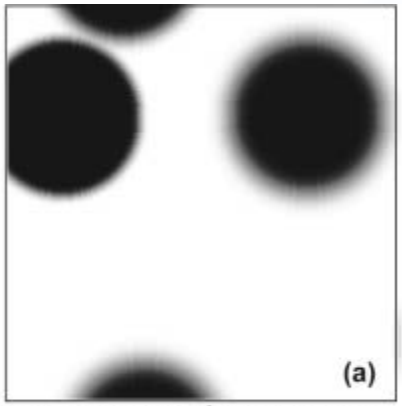
Line profile of etched surface. Displays the depth of three-pointed features.

Size and Density of Star-Shaped Features and Their Effect

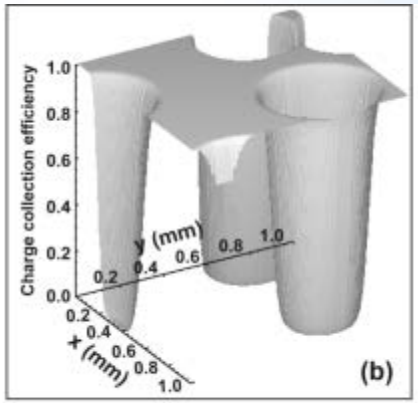


Demonstration of size and density of star-shaped features

- The size of star-shaped corona is in the range of 50 μm to 500 μm diameter with a similar depth.
- The density of these features is in the range of $2x10^2$ - $1x10^3$ per cm^3.



Detector- area: 1x1 mm^2; thickness: 2 mm
Features - diameter: 400-μm; conc.:10^3 cm^{-3}



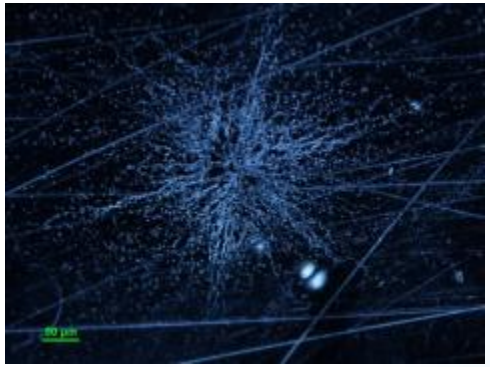
3-D representation of charge collection.
Almost entire charges lost over the features.

Simulation of charge losses for big size features

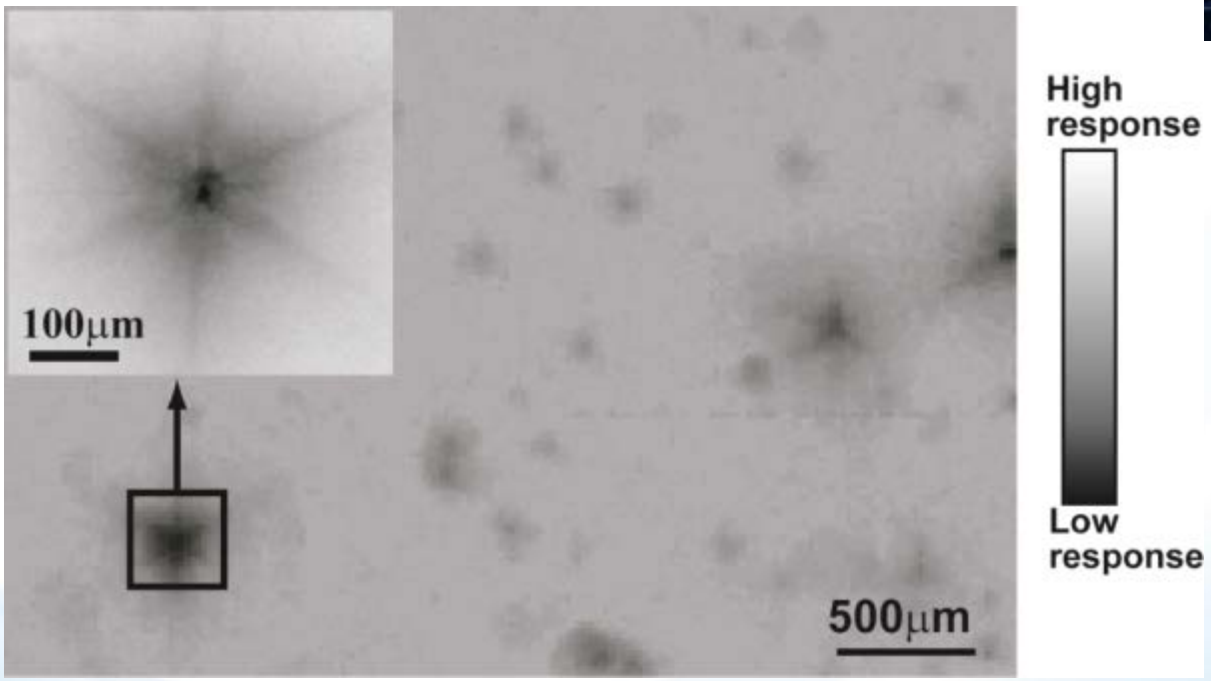
A. Hossain et al., Journal of Crystal Growth 312 (2010) 1795–1799

Evidence of Charge Losses by Star-Shaped Features

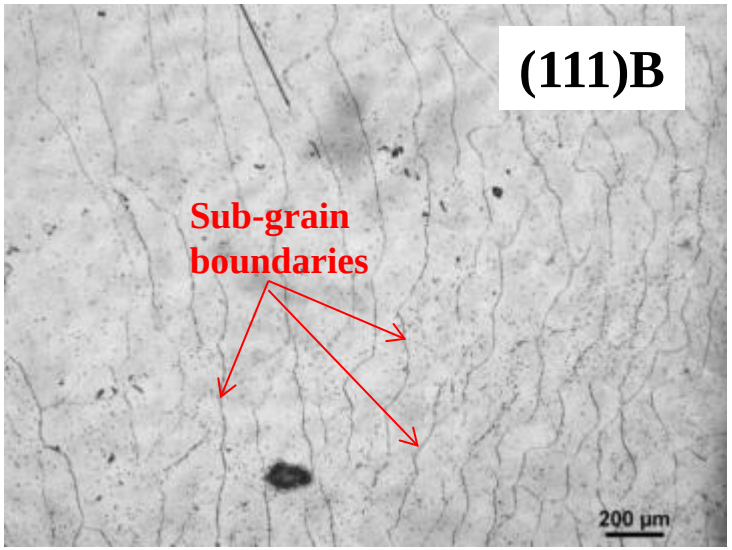
Raster-scan image of X-ray response for a CdZnTe detector duplicates the shape of the six-pointed star-shaped features.



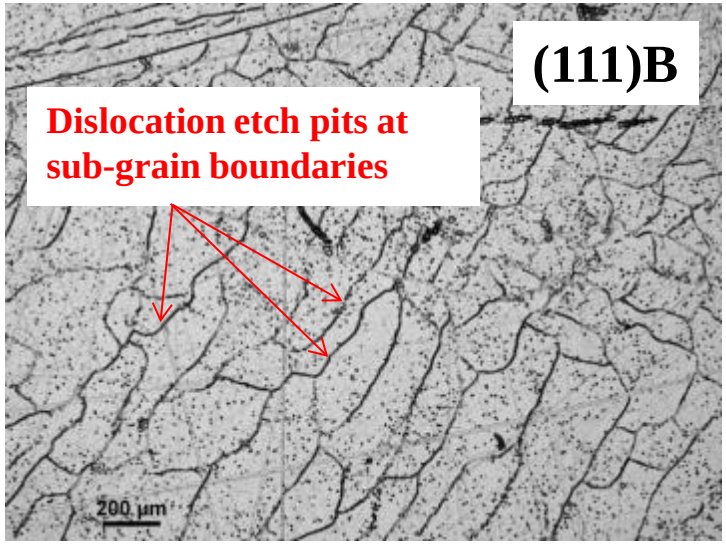
Optical image of six-pointed feature



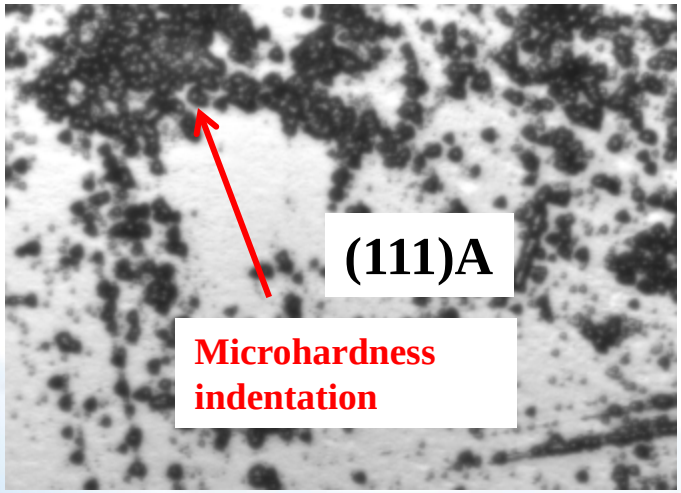
Grown-in Dislocations and Sub-grain Boundaries



CZT crystal grown by the FZ method



CZT crystal grown by the THM method

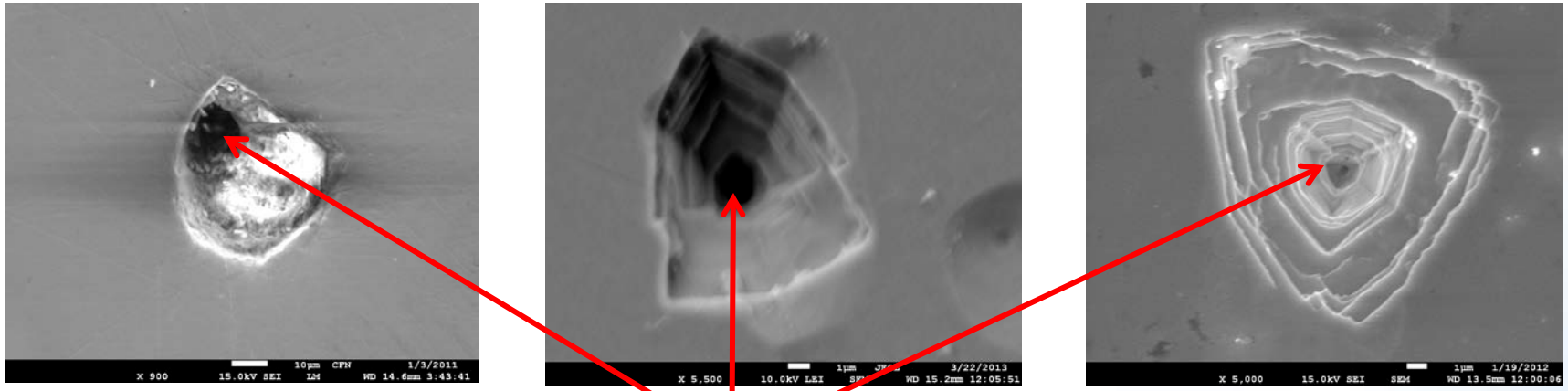


CZT crystal grown by HPB method

- Dislocation etch pits align along the lines of sub-grain boundaries;
- High concentration of EPD clustered as cell structure;
- High density saucer pits form around the indentation due to deformation dislocations

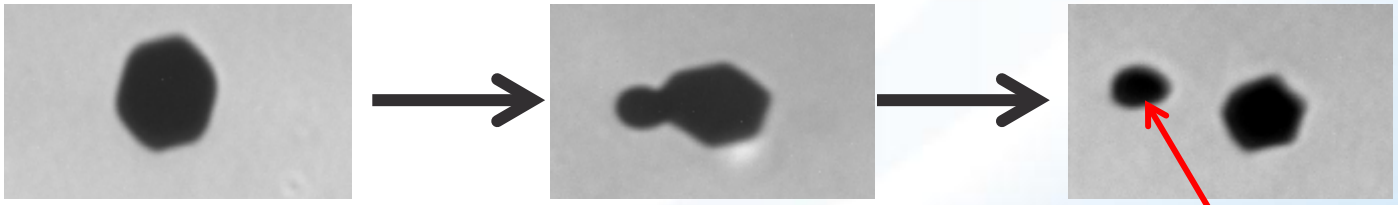
Inclusions with Voids

Evidence of void under the inclusions



Voids

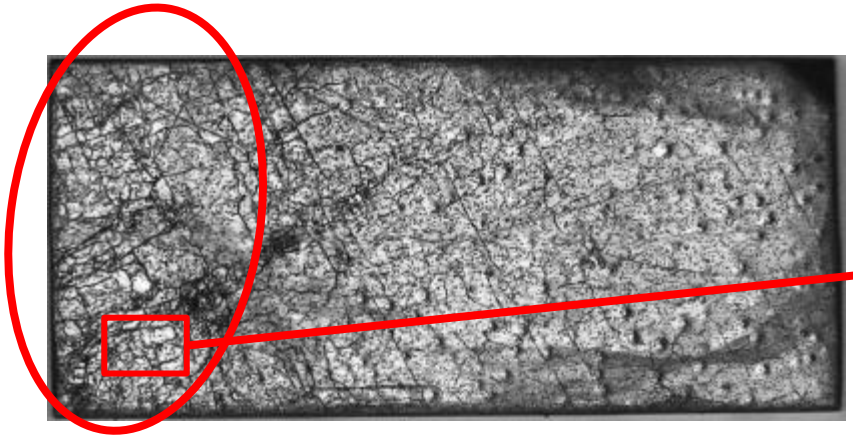
Thermo-migration mechanism of Te inclusions



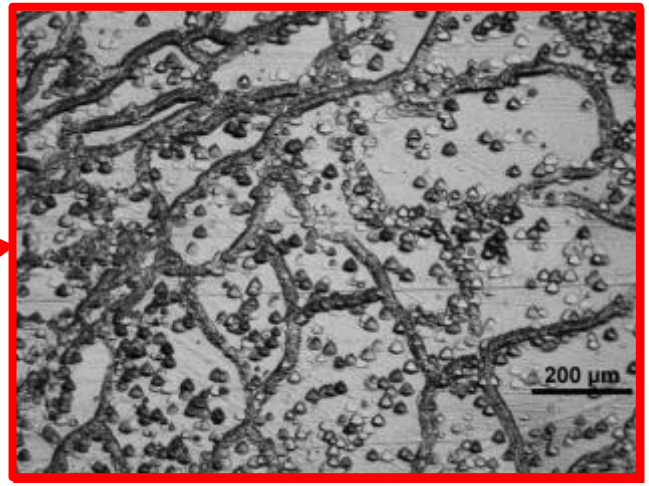
Low temperature → **High temperature**

Void

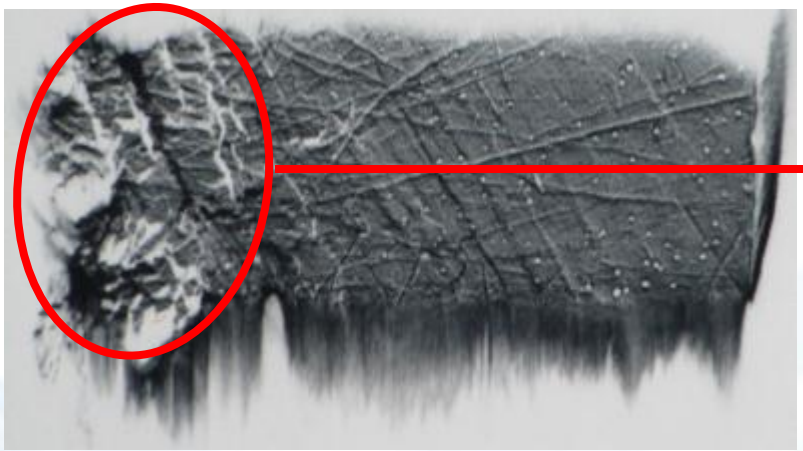
High-Density Dislocation Pits in VB Grown CdMnTe Crystal



High density of dislocation pits lined up along sub-grain boundaries. Such dislocations extend deep into the crystalline bulk.



Pyramidal etch pits on (111)B surface formed cellular structures.

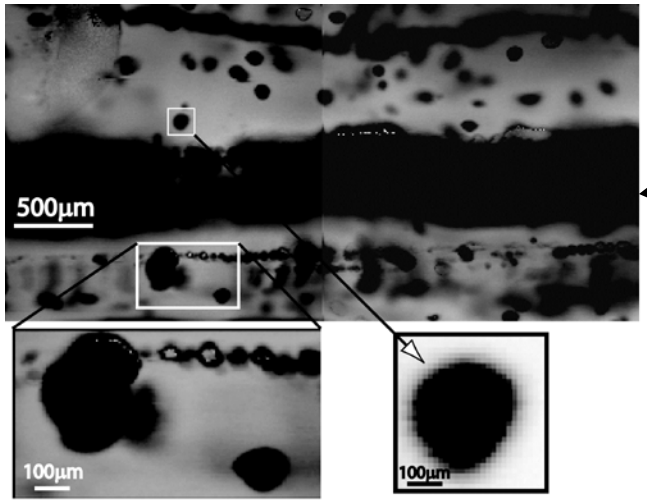


XRT image of a polished CMT crystal

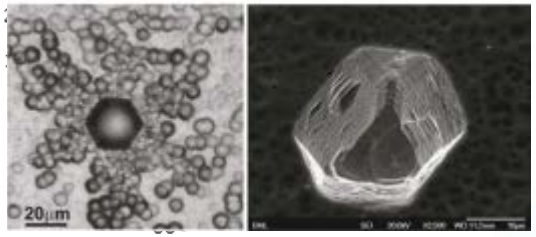
Sub-grain boundaries extending across the crystal thickness produced the distorted X-ray image.

Charge Losses for VB Grown CdMnTe Detector

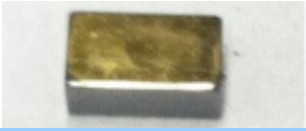
Scanned along the grain boundary area



Large size Te inclusion



5x5x12 mm^3



CMT:In detector
Resistivity: ~10^{10} Ω-cm
μτ value: ~$5x10^{-3}$ cm^2/V
X-ray energy: 25 keV

- **Dislocation lines and big inclusions were observed in VB grown CdMnTe crystals.**
- **No metal remnant in the core.**

- ❑ **Good charge collection at defect-free regions;**
- ❑ **Big Te inclusions or star-shaped defects trap charges.**

Summary

- Different types of structural defects (e.g. sub-grain boundaries, dislocations and Te inclusions) present in commercial-grade CdZnTe and CdMnTe crystals;
- Dislocation etch pits usually align along the sub-grain boundaries and possibly the direction of slip planes;
- Traced dislocation lines stretching deep inside the bulk of the crystal and representing walls of dislocations;
- Six-pointed features are randomly distributed inside annealed crystals; they are likely generated by the reaction of Cd atoms and Te inclusions during Cd-annealing;
- Both simulations and experiments indicate that the six-pointed features can seriously affect the charge collection efficiency and hence, degrade the performance of individual pixels and overall device quality.

Acknowledgement

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~:Thank you:~