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Study on Floating-zone-grown CdMnTe Crystals for Radiation-Detector Applications

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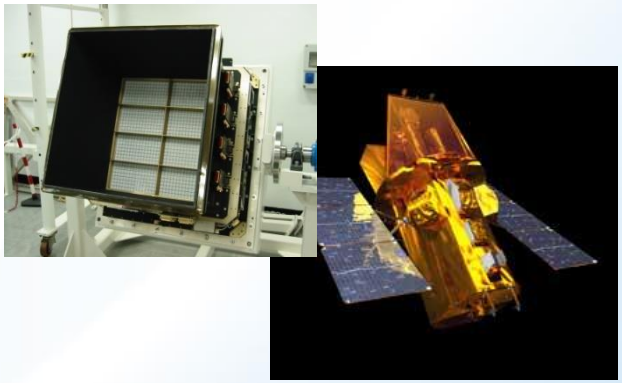
Outline

- **Background and motivation:** Explore a new approach, the modified floating-zone technique, to grow CdMnTe crystals for radiation detector applications
- **Infrared (IR) transmission measurements**
- **White-beam X-ray diffraction topography (WBXDT) measurements**
- **Current-Voltage (I-V) measurements**
- **Low-temperature PL and PICTS measurements**
- **Summary**

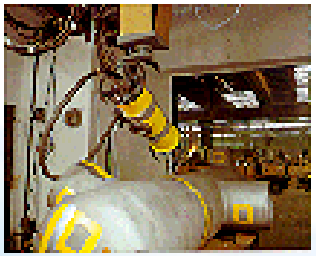
Semiconductor room temperature X-ray and gamma ray detectors ––– A wide range of applications

Nonproliferation and National Security

Medical diagnostics



Space and astrophysics



Industrial process monitoring

Key properties for room temperature X-ray and gamma-ray detector materials

- High atomic number (Z)

Cross section for photoelectric absorption is Z^n, where $4<n<5$

- Suitable band gap (E_g) = 1.5 eV - 2.2 eV

- Good mobility-lifetime product ($\mu\tau$) of charge carriers

Previous efforts were mainly focused on CdZnTe.

Recently CdMnTe (CMT) material, possessing the above merits as well, was found to be a promising material for this application.

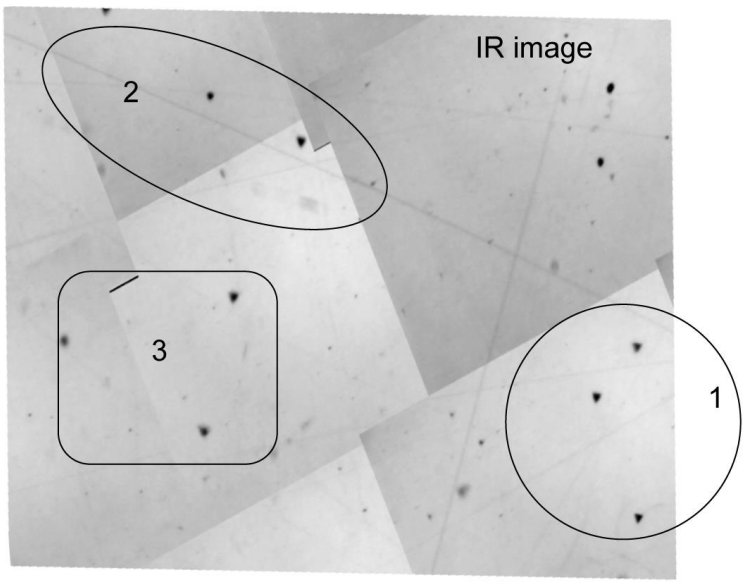
Why is CdMnTe (CMT) a promising material for fabricating room-temperature radiation detectors?

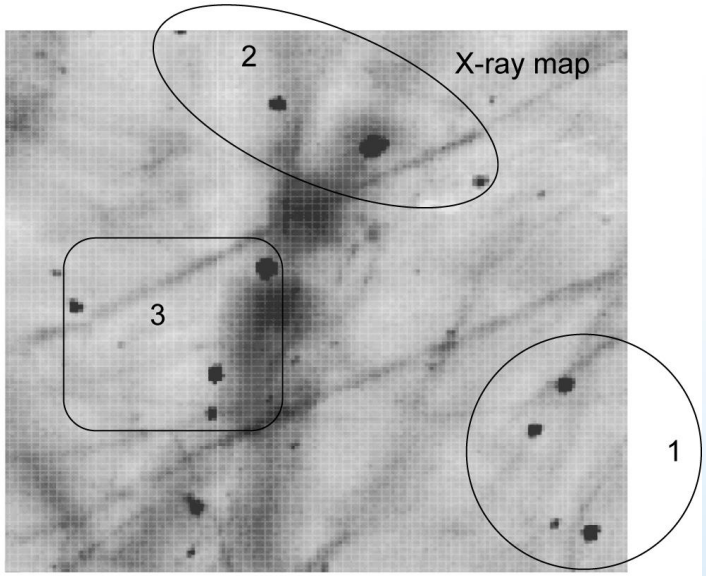
- **Potential advantages of CdMnTe over the current leading material, CdZnTe**
  - Good homogeneity
    - Segregation coefficient of Mn is ~1 in CdTe (1.35 for Zn)
    - Possibility to grow large-area uniform single crystal
  - Alloy mole fraction (13 meV/[%Mn])
    - 50% less of Mn than Zn in CdTe in order to achieve the same band gap

CdMnTe material can be a good candidate for X-ray and gamma-ray room-temperature detectors.

Material defects limit the development of CdMnTe detectors

An example: Effects of Te inclusions on CdTe-based detector performance

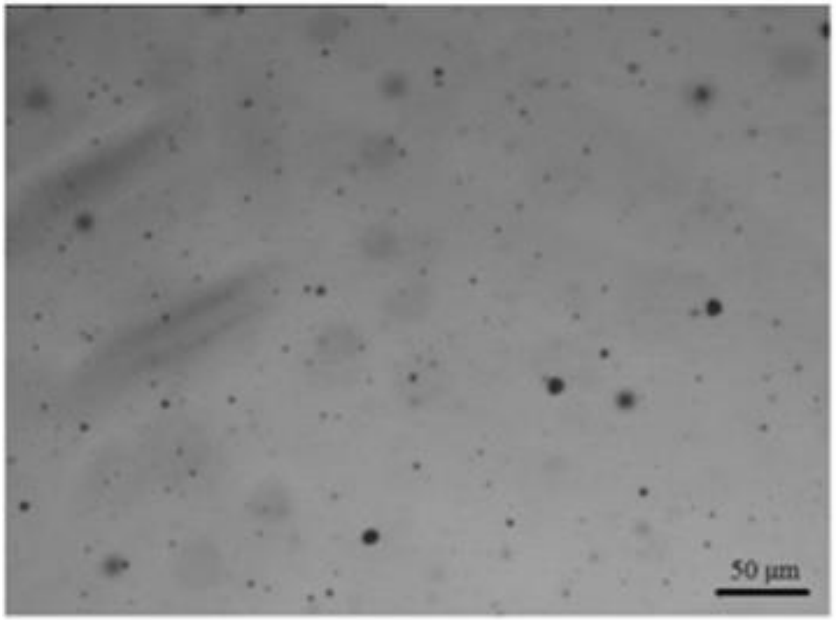


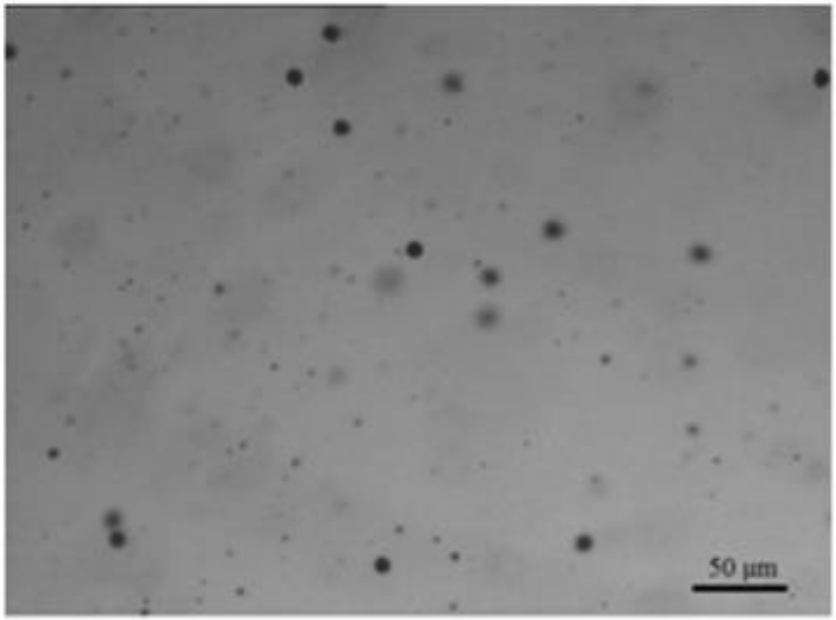


- Tellurium inclusions and other extended defects (e.g., dislocations) are found in typical CdMnTe crystals
- These defects are less important in thin detectors, but their role is critical for thick devices

Most of bulk-crystal growth attempts for CdMnTe have been accomplished with various Bridgman methods

Te inclusions are common in these crystals



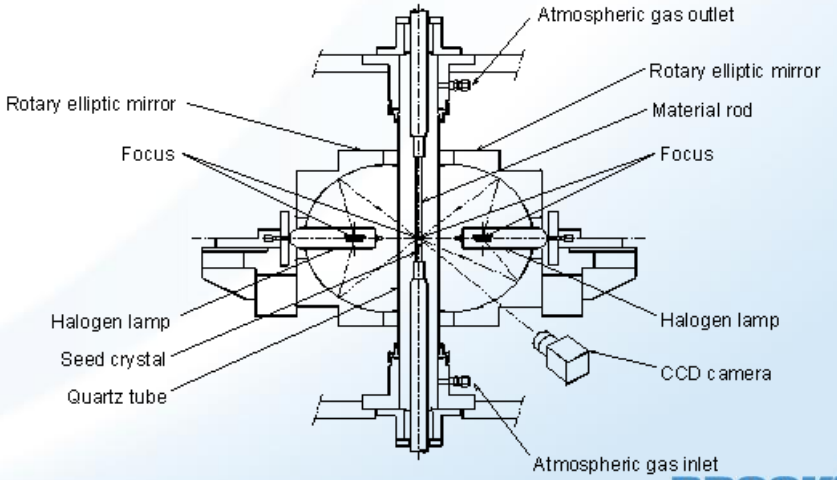


Representative Infrared (IR) transmission images from a Bridgman-grown CdMnTe sample. (a) without excess Te, and (b) from a sample with 1.2 at% excess Te.

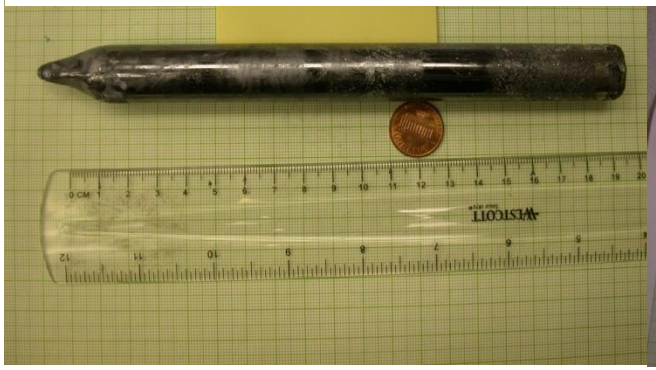
* J. Zhang et. al., Phys. Status Solidi C, 1–4 (2014)

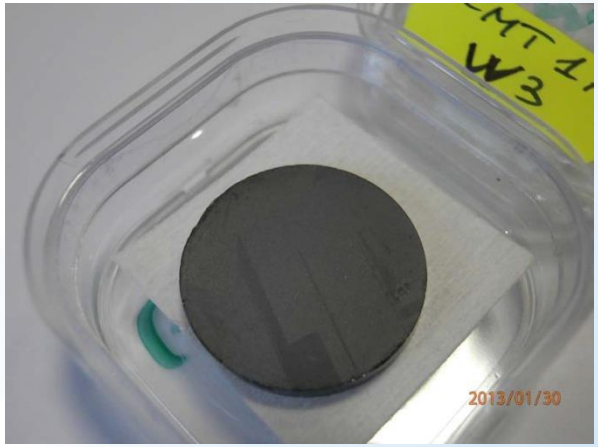
Our efforts to explore new growth approach to improve the crystal quality of CdMnTe

Modified floating zone (MFZ) technique



CdMnTe ingots grown by the modified floating-zone (MFZ) technique

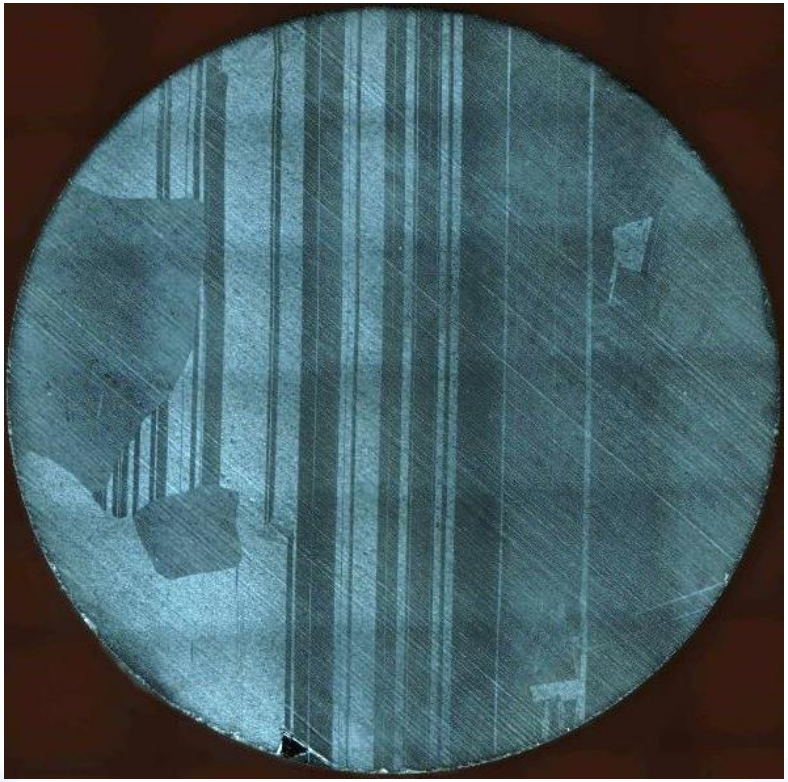




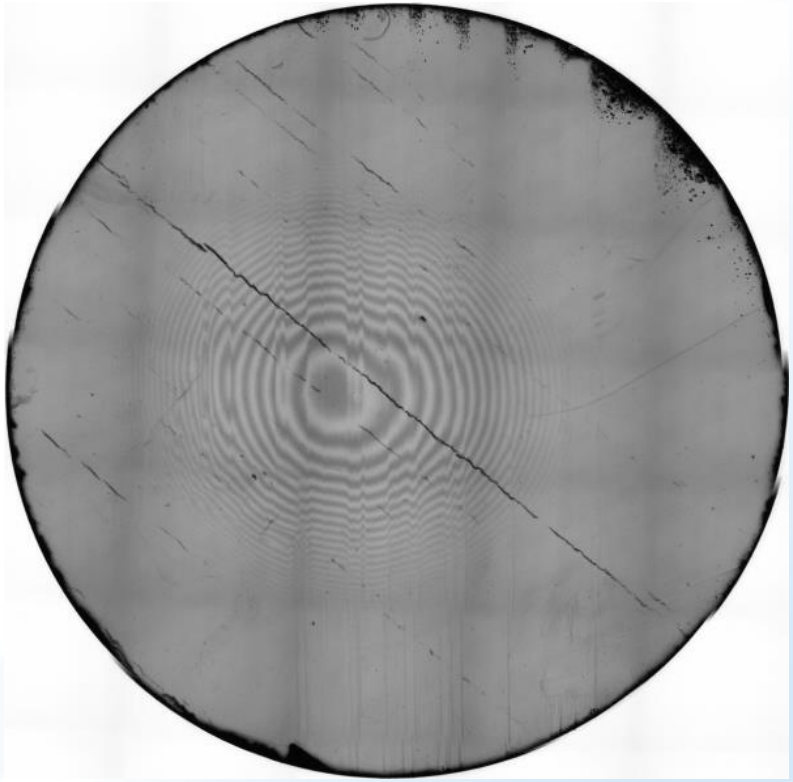
Photographs of CdMnTe ingots grown by the MFZ technique. A cross-section of a wafer cut from the ingots is shown as well.

No Te inclusions in as-grown CdMnTe crystals by MFZ ––– a new and distinct feature, compared to CdMnTe grown by Bridgman methods

Morphology of a representative MFZ-grown CdMnTe

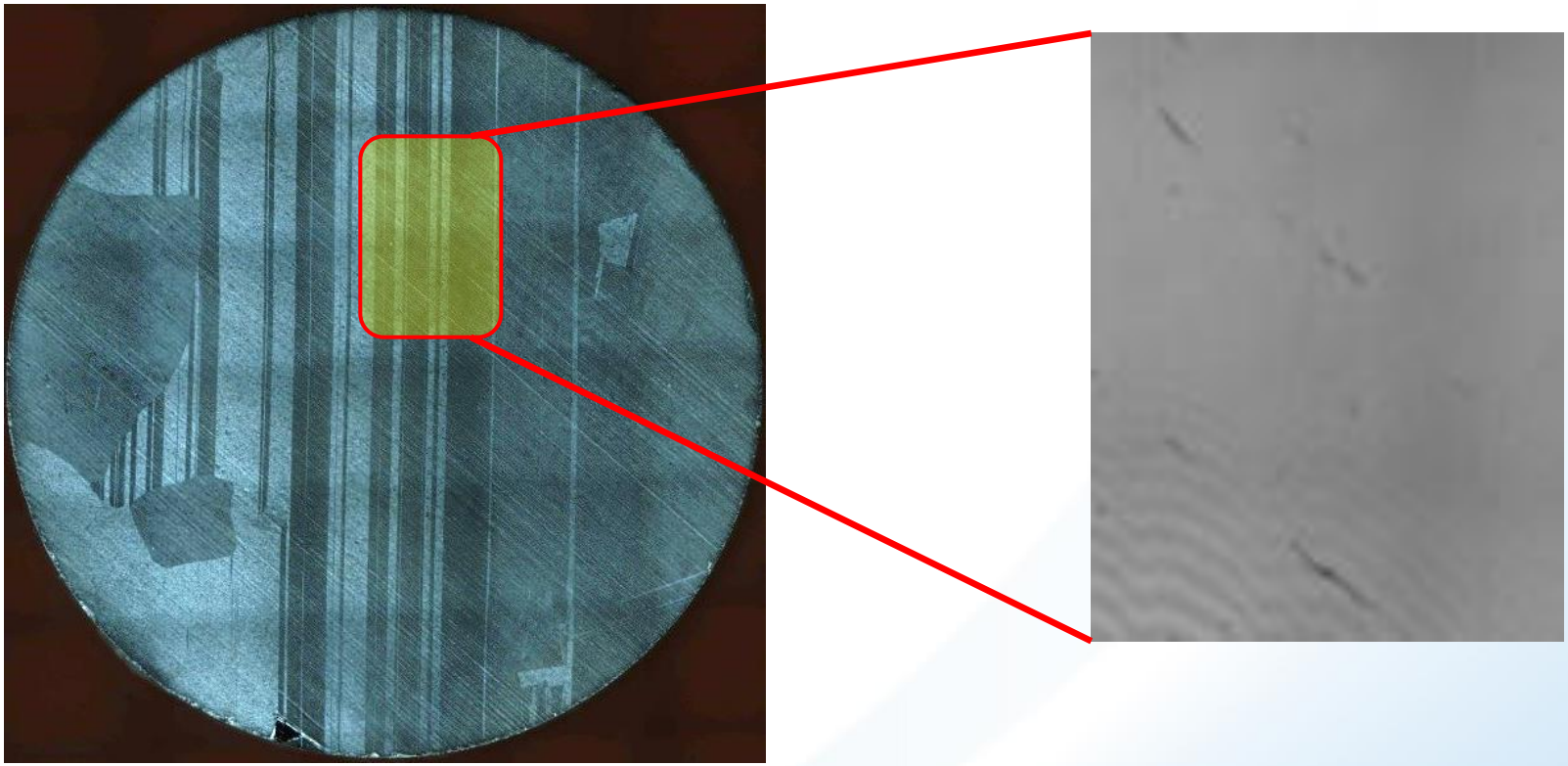


Polarized light microscopy image



Infrared (IR) transmission image

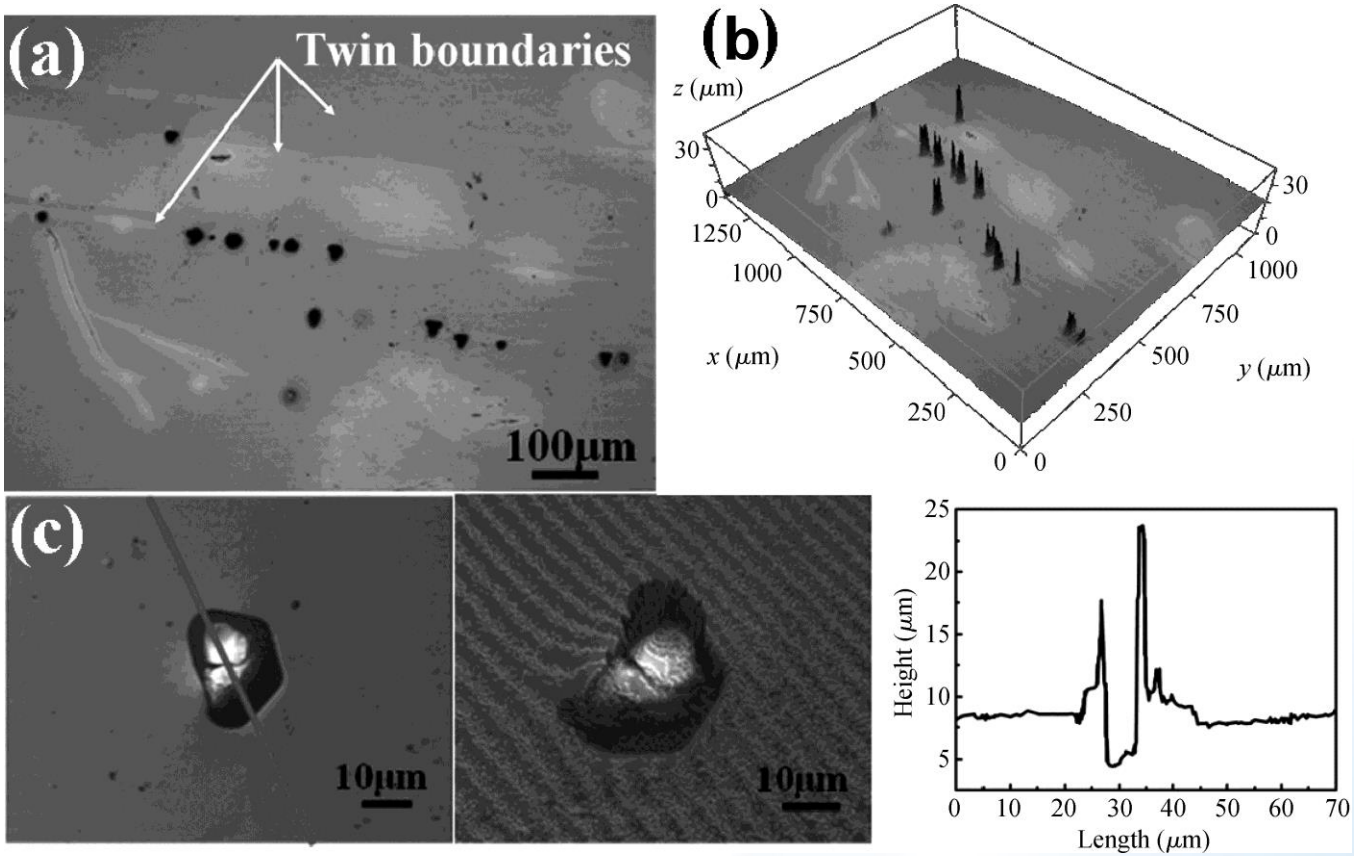
Even twin boundaries provide energetically-favorable sites for the formation of inclusions, no Te inclusions were observed along twins in as-grown MFZ CdMnTe crystals



Polarized light microscopy image

Infrared (IR) transmission image

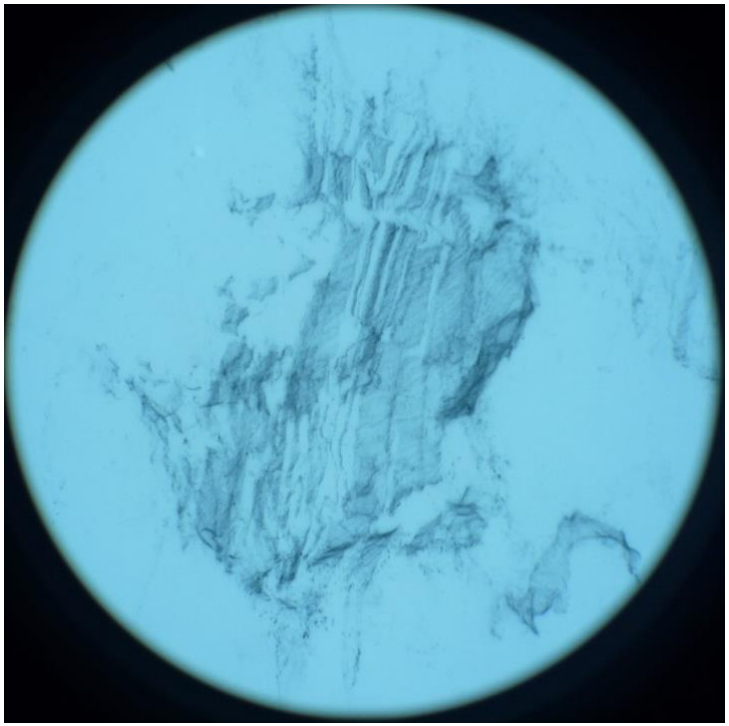
In contrast, twin boundaries are usually decorated by Te inclusions in Bridgman-grown CdMnTe crystals

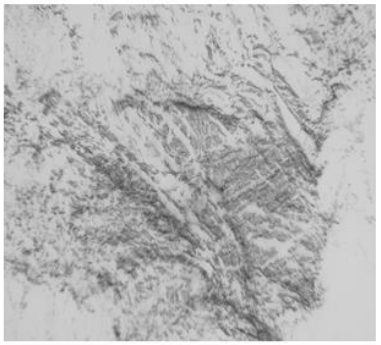


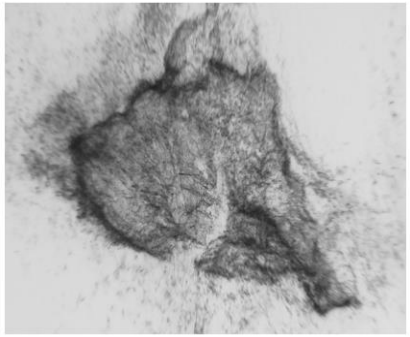
Morphology of twins and decorated Te inclusions shown by a laser confocal microscope

* Y. Du et.al., Journal of Semiconductors, 34, 043003-1 (2013)

Crystalline quality of as-grown MFZ CdMnTe crystals



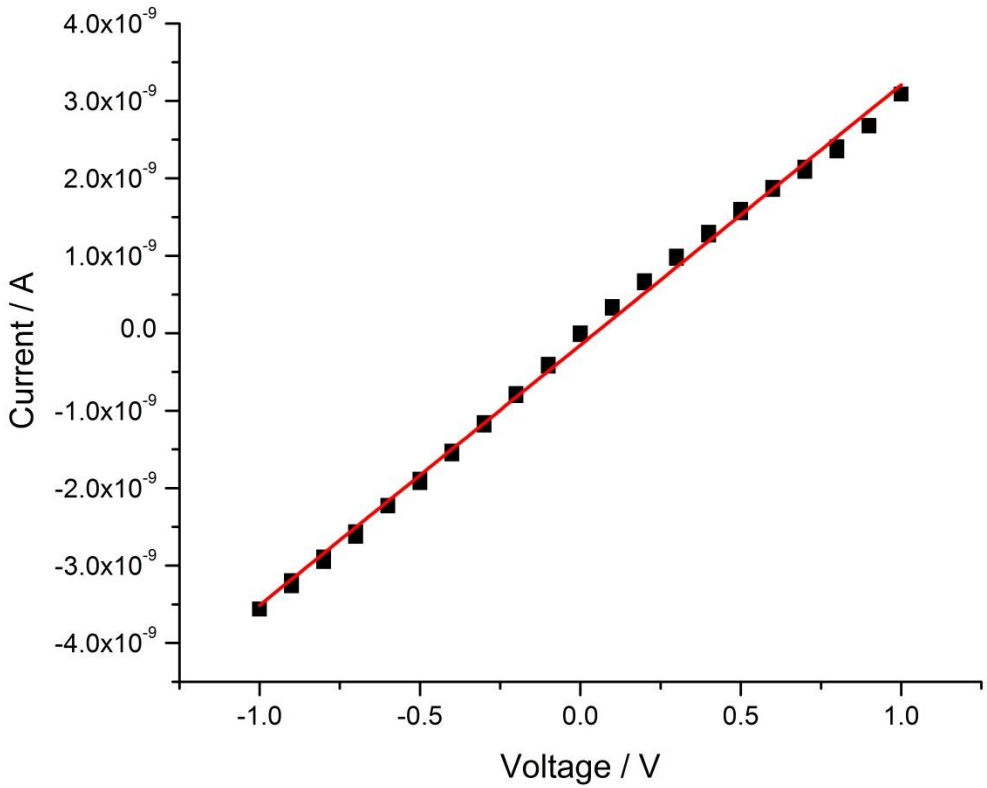




White-beam X-ray diffraction topography (WBXDT) of MFZ-grown CdMnTe crystals

A high stress field, causing the lattice distortion, exists within the MFZ-grown CdMnTe crystals. This originates from the **very large temperature gradient** near the liquid/solid growth interface during the MFZ growth process.

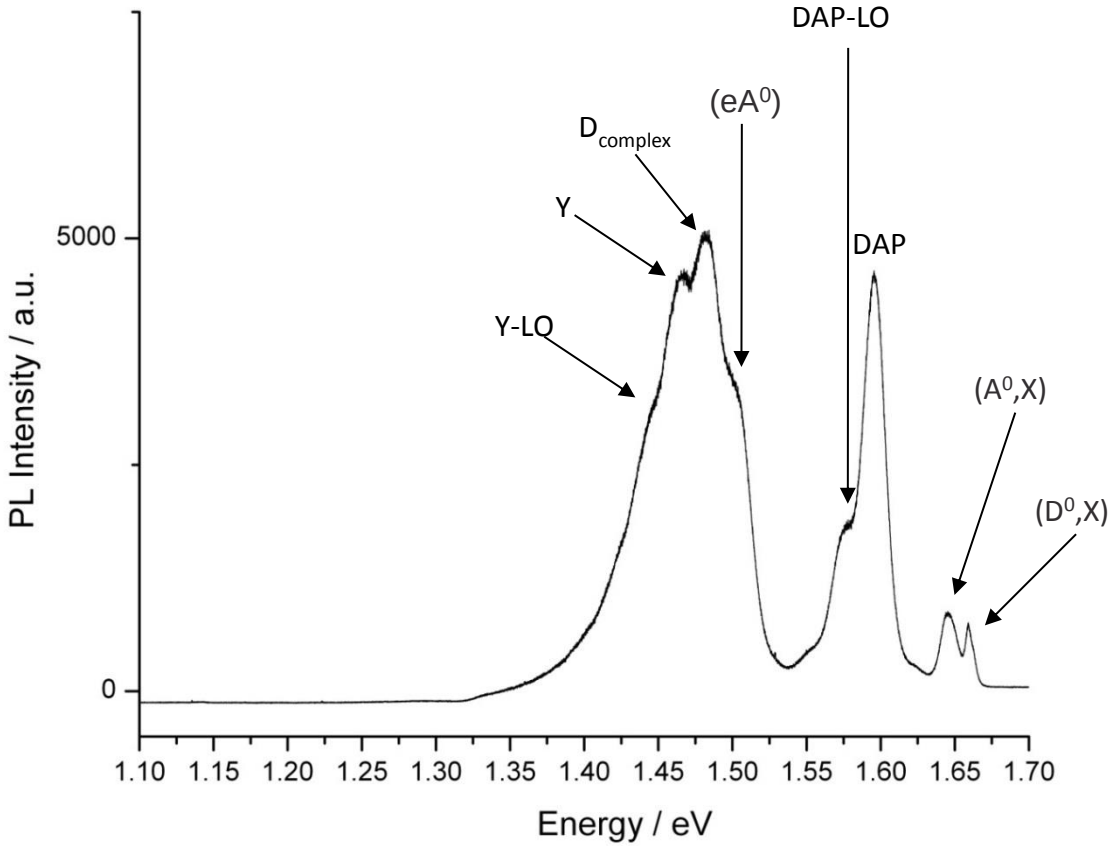
Resistivity of as-grown MFZ CdMnTe crystals



Current-Voltage (I-V) curve of a typical MFZ-grown CdMnTe wafer.

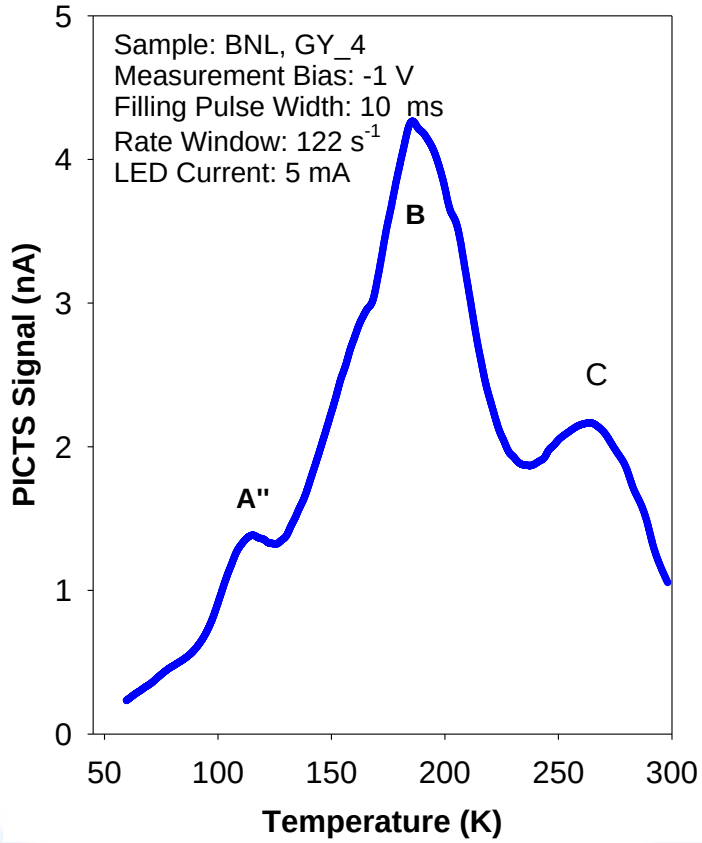
The corresponding resistivity is 4.2×10^9 Ω-cm

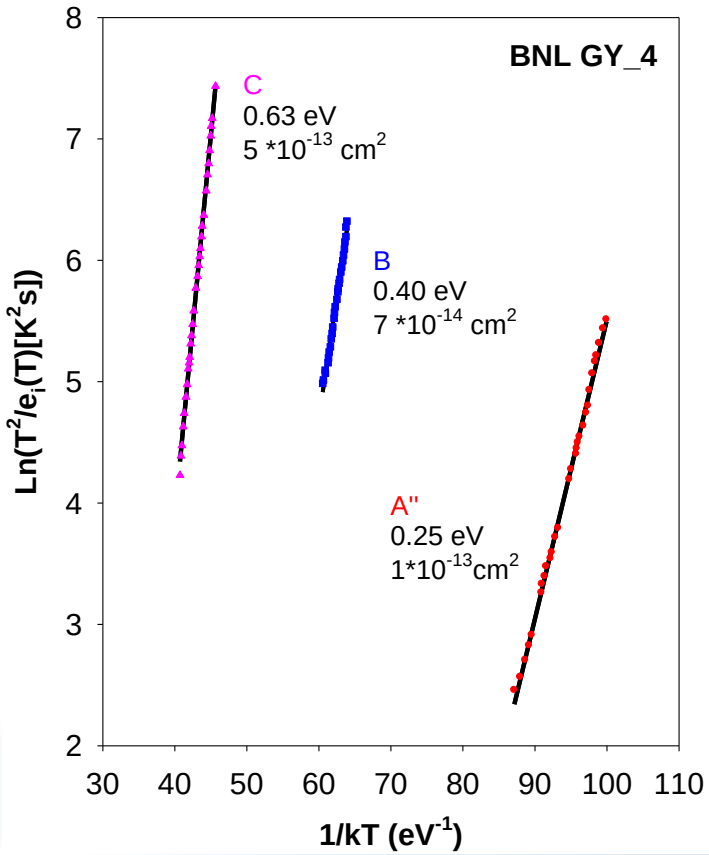
Low-temperature photoluminescence (PL) study of MFZ-grown CdMnTe crystals



A representative PL spectrum of MFZ-grown CdMnTe crystals. The PL spectrum was measured at 4.2 K.

Photo-induced current transient spectroscopy (PICTS) study of a typical MFZ-grown CdMnTe crystal





Summary

- We explored a new approach, the modified floating-zone technique, to grow CdMnTe crystals for radiation detector applications
- We obtained as-grown CdMnTe crystals totally free of Te inclusions, which represents a new and distinct feature, compared to CdMnTe grown by Bridgman methods
- White-beam X-ray diffraction topography (WBXDT) measurements exhibit the existence of a high stress field within the MFZ-grown CdMnTe crystals
- We obtained a resistivity of 10^9 Ω-cm for as-grown MFZ CdMnTe crystals
- We used low-temperature PL and PICTS measurement to investigate MFZ-grown CdMnTe crystals and analyzed several related defect levels

Acknowledgement

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Thank you for your attention!

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