BNL-108503-2015-CP

Low-temperature photoluminescence analysis of CdTeSe crystals for radiation-detector applications

G. Yang
U. N. Roy, A. E. Bolotnikov, Y. Cui, G. S. Camarda, A. Hossain, and R. B. James

Presented at the 2015 Workshop of II-VI Materials
Chicago, Illinois
OCTOBER 5-8, 2015

October 2015

Nonproliferation and National Security Department
Radiation Detector R&D Group

Brookhaven National Laboratory
P. O. Box 5000
Upton, New York 11973
www.bnl.gov

U.S. Department of Energy
Defense Nuclear Nonproliferation research and Development NA-22

Notice: This manuscript has been authored by employees of Brookhaven Science Associates, LLC under Contract No. DE- SC0012704 with the U.S. Department of Energy. The publisher by accepting the manuscript for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

This preprint is intended for publication in a journal or proceedings. Since changes may be made before publication, it may not be cited or reproduced without the author's permission.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

2015 II-VI Workshop
October 05 - October 08, 2015, Chicago, IL

Low-temperature photoluminescence analysis of CdTeSe crystals for radiation-detector applications

G. Yang, U. N. Roy, A. E. Bolotnikov, Y. Cui, G. S. Camarda, A. Hossain, and R. B. James

Brookhaven National Laboratory, Upton, NY 11973, USA

October 7, 2015

BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

Outline

- **Goal:** Understanding the changes of material defects in CdTeSe following annealing

- **Experimental results and discussions**

❖ Infrared (IR) transmission microscopy

❖ Current-voltage measurements (Highlight: Improvement of resistivity of un-doped crystals after annealing)

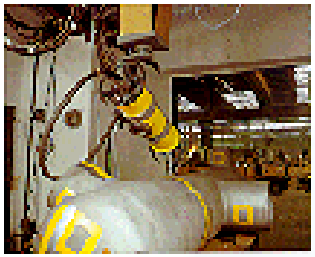
❖ Low-temperature photoluminescence (PL) spectrum of as-grown and annealed samples

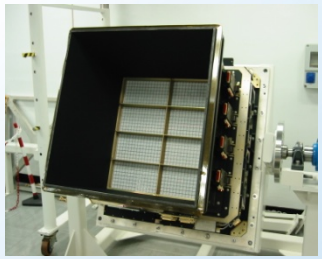
- **Summary**

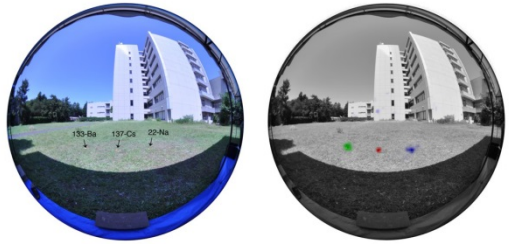
Background and motivation

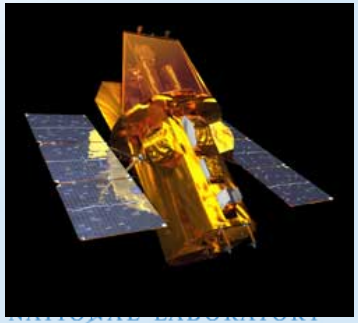
Room-temperature Semiconductor Radiation Detector Technology

- Nonproliferation and National Safety
- Medical imaging
- Industrial process monitoring
- Environmental surveys
- Space and astrophysics





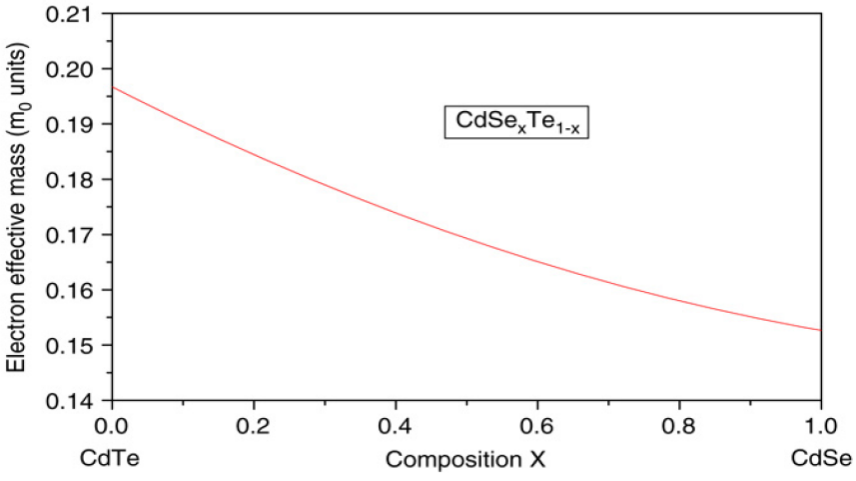




Vibrant R&D --- driven by many applications

In particular, exploration of potential alternative materials to surpass current CdZnTe

CdTeSe (CTS) is expected to be an ideal candidate for gamma-ray detectors *



L. Hannachi et al., Superlattices and Microstructure 44 (2008) 794.

- **Better solution hardening with Se**
- **Better Compositional uniformity (segregation coefficient is close to unity)**

* U. N. Roy et al., Proc. of SPIE Vol. 9213, 92130F (2014).

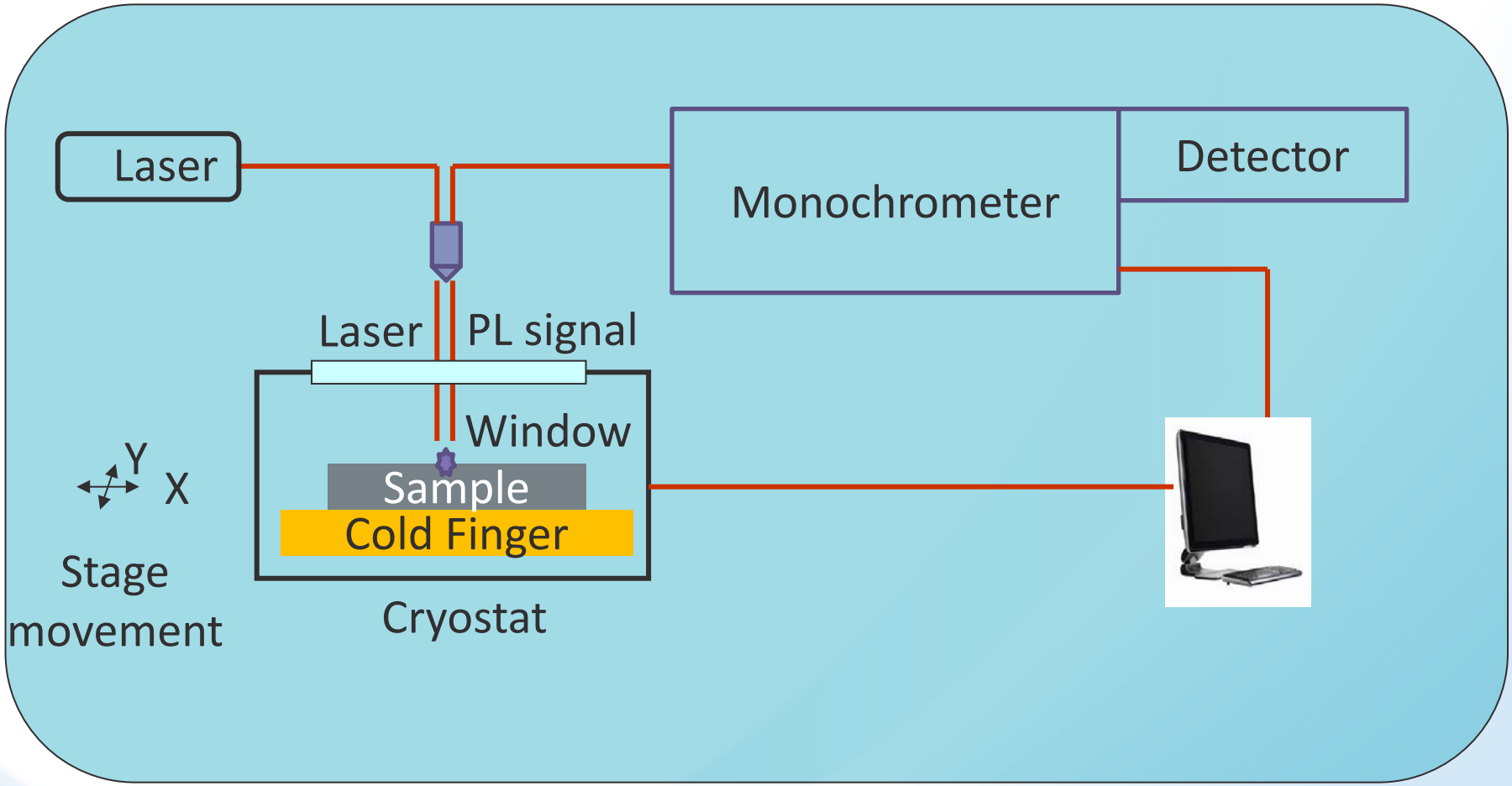
Material defects need to be better resolved to improve the properties of CdTeSe

Typical Issues

- Existence of Te inclusions
- Relatively low resistivity

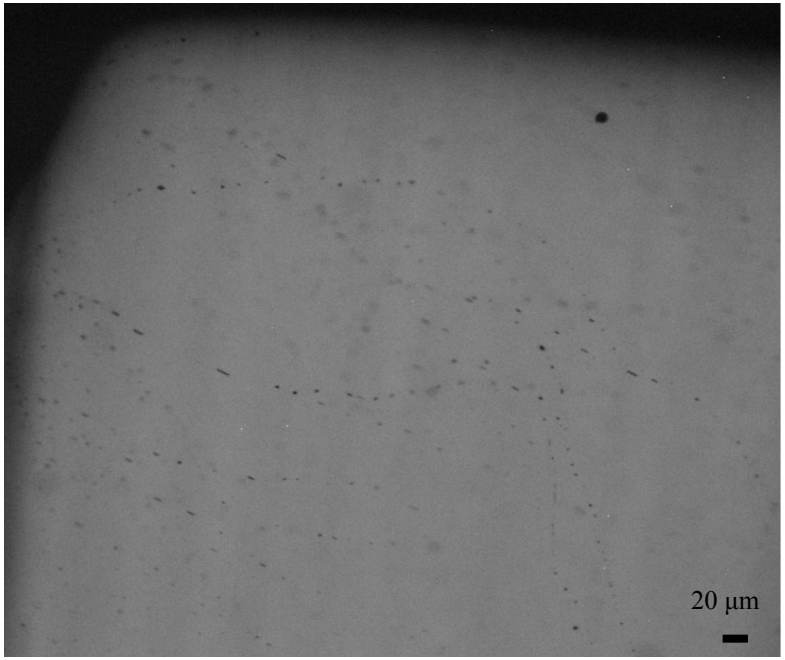
Here, we annealed as-grown un-doped CdTeSe crystals and compared the changes of the material properties with different characterization techniques, including low-temperature photoluminescence (PL) spectroscopy, current-voltage (I-V) measurements and infrared (IR) transmission microscopy.

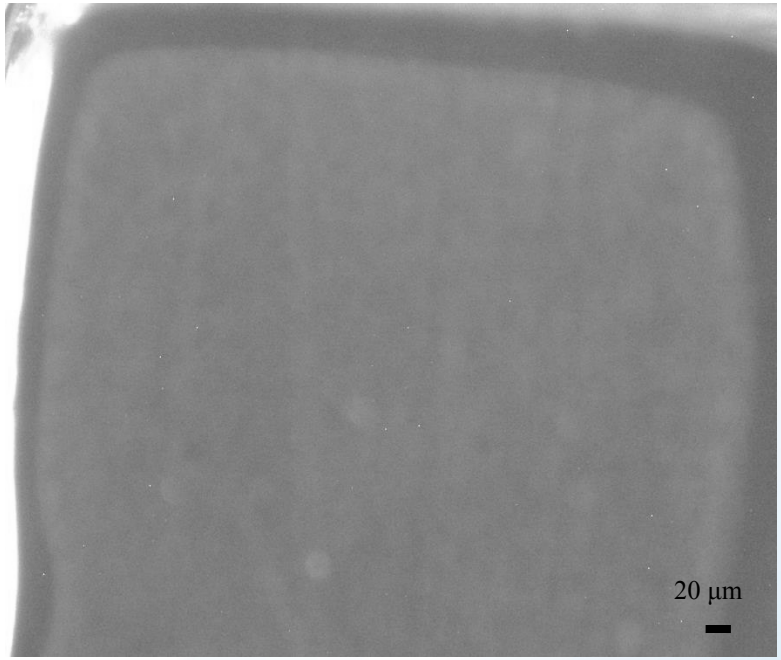
Low-temperature PL technique to investigate both as-grown and annealed CdTeSe crystals



PL System Layout

Changes of Te inclusions of CdTeSe after annealing



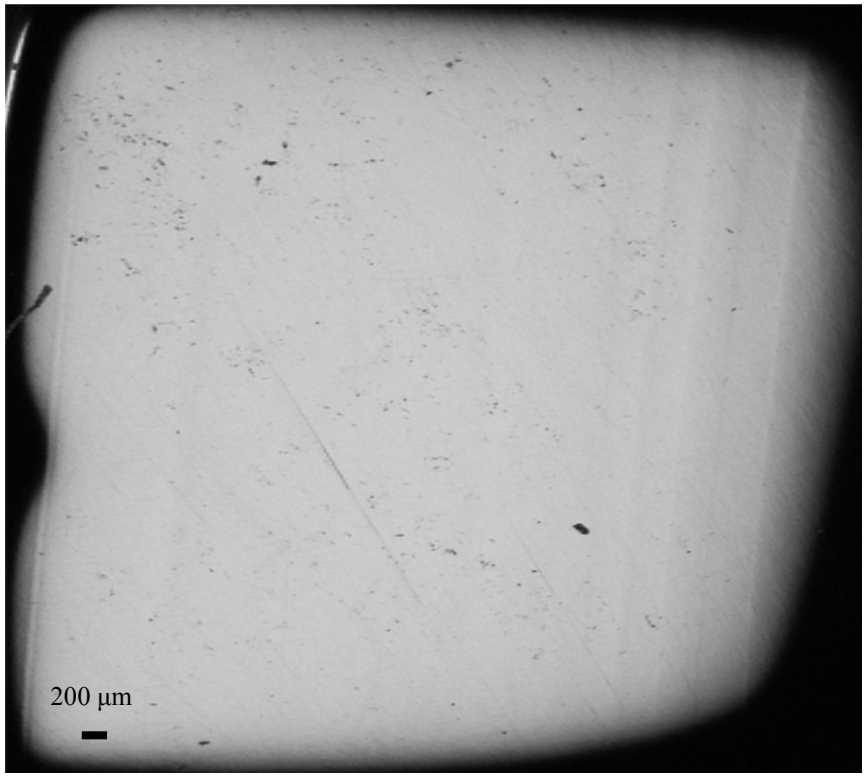


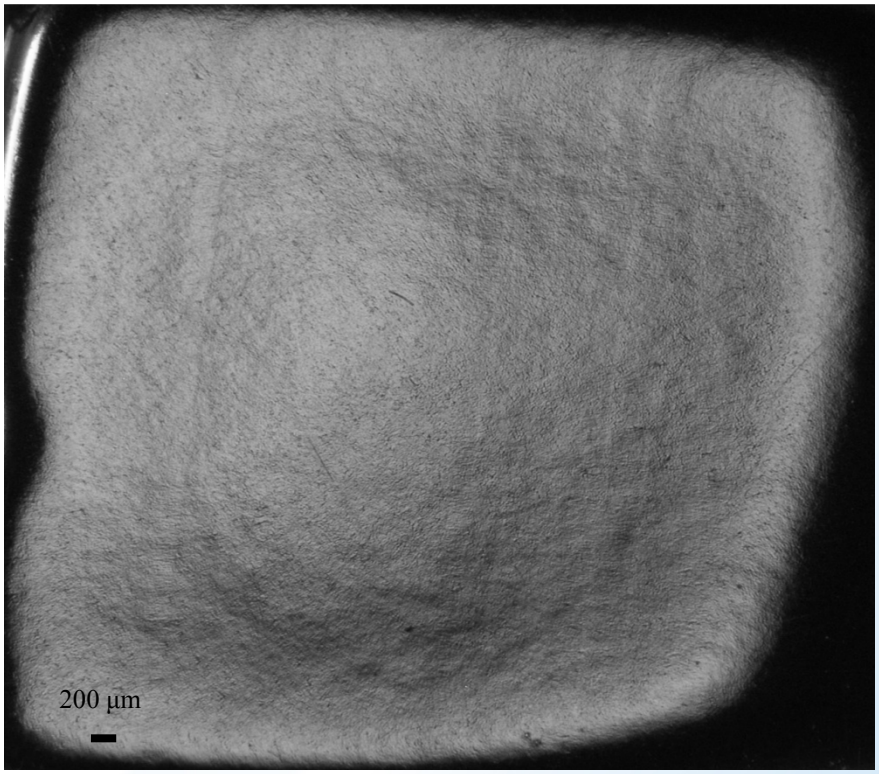
IR transmission images

Te inclusions were completely eliminated!

Annealing conditions: 750 ^{0}C, saturated CdSe and Zn vapor environment

Change of surface morphology



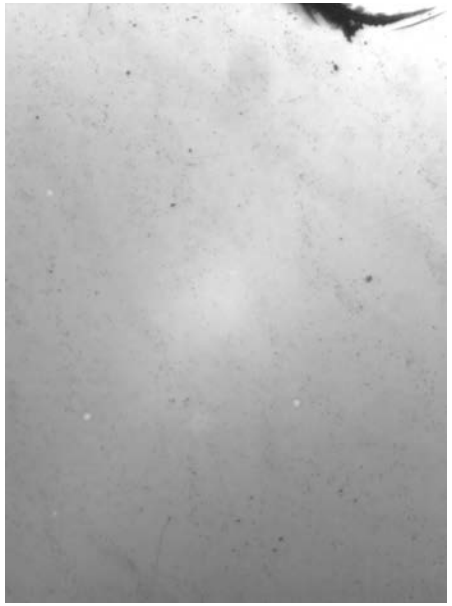


Unlike CdZnTe, we did not observe parallel patterns formed after annealing in Zn vapor (see the following slide for comparison)

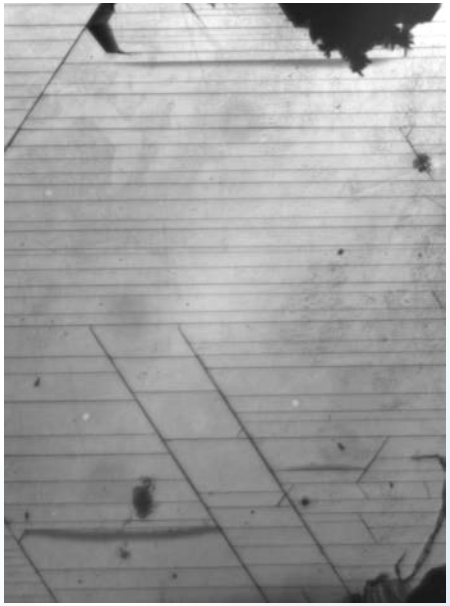
Annealing of CdZnTe under controlled Cd pressure and Zn over-pressures

Surface morphology

Before annealing



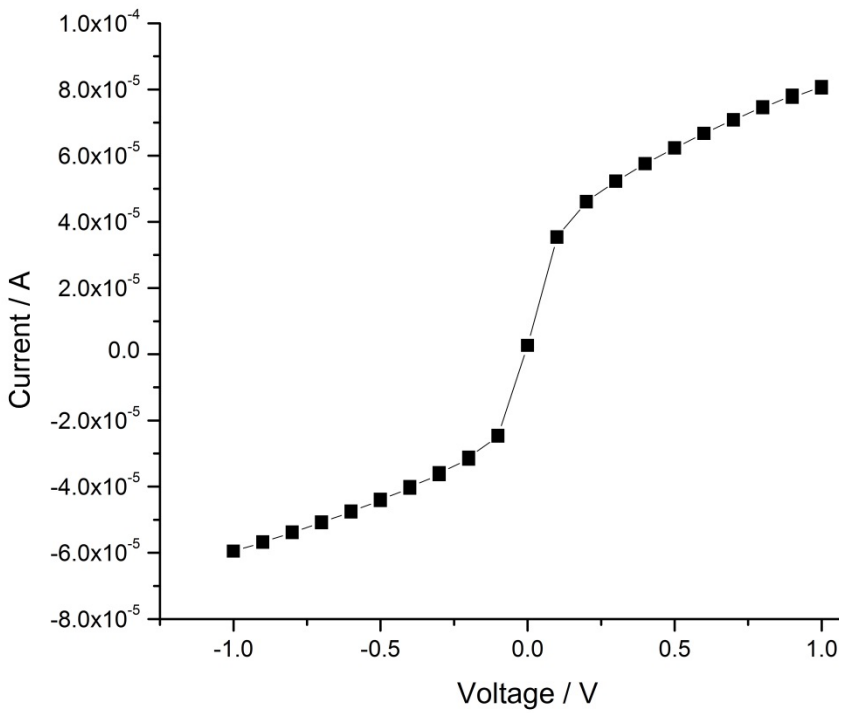
After annealing

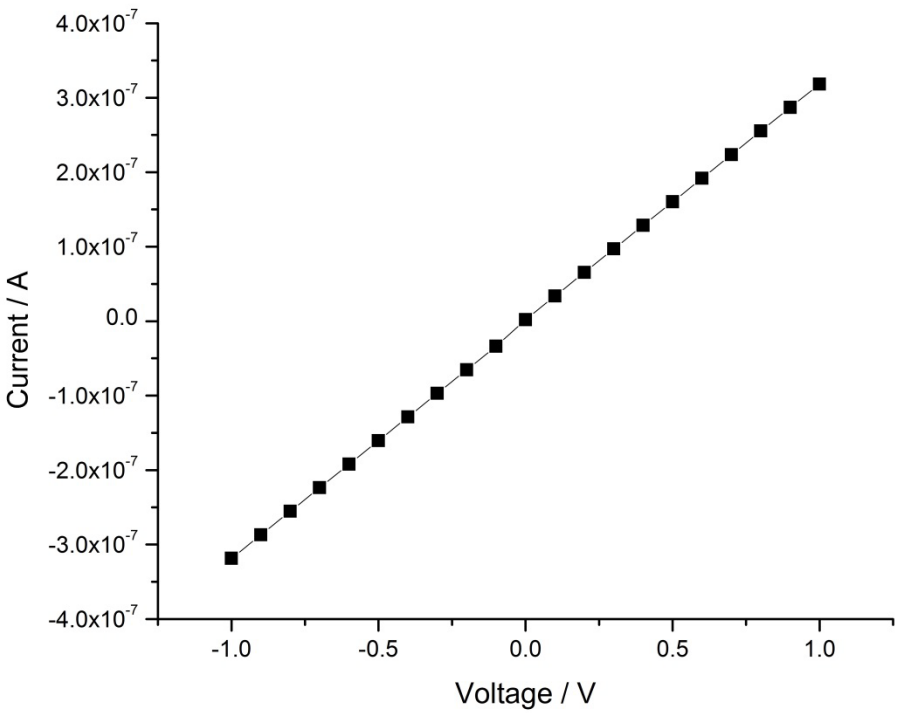


Condition: 750 ℃, Cd and Zn overpressure

Parallel line patterns were formed on the surfaces. They look like newly-formed twins.

Change of resistivity of CdTeSe after annealing





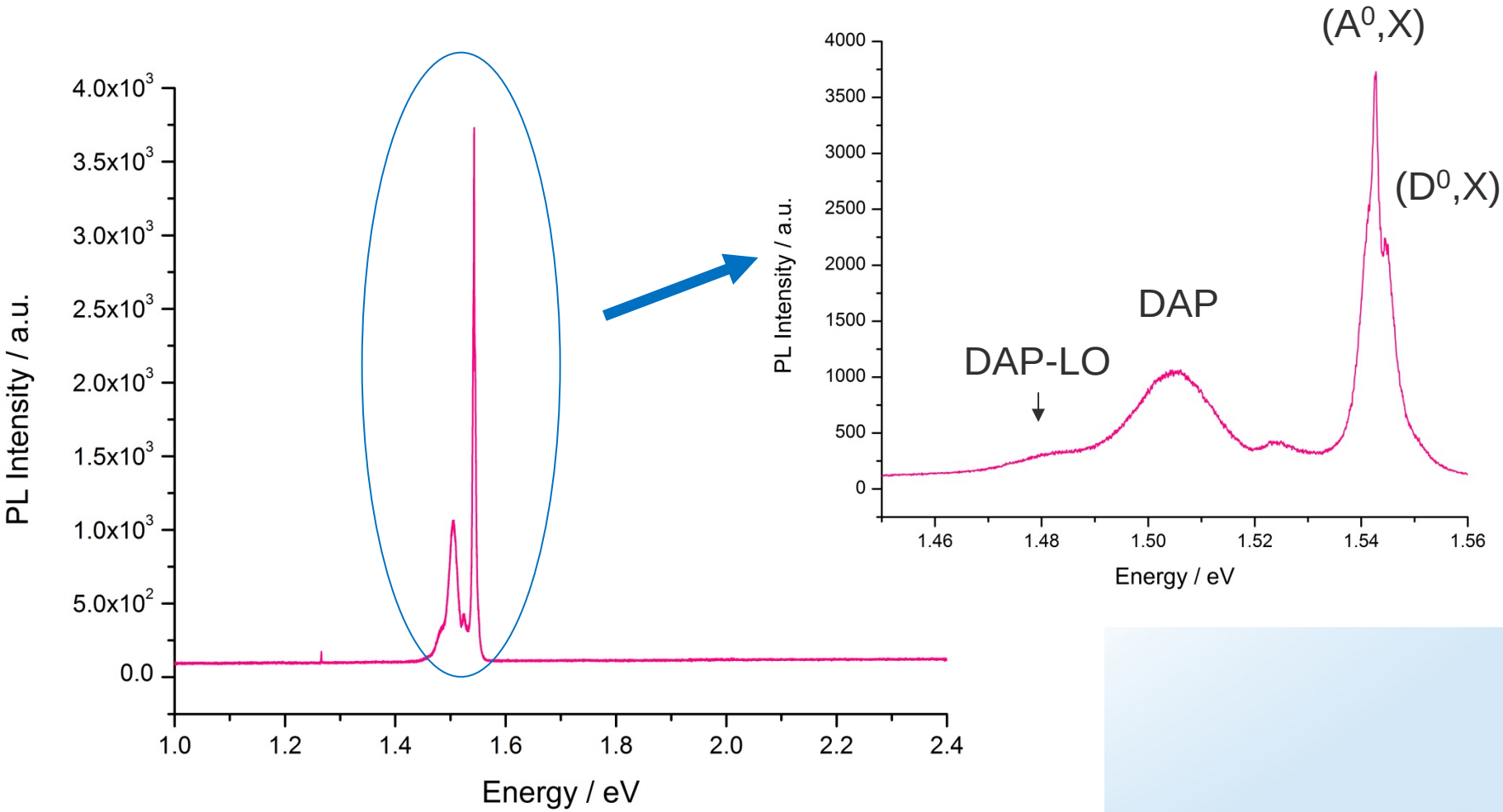
Before annealing

After annealing

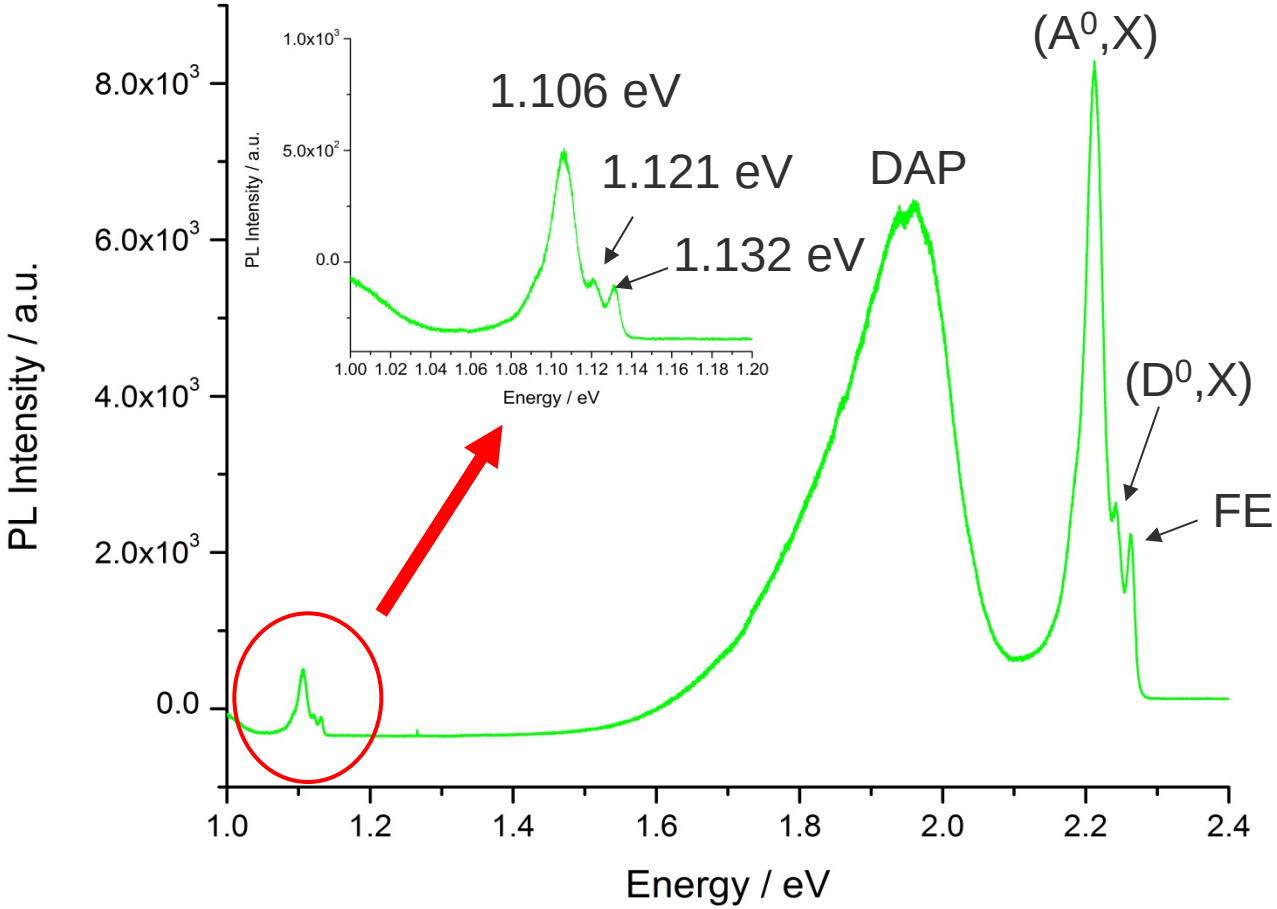
Three orders higher, from 8 x 10^3 Ω-cm (un-doped, as-grown) to 2 x 10^6 Ω-cm (annealed)

Annealing conditions: 750 ^{0}C, saturated CdSe and Zn vapor environment

4.2-K PL spectrum of as-grown CdTeSe crystal (un-doped)



4.2-K PL spectrum of annealed CdTeSe crystal (un-doped)



Interesting emission peaks around 1.1 eV.
Related to large resistivity improvement?

Findings and discussions

Three peaks around 1.1 eV are distinguishable -- - 1.106 eV, 1.121 eV and 1.132 eV

Prior PICTS and CL measurements show that 1.1 eV peaks are electron traps. The possible origins are:

(1) Te vacancies*: May be true since no 1.1 eV peaks are present in Te-rich as-grown crystals.

(2) Zn-related defects / Dislocations induced by Te inclusions*: also consistent with the introduction of Zn during annealing

The presence of multiple peaks indicates both assignments may contribute to the 1.1 eV emissions.

* A. Castaldini, et al., J. Appl. Phys. 94, 3135 (2003).
K. H. Kim, et al., J. Korean Phys. Society 62, 623 (2013).

Findings and discussions (continued)

- Free exciton (FE) peak appears after annealing while the donor-bound exciton (D^0, X) peak shifts towards higher energy side, indicating the crystalline quality is improved with the introduction of Zn

- The relative intensity of the donor-acceptor pair (DAP) emission becomes much stronger after annealing, which may be related to impurities released from the original Te inclusions during annealing

Summary

- Resistivity of un-doped CdTeSe was improved three orders after annealing in controlled CdSe and Zn vapor environment
- Te inclusions of different sizes were completely eliminated during the process
- Three peaks around 1.1 eV in the PL spectra appear after the annealing process, possibly related to the improvement of resistivity
- Free-exciton (FE) peak appears and the relative intensity of donor-acceptor pair (DAP) emission becomes stronger after annealing
- More work is going on to understand the change of the electrical properties and to optimize the annealing conditions

Acknowledgement

This work was supported by U.S. Department of Energy/NNSA, Office of Defense Nuclear Nonproliferation Research and Development, DNN R&D.

Thank you for your attention!