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CdTeSe Crystals for Gamma-Ray Detectors

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Project overview

- $CdTe_xSe_{1-x}$ (CTS) is expected to be an excellent candidate as a gamma-ray detection material
- Density is ~5.8 gm/cc (nearly the same as CZT and CdTe)
- The effective mass of the electron is less than CdTe. Thus, higher electron mobility and μτ product are expected for $CdTe_xSe_{1-x}$. Hence, enhanced charge transport properties are expected.
- The segregation coefficient of Se in the CdTe host is nearly unity, ensuring the compositional uniformity throughout the whole ingot, both in the axial and radial directions, resulting in higher yield and reduced cost of production.
- Se is known to be an effective solid-solution hardening component for reduced/absence of sub-grain boundaries and networks.

Goal

- Growth of as-grown detector-grade $CdTe_{0.9}Se_{0.1}$ (CTS)
- Growth of large ingots with uniform composition throughout the whole ingot, hence a drastic reduction of the production cost
- Characterization of the grown ingots by X-ray topography, IR transmission microscopy, compositional uniformity by X-ray fluorescence mapping, photoluminescence, high resolution X-ray response mapping, I-V, and charge-transport measurements
- Detector fabrication and investigations of device performance

Importance of the proposed work

Availability of large-volume CdZnTe detectors is hindered by the technological problems of growing high-quality crystals, associated with poor thermo-physical properties.

Present day CdZnTe contains:

i) High concentration of Te inclusions/precipitations, typically ranging from 2-7x10^5 cm^{-3}.

ii) Large concentration of sub-grain boundaries.

iii) Compositional non-homogeneity (Segregation coefficient of Zn is 1.3).

CTS on the other hand is more compositionally homogeneous due to near-unity segregation of Se in CdTe and the presence of much less sub-grain boundaries, hence a higher yield and lower cost of production are expected.

Technical approach

- Growth of detector-grade $CdTe_xSe_{1-x}$ by THM technique for room-temperature radiation detector applications
- Motivation for pursuing the growth by THM technique. Advantages include:

i) Low-temperature growth

ii) Less chance of incorporation of impurities from the crucible during growth

iii) Less/no chance of ampoule explosion

iv) Enhanced purity of the ingot

v) Less defects due to the lower growth temperature

Crystals were also grown by Bridgman technique for seed preparation and for comparison with THM ingots.

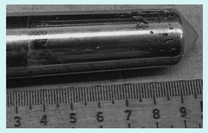
Extensive characterization of the as-grown ingots were carried out for feedback for successive growth runs to continuously improve the quality of the crystals.

Expected technical challenges

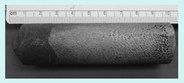
i) Growth of high resistivity (> 10^{10} ohm-cm) CTS.
ii) Reduced concentration of sub-grain boundaries
iii) Lower concentration of Te inclusions/precipitates in CTS crystals (one order of magnitude less than CZT).
iv) High compositional uniformity

Progress to date

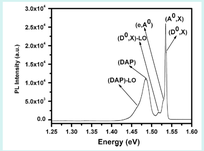
- Optimized THM growth process
- Grew various CTS crystals by THM with nominal Se concentration of 5, 7 and 10% with different In concentrations
- Grew various undoped CTS crystals by vertical Bridgman technique with nominal Se concentration of 5, 7 and 10%
- Characterized the grown ingots through X-ray topography, IR microscopy, X-ray and PL fluorescence mapping, low-temperature PL, high resolution X-ray response mapping, I-V, and charge-transport characterization and device fabrication



Typical CTS ingot grown by THM

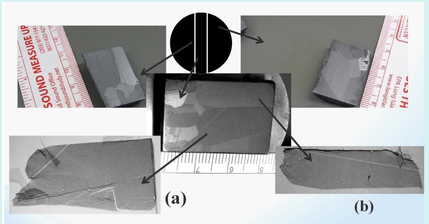


Typical CTS ingot grown by Bridgman technique



PL spectrum of as-grown CTS crystal at 4.2 K (grown by THM)

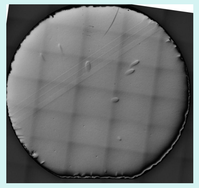
Structural evaluation:



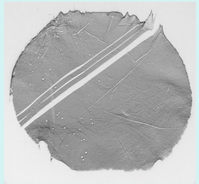
Longitudinal section of CTS ingot with nominal concentration of 10% Se grown by THM and X-ray diffraction topography of the grains (shown by the arrows).

Very few sub-grain boundaries were observed, and crystals were virtually free from a sub-grain boundary network. However, presence of sub-grain boundaries were observed for CTS ingots with 5% Se concentration grown by THM.

As-cut wafer



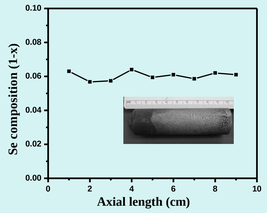
Polished wafer



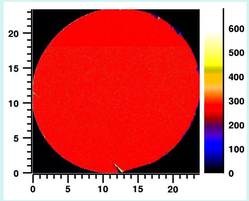
X-ray topography

Cross-sectional view of CTS (22-mm diameter) ingot with concentration of 5% Se grown by the Bridgman technique, and measured by X-ray diffraction topography.

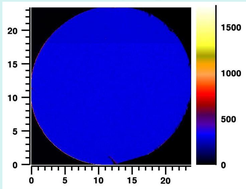
Compositional homogeneity:



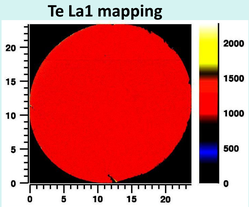
Se composition measured by EDS for typical CTS ingot with nominal concentration of 5% Se grown by the Bridgman technique.

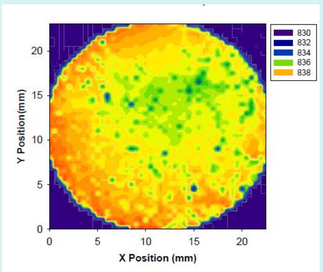


Cd La1 mapping



Te La1 mapping





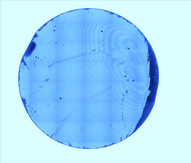
PL mapping at RT

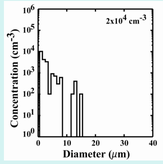
Se K_α mapping

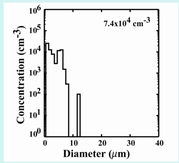
X-ray fluorescence and room-temperature PL mapping of the same wafer of as-grown CTS crystal (10% Se) (diameter ~23 mm) grown by THM

Bridgman grown CTS crystals also showed high compositional uniformity as measured by X-ray fluorescence and PL mapping.

Evaluation of secondary phases:



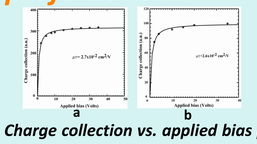




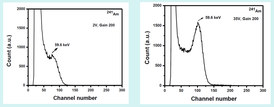
Typical IR transmission image of as-grown CTS (10% Se) wafer (~23-mm diameter and 6.65-mm thick) grown by THM, maximum and minimum concentration and size distribution of Te inclusions/precipitates in the ingot.

The average value of Te inclusions/precipitates observed in our CTS samples grown by THM and Bridgman techniques are found to be 5-8 times lower than conventional CZT.

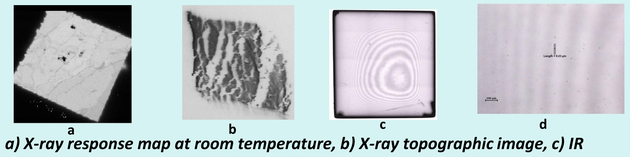
Charge transport characteristics and device performance:



Charge collection vs. applied bias plot at room temperature for a planar detector of dimension 6.5x6x1.8 mm^3 fabricated from as-grown CTS by THM with 5% Se concentration. a) For alpha-particle line, and b) for gamma-ray line of ^{241}Am source.

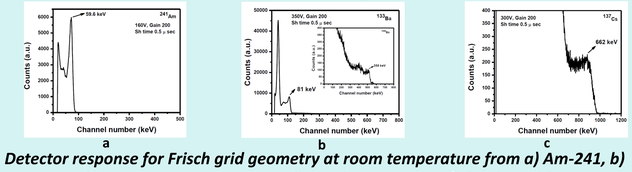


Room temperature detector response of the same planar detector for gamma line of ^{241}Am source. The resistivity of the sample is 4-5x10^9 ohm-cm.



a) X-ray response map at room temperature, b) X-ray topographic image, c) IR transmission image, and d) high magnification IR transmission image of the same sample described above. Sample dimension: 6.5x6x1.8 mm^3.

It is to be noted that even with the presence of a sub-grain boundary network, the μτ value is very high. CTS crystals with 10% Se content are generally free from a sub-grain boundary network and can produce an even higher μτ value.



Detector response for Frisch grid geometry at room temperature from a) Am-241, b) Ba-133 and c) Cs-137 source. Detector dimension: 2x2x5 mm^3, fabricated from as-grown CTS by THM with 5% Se concentration.

Salient findings:

- Very high compositional uniformity for all CTS crystals ranging from 5-10% Se for both THM- and Bridgman-grown ingots.
- CTS crystals with 10% Se content were virtually free from a sub-grain boundary network.
- Concentration of Te inclusions/precipitates is 5-8 times lower than conventional CZT for both THM and Bridgman ingots.
- Achieved very high μτ value (2-3x10^{-2} cm^2 /V).
- Concentration of sub-grain boundary network and Te inclusions /precipitates reduces with Se concentration in CTS crystals.

Future work

- Optimization of In concentration for CTS with 10% Se composition is in progress to achieve >10^{10} ohm-cm resistivity.
- Seeded growth of CTS by THM is in progress to increase the grain size.

Acknowledgments

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