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Distribution of Te inclusions in a CdZnTe wafer and their effects on the electrical properties of fabricated devices

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Abstract:

We quantified the size and concentration of Te-inclusions along the lateral- and the growth-directions of a ~6 mm thick wafer cut axially along the center of a CdZnTe ingot. We fabricated devices, selecting samples from the center slice outward in both directions, and then tested their response to incident x-rays. We employed, in concert, an automated IR transmission microscopic system and a highly collimated synchrotron X-ray source that allowed us to acquire and correlate comprehensive information on Te inclusions and other defects to assess the material factors limiting the performance of CdZnTe detectors.

Keywords: CdZnTe, detectors, Te inclusions, dislocations, pipes, IR transmission.

Introduction:

Cadmium Zinc Telluride (CdZnTe) crystals have emerged as the leading semiconductor material for room-temperature X- and gamma-ray detectors. They are increasingly used in various applications, such as nonproliferation, national security, medical and industrial imaging. However, their commercialization primarily is restricted due to low availability of high-quality large-volume single crystals with low concentration of defects, like Te inclusions and dislocations which are typically generated during crystal growth. High concentrations of such defects in CdZnTe crystals generally cause severe charge trapping that degrades the detector's charge-transport properties and reduces the carrier lifetime, thereby significantly lowering the device's performance [1-3]. CdZnTe crystals grown by the high-pressure Bridgman (HPB) method generally encounter problems arising from Cd evaporation due to the high vapor pressure and the deposition of segregated Te during the decomposition of the melt, so entailing the formation of Te inclusions in the CdZnTe ingot. In this study, we determined the size, concentration, and the distribution pattern of defects, especially Te inclusions, in the bulk of chosen samples along the growth- and the radial- directions of CdZnTe wafers (Figs. 1a and 1b). To do so, we employed an automated IR transmission system to record 100 images from 6mm-thick bulk material and reconstructed them to obtain detailed information about the existing defects. Inclusions less than <2µm were not visualized in our system. We estimated that the Te inclusions ranged from 2µm to 40µm, and their concentration from 4×10^5 to 8×10^5 cm^{-3}. We deposited Au contacts on the two opposite surfaces of the wafers, and tested them as radiation detectors using a highly collimated x-ray beam. We measured their spectral responses and peak heights at various applied biases over the detector's area and

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estimated the mobility-lifetime values from the best fit to the Hecht equation [4]. We correlated the results for the bulk defects with the electrical properties to understand the nature of the defects and their influence on the devices' performances.

Experimental procedures:

We diced the center region of a 6"-diameter wafer into 10-15 mm long and 6x6 mm^2 area of 8 pieces using an inside-diamond wire saw. All samples were mechanically polished using 5-μm grit Al_2O_3 abrasive papers, followed by alumina powders with decreasing levels of grit. For the final polishing, we used 0.05-μm alumina powder followed by chemo-mechanically polishing (CMP). We employed an automated IR system to record 100 frames for each 1.5x1.1mm^2 frame through the crystal's depth. We generated such a data set for each position side-by-side for all samples from the head to tail of the ingot, and then reconstructed those data by collapsing the 100 frames into a 2D image. Afterwards, we deposited metal contacts on processed surfaces of all 8 pieces by electroless chemical deposition of gold from an $AuCl_3$ solution. The resulting fabricated devices were mounted one-by-one in front of a highly collimated (10$μm^2$) high-intensity monochromatic synchrotron x-ray beam, and their performances were assessed.

Results and discussion:

We analyzed the recorded IR images and, from this information, generated various data figures, along with reconstructing the 2D images. Fig. 1 shows various defects extending from the head and continuing toward the tail of the ingot. It reveals that Te inclusions were distributed throughout the samples both in the growth- and radial-directions. The size of those inclusions is mostly less than 5 μm, and their concentration is about 10^5 cm^{-3}. In the head region, no other defects were observed. Some large-scale defects became apparent around the center of the ingot. Towards the tail, we noted a high concentration of the so-called pipes probably produced as the result of the formation of Ar- or Cd-bubbles at the liquid-solid interface during growth. These pipes are hollow tubules, usually 500 μm to a few mm long, and about 20–50 microns wide; they lie parallel to the growth axis and act as trapping centers. They can also cause excessive leakage current. James et al. [5] described in detail these large defects in HPB-grown CZT crystals. Linear dislocations decorated with large Te inclusions were apparent towards the tail of the ingot. Such dislocations usually extended into the bulk, forming dislocation walls and significantly affecting charge-carrier transportation [6]. There was less variation in the large defects distributed along the radial direction; although, we noted that the density of the small Te inclusions tended to slightly increase towards the ingot's center.

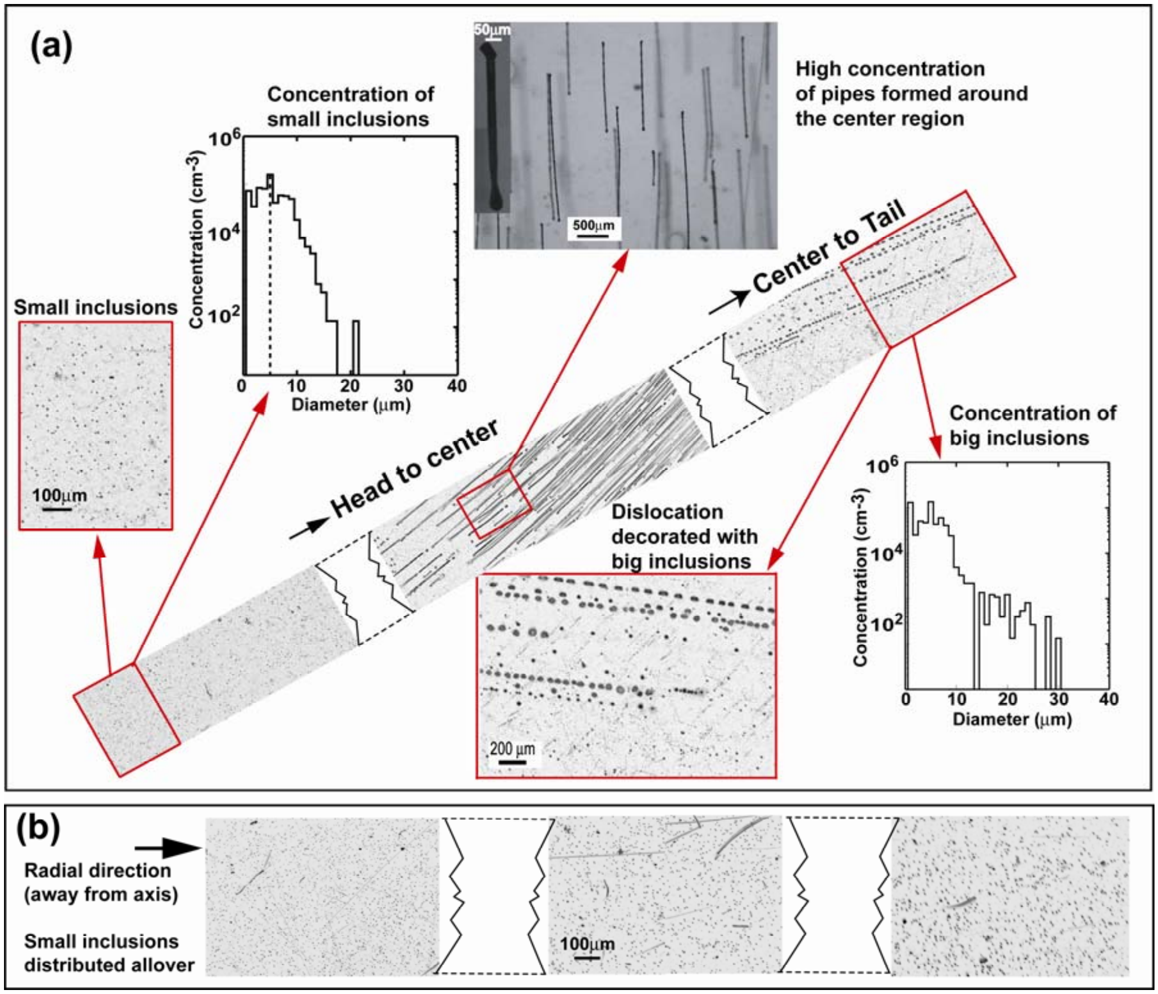

Fig.1. IR microscopic images of various defects, including Te inclusions, their size, and concentration. (a) Along the growth direction. (b) Along the radial direction.

Fig. 2(a) shows the concentration profile of Te inclusions in the samples along the growth direction, and Fig. 2(b) is the corresponding mobility-lifetime values. There is no direct correlation between the two; however, the mobility-lifetime value was higher at head region, gradually declining towards the tail. From the existing defects shown in Fig. 1, we consider that the small Te inclusions do not greatly affect charge collection. However, the pipes and other extended defects, such as large Te inclusions significantly degrade charge collection, in agreement with our previous findings. [7]. Figs. 2c and 2d also illustrate the concentration of Te inclusions along the radial direction and the corresponding mobility-lifetime value. Its value remains almost the same throughout the radial direction; we did not observe any large scale defects in this direction, thereby verifying our previous statement.

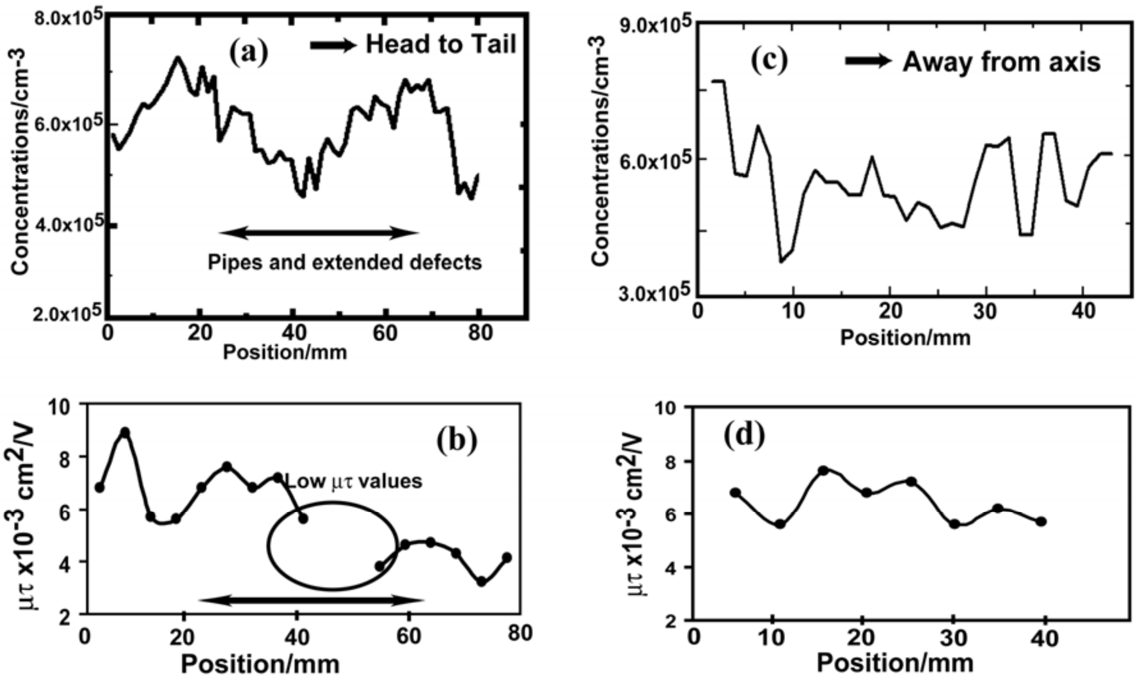

Fig. 2. (a,b) Concentration profile of Te inclusions, along with large- scale defects, along growth direction and the corresponding mobility-lifetime value. Not signal was acquired due to high density pipes within the circled region in (.b). (c,d) Concentration profile of Te inclusions along the radial direction and the corresponding mobility-lifetime value.

Conclusions

We demonstrated various defects in a CZT ingot along the growth and radial directions, and detailed their effect on the mobility-lifetime values. Small Te inclusions were randomly distributed throughout the ingot; however, they have a small effect on the mobility-lifetime product of the material. Large-scale defects, like pipes and dislocations, along with big Te inclusions, were generated during crystal growth, starting from center region to the tail of the ingot; they significantly lowered the mobility-lifetime value. Further investigations are warranted on the formation of such defects so that their deleterious effects can be mitigated.

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References:

[1] T. E. Schlesinger, J. E. Toney, H. Yoon, E. Y. Lee, B. A. Brunett, L. Franks, and R. B. James, Mat. Sci. Eng. R32 (2001) 103-189.

[2] P. Rudolph, Cryst. Res. Technol. 38, n. 7-8 (2003) 542-554.

[3] C. Szeles, *IEEE Trans. Nucl. Sci.* 51, n. 3 (2004)1242-1249.

[4] K. Hecht, Z. Physik, 77 (1932) 235.

[5] R. B. James et al., J. Electron. Mater 27(1998) 788-799.

[6] A. Hossain, A. E. Bolotnikov, G. C. Camarda, Y. Cui, G. Yang, and R. B. James, J. Cryst. Growth 310 (2008) 4493.

[7] A. E. Bolotnikov, G. S. Camarda, G. A. Carini, Y. Cui, K. T. Kohman, L. Li, M. B. Salomon, R. B. James, IEEE Trans. Nucl. Sci, 54 (2007) 821-827.