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Study of Te inclusions in CdMnTe crystals for nuclear detector applications

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ABSTRACT

The concentration, size and spatial distribution of Te inclusions in the bulk of CdMnTe crystals mined from two batches of ingots were studied. An isolated planar layer decorated with Te inclusions was identified in CdMnTe crystals from the second ingot. The internal electric field of a CMT crystal was probed by infrared (IR) imaging employing Pockels electro-optic effect. The effect of an isolated plane of Te inclusions on the internal electric-field distribution within the CdMnTe crystal was studied. Space charge accumulation around the plane of Te inclusions was observed, which was found to be higher when the detector was reverse-biased. The effects of the plane of Te inclusions on the electric-field distribution within the CdMnTe crystal, and the quality of CdMnTe crystals for nuclear detector applications are discussed.

1. Introduction

CdMnTe (CMT) has recently been shown to be a promising material for room-temperature nuclear detector semiconductor [1,2] as well as other applications [3,4]. Advantages of CdMnTe include better lattice strengthening [5] and wider bandgap energy in comparison to CdTe due to the addition of Mn. The energy bandgap of CdMnTe has been found to increase at a rate of 13 meV per atomic percent of Mn [6], which is twice as fast as 6.7 meV per atomic percent of Zn added to CdZnTe, the reported rate at which Zn increases the bandgap in CdZnTe. [7] Mn in CdTe has a segregation coefficient of 0.95 and axial distribution of 0.001 mole fraction [8]. The near-unity segregation coefficient of Mn in CdTe crystal compared to 1.35 for Zn in CdTe results in a more homogeneous Mn distribution and therefore more uniform CdMnTe crystals.

For CdMnTe to become advantageous in gamma ray detector applications, high-quality crystals are needed. Crystals should have good uniformity of composition and low-defect concentrations. However, there are problems associated with production of good-quality defect-free CdMnTe crystals. Commercially available Mn used for CdMnTe crystal growth has a low purity of about 99.99%, so that there is need to further purify Mn and achieve lower impurity concentration. Also CdMnTe crystals grown by the Bridgman method are found to contain high concentration of twins [7]. Twin boundaries are highly decorated with Te inclusions. Te inclusions have been identified in CdTe crystals as solidified Te-rich melt captured at the interface of crystal growth, due to morphological instabilities and incorporated into the ingot [8,9]. They are usually $\geqslant 1\,\mu m$ [10–12]. The effects of such twins and associated Te inclusions on CMT nuclear detector devices, however, have not been well documented.

In this work, we studied CdMnTe crystals grown by modified low-pressure Bridgman (MLPB) technique at Yinnel Tech [13]. Infrared (IR) microscopy was used to screen the crystals for the presence of defects, specifically twins and Te inclusions. The different sizes and concentrations of Te inclusions have been

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observed in the CdMnTe samples. A distinct pattern of twinning was also observed.

CdMnTe, like other Zinc-blende crystals such as CdZnTe, belongs to a class of crystals that undergo birefringence, making it possible to probe the internal electric field using Pockels imaging. Pockels electro-optic effect has been used to probe the internal electric field of other crystals in the past [14–16]. However, there is no data reported on imaging the internal electric field in CdMnTe crystals. In this study, Pockels effect was used to measure the distribution of internal electric field of CdMnTe crystals. We noticed a buildup of electric field in the region surrounding an observed twin plane decorated by a narrow layer (plane) of Te inclusions. This study shows, for the first time, the effect of a plane of Te inclusions on the internal electric-field distribution of CdMnTe radiation detectors. This distortion in the electric field shows different behavior relative to whether a positive or negative bias was applied to the detector. These observations are explained in this paper.

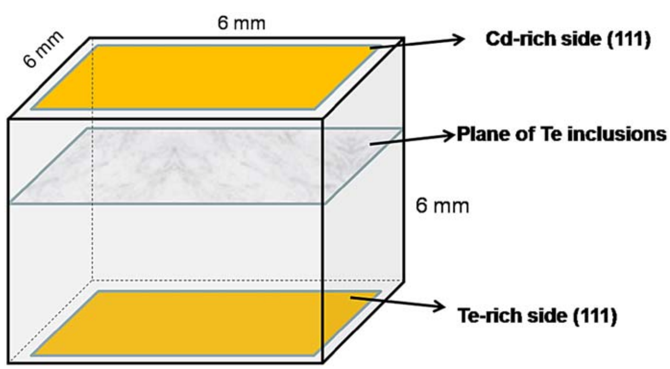

Fig. 1. Schematic representation of the CMT crystal showing a layer (plane) of tellurium inclusions.

2. Experimental procedure

Four sets of $6 \times 6 \times 12\,mm^3$ CdMnTe crystals from two different ingots were used in this experiment. Ingot one crystal was indium-doped at 4 ppm, while ingot 2 was 2.5 ppm indium doped. All other growth conditions were the same for both ingots. The crystals were mechanically polished with decreasing grit sizes of Al_2O_3 abrasive papers followed by alumina slurry also of decreasing sizes. Final polishing was achieved by using 0.05-μ alumina slurry. The crystals were then etched with 2% bromine–methanol (BM) solution for 3 min, flushed with methanol and carefully cleaned to remove any residue from etching, and then blow-dried using nitrogen gas. A total of $6 \times 6 \times 2.4\,mm^3$ samples were prepared for mobility-lifetime measurements, while $6 \times 6 \times 12\,mm^3$ samples were prepared for radiation response measurements. The sizes and distributions of Te inclusions in the bulk of the CdMnTe crystals were studied with an IR microscope system developed at BNL to reveal the patterns of Te inclusions. The system consists of a microscope with a large field of view objective and a 2208×3000 pixels CCD camera. Details of the IR system can be found in an earlier publication [17]. The IR system is coupled with a reiterative algorithm [17] for locating and identifying the shapes and sizes of Te inclusions. The IR images of the crystal from ingot 2 reveals a region that has a thin plane of Te inclusions. This region was selected and a $6 \times 6 \times 6\,mm^3$ sample was carefully cut out to feature the Te inclusion plane. This CdMnTe sample has only a single twin plane and was used for Pockels imaging and electric-field studies. The sample was polished, etched and cleaned as described above. A Lesker sputtering system utilizing radio frequency (RF) magnetron was used to deposit Au electrodes on the (1 1 1) planes, as shown schematically in Fig. 1.

Materials with zinc-blende structure possess a linear electro-optic effect, known as Pockels effect, in which the refractive index is modified anisotropically. The crystal is placed between a cross polarizer and analyzer. It is then irradiated with infrared light of wavelength below the bandgap of the crystal, and the total intensity of light is detected with a CCD camera. The intensity is given by

$$I = I_o \sin^2(\partial) \quad (1)$$

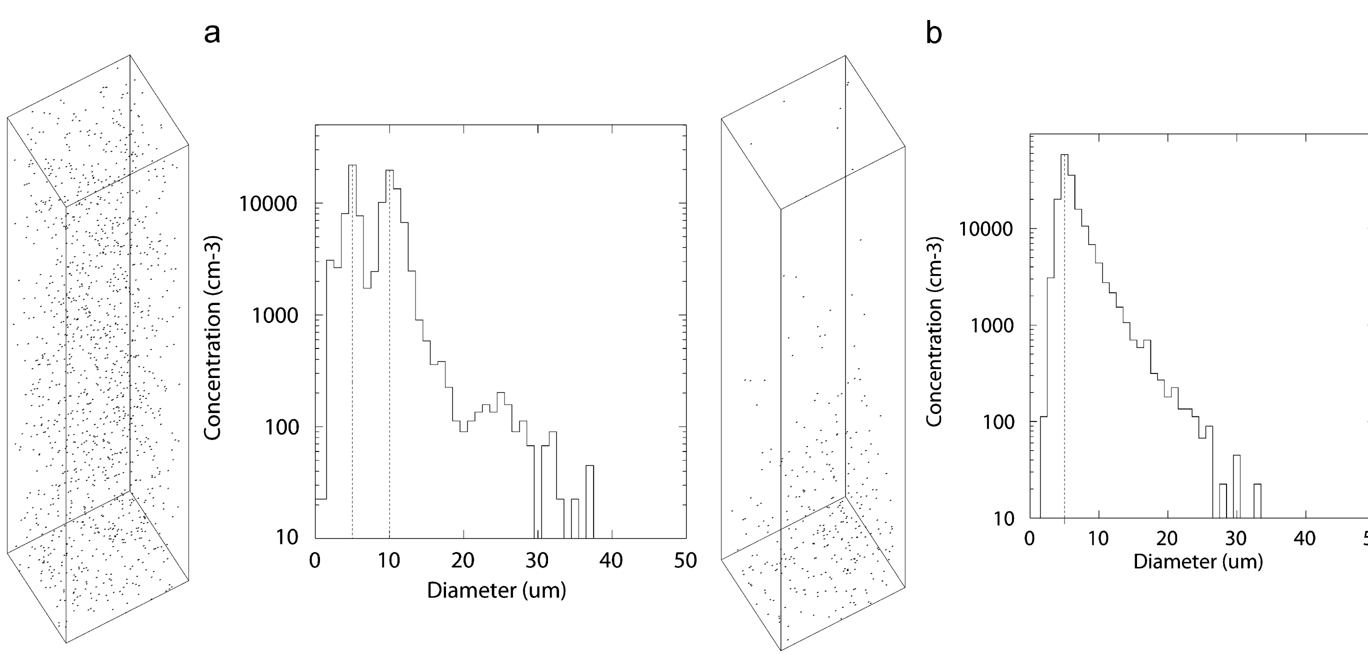

Fig. 2. Concentration and size distribution of Te inclusions in a $1.5 \times 1.5 \times 6\,mm^3$ region of CdMnTe from (a) ingot 1 and (b) ingot 2.