BNL-106004-2014-CP

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August 2014

Nonproliferation and National Security

Brookhaven National Laboratory

U.S. Department of Energy

Office of Nonproliferation and Verification Research and Development

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

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1. INTRODUCTION

CdMnTe (CMT) has recently attracted increasing interest, since it is considered a promising material for fabricating high performance room-temperature X-ray and gamma-ray detectors.[1-5] Compared with CdZnTe (CZT), a current leading material in such applications, CMT offers several distinct advantages that make it a good candidate in this field. First, the segregation coefficient of Mn in CdTe is nearly unity in contrast to 1.35 for Zn in CdTe. This difference accounts for a more uniform distribution of Mn in CdTe, compared to the relatively high variation of Zn concentration in CdZnTe. This would increase the yield of suitable crystals for detectors, and help to reduce the costs of producing large-area detector arrays. Another significant advantage of CMT crystals is their greater tunability of the band-gap due to the large compositional influence of Mn, i.e., adding Mn increases the room-temperature band gap at a rate of 13 meV/[at% Mn] in contrast to 6.7 meV/[at% Zn] after the addition of Zn to CdTe. Most of the crystal growth attempts for CMT have been accomplished with various Bridgman methods. In Bridgman-grown CMT crystals, a common phenomenon is the presence of a high density of Te inclusions. High densities of Te inclusions can entail significant fluctuations in the total collected charge by trapping free charge-carriers generated by incident radiation, thereby strongly degrading the energy resolution of thick detectors. As a result, it is important to explore new growth approaches to improve the crystal quality of CMT. In this work, we used the modified floating zone (MFZ) technique to grow CMT crystals. To our knowledge, this is the first attempt to grow CMT crystals using the floating-zone method. The detailed structural, electrical and optical properties of MFZ-grown CMT crystals were investigated, and they were compared with those grown by Bridgman methods as well. In particular, we demonstrate that the MFZ

technique can be used to produce CMT crystals free of Te inclusions. A large temperature gradient across the growth interface could play a crucial role during the corresponding growth process.

2. RESULTS AND DISCUSSION

Figure 1 (a) shows the morphology of a representative MFZ-grown CMT wafer. The wafer consists of one large-size grain, one small grain starting from the wafer edge, and two tiny grains embedded inside the large grain. It is noteworthy that many twins prevail within the majority of the crystals. For comparison, Figure 1 (b) exhibits the IR transmission image of the same wafer. Clearly one can see that the single crystalline portions of MFZ-grown CMT are totally free of Te inclusions. Furthermore, there are no Te inclusions decorating either grain boundaries or twin boundaries, although both provide energetically-favorable sites for the formation of inclusions. We noted several tiny dark areas exist at the edge of the wafer, which could originate from the excess Te of the starting materials. The absence of Te inclusions in MFZ-grown CMT crystals offers a distinct feature not seen in CMT ingots grown by the Bridgman method. In the latter, it was commonly observed that a high density of Te inclusions is formed in as-grown crystals, especially along grain or twin boundaries. These inclusions can distort the local internal electric field in CMT detectors, entail significant fluctuations in the total charge-collection by trapping free charge-carriers and therefore, seriously deteriorate the performance of radiation detectors. A concave growth interface of CMT material can result in the trapping of Te-rich liquid droplets as a consequence of morphological instability, and therefore, a high density of Te inclusions may be formed during the following cool-down period. This is considered as the main origin of large-size Te inclusions in as-grown CMT and CZT crystals. The shape of the melt/crystal growth interface is closely related to the convection behavior in the melt zone. In our MFZ-growth process, the optical heating by halogen lamps forms a narrow melting zone within the feed rod, where the temperature gradient at the interface between the liquid and the solid is very high, much larger than that of Bridgman growth. In this case, thermo-capillary convection dominates over natural convection of the melt zone, which tends to increase the convexity of the melt/crystal growth interface. In fact, it has been recognized that a convex or flat growth interface offers a unique advantage in terms of producing larger crystals and preventing the

trapping of Te-rich droplets during the growth. The rotation of the feed rod/crystal applied in our crystal growth also helps to promote the shape of the growth interface towards 'flat' in addition to making the heating more uniform.

We measured the low-temperature (4.2 K) photoluminescence spectrum of the MFZ-grown CMT crystal, as illustrated in Figure 2. The spectrum consists of three regions: I: near-band-edge region; II: donor–acceptor pair (DAP) recombination region; and III: defect-related region associated with some impurity-complex energy levels ($D_{complex}$) and extended defect levels. The two peaks at 1.659 eV and 1.645 eV are ascribed to the neutral donor-bound exciton (D^0,X) transition and the neutral acceptor-bound exciton (A^0,X) transition separately. A peak from the donor-acceptor pair (DAP) recombination at 1.596 eV and its phonon replica at 1.575 eV can be clearly distinguished. In the defect-related region III, the feature peak at 1.482 eV originates from the A center, a cation-Cd vacancy complex. Another peak at 1.5562 eV most probably is due to an (eA^0) emission, i.e., a recombination of free electrons on the acceptor. We also observed the so-called Y band at 1.467 eV, which is related to dislocations. The peak at 1.445 eV, on the lower energy shoulder of the Y band, is the corresponding phonon-replica. It should be noted that the intensity of the Y band is much higher than that of the exciton peaks, indicating that the crystalline quality is deteriorated by the high stress field in as-grown CMT. A long-term in-situ or post-growth thermal annealing phase will probably help to release such type of stress to improve crystalline quality.

ACKNOWLEDGEMENTS

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

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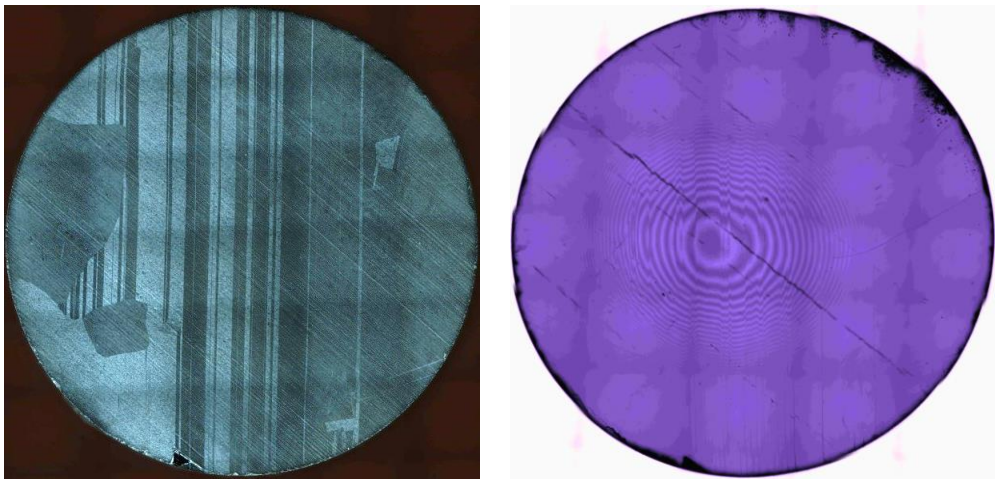

(a) (b)

Figure 1 Morphology of a representative MFZ-grown CMT wafer (The diameter of the wafer is 19 mm). (a) Polarized light microscopy image; (b) Infrared (IR) transmission image.

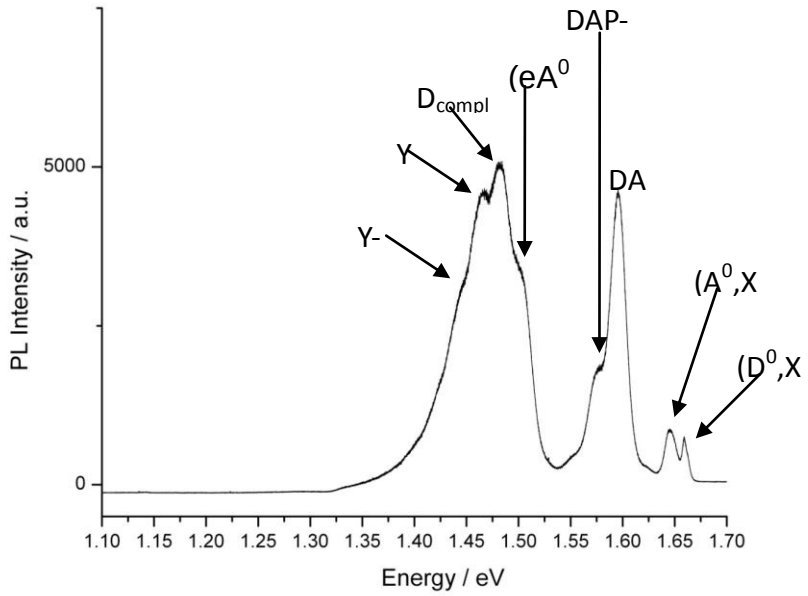

Figure 2 Representative photoluminescence (PL) spectrum of a MFZ-grown CMT crystal. The PL spectrum was measured at 4.2 K.