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Manufacturing detectors for digital X-ray images of melt-grown CdTe and CdZnTe single crystals

M.D. Pavlyuk [a], V.M. Kanevsky [a], V.F. Dvoryankin [b], A.A. Kudryashov [b], A.G. Petrov [b], Yu.M. Ivanov [a,*]

[a] Institution of Russian Academy of Sciences, A.V. Shubnikov Institute of Crystallography of RAS, Leninskii pr. 59, Moscow 117333, Russia
[b] Institution of Russian Academy of Sciences, V.A. Kotel'nikov Institute of Radio Engineering and Electronics of RAS, Vvedensky Sq. 1, Fryazino Moscow Region 141120, Russia

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ABSTRACT

In this work, a progress in the high-yield growth of large detector-grade CdTe and CdZnTe single crystals was made; this seems to be a step to the mass production of sensing element of X-ray images. The scheme of obtaining crystal blocks with minimal loss of material was developed, the technology of manufacturing multi-element X-ray detectors based on these blocks was implemented, the detectors obtained were tested, and digitized X-ray images were taken using them.

Multi-element detectors made of CdTe and its solid solutions find high-tech application in X-ray imaging for purposes of medical diagnostics, nondestructive inspection in industry, and custom-house examination. At the same time, the growth of CdTe-based single crystals suitable for the manufacture of X-ray detectors is recognized to be a rather difficult problem: this is, for instance, proved by the fact that less than a tenth of works presented at the conference held in 2008 in Dresden (see e.g. [1–3]) dealt with this material.

Organization of mass production of multi-element X-ray detectors of CdTe requires that large ingots consisting of more than 50% homogeneous high-perfection single-crystal material are obtained in a reproducible growth process. Yet, these conditions have not still seemingly been met.

In an attempt to prepare detector-grade crystals, various methods of growing CdTe-based crystals from nearly stoichiometric and Te-rich melts, from flux, and from the vapor phase were tested.

Vapor growth of large crystals required the use of large (50 cm in diameter) and therefore scarce and expensive CdTe substrates and resulted in the growth of strained deposits with tellurium precipitates [4]. The use of more easily obtainable and cheaper GaAs substrates [4] led to a heavy ($2\times10^{15}\,cm^{-3}$) CdTe contamination with Ga atoms. These exist in CdTe in the form of electron traps (A centers) that decrease the lifetime of electrons and make the deposits unsuitable for manufacturing X-ray detectors. The deposits $10^9\,\Omega\,cm$ in resistance were grown on single-crystal Ge substrates 100 mm in diameter [1]. However, Ge is known to form a deep level in the forbidden zone of CdTe; therefore, a sufficient quantum yield could only be obtained with the radiation energies below 40 keV while deposit thicknesses were less than several hundred micrometers.

Yet, Shiraki et al. [2] have grown extraordinarily large CdTe single crystals (100 mm in diameter) from solution in Te melt; they used the travelling heater method with which 20-mm-diameter crystals were typically obtained. The aim was to use the material obtained for X-ray imaging. Solution-grown crystals typically contain a number of tellurium inclusions, which is objectionable bearing in mind the general trend of making multi-element detectors with smaller and smaller pixel or strip size. Low-angle boundaries were observed in solution-grown CdZnTe crystals by Bolotnikov et al. [3].

The crystals grown from the liquid phase typically contain detector-grade areas no greater than 5–10 mm in size [4].

Pulling of CdTe crystals by the Czochralsky technique was found to be unsuccessful [5]: massive crystals could not be obtained because of low thermal conductivity of the material.

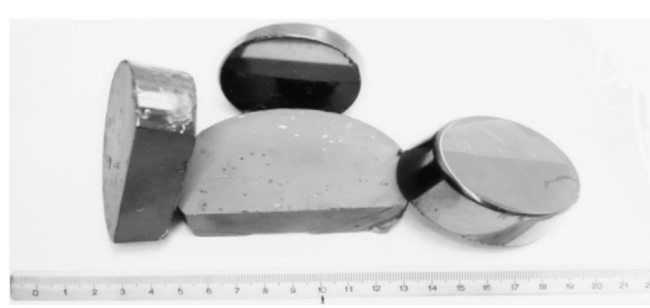

Fig. 1. As-grown single-crystal ingots of CdTe and CdZnTe.

* Corresponding author.
E-mail address: yurivanov@ns.crys.ras.ru (Yu.M. Ivanov).

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The “HPB” Bridgman technique and its modifications yielded CdTe crystals consisting of multiple grains or twins (see, for instance, [6]).

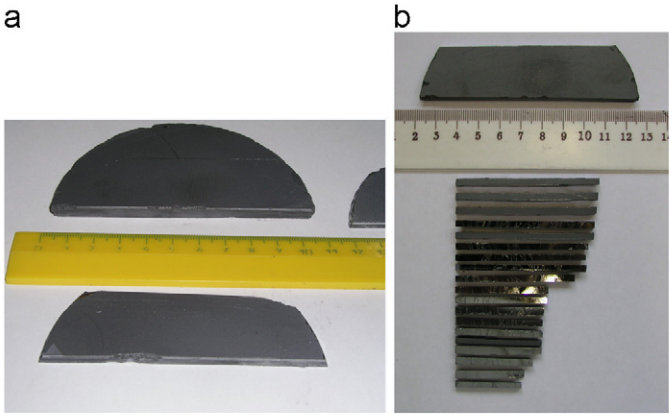

Fig. 2. Disk-shaped slices with the (1 1 1) orientation (a) and bars split of them (b).

In this work, CdTe and CdZnTe (Fig. 1) crystals were grown by the Obreimov–Shubnikov method (this method is also referred to in the foreign literature as “vertical-gradient freezing” or VGF). A “reverse” axial temperature gradient was used in combination with self-seeding of the molten charge from the upper side, so that the growth front moved from the top down [7], in contrast to the conventional Obreimov–Shubnikov and the VGF configuration [8]. These expedients and the use of a specially designed furnace [9] and tailor-made accessories allowed us to reliably obtain totally single-crystal ingots absolutely free of twins and grain boundaries. Actually, high-grade single-crystal material constituted from 90% to 100% of the ingot in about 80% of grown runs, which seems to be a very good result for such a cheap and simple growth method.

Another important advantage of the growth method used is that in the absolute majority of cases, seeding and further growth of the crystal occur in the ⟨1 1 1⟩ direction [7]. Owing to this feature, disk-shaped slices with the (1 1 1) orientation, 100–120 mm in diameter and 2 mm in thickness, cut of these crystals normal to the growth axis, are easily split by the (1 1 0) planes normal to the disk plane into single-crystal bars (Fig. 2). These bars possess smooth lateral surfaces that do not need mechanical treatment and can directly be used for manufacturing strip

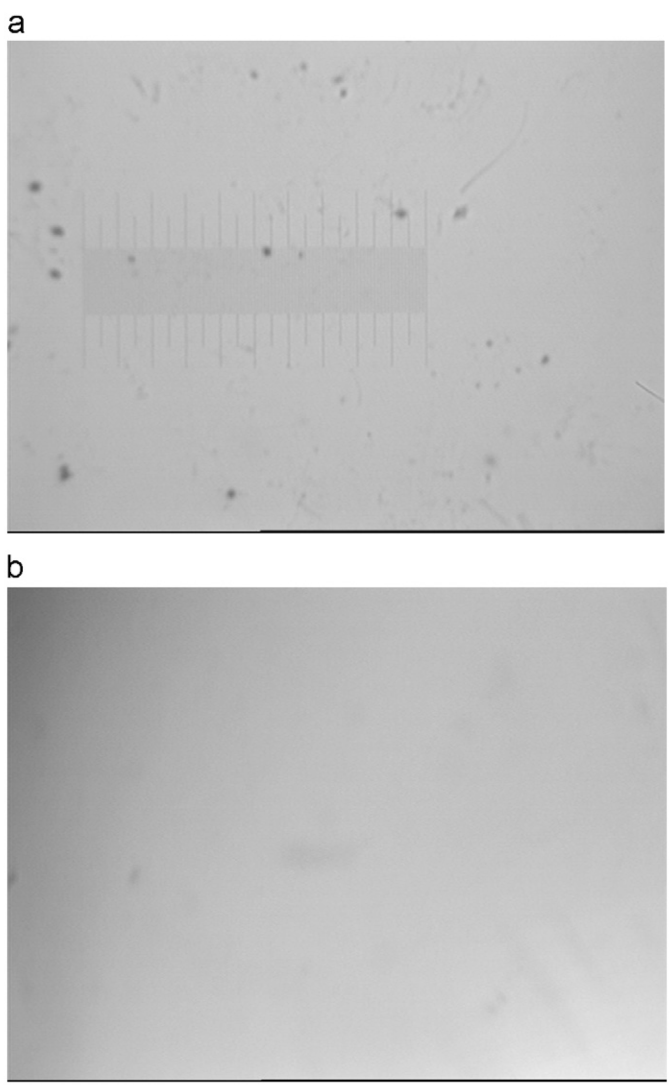

Fig. 3. Typical IR micrograph of a CdTe single crystal (× 200): (a) conventionally grown crystal with precipitates and (b) stepped postgrown crystal without precipitates.

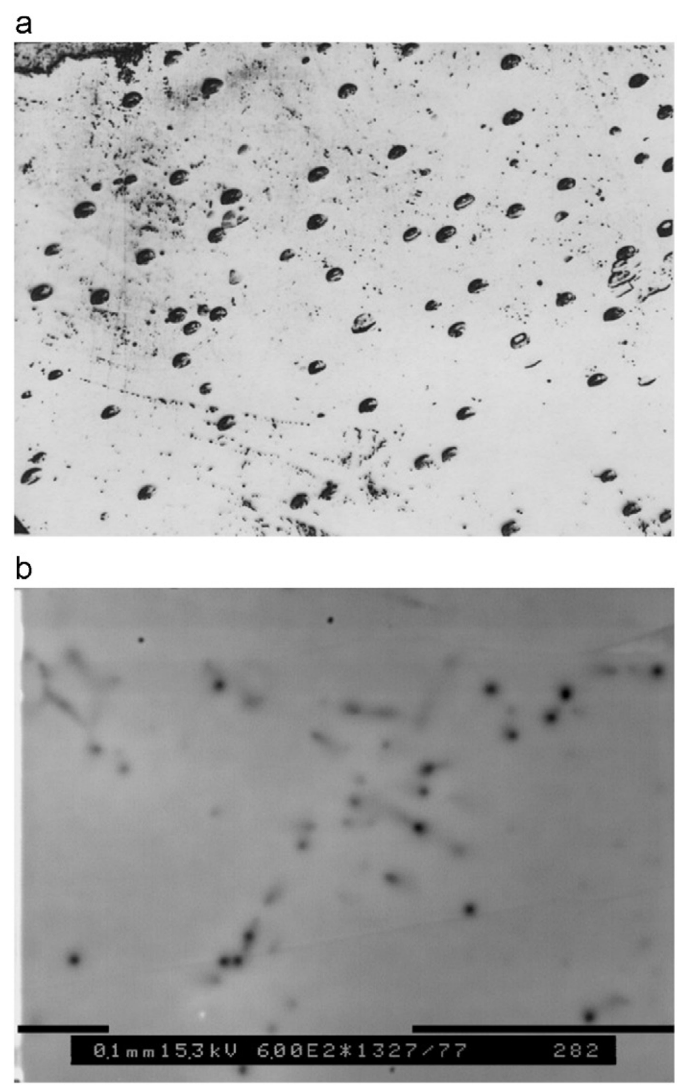

Fig. 4. Dislocations revealed in CdTe crystals by etching (1 1 0) surfaces; observation by traditional microscopy (× 200, INOE dislocation etchant [14]) (a) and cathodoluminescence (b).