# Structural defects in $Hg_{1-x}Cd_xI_2$ layers grown on CdTe substrates by vapor phase epitaxy

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$Hg_{1-x}Cd_xI_2$ 20–25-$\mu$m-thick layers with a uniform composition in the range of $x=0.1-0.2$ were grown on CdTe substrates by vapor phase epitaxy (VPE). The growth was carried out using an $\alpha$-$HgI_2$ polycrystalline source at 200 °C and in the time range of 30–100 h. The layers were studied by scanning electron microscopy (SEM) and high resolution synchrotron x-ray topography (SXRT). The SEM and SXRT images of $Hg_{1-x}Cd_xI_2$ VPE layers allow one to identify the defects affecting the layer structure. The two main types of structural defects in the layers are subgrain boundaries and densely spaced striations similar to those referred generally to as vapor grown $HgI_2$ bulk crystals. The effect of the growth time on these defects has been analyzed and on the basis of this it has been possible to grow $Hg_{1-x}Cd_xI_2$ layers with low defect density. © *1997 American Institute of Physics.* [S0021-8979(97)04122-4]

## I. INTRODUCTION

As important semiconductor materials for manufacturing x-ray and $\gamma$-ray detectors operating at room temperature, $HgI_2$ ($\alpha$ modification) and CdTe bulk crystals and, more recently, epitaxial layers have been the subject of many research laboratories and industries.[1–7] Although these materials have usually been considered as competitors and have been studied and used independently, the combination of their advantages like high absorption coefficients for ionizing radiation, good electrical properties, and wide band gaps could be a matter of concern. Recently, an example of the technological compatibility of $HgI_2$ and CdTe has been demonstrated by growing $HgI_2$ and $Hg_{1-x}Cd_xI_2$ layers on CdTe substrates by vapor phase epitaxy (VPE).[8,9] Despite significantly different crystallographic structures of the layer and the substrate (layered tetragonal[10] and cubic zinc blende[11] types, respectively), $Hg_{1-x}Cd_xI_2$/CdTe heterostructures have shown a good stability at room and elevated temperature and a structural and compositional uniformity of the layer in the wide composition range of $x<0.7$.[8]

Due to the fact that the performance of the detectors made from $HgI_2$ and CdTe depends strongly on the crystalline quality of these materials,[1,12] the investigation of the structural properties of both components in $Hg_{1-x}Cd_xI_2$/CdTe heterostructures is crucial. The structural defects in CdTe substrates generated by the VPE growth has recently been studied by the cathodoluminescence microscopic technique.[9] Following this work, in the present article we report on the structural defects in $Hg_{1-x}Cd_xI_2$ VPE layers studied by scanning electron microscopy (SEM) and high resolution synchrotron x-ray topography (SXRT).

## II. EXPERIMENT

$Hg_{1-x}Cd_xI_2$ 20–25-$\mu$m-thick layers with a uniform composition in the range of $x=0.1-0.2$ were grown by the isothermal VPE technique on CdTe (111) $10\times10\times1.5\ \mathrm{mm}^3$ single-crystalline substrates. The VPE growth was carried out under optimal conditions determined previously.[8] $\alpha$-$HgI_2$ polycrystal was used as source, the growth temperature was 200 °C, and the growth time was in the range of 30–100 h. More details on the VPE growth process, $\alpha$-$HgI_2$ source preparation, and CdTe substrates characteristics can be found elsewhere.[8,13,14]

The cleaved cross sections of $Hg_{1-x}Cd_xI_2$/CdTe heterostructures and the layer surface morphology were studied by SEM (Hitachi S-4100). The SXRT characterization was carried out using the ''Topography and High Resolution Diffraction'' beamline at the European Synchrotron Radiation Facility. The SXRT images were recorded using an x-ray white beam in transmission mode (''Laue technique''). Details on the SXRT experimental setup have been reported in Ref. 15. The SXRT characterization has been shown earlier to be the most appropriate method for the structural studies of $HgI_2$ bulk crystals.[16] This is because of a high x-ray absorption of this material as well as other Hg-based compound semiconductors, which limits the use of the conventional x-ray topography with Cu $K_\alpha$ radiation source (as recent examples, see Refs. 17 and 18).

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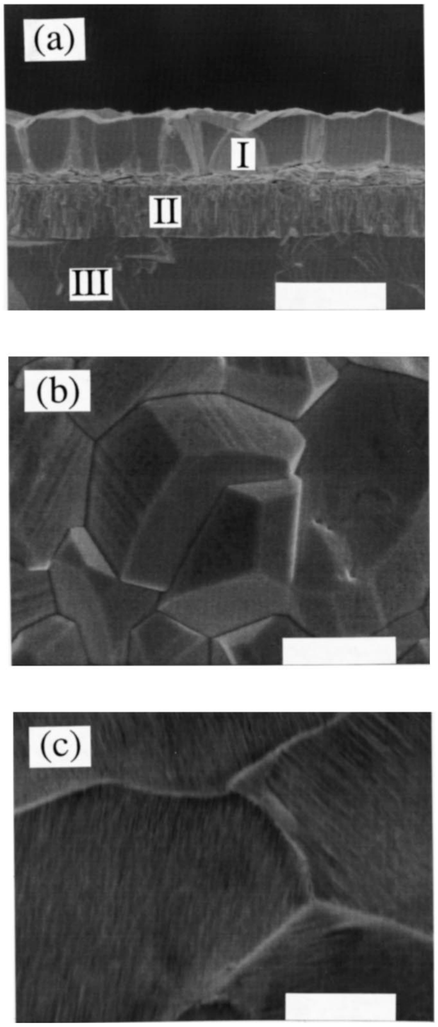

FIG. 1. SEM images of $Hg_{1-x}Cd_xI_2$/CdTe VPE heterostructures: (a) cleaved cross section of the heterostructure grown for 50 h (I)-$Hg_{1-x}Cd_xI_2$ layer, (II)-interface platelet layer, and (III)-CdTe substrate, (b) surface morphology of the $Hg_{1-x}Cd_xI_2$ layer in the same heterostructure, and (c) surface morphology of the $Hg_{1-x}Cd_xI_2$ layer grown for 80 h. Markers correspond to 10 $\mu$m (a) and 5 $\mu$m (b) and (c).

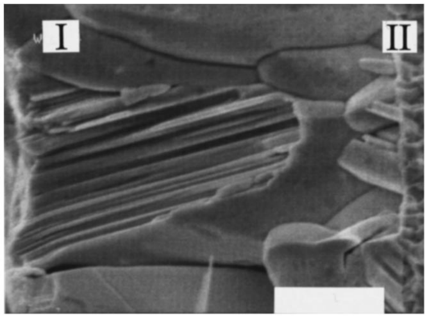

FIG. 2. SEM image of a cleaved subgrain in the $Hg_{1-x}Cd_xI$ layer grown for 30 h [regions (I) and (II) are only shown]. Marker corresponds to 5 $\mu$m.

## III. RESULTS AND DISCUSSION

Figure 1 shows (a) the typical cleaved cross section of $Hg_{1-x}Cd_xI_2$/CdTe VPE heterostructure and the surface morphology of the $Hg_{1-x}Cd_xI_2$ layers grown (b) for 50 h and (c) for 80 h. The cross section independent of the growth time exhibits three regions of different contrast which are the $Hg_{1-x}Cd_xI_2$ layer (I), the interface platelet layer (II), and the CdTe substrate (III). These regions are specific to every $Hg_{1-x}Cd_xI_2$/CdTe VPE heterostructure and their origin has been reported earlier.[8] Hereafter, we will discuss the properties of $Hg_{1-x}Cd_xI_2$ layers (I) which are the subject of this work.

Similar to other epitaxial layers grown on strongly lattice-mismatched substrates (for example, see Ref. 19), the $Hg_{1-x}Cd_xI_2$ layers have a rough surface whose particular microrelief shows the evolution of the layer structure during VPE growth. The surface morphology, which is presented in Fig. 1(b), exhibits the subgrained structure of the 50 h grown layer. The subgrains have a size in the range from 5 to 10 $\mu$m and are separated by well defined sharp boundaries of regular shape. Inside each subgrain there is a system of densely spaced striations like parallel lines of different contrast. When the growth time increases to 80 h [Fig. 1(c)], the subgrain size increases by a factor of 4–5, the subgrain boundaries become irregular and hazy, and the striations disappear almost completely. A further increase of the growth time produces a further deterioration and contrast reduction of subgrain boundaries.

On the contrary, a decrease of the growth time results in a decrease of the subgrain size with sharp striations inside. This case is illustrated in Fig. 2 which shows a cleaved subgrain in the $Hg_{1-x}Cd_xI_2$ VPE layer grown for 30 h. It is also apparent from Fig. 2 that the striations extend through the entire subgrain volume from the interface into the layer.

Figure 3 reports the typical SXRT images of $Hg_{1-x}Cd_xI_2$ VPE layers grown for different periods of time. On a macroscale [Fig. 3(a)], the low magnification SXRT image exhibits a uniform contrast over the whole area of the layer grown for 50 h. It indicates that the layer is single-crystalline and has no elastic curvature in spite of the layer-substrate lattice mismatch and the difference in thermal expansion coefficients. This result seems to be related to an expected large plasticity of $Hg_{1-x}Cd_xI_2$ similar to that of $HgI_2$ (for details see Ref. 10).

On a micro-scale [Fig. 3(b)], the higher magnification SXRT image of the 50 h grown layer has a cellular structure arisen obviously from the subgrain boundaries in the layer and a uniform hazy contrast related to the striations. The image of the 80 h grown layer, shown in Fig. 3(c), has a more homogeneous contrast and its cellular structure becomes less pronounced. Additionally, this image shows the dark and bright blurs corresponding to the regions with a high and low density of structural defects, respectively. In the image of the layer grown for 100 h [Fig. 3(d)], the cellular structure disappears completely, and the image exhibits a bright background in which elongated dark features are seen. Thus, the images of Figs. 3(c)–3(d) are evidence that an increase of growth time results in a general decrease of the structural defects in $Hg_{1-x}Cd_xI_2$ layers while the distribution of defects over the layer area becomes nonuniform due probably to the gettering effect. The combined analysis of Figs. 1(a)–1(c) and Figs. 3(a)–3(d) shows that the reduction of structural defects within the layer with the growth

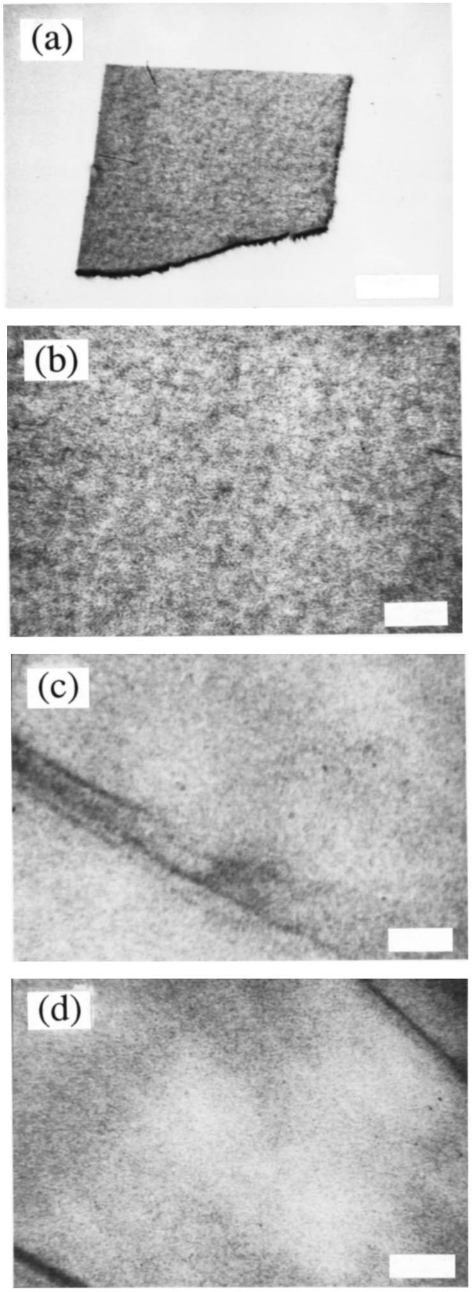

FIG. 3. SXRT images of $Hg_{1-x}Cd_xI$ layers: (a) low magnification image of a piece of the layer grown for 50, h (b) high magnification image of the same layer, and (c) and (d) high magnification images of the layers grown for 80 and 100 h, respectively. Markers correspond to 2 mm (a) and 200 $\mu$m (b)–(d).

time is not only a surface (SEM) but a bulk (SXRT) effect.

Structural defects like subgrain boundaries and striations (but of larger size) are common in vapor grown $HgI_2$ bulk crystals, whose appearance has been attributed to the effect of the accumulated thermal stresses inside the crystals during growth.[2,16] The density of these defects in $HgI_2$ bulk crystals increases with growth time and crystal size.[16] Nevertheless, our findings show the opposite for $Hg_{1-x}Cd_xI_2$ VPE layers. They may suggest that the subgrain boundaries and striations in the layers are due to mechanical strains which have arisen from the layer-substrate lattice mismatch at the interface.

## IV. SUMMARY

We have reported on a combined SEM and SXRT study of $Hg_{1-x}Cd_xI_2$ VPE layers grown on CdTe substrates. It is shown that the main structural defects in the layers are subgrain boundaries and densely spaced striations similar to those referred generally to vapor grown $HgI_2$ bulk crystals. The improving effect of the growth time on these defects has been proved, and $Hg_{1-x}Cd_xI_2$ layers with low defect density have been grown.

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