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Cathodoluminescence study of ytterbium doped GaSb

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Abstract

Yb-doped GaSb ingots have been grown by the Bridgman method. The defect structure and compositional homogeneity of the crystals have been investigated by cathodoluminescence and X-ray microanalysis in the scanning electron microscope. The nature of the point defects has been found to depend on the position along the growth axis. Doping with Yb has been found to reduce the luminescence intensity of GaSb and no infrared emission related to intra-ionic transitions of the Yb^{3+} ions has been detected.

Keywords: Cathodoluminescence; Gallium antimonide; Rare earth doping

1. Introduction

The interest on rare earth doped semiconductors is related to the applications which combine the luminescence of rare earth ions and the electronic properties of semiconductors. The optical properties of various combinations of rare earth elements (Er, Nd and Yb) and III–V semiconductors have been studied. GaSb, with a band gap of about 0.8 eV, and GaSb based structures are materials of increasing interest for a number of potential applications in the infrared range [1] as for instance thermo-photovoltaic cells, laser diodes or photodetectors with high quantum efficiency. Rare earth ions (Er, Nd and Gd) have been incorporated into GaSb by doping during the growth process and the structural and luminescence properties of the crystals have been investigated [2–8]. Er doping has been found [2,7] to produce a marked increase of the cathodoluminescence intensity of GaSb as well as a decrease of the emission bands related to native acceptors (band A) and to the presence of Te. The efficiency of Er to reduce the acceptor concentration depends on its possible aggregation state so that for high Er concentrations, Er–Sb precipitates are formed and the band A is not significantly reduced [2]. The influence of Nd [8] and Gd [6] doping on luminescence and defect structure of GaSb has been also reported.

The behavior of Yb ion in III–V semiconductors depends on the host matrix. In the case of InP and GaN, a rather high Yb-4f photoluminiscence has been often reported [9,10], while no Yb-related luminescence was observed for GaAs [11]. In the present work, the luminescence of Yb doped GaSb crystals grown by the Bridgman method has been studied by cathodoluminescence (CL) in the scanning electron microscope (SEM).

2. Experimental

An Yb-doped GaSb single crystalline ingot was grown by the vertical Bridgman technique by tip nucleation without a seed [1]. The ingot was 50 mm long and 12 mm in diameter. The initial Yb concentration in the melt was 10^{18} cm^{-3}. For the characterization of the crystal along the growth direction, three wafers were cut, perpendicular to the growth axis, at different places along the length of the ingot. The wafers were then chemo-mechanically polished to a mirror finish. The samples, corresponding to the bottom, the middle and the top of the ingot are labeled Y1, Y2 and Y3, respectively. The CL measurements were performed with a cooled ADC germanium detector, in a Hitachi S-2500 SEM at liquid

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nitrogen temperature and at electron accelerating voltage of 20 kV. In order to investigate the composition of some of the features observed in the SEM images, mapping of the elements Ga, Sb and Yb was performed by energy dispersive X-ray microanalysis in a Jeol JXA-8900 M Superprobe.

3. Results and discussion

Fig. 1 shows representative infrared CL spectra of the three wafers investigated. The CL spectrum from wafer Y1 consists of two main emission bands, as obtained by Gaussian deconvolution of the recorded band, peaked at 797 and 775 meV which correspond to the near band edge (NBE) emission and the native acceptor related band (called band A), respectively. The NBE band is dominant while the defect band appears as a shoulder in the CL spectrum. The sample Y2 exhibits a similar spectrum but with a less intense native defect band and a weak luminescence related to tail states at 820 meV. The total CL intensity of sample Y2 is higher than in Y1. Spectra from sample Y3 show the abovementioned features but in some areas of the sample a band at about 756 meV appears. This is the so-called band B, which has been previously reported [12,13] and is associated to the complex $V_{Ga}Ga_{Sb}V_{Ga}$ arising from an excess of Ga [14,15]. This indicates that a segregation process can take place during growth leading to the excess of Ga in the top of the ingot revealed by the presence of band B.

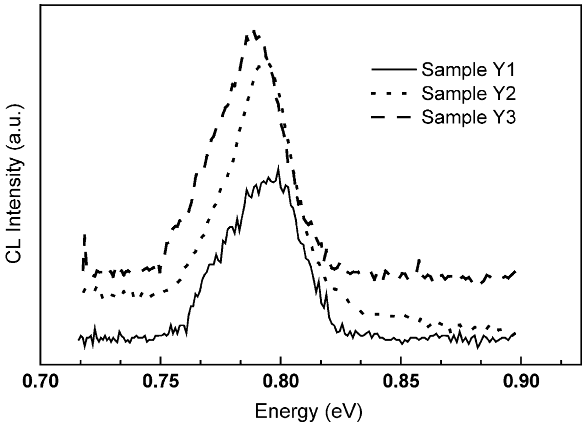

Fig. 1. CL spectra of samples Y1, Y2 and Y3.

CL image of sample Y1 shows elongated dark spots with sizes of about 10–20 μm forming dark lines, associated with dislocations, (Fig. 2) not observed in the corresponding topographic (secondary electron) electron image. On the other hand, features, hereafter called islands, of about 200 μm appear in the secondary electron images of certain regions of the sample (Fig. 3) and show dark CL contrast. X-ray microanalysis of the islands show a composition of atomic percentage of 29.71(Ga), 70.23(Sb) and 0.05(Yb) while in the sample background the percentage data are 49.40(Ga), 50.55(Sb) and 0.06(Yb). In the background the ratio between Ga and Sb is nearly stoichiometric while the defects observed in the secondary electron images are Sb rich regions. The corresponding X-ray mapping is shown in Fig. 4. The islands show a structure with areas of different Ga and Sb content. The average value of 29.71% for Ga decreases in some points down to 1.72% while Sb increases to 98.21% and the Yb concentration remains close to the average value. The islands have been observed only in the wafer Y1. CL image from sample Y2 (Fig. 5) shows a more homogeneous defect distribution than sample Y1 and a lower defect density. The higher quality corresponds to the center of the wafer. No Sb rich areas are observed in this crystal.

The present results show that no luminescence from the intra-ionic 4f-shell of the Yb ion appears in Yb-doped GaSb. In addition, a consequence of Yb doping is the quenching of luminescence. The luminescence bands observed here have been previously reported on GaSb wafers [12,16]. GaSb has a high quantum efficiency and the CL signal is usually high as we have found in most of our previous works as those appearing here as references. In particular, we have found [2] a significant increase of the CL signal of GaSb by Er incorporation. Other feature of the spectra is the presence of the band B at 756 meV in the top of the ingot (Y3) while in the

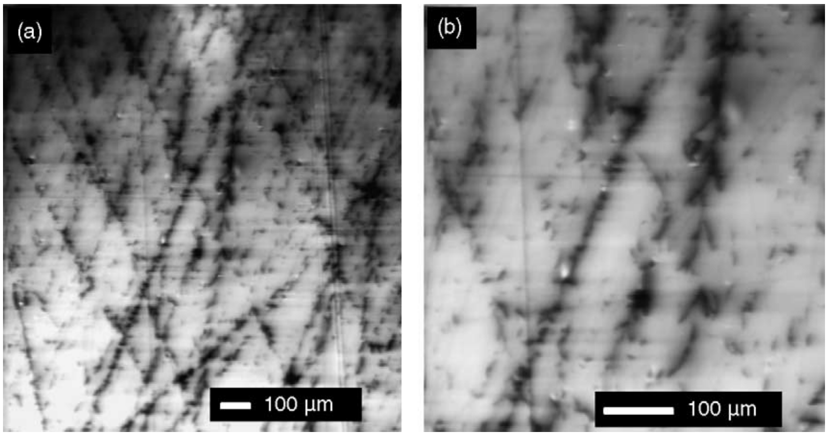

Fig. 2. (a) CL image of sample Y1; (b) CL image at higher magnification showing a detail of defects.

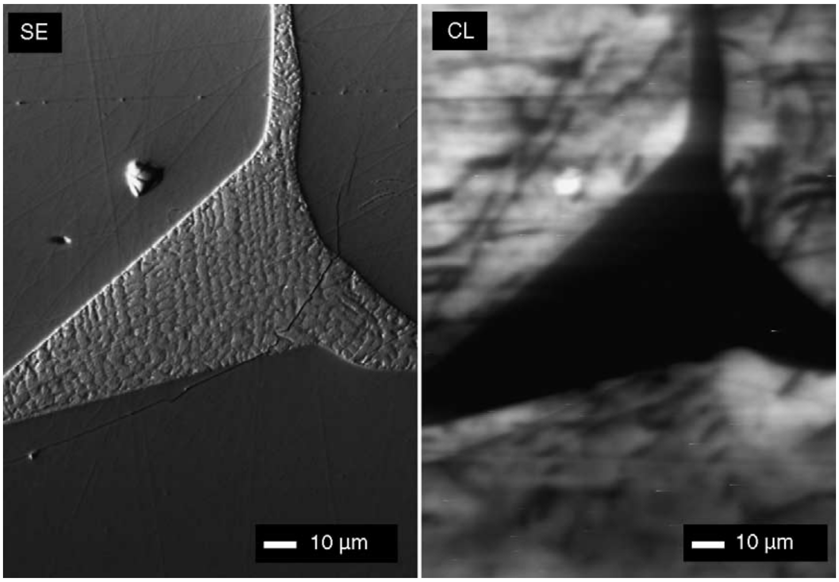

Fig. 3. Images of an island in sample Y1. (a) Secondary electron image and (b) CL image.

bottom (Y1) the band A of the native acceptors is observed. However, in all cases the defect related bands are weak as compared with the near band edge emission. This indicates a reduction of the radiative defects concentration when Yb is added to the melt.

In the case of Yb^{3+} ions embedded in InP matrix a photoluminescence peak related to the 4f intra-shell transition was detected [9,10]. However in GaAs, Yb doping forms deep electron traps in the band gap which do not favor the transfer of energy necessary to excite the Yb ions [17]. An energy

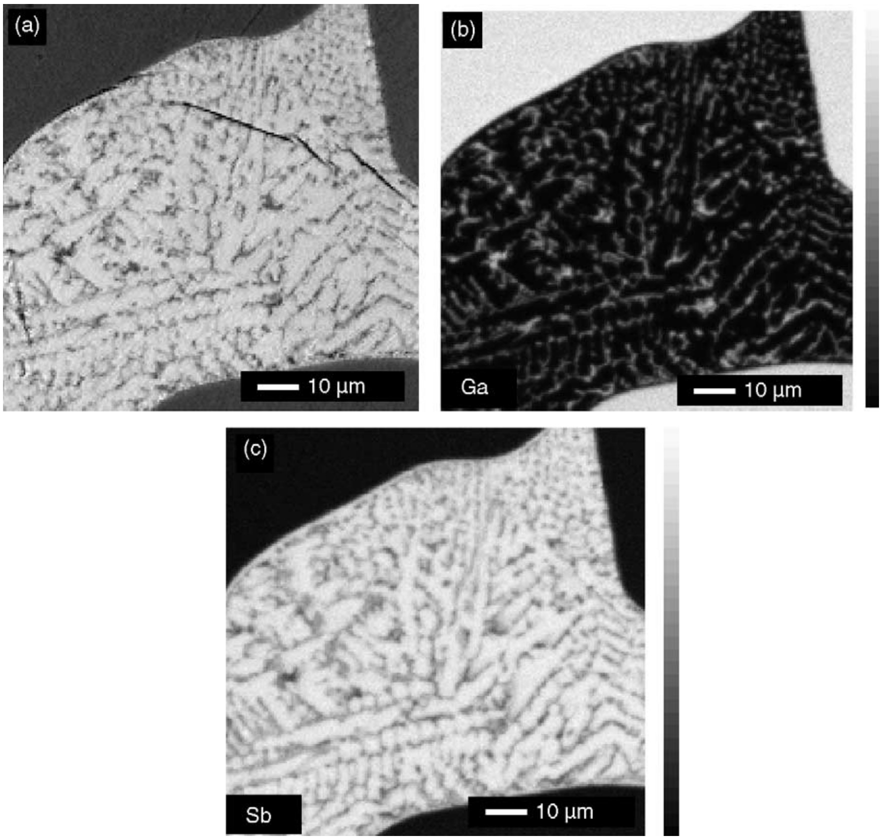

Fig. 4. (a) Secondary electron image of an island in sample Y1; (b) X-ray mapping of Ga of the island shown in (a); (c) corresponding X-ray mapping of Sb.

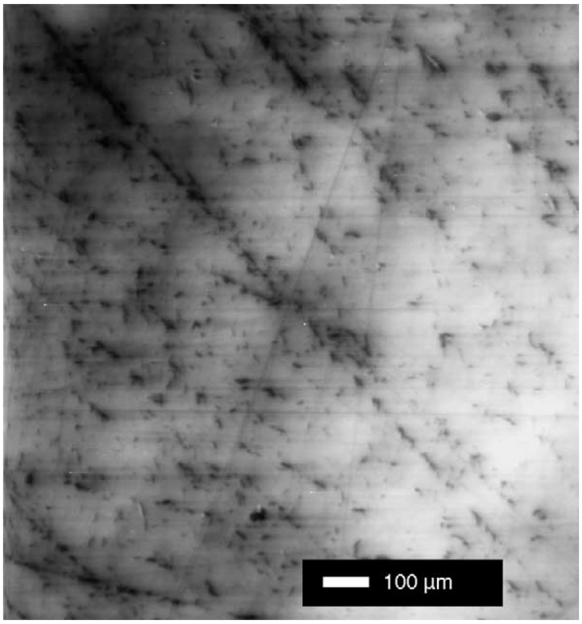

Fig. 5. CL image of sample Y2.

transfer mechanism between the rare earth ions and the host has been proposed as the responsible for the luminescence in InP. Also, the authors suggested that their conclusions may be valid for other semiconductors/rare earth systems [18]. The band gap of InP is close to this transition at 1.26 eV which is a similar situation of that of Er^{3+} in GaSb. The band gap of GaSb is close to 0.8 eV which is the energy between levels of the Er^{3+} ions. And in both cases, strong luminescence from de 4f-shell rare-earth ion has been detected. In GaSb, the band gap energy is smaller than the energy between intra 4f shell levels of Yb^{3+} and the host should absorb the intra-ionic emission. Here, a reduction of the intrinsic GaSb emission is observed. This result may be explained in terms of the formation of deep levels in the band gap associated with Yb doping, as observed in GaAs:Yb.

4. Conclusions

The defect structure and the compositional homogeneity has been studied in Yb-doped GaSb ingots obtained by the Bridgman method. The characterization of samples from different positions in the ingot by cathodoluminescence and X-ray microanalysis techniques shows the formation of different defect complexes along the ingot axis. A quenching of the near band edge luminescence of the GaSb has been detected as a consequence of Yb doping.

Acknowledgements

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