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2002 J. Phys.: Condens. Matter 14 13211

(http://iopscience.iop.org/0953-8984/14/48/370)

INSTITUTE OF PHYSICS PUBLISHING JOURNAL OF PHYSICS: CONDENSED MATTER

J. Phys.: Condens. Matter **14** (2002) 13211–13215 PII: S0953-8984(02)54013-3

Cathodoluminescence from Er_2O_3-doped n-type GaSb:Te crystals

P Hidalgo[1], J L Plaza[2], B Méndez[1], E Diéguez[2] and J Piqueras[1]

[1] Departamento de Física de Materiales, Facultad de Ciencias Físicas, Universidad Complutense de Madrid, 28040 Madrid, Spain
[2] Departamento de Física de Materiales, Facultad de Ciencias, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain

Received 27 September 2002
Published 22 November 2002
Online at stacks.iop.org/JPhysCM/14/13211

Abstract

The luminescence of Te-doped GaSb crystals codoped with Er_2O_3 has been studied by means of cathodoluminescence (CL) using a scanning electron microscope. Doping with erbium oxide causes a substantial increase of the luminescence intensity of the crystals and spectral broadening. Deconvolution of the CL spectra reveals the existence of four components. The presence of erbium oxide induces a decrease of the 746 meV emission characteristic of Te-doped samples. CL images show a complex distribution of recombination centres which depends to a large extent on the local Te concentration.

1. Introduction

Rare-earth-doped semiconductors are promising materials in the field of optoelectronics. These systems present a temperature-stable luminescence wavelength which is nearly independent of the semiconductor host. One point of interest of rare-earth-doped semiconductors is as regards the fabrication of new electroluminescent devices which can combine the luminescence of the rare-earth ions with the electronic properties of semiconductors. A sharp and temperature-independent luminescence emission is due to the intra-4f-shell transitions of the ions. In the case of erbium, one transition between the 4f levels corresponds to an energy of about 800 meV which is in the region of minimum transmission loss in silica-based optical fibres. On the other hand, it has often been reported [1–3], and is generally accepted, that the presence of oxygen enhances the efficiency of Er emission in semiconductor hosts. In this work the luminescence of Er-doped and Te-codoped GaSb crystals has been investigated by means of cathodoluminescence (CL) using a scanning electron microscope (SEM). Er was introduced in the form of oxide (Er_2O_3) to enhance the luminescence of the Er^{3+} ions. Te doping leads to n-type behaviour of the GaSb crystals, which in the as-grown state present p-type behaviour.

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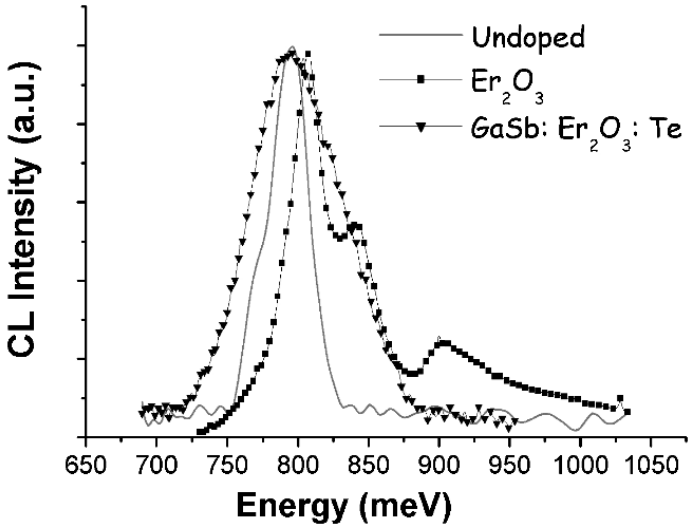

Figure 1. CL spectra of undoped GaSb, erbium oxide and GaSb doped with Er and Te.

2. Experimental method

Three Er-doped and Te-codoped polycrystalline GaSb ingots, 12 mm in diameter and 70 mm in length, were grown in a single-zone rotating Bridgman furnace. Details of the growth method are described in [4]. The ingots were grown with a constant Er concentration of 2×10^{19} cm^{-3} and Te concentrations in the melt of 2×10^{19} cm^{-3} (ingot A), 1×10^{19} cm^{-3} (ingot B) and 4×10^{19} cm^{-3} (ingot C) respectively. Wafers were cut perpendicular to the growth axis, chemomechanically polished to a mirror finish and observed using a Hitachi S-2500 SEM or a Leica 440 SEM at accelerating voltages of 20–30 kV in the secondary-electron and CL modes. CL emission of pure Er_2O_3 powder was also measured for comparison. The CL measurements were performed at liquid nitrogen temperature by using a cooled ADC Ge detector.

3. Results and discussion

Doping with Er_2O_3 causes increase of the total CL intensity as well as spectral changes. It has been previously reported [4] that Te codoping favours Er emission. Figure 1 shows the CL spectra of undoped GaSb, of Er_2O_3 powder and of the Te-doped and Er_2O_3-codoped samples investigated in this work. Undoped GaSb shows near-band-edge emission at about 796 meV and a shoulder corresponding to the 777 meV emission, usually referred to as band A, attributed to native acceptors. The peaks observed in erbium oxide are attributed to intra-ionic transitions from different excited levels in the Er^{3+} ions to the fundamental state [5]. The spectrum of the GaSb:Te:Er_2O_3 sample includes some of the emissions observed in both (GaSb and Er_2O_3) reference samples. However, to explain the shape of this spectrum it has to be considered that Te doping of GaSb induces a luminescence band centred at about 746 meV [6, 7] which contributes to band broadening in the low-energy part of the spectrum. The 746 meV emission is attributed [6] to a transition from the conduction band to an acceptor state associated with the complex defect $V_{Ga}Ga_{Sb}Te_{Sb}$. Figure 2 shows the Gaussian deconvolution of the spectrum of GaSb:Te:Er_2O_3 obtained by fitting the Te band, the A band, the near-band-edge band of GaSb, the main Er band and a high-energy band of GaSb at about 835 meV, possibly related to tail

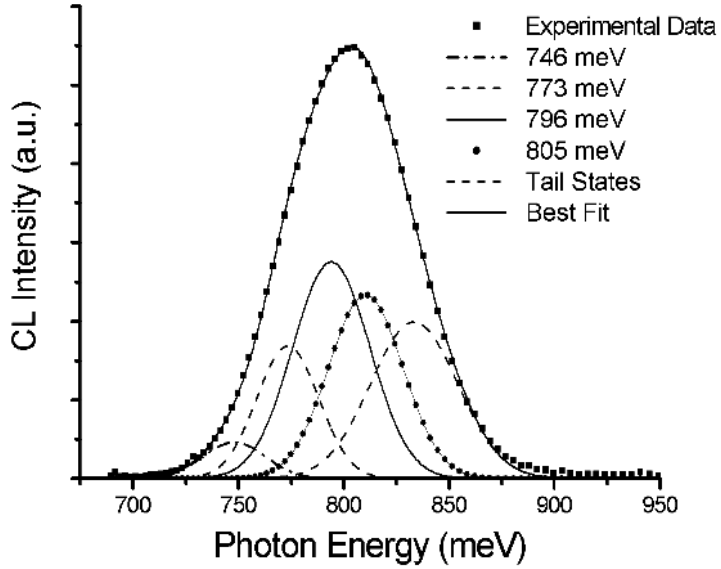

Figure 2. The CL spectrum of GaSb:Er_2O_3:Te deconvoluted to the best fit.

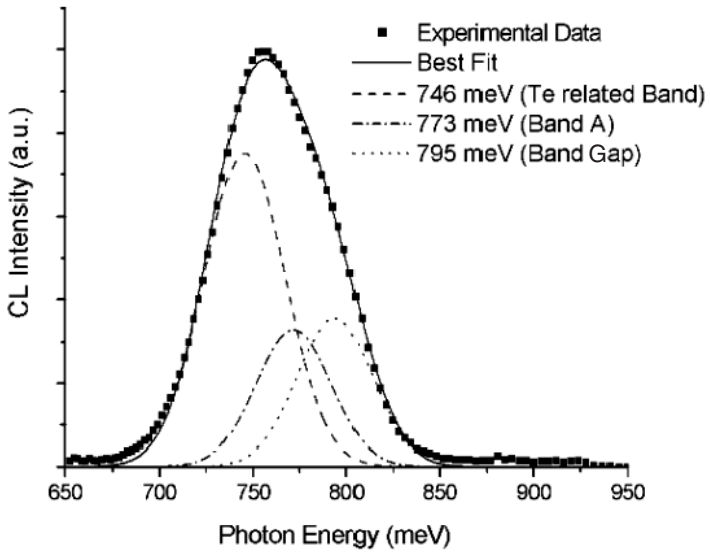

Figure 3. The CL spectrum of GaSb:Te deconvoluted to the best fit. The peak related to Te is observed.

states and shallow acceptors [8]. The reliability of the deconvolution was better than 99.999. The spectrum of figure 2 corresponds to ingot A but is qualitatively representative of the other ingots, B and C, investigated. The relative weight of the components, in particular of the Te- and Er-related bands, depends on the ingot and on the specific position on the ingot growth axis where the wafer was obtained, which is a consequence of the dopant gradient generated during growth. These measurements show that the presence of erbium induces a strong reduction

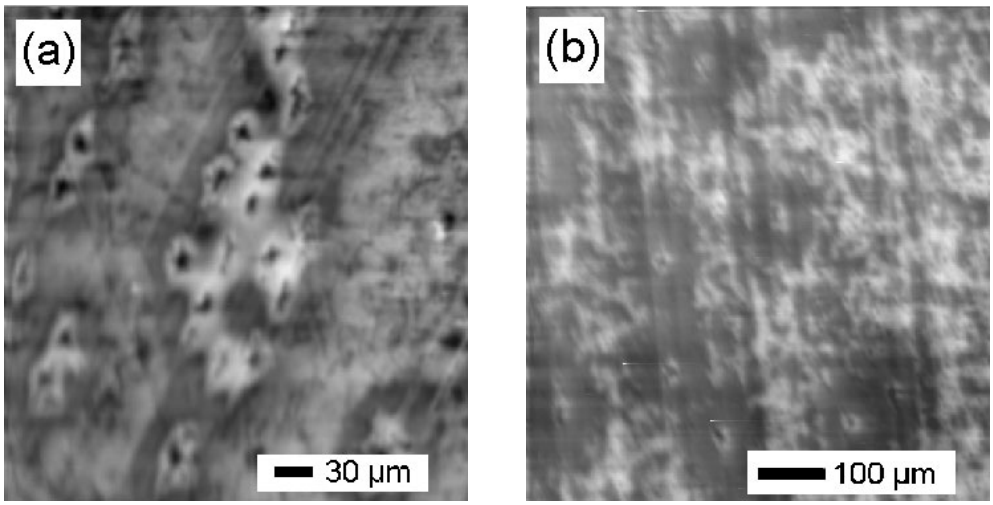

Figure 4. CL images showing inhomogeneous distribution of Te around defects in two samples of ingot A.

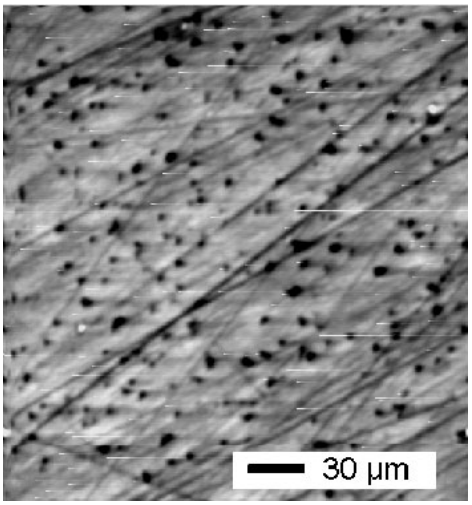

Figure 5. A CL image of sample with higher Te concentration at 77 K (ingot C).

of the Te-related emission. In the CL spectrum of a sample doped with 2×10^{19} cm^{-3} of Te, an intense Te band at 746 meV is observed (figure 3). The Er-induced reduction in the number of acceptor states in GaSb has been previously reported [9–11] and, in particular, CL measurements showed [11] the reduction of the band A, related to the native acceptor $V_{Ga}Ga_{Sb}$ by erbium doping. The present results show that erbium has a similar quenching effect on the $V_{Ga}Ga_{Sb}Te_{Sb}$ acceptor.

The efficiency of a dopant in reducing the acceptor concentration depends not only on the nominal dopant concentration but also on its possible aggregation state. It has been found [11] that in samples doped with high erbium concentrations, Er–Sb precipitates were formed and the band A was not significantly reduced. To investigate possible aggregation or highly inhomogeneous impurity distribution in the samples, CL images, which are very sensitive

to distributions of recombination centres, were recorded. The CL images showed differences not only among different ingots but also from samples obtained from different positions along the growth axis of a given ingot. This is due to the inhomogeneous distribution of Te around defects and cracks in the samples as measured by x-ray microanalysis [4]. Figure 4(a) shows a CL image of ingot A, showing parallel bands with sets of aligned dots surrounded by intense haloes and figure 4(b) shows a more complex halo contrast. This CL dot-and-halo contrast is typical of dislocations decorated with point defects in semiconductors; see e.g. [12]. Figure 5 shows a CL image of a sample of the ingot with higher Te concentration, ingot C. The defects show in this case a dark contrast with absence of haloes. This is explained by the higher Te concentration in this sample which influences the dislocation CL contrast and suppress the halo observed in samples with lower doping level [12, 13].

4. Conclusions

Er_2O_3 codoping of Te-doped GaSb produces a marked increase of the CL intensity of the samples. Luminescence spectra show that the presence of Er causes a decrease of the 746 meV Te-related emission band. This is explained by the erbium-induced reduction in the number of Te-related acceptor centres, similar to the effect of erbium on the native acceptors responsible for the A-band luminescence. CL microscopy shows that the spatial distribution of the luminescence is strongly influenced by the Te concentration.

Acknowledgment

This work was supported by MCYT (Project MAT2000-2119).

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