Vol. 87 (1995) *ACTA PHYSICA POLONICA A* No. 2

Proceedings of the XXIII International School of Semiconducting Compounds, Jaszowiec 1994

DEEP-LEVEL DEFECTS AT LATTICE-MISMATCHED GaAsSb/GaAs INTERFACE

T. Wosiński, A. Mąkosa

Institute of Physics, Polish Academy of Sciences
Al. Lotników 32/46, 02-668 Warszawa, Poland

and J. Raczyńska

Institute of Technical Physics, Military University of Technology
Kaliskiego 2, 01-489 Warszawa, Poland

Lattice-mismatch-induced defects were studied by means of deep-level transient spectroscopy in high-purity $GaAs_{1-x}Sb_x$ layers ($x = 0$ to 3%) grown by liquid phase epitaxy on GaAs substrates. Microscopic nature and formation mechanism of two electron traps and two hole traps, which appeared in the layers as a result of Sb incorporation into the crystal lattice, are briefly discussed.

PACS numbers: 73.20.Hb, 61.72.Lk, 71.55.Eq

In this paper we report first results of our study of electrical properties of lattice-mismatched GaAsSb/GaAs heterostructures. Such heterostructures are at present of considerable interest because of their potential application in high-speed and optoelectronic devices.

High-purity $GaAs_{1-x}Sb_x$ layers ($x = 0$ to 3%) were grown by liquid phase epitaxy (LPE) on (001) oriented p-type GaAs:Zn ($p = 10^{18}$ cm^{-3}) substrates. A multiple bin quartz boat was used in which four layers were grown simultaneously to ensure the same growth conditions of the layers. Ga solutions in each bin differed in concentration of antimony and arsenic in order to obtain the layers containing 0, 1, 2 and 3% of Sb. Prior to the growth the solutions were backed at 850°C for 5 hours in hydrogen and the growth was performed from thin film solution placed between two GaAs substrates. The crystallization process occurred during cooling the system from the temperature of 850°C down to the room temperature at a cooling rate of 0.5°C/min, resulting in n-type ($n \approx 10^{15}$ cm^{-3}) layers of about 70 μm thickness.

The GaAs epilayer ($x = 0$) was considered as a reference one. Sb content in the three other epilayers was estimated by means of spectrally resolved cathodoluminescence (CL) in a scanning electron microscope employed to the angle-lapped

TABLE

Parameters of the $GaAs_{1-x}Sb_x$ epilayers.

x [%]	x^{CL} [%]	$(x^l_{AS} + x^l_{Sb})/x^l_{Ga}$	n [cm^{-3}]
0	–	0.037	2.7×10^{15}
1	1.1	0.094	1.4×10^{15}
2	1.9	0.16	5×10^{15}
3	2.7	0.20	8×10^{15}

heterostructures. The results obtained from the layers of several μm thickness near the interface, presented in the second column of Table, are in good accordance with the values assumed in the technological process. Fractions of the group V elements in the Ga solutions employed for the growth of various epilayers are written in the third column of Table. In the fourth column the electron concentrations in the epilayers are listed which were determined from capacitance versus bias voltage measurements while employing p^+n junctions formed at the interfaces.

A difference in lattice constant between the substrate and the Sb-contained epilayer (about 0.2% at $x = 3\%$) resulted in generation of misfit dislocations to relieve some of the strain in the layer. They form a two-dimensional array of α and β dislocations gliding along two orthogonal $\langle 110\rangle$ directions at the interface which was revealed by means of spatially resolved CL.

The spectrum of lattice-mismatch-induced defects at the interfaces was studied by means of deep-level transient spectroscopy (DLTS) with the p^+n junctions which allowed for investigation of both electron traps in the upper half of the band gap and hole traps in the lower half. No impurity deep levels in concentration exceeding the detection limit of 10^{11} cm^{-3} were revealed. Two hole traps and one electron trap, attributed to native defects, were detected with DLTS in the reference structure. The hole traps, referred to as A and B, with the hole-emission activation energies of 0.40 eV and 0.70 eV and the concentrations of 7×10^{13} cm^{-3} and 2×10^{14} cm^{-3}, respectively, are commonly observed in LPE-grown GaAs. The traps were assigned to native point defects related to excess gallium in a crystal [1, 2], however, their precise microscopic nature remains unresolved.

The only deep electron trap revealed in the reference structure, with the electron-emission activation energy of about 0.7 eV and a low concentration of about 1×10^{12} cm^{-3}, was attributed to electron states associated with dislocations in the epilayer. The same trap, called ED1, had been previously found in plastically deformed bulk GaAs and related with 60°-α dislocations [3, 4]. The appearance of the ED1 peak in the DLTS spectra of the reference structure points out a large density (about 10^5 cm^{-2}) of dislocations in the GaAs epilayer near the interface which are probably threading dislocations originated in the substrate.

Two new hole emission peaks and one electron emission peak appeared in the DLTS spectra as a result of Sb incorporation into the epilayer lattice. Two new hole traps, which will hereafter be called HD2 and HD3, are, to our knowledge, reported for the first time here. The temperature dependence of the thermal emission rates

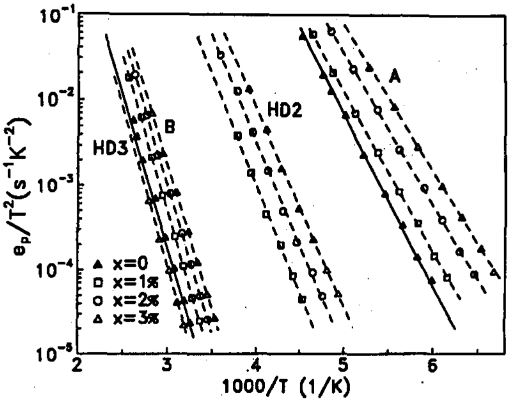

Fig. 1. Temperature dependence of the thermal emission rates for the hole traps revealed in the $GaAs_{1-x}Sb_x/GaAs$ heterostructures. Solid lines represent the data for *A* and *B* traps in GaAs after [2].

(Arrhenius plots) for the both traps, together with those for the *A* and *B* hole traps, obtained from the investigated heterostructures is presented in Fig. 1. The hole-emission activation energy of the HD2 trap, 0.51 eV at $x = 1\%$, decreases with an increase in the Sb composition in the epilayer similarly to the decrease in the energy gap of the $GaAs_{1-x}Sb_x$ compound. Similarly, the activation energies of the traps *A* and *B* decrease with an increase in the Sb content in the epilayer so that their energy levels remain constant with respect to the bottom of the conduction band. On the other hand, the activation energy of the HD3 trap, about 0.74 eV, was roughly the same in all the investigated structures, however, its precise evaluation was strongly disturbed owing to the position of the HD3 peak on the high-temperature slope of the much larger *B* peak in the DLTS spectra. The concentrations of the HD2 and HD3 traps increased systematically with an increase in the Sb content in the epilayer while the concentrations of the *A* and *B* traps decreased. We tentatively ascribe the HD2 and HD3 hole traps to defects associated with the lattice-mismatched interface of the heterostructures.

Two electron emission peaks were revealed in the DLTS spectra of the lattice-mismatched epilayers. Besides the dislocation-related ED1 peak, which was already present in the spectra of the reference structure, a new peak appeared which we ascribed to the well-known EL2 defect, the dominant deep-level defect in melt-grown GaAs crystals. The Arrhenius plots of the electron traps are shown in Fig. 2. The activation energies of both traps decrease with an increase in the Sb content in the epilayer so that the energy levels of the traps remain constant with respect to the top of the valence band. The concentrations of the ED1 and EL2 traps, in the region of the epilayer up to about 1 μm from the interface, increased with an increase in the lattice mismatch reaching the values of about 5×10^{12} cm^{-3} and 2.5×10^{12} cm^{-3}, respectively, in the epilayer with 3% Sb content.

Rather unexpected appearance of the EL2 defects in the LPE-grown layers needs a comment. EL2, undoubtedly related with the arsenic antisite, As_{Ga},

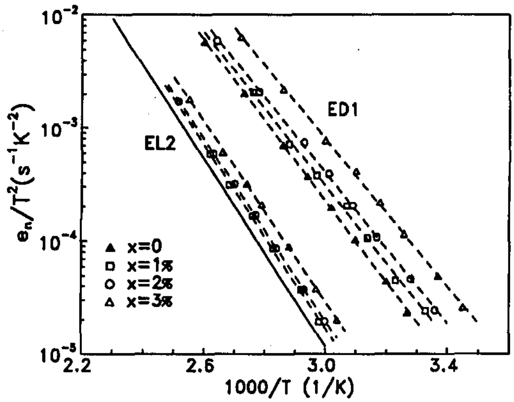

Fig. 2. Temperature dependence of the thermal emission rates for the electron traps revealed in the $GaAs_{1-x}Sb_x$/GaAs heterostructures. Solid line represents the data for EL2 trap obtained from melt-grown bulk GaAs.

commonly occurs in GaAs crystals grown under arsenic-rich conditions. However, there are three circumstances that can favor the EL2 defect formation in our lattice-mismatched $GaAs_{1-x}Sb_x$ epilayers. First, incorporation of antimony into the Ga solution increases distinctly the ratio of the group V elements to gallium in the liquid; cf. Table. Second, it was shown that the EL2 defects can be created by moving dislocations [5] and a high density of misfit dislocations is, actually, generated at the interface during the epilayer growth. Third, the crystallization of our epilayers begins at the temperature of 850°C at which, actually, the maximum formation rate of the EL2 defects occurs [6].

In conclusion, two electron traps and two hole traps were found with DLTS in the lattice-mismatched GaAsSb epilayers. The electron traps were attributed to dislocations and the EL2 defects, whereas the hole traps, reported for the first time here, are likely related to defects associated with the GaAsSb/GaAs interface.

References

[1] D.V. Lang, R.A. Logan, *J. Electron. Mater.* **4**, 1053 (1975).

[2] Z.-G. Wang, L.-A. Ledebo, H.G. Grimmeiss, *J. Phys. C* **17**, 259 (1984).

[3] T. Wosiński, *J. Appl. Phys.* **65**, 1566 (1989).

[4] T. Wosiński, T. Figielski, *Acta Phys. Pol. A* **83**, 51 (1993).

[5] T. Figielski, T. Wosiński, A. Mąkosa, *Phys. Status Solidi A* **131**, 369 (1992).

[6] J. Lagowski, *Acta Phys. Pol. A* **77**, 311 (1990).