Evaluating Bi distribution within GaAsBi epilayers

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In the past forty years, intensive research has been performed for active region laser diode materials and photodetectors operating in the infrared and near infrared regions [1]. Material systems based on GaAs alloys with diluted nitrogen, antimony and/or bismuth present several advantages over competing technologies. However, bismuthides had received very little attention principally due to the high miscibility gap between GaBi and GaAs and to the tendency of Bi to surface segregate, which requires low growth temperatures to achieve significant Bi incorporation into GaAs[2]. Nevertheless, recently diluted bismuth alloys have generated great interest; mainly due to the bandgap reduction of up to 88 meV/%Bi, which is much larger than that of the Sb, and only lower than the 130 meV/%N alloying [2,3]. Therefore, it is important to know how much bismuth is incorporated and how it is distributed into the nanostructures in order to understand their properties.

The present work aims to study the structural and compositional distribution of bismuth in GaAsBi layers grown on GaAs. Two samples were grown by molecular beam epitaxy (MBE). They comprise a 500 nm GaAs buffer grown at 580 °C, followed with either a 25 nm (sample S25) or a 100 nm (sample S100) GaAsBi layer grown at 380 °C. A As_4:Ga:Bi beam equivalent pressure ratio (BEPR) of 40:2:1 was used for both samples. Finally the GaAsBi was capped with a 100 nm GaAs layer grown at the GaAsBi growth temperature. The sample was then removed from the system without post growth annealing and characterised by transmission electron microscopy (TEM).

TEM images show good crystallinity in both samples with a uniform GaAsBi layer thickness and almost free of defects. Furthermore, dark-field (DF) images (sensitive to composition) reveal that Bi content is not homogenous along the layer, presenting a gradient with higher content at the bottom. Energy Dispersive X-ray (EDX) studies also reveal a decrease in the incorporation of Bi along the growth direction. The maximum Bi content in both samples is obtained in the firsts 5 nm approximately and progressively decays until 25 nm. However, the Bi content in S100 is almost constant from 25 nm to the end of the GaAsBi layer. The average composition of Bi measured at the bottom and the top zone of the GaAsBi layer are 6.1% ± 0.5 and 2.6% ± 0.6 respectively in the S100 sample and 4.2% ± 0.4 and 2.5% ± 0.5 in the S25 sample.

Nevertheless, to obtain extended composition maps, simulations confirm that 002 DF images are appropriate to perform reliable chemical analysis on these layers. Intensity on these images are directly proportional to square of the modules of the structure factor $|F_{002}|^2$ which allows the analysis of the Bi content of these ternary alloy zinc-blende nanostructures [4]. The methodology adopted to extract Bi content from 002DF images is as follows: (i) image is acquired from cross-section TEM specimens tilted away from the [110] zone axis to excite mainly the 00-2 Bragg reflection; (ii) the linearly descending background due to specimen thickness is subtracted from the image; (iii) intensity is normalised with respect to GaAs (substrate); (iv) then, the Bi composition is determined comparing the measured normalised intensities with respect to those calculated using an exact two-beam condition. Figure 1 shows the Bi composition map for the two samples, following the explained methodology. In addition to the reduction of the Bi content along the growth direction, already observed in EDX, these maps depict lateral fluctuations and an undulating boundary between the higher Bi-content area and the rest of the GaAsBi layer. Averaged Bi content profiles of the two samples extracted from the 002DF images are shown in Figure 2. Bi content in S25 sample varies approximately from 3.5% to 1.5%, depicting a good correlation with EDX measurements. Nevertheless, Bi content in S100 approximately varies from 3.3% to 1.5%, showing a greater deviation with respect EDX. In order to obtain enhanced accuracy on compositional analysis with the proposed methodology, control of the TEM specimen thickness and dynamical image intensity simulations are needed.

In conclusion, we present a procedure to spatially resolve the Bi content on GaAsBi/GaAs epilayers by using 002DF micrographs that is in good agreement with EDX measurements. The results expose the inhomogeneity of the Bi incorporation during the growth of GaAsBi layers on GaAs substrates. The bismuth content undergoes a strong and irregular decrease in the first 25 nm which is then remains almost constant till the end of the layer. As a result, the layer behaves as a GaAsBi bilayer with two different compositions. The reasons for this behaviour are under study.

References

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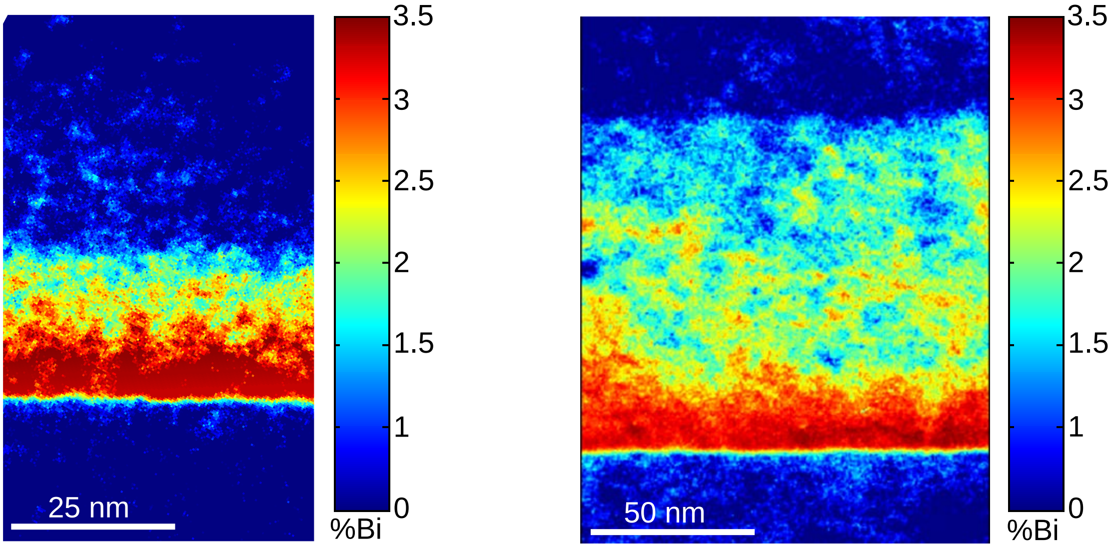

Figure 1. *002DF image composition color map of the bismuth content of a GaAsBi layer embedded in a GaAs matrix of sample S25 (left) and S100 (right)*

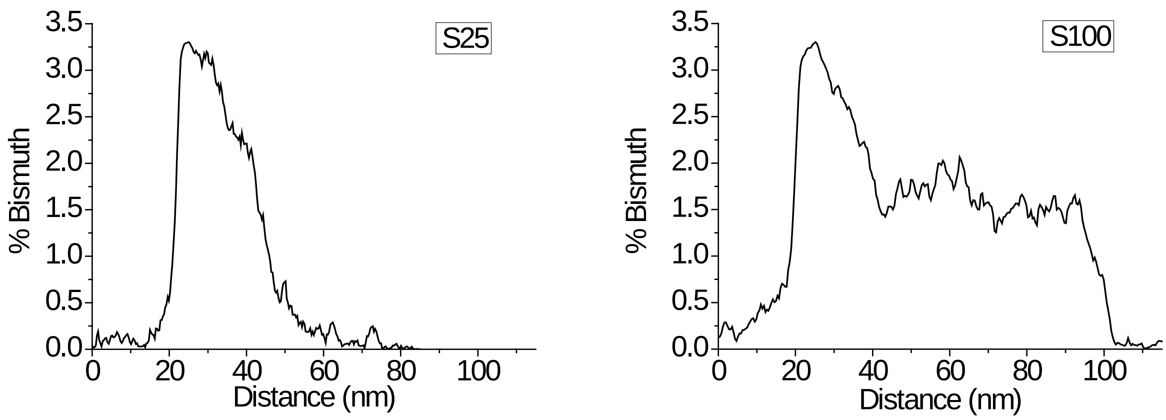

Figure 2. *Averaged Bi content profile of sample S25 (left) and S100 (right) using the 002DF imaging composition procedure*