Invited Talk

Transmission Electron Microscopy of (In,Ga)(Sb,Bi) epilayers and quantum wells

E. Luna[1], O. Delorme[2], L. Cerutti[2], E. Tournié[2], J.-B. Rodriguez[2] and A. Trampert[1]

[1]*Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5-7, D-10117, Berlin, Germany*

[2]*IES, Univ. Montpellier, CNRS, F-34000 Montpellier, France*

luna@pdi-berlin.de

The recent demonstration of a mid-infrared laser based on Ga(Sb,Bi)/GaSb quantum wells (QWs) [1] has prompt the interest on emerging dilute bismide alloys based on antimonides. Despite the promising perspectives, dilute bismides based on antimonides are far less developed and studied compared to other dilute bismide compounds such as Ga(As,Bi). Fundamental questions such as alloy stability, segregation, or solubility limits are still under investigation, evidencing that material developments are still required for the further use of Ga(Sb,Bi) in practical devices.

As shown here, our recent investigations of the microstructure and chemical homogeneity of Ga(Sb,Bi) epilayers and QWs with Bi contents up to 12% demonstrate its high quality, high stability, and feasibility for use in the active zone of optoelectronic devices. No extended defects, nanoclusters, or composition modulations are detectable in the pseudomorphic layers. There are nevertheless droplets on the surface of Ga(Sb,Bi) epilayers with high Bi content (> 12%) which lead to surface irregularities and local inhomogeneities.

Ga(Sb,Bi)/GaSb QWs exhibit regular and homogeneous morphologies including smooth and stable interfaces with a chemical width on the same order as in other high-quality III–V heterointerfaces [2] Some QWs are nevertheless affected by (1) lateral thickness fluctuations and slight thickness variations from QW to QW, and (2) a rougher Ga(Sb,Bi)-on-GaSb interface compared to the GaSb-on-Ga(Sb,Bi) one [3]. The morphological smoothing effect at the GaSb-on-Ga(Sb,Bi) interface is attributed to the well-known surfactant behavior of Bi in connection with Bi surface segregation, as evidenced from experimental Bi distribution profiles. The QWs comprising reference laser structures as well as further working laser devices are characterized by narrower and symmetric interfaces with reduced thickness fluctuations.

To date, the maximum Bi incorporated into GaSb is about 14%, which is smaller than the reported maximum 21% Bi incorporation into GaAs [4]. Beyond 12% Bi, the systematic presence of droplets in Ga(Sb,Bi) strongly impacts the optical properties, especially above 3 µm. In this context, the addition of In may enhance Bi solubility into GaSb and allow reaching longer wavelengths. We find that droplet-free (In,Ga)(Sb,Bi) epilayers are of high quality with a microstructure that resembles that of high quality Ga(Sb,Bi). Both In and Bi are simultaneously incorporated in the layer. It seems, however, that In reduces Bi incorporation efficiency into GaSb. In analogy to Ga(Sb,Bi)/GaSb QWs, there is a morphological smoothing at GaSb-on-(In,Ga)(Sb,Bi) interfaces of QW structures, probably due to the surfactant behavior of Bi. Finally, we discuss the challenges in the investigation of the new quaternary (In,Ga)(Sb,Bi) alloy.

[1] O. Delorme *et al.*, Appl. Phys. Lett. **110**, 222106 (2017)
[2] E. Luna *et al.*, Appl. Phys. Lett. **112**, 151905 (2018)
[3] E. Luna *et al.*, Semicond. Sci. Technol. **33**, 094006 (2018)
[4] R. B. Lewis *et al.*, Appl. Phys. Lett. **101**, 082112 (2012)