Strain analysis of thin III-antimonide layers grown on InAs

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1. INTRODUCTION

The production of photonic devices emitting in the mid infra-red spectral range (i.e. $2<\lambda<5\mu m$) is required for developing systems for environmental monitoring, medical diagnosis, and also for laser surgery, free space communications etc... Quantum heterostructures composed of group III - arsenide and antimonide compounds are among the most promising structures for the development of mid-IR photonic devices. Thanks to the very large conduction band discontinuity of 2.1 eV, the InAs/AlSb system used in quantum cascade laser (QCL) allowed emission wavelengths as short as 2.6µm [1,2]. However the understanding of mechanisms occurring during the growth of these structures is not yet fully completed. The lattice mismatch between the layers is moderate (1,3%) but the lack of atoms in common between InAs and AlSb induces significant structural, electronic and chemical discontinuities at interfaces that have to be controlled to master the properties of the whole structure. The interfacial zones consist of AlAs or InSb bonds that result in important elastic strain levels either in tension or in compression due to the very large misfit between bulk InSb or AlAs with InAs of about +6.6% and -6.6%, respectively.

The aim of this work is to study ternary alloys $AlAs_xSb_{1-x}$ instead of pure AlSb barriers in InAs/AlSb multilayers. The use of these alloys with lattice parameters close to those of InAs could reduce or even suppress the epitaxial strain of the device while controlling the nature of interfaces. It would thus allow developing low-stressed mid-IR photonic devices.

2. EXPERIMENTAL CONDITIONS

Multilayer structures alternating 20-nm-thick InAs and 4-nm-thick $AlAs_xSb_{1-x}$ layers were grown on (001) InAs substrates by molecular beam epitaxy (MBE) at 700K with a growth rate of 1 Å.s^{-1}. A V/III flux ratio of about 2 was kept constant during the growth of the different layers. A growth interruption of 3 s with no V element flux was performed at interfaces. Four compositions of ternary allow were studied for x ranging from 0 to 0.24. The lattice match between the InAs and the ternary allow is expected for an arsenic rate of 0.16. The samples were studied by high resolution transmission electron microscopy (HREM) in a Tecnai F-20 microscope operating at 200 kV and equipped with a spherical aberration corrector. The strain profiles were determined by applying the geometrical phase analysis (GPA) with some precautions to get reliable local strain value at the interfaces.

3. RESULTS AND CONCLUSION

Figure 1 shows a typical HREM image of an AlSb layer in InAs substrate and its corresponding strain profile along the growth direction (y). The in-plane strain mapping, ε_{xx}, (not shown here) does not show significant variation of the strain suggesting a fully elastic accommodation of the lattice mismatch. The ε_{yy} profile displays on the contrary important variations of the strain compared to InAs taken as a reference. It reveals a plateau of strain around +3% that is in good agreement with the theoretical value expected from the elasticity theory considering the lattice mismatch between InAs and AlSb. Two negative peaks corresponding to the interfacial zones of AlAs-type are also obtained as previously reported [3]. Figure 2 shows the same analysis carried out in the $AlAs_xSb_{1-x}$ layer with x = 0.16. This composition is assumed to get the same lattice parameter as InAs and thus should not produce epitaxial strain. However a negative strain profile is obtained. That clearly indicates that the layer is stressed in tension with a measured out-of-plane strain around -1.5%. This result tends to indicate that the composition of the layer is thus not the one expected but should be slightly richer in arsenic. High tensile strains are also observed at both interfaces confirming the formation of AlAs-type interfaces. However the strain level is higher than the one obtained for pure AlSb suggesting an increase of the AlAs-type bonds at interfaces. Moreover we can note that the interfacial zones are not homogeneous through the sample.

For each ternary allow, strain levels of the layer are very different than expected. For some composition the layers seem richer in As than intended, while for others a phase separation could occur. The addition of a small amount of As in AlSb significantly modifies the strain level in the layer and thus suggests that a competition between As and Sb incorporation and segregation phenomena of Sb occurred during growth. STEM HAADF coupled with EELS experiments will soon be carried out in order to get chemical information on the composition of layers and interfaces.

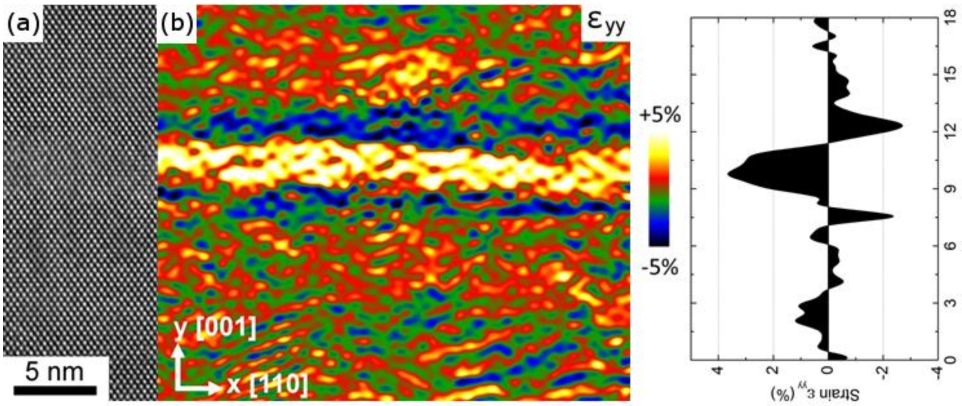

Figure 1. HREM image of the AlSb layer embedded in InAs (a) and the out-of-plane strain profile (ε_{yy}) obtained by GPA for the same area (b). (c) intensity of (ε_{yy}) averaged along the [110] direction over 8 nm. Scale marker applies to (a) and (b)

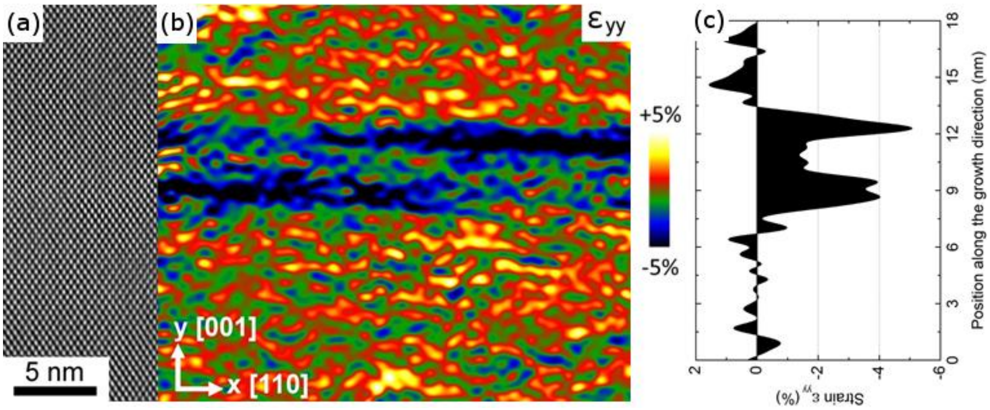

Figure 2. HREM image of the $AlAs_{0.16}Sb_{0.84}$ layer embedded in InAs assumed to be in lattice matching (a) and the out-of-plane strain profile (ε_{yy}) obtained by GPA for the same area (b). (c) intensity of (ε_{yy}) averaged along the [110] direction over 8 nm. Scale marker applies to (a) and (b)

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