ELSEVIER

Applied Surface Science 144–145 (1999) 488–491

applied surface science

Transmission electron microscopy study of InGaAs/InP superlattices grown on V-shaped surface InP substrates

S.I. Molina [a,*], D. Araujo [a], T.C. Rojas [a], R. Garcia [a], F. Morier-Genoud [b], U. Marti [b], F.K. Reinhart [b]

[a] Departamento de Ciencia de los Materiales e I.M. y Q.I., Universidad de Cádiz, Apdo. 40, 11510 Puerto Real, Cádiz, Spain
[b] Institut de Micro- et Optolectronique, Ecole Polytechnique Fdrale de Lausanne, CH-1015 Lausanne, Switzerland

Abstract

Fabrication of InGaAs/InP quantum well wires obtained by growing InGaAs/InP superlattices on V-grooved surface (001) InP substrates is evidenced. The density of planar defects propagated through the epilayers of these heterostructures depends on the type (A or B) of atoms which constitute the surface of the V-grooved (111) planes. The (111)B V-grooved surfaces are shown to generate more defects propagating through the heterostructure. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: InGaAs/InP; V-grooved surface InP substrate; TEM

1. Introduction

The quantum well wire (QWW) structures have generated a great deal of interest over the past few years, primarily motivated by their important electronic and optical properties. QWWs can be used to fabricate semiconductor lasers to improve their performance, reduce temperature sensitivity, obtain low threshold currents, narrower linewidths, increased gain and higher bandwidths [1]. Such properties are expected as a result of the two-dimensional (2D) quantum confinement, including very large exciton binding energy, modified electroabsorption and electrorefraction spectra [1], enhanced optical nonlinearities [2] and optical gain [3]. In addition, QWWs are expected to show unique transport properties [4] and to have extremely high electron mobility [5,6].

To achieve efficient 1D structures, some criterium must be taken into account [1]: (i) lateral dimensions; (ii) low defect density, to reduce non-radiative recombination process; (iii) low size fluctuations, to restrain inhomogeneous broadening; (iv) high density of wires, to maintain high interaction with light.

In this paper, good morphological quality of quantum well wires obtained by growing InGaAs/InP superlattices on V-grooved surface (001) InP substrates is shown. The crystalline quality of the heteroepitaxial growth of the QWWs is shown to depend on the type -(111)A or -B V-groove surface.

2. Experimental

The V-grooves are obtained by holographic laser patterning followed by wet-etching. Ridges oriented

* Corresponding author. Tel.: +34-956-830828; Fax: +34-956-834924; E-mail: sergio.molina@uca.es

PII: S0169-4332(98)00846-0

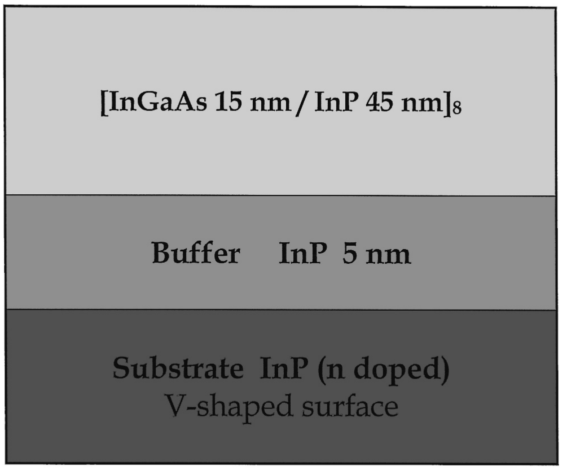

Fig. 1. Layer scheme of the studied samples.

along either [1 − 10] or [110] with respectively {111}A or {111}B sidewall planes are prepared by etching (100)-oriented InP substrates with a pure HBr solution cooled at 3°C. On the resulting non-planar substrates is then grown the heteroepitaxial structure by MBE.

Fig. 1 shows the layer structure of the studied samples. V-shaped surfaces have been produced on the substrate by a combination of holographic lithography and etching. The V-grooves orientation is

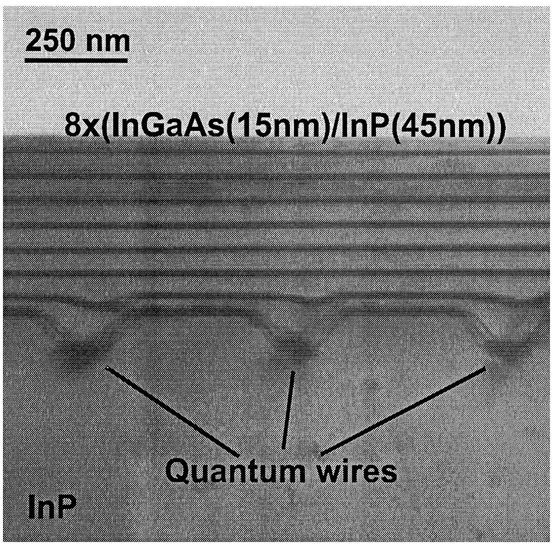

Fig. 2. Bright field cross-section TEM image of sample A.

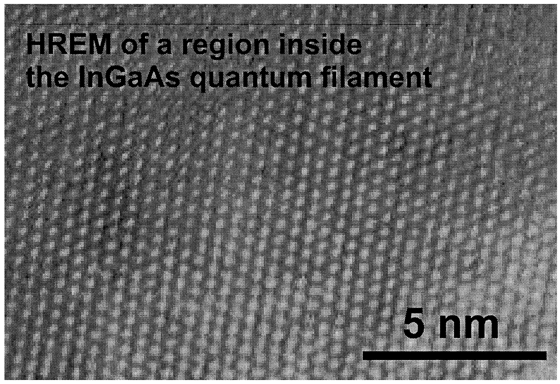

Fig. 3. HREM image recorded from the inner region of an InGaAs quantum filament.

chosen along the [110] direction with the side facet orientations close to {111}A (labelled as sample A) or {111}B (labelled as sample B).

A number of samples were prepared to be studied by transmission electron microscopy (TEM) using cross-section and planar view orientations. The TEM

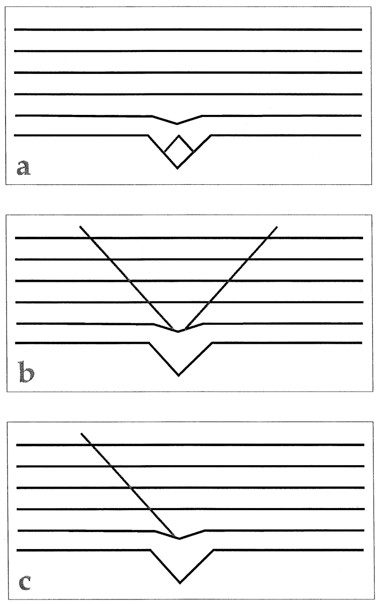

Fig. 4. Configurations of planar defects observed in samples A and B. A couple of planar defects are generated close to a quantum filament, and: (a) react and are no propagated through the epilayer surface, or (b) are propagated through the epilayer surface. (c) The only planar defect is propagated upper in the epilayer. These configurations are labelled as ‘a’, ‘b’ and ‘c’, respectively.

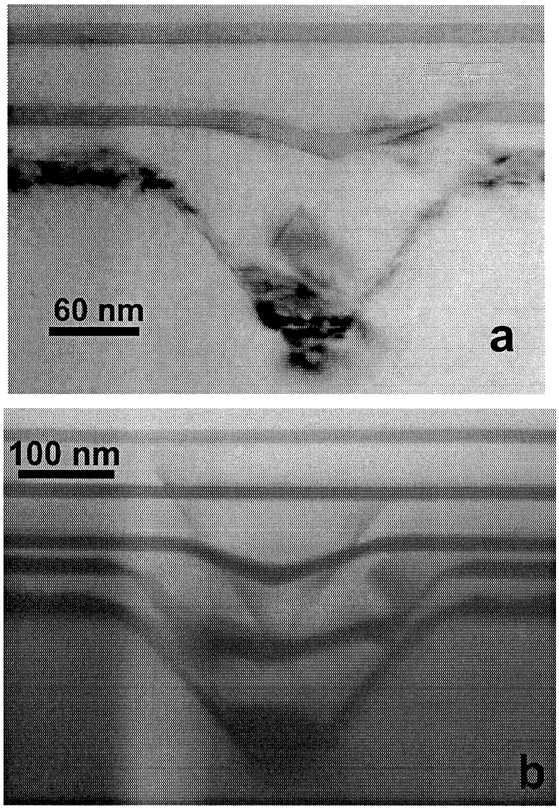

Fig. 5. Cross-section TEM images showing regions in which the planar defect configurations ‘a’ (a) and ‘b’ (b) are observed.

study has been performed with two transmission electron microscopes, a Jeol 2000EX, for high resolution electron microscopy (HREM) work, and a Jeol 1200EX, for diffraction contrast work. The cross-sections were prepared using the conventional procedure (mechanical thinning and Ar^+ ion milling) while the planar view preparations were carried out by Br_2/CH_3OH chemical etching.

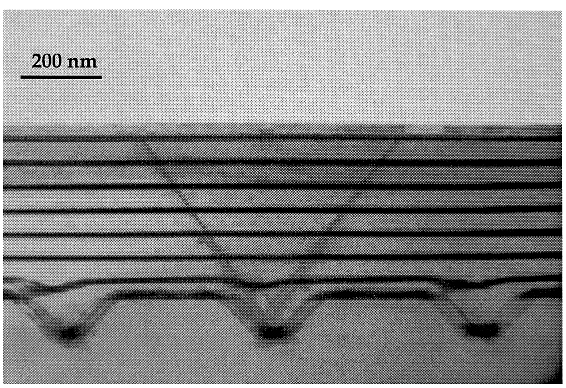

Fig. 6. Cross-section TEM image showing the planar defect configuration ‘b’. Note that the planar defects are generated in the first InGaAs layer.

3. Results and discussion

The low magnification bright field TEM image of Fig. 2 shows a general view of the observed layer stacking of sample A. This image evidences that the (001) plane growth front is reached for the third InGaAs quantum well in sample A, i.e., standard

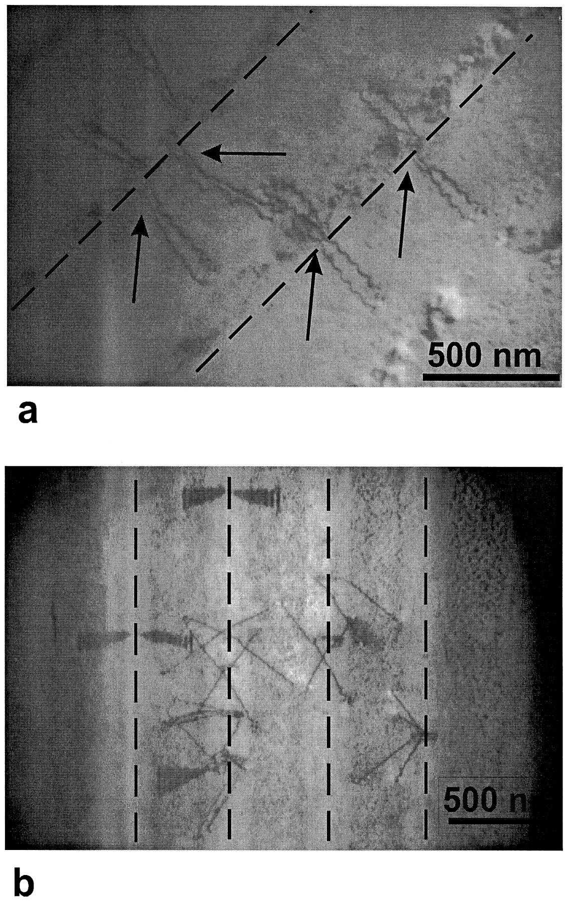

Fig. 7. Planar view TEM image corresponding to samples B (a) and A (b) showing defects generated in or close to the quantum filaments.

growth parallel to the (001) plane is followed above this. For sample B, the (001) growth happens for the fourth InGaAs quantum well. The strong contrast at the tip of the V-shaped grooves is attributed to the composition variations that induce a lattice strain. This evidences that a concentration of InGaAs has been obtained along the wires orientated with their length parallel to the [110] direction. This is verified because such contrast appears bright in the TEM images recorded using reflections sensitive to the composition. At the V-shaped tips, no defects have been observed, as shown in the HREM of Fig. 3.

Cross-section TEM observations permit to confirm that planar defects emanate from regions close to the tips and propagate through the epilayer for both samples (A and B). Nevertheless, the propagated planar defects are much more abundant for sample B with respect to sample A. Fig. 4 shows the different observed planar defect configurations (labelled as ‘a’, ‘b’ and ‘c’) for both studied samples. Configuration ‘a’ is frequently observed in sample A while as ‘b’ configuration is mostly observed in sample B. ‘c’ configuration only appears for sample A and is quite infrequent. Fig. 5a and b shows cross-section TEM images corresponding to configurations ‘a’ and ‘b’, respectively. The planar defects with the configuration ‘b’ are observed to be generated in the first (Fig. 6) or second (Fig. 5b) InGaAs quantum wells.

Planar view observations confirm this result. The configuration of planar defects showed in the planar view TEM image of Fig. 7a shows the partial dislocations associated with pairs of propagated planar defects observed in cross-section TEM images. The dashed lines in this figure indicate the location of the QWWs. As above mentioned, these configurations are typically observed in sample B and scarcely appear in sample A. However, some isolated complicated combinations of planar defects and dislocations are observed also in sample A; the image of Fig. 7b shows an example of such contaminated regions. Planar defects are shown to be generated close to the QWWs while dislocations are observed to be born away from them. This could be explained by preferential atomic segregation at the V-grooved (111) planes, provocating local compression strain on them, therefore originating planar defects at such compressed regions.

4. Conclusions

The growth of InGaAs/InP superlattices on V-grooved surface (001) InP substrates has permitted to obtain good quality quantum wires along [110] directions. The density of planar defects propagated through the epilayers of these heterostructures depends on the type of atoms (A or B) which constitute the surface of the (111) planes of the V-grooves. These propagated defects are more abundant for the (111)B surface V-grooves.

References

[1] E. Kapon, Optoelectronics S429 (1993) .
[2] D.A.B. Miller, D.S. Chemla, S. Schimt-Rink, Appl. Phys. Lett. 52 (1988) 2154.
[3] S. Schimt-Rink, D.A.B. Miller, D.S. Chemla, Phys. Rev. B 35 (1987) 8113.
[4] Y. Arakawa, A. Yam, IEEE J. Quantum Electron. 22 (1985) 1887.
[5] E. Kapon, D.M. Hwang, B. Bhat, Phys. Rev. Lett. 24 (1989) .
[6] H. Sukaki, J. Appl. Phys. 19 (1980) 94.