ON THE MECHANISM OF STRAIN RELEASE IN $In_xGa_{1-x}As/GaAs$ SINGLE HETEROSTRUCTURES

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Abstract: $In_xGa_{1-x}As/GaAs$ single heterostructures having different epilayer thicknesses and compositions have been studied by means of several complementary microanalytical techniques in order to determine the mechanism of strain release and to compare the predictions of the available theoretical models.

1. Introduction

The study of the growth of epitaxial strained-layers is increasing because of their potential applications in both fundamental and device-oriented research. It is well known that if a material is epitaxially grown on a substrate having slightly different lattice parameter the first few atomic layers which are deposited will be strained in order to match the substrate atomic arrangement. A coherent (pseudomorphic) structure is thus formed.

However pseudomorphic growth is possible only if the epilayer thickness does not exceed some critical value[1] above which the lattice mismatch is partly accomodated by misfit dislocations (MD's) which deteriorate the electronic properties of the material. For this reason a lot of theoretical and experimental work has been recently performed in order to understand the process of the strain release and to predict the critical thickness for the onset of the MD's network.

From the theoretical point of view the main difficulties arise from the need of understanding the validity of the continuum elasticity theory at the scale of few atomic layers and form the complex dynamics of the formation process of the dislocation network.

The aim of the present work is a systematic investigation of the strain release as a function of both the composition and the thickness of the strained single layers and the comparison of the present results with the available theoretical models[2,3] and other literature data[2,4].

2. Experimental and results

$In_xGa_{1-x}As/GaAs$ single heterostructures having x ranging from 3.5% to 15% and thicknesses varying from 20 to 1160 nm have been grown by MBE. The growth rate was also varied from 0.114 to 0.330 nm/sec.

Indium concentrations and film thicknesses have been measured by Rutherford Backscattering Spectrometry (RBS) and Auger Electron Spectroscopy (AES). Residual strain measurements have been performed by Double Crystal X-Ray Diffraction and a newly developed RBS-Channeling method. Cathodoluminescence, X-Ray Topography, Transmission Electron Microscopy and Ion-dechanneling methods have been employed to characterize the dislocation network and to measure the dislocation density.

The strain-induced tetragonal distortion of the lattice cell has been directly measured in terms of the ratio between the lattice parameters perpendicular and parallel to the growth plane ($a_{//}/a_{\perp}$). Asymmetric DCD measurements have been performed on samples having thicknesses greater than 50 nm in order to obtain a separate measure of the parallel and perpendicular lattice parameters.

The angles between several axial and planar directions have been determined by ion-channeling in all the samples and the data set from each sample has been fitted using $a_{//}/a_{\perp}$ as the fitting parameter.

The parallel strain can be determined as a function of the tetragonal distortion : $\varepsilon_{//} = (a_{\perp}/a_{//} - 1)/(a_{\perp}/a_{//} + \alpha)$, α being the ratio between the perpendicular and the parallel strains.

The α parameter has been experimentally determined on the samples which do not show any evidence of strain release and therefore having their parallel cell parameter equal to the substrate lattice parameter a_s, obtaining $\alpha = 0.93 \pm 0.11$ in perfect agreement with the prediction of the continuum elasticity theory: $\alpha = 0.92$.

The measured parallel strain values have been compared with different theoretical models. After the beginning of the strain relaxation all the data point follow a unique relation as a function of the film thickness (t) independently of the In concentration of the layer. This relation can be approximately described as a $t^{-1/2}$ dependence while the equilibrium elastic theories suggested a t^{-1} slope. A better agreement is found with respect to the nucleation theories[2]. The critical thickness for having detectable strain relief is much greater than expected on the basis of the equilibrium theories. This does not mean that in the samples having parallel strain equal to the misfit MD's are not present, as shown by TEM and Cathodoluminescence images, but that their density is still too low to produce significant strain relaxation.

Different models based on the description of the kinetics of the process of MD's formation and multiplication[3] have also been checked but no unique set of fitting parameters has been found to reproduce the experimental results. Moreover a small number of samples have been further annealed at temperatures and times higher and longer than during the MBE growth and expected to produce full relaxation on the basis of the kinetic model[3], in order to check a possible metastability of the as-grown layers. In all the cases more than 50% of the original strain was still present after the annealing confirming a substantial stability of the structure.

3. References

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