GROWTH PHENOMENA AND CHARACTERISTICS OF STRAINED In$_x$Ga$_{1-x}$As ON GaAs

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We have investigated the molecular beam epitaxial growth, structural and optical properties of InGaAs on GaAs. We have focused first on the initial stages of growth where the growth is expected to be under coherent strain and second on the nature of single and multiple quantum well heterointerfaces.

In the present study, we have critically examined two aspects of strained layer epitaxy: (a) the initial growth modes as a function of the growth parameters, and (b) the nature of heterostructures and quantum wells with thicknesses extending well beyond the equilibrium critical thickness. For case (a) theoretical and experimental studies have been made and from thermodynamic considerations, it is clear that as the strain increases, the free energy minimum surface of the epitaxial layer is not atomically flat, but three-dimensional (3D) in form. Photoluminescence (PL) and absorption measurements on thick multiple quantum well (MQW) structures grown with and without intermediate composition buffer layers indicate that these structures are comparable in quality to lattice matched GaAs/AlGaAs MQWs. Further transmission electron microscopy (TEM) results confirm that dislocation free MQW regions with thicknesses extending well over the equilibrium critical thickness can be achieved by molecular beam epitaxy (MBE).

In fig. 1, we show the measured change in surface lattice constants as obtained from the reflection high energy electron diffraction (RHEED) integral order spacings, from video recording. Data were obtained by digitizing individual frames of the videotape into a 480 × 480 array with 256 grey scale and loaded into the computer. Slices through the array were taken across the integral order RHEED lines and the intensity distribution plotted. By analysis of the dynamic changes of these peaks, we see dramatic movement at higher temperatures. At low temperatures, where impinging atoms are unable to move in a correlated manner to reach the free energy minimum surface, the lattice constant remains close to the substrate's. However, at higher temperatures, a monotonic change of the lattice constant is observed. It should be mentioned that similar data has recently been
The linewidths for p-i strained MQW-n samples grown with and without intermediate composition buffers (1.5–2.5 meV) are almost identical as are the peak intensities. These linewidths confirm the high quality of the heterointerfaces. Low temperature absorption spectra for the samples are well resolved, showing both the light- and heavy-hole transitions. The assignments for these peaks were made from a theoretical model which takes into account size quantization and strain effects [3]. Stokes shifts as small as 1.7 meV confirm the superior quality of the heterointerfaces. These results, coupled with those for the strained SQWs and MQWs, indicate that as far as optical properties are concerned, the incorporation of an intermediate composition buffer layer has little impact. The growth kinetics and growth modes play a more important role.

The surface morphology of the SQW structures was featureless. In the other samples we observed that, in general, samples with intermediate composition buffers showed a very slight cross-hatch pattern, while those without the buffer layers showed none, even in the 2 μm thick p-i n diodes. The cross-sectional TEM (XTEM) data shown in fig. 2, indicate clearly that there are no propagating dislocations in the MQW region, with and without an intermediate composition buffer layer. This result is puzzling in terms of the existing models of critical thickness. However, Van der Merwe and Jesser [4,5] have recently made calculations which show that the critical thickness of free-standing superlattices with small misfits is more than 4 times that of a single epilayer on a thick substrate. However, even this four-fold enhancement does not explain results in our samples without intermediate composition buffers, which have strained MQWs with total thicknesses greatly exceeding that predicted by Van der Merwe and Jesser [4,5]. To further study these phenomena, the MQW samples, which previously showed no dislocations, were annealed in a hydrogen ambient at...
830°C for 30 min and characterized in the same manner as the other strained MQW samples. Upon annealing the samples showed an increase in the PL linewidth, by a factor of 5.5. The samples also showed the presence of dislocations with XTEM, though the surface morphology remained unchanged. Therefore, at this point, it can be stated that: (a) with our growth conditions, there exists a metastable state where dislocation free growth is possible with MBE, a non-equilibrium growth technique, and (b) the cross-hatch pattern is a growth related phenomena due to the generation of misfit dislocations and the consequent step growth which takes place.

Fig. 2. Cross-sectional TEM results of a p-i(strained MQW)-n modulator. The absence of dislocations in the MQW region should be noted.
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References


