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PREPARATION AND CHARACTERIZATION OF STRAINED SUPERLATTICES STRUCTURES OF InGaAs/GaAs BY MBE

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Abstract: Strained superlattices $\text{In}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$ have been epitaxially grown on GaAs substrates around the composition $x = 0.1$, which corresponds to a strain free lattice mismatch as large as $+7 \times 10^{-3}$. The films, grown by Molecular Beam Epitaxy (MBE), were made of successive alternating layers of $\text{In}_x\text{Ga}_{1-x}\text{As}$ (100 Å) and GaAs (200 Å). Characterization have been performed by transmission electron microscopy, X ray simple and double diffraction, photoluminescence and absorption at low temperature. Periodicity can be measured with high accuracy frow X ray diffraction profiles. P.L. efficiency of the quantum size InGaAs layers is 1 to 2 orders of magnitude higher than GaAs thick epilayers grown in the same conditions. Absorption spectroscopy shows a strong excitonic contribution in the InGaAs wells.

1-Introduction

Misfit between an epitaxial film and its substrate can be accommodated by uniform elastic strain and by dislocations. Frank and Van der Merwe [1,2,3] have shown that a misfit smaller than about 7 percent will be accommodated by uniform elastic strain only until a critical thickness $h_c$ is reached. Beyond that limit, it is energetically favorable to generate dislocations, and the misfit is shared between strain and dislocations. Experiments performed on various systems have generally resulted in a larger fraction of misfit accommodation attributed to strain than predicted by the theory. (For instance $h_c = 350$ Å whereas 250 Å is predicted in the case GaAs$_{0.5}$P$_{0.5}$ on GaAs [4]). It is thus possible to grow epilayers very far from lattice matching to the substrate...
provided that the layer thickness is small enough. Matthews and Blakeslee [4] tried to apply this idea to GaAsP/GaAs multilayers using VPE. They could not obtain good material unless they gradually accommodate the lattice parameter of the substrate to that of the multilayer taken as a whole. This way out was found unsatisfactory because the graded layer itself generated strain and dislocations.

In this paper, strained InGaAs/GaAs multilayers grown by MBE are considered. If the layers were strain free, the corresponding relative lattice mismatch would be 0.7%. The calculated critical thickness for a single layer would be, according to Franck and Van der Merwe's model, about 1000 Å. The thickness of each InGaAs layer will lie far below this expected critical thickness.

It has to be pointed out that a relaxed, dislocation free InGaAs/GaAs multilayer taken as a whole, would have a lattice parameter in the direction parallel to the surface different to that of the GaAs substrate (see section 2.2 in reference 4,C). A critical thickness can thus be defined also for a given alternating multilayer structure. Beyond that critical thickness, dislocation should be generated at the interface with the substrate. Serrano and Chang [5] have shown that in case of MBE growth of InGaAs on GaAs, the misfit dislocations are confined close to the interface (300 Å) if x is large enough (x = 0.15). Besides, saw-tooth like graded regions [6] or super-lattices [7] have proved efficient for dislocation confining. So misfit dislocations, if any, between the InGaAs/GaAs multilayer considered as a whole and the GaAs substrate are expected to be confined at the vicinity of the first heterointerface. Experimental results show that this indeed occurs.

II-Experiment : sample preparation and growth procedure

The MBE vacuum system consists of a ionic and titanium sublimation pumped stainless steel bell jar equipped with a load-lock set up. The flux are directed nearly vertically towards the substrate.

The GaAs substrates were etched using a 2% Bromide, Methanol solution and mechano-chemically polished on a lens paper. At the end of the etching process, the substrate surface was flushed in water in order to passivate the clean surface with oxides. Before growth, the substrate was heated at 630°C inder an As flux with a background arsenic pressure of 10⁻⁶ torr to remove oxide. During growth, the gallium and arsenic flux are kept constant. The indium cell shutter is periodically opened and shut down as to obtain the desired structure. Adjustment of proper composition and growth rate are selected by choosing appropriate cell temperatures. Composition measurements of thick InGaAs layers performed by electron microprobe show good homogeneity (x=0.1) with lateral compositional gradient less than 1%. A 1 μm thick buffer layer was first deposited on the substrate followed by alternating layers of 100 Å thick InGaAs wells and 100 Å thick GaAs barriers. In most cases the structure was covered by a 1μm GaAs caplayer. The substrate temperature was 520°C. A few experiments performed at higher substrate temperature (580°C) resulted in poor crystallographic quality.
Results and characterization

Three samples have been analysed:
They were made of 10 periods of alternating layers In$_{0.1}$Ga$_{0.9}$As (thickness $L_T$) and GaAs (thickness $L_B$)
Sample a: $L_T = L_B = 100$ Å
Sample b: $L_B = 200$ Å, $L_T = 100$ Å
Sample c: $L_B = 200$ Å, $L_T = 100$ Å, and a 1000 Å In$_{0.1}$Ga$_{0.9}$As layer was grown on top of this multilayer.

a) Transmission electron microscopy

The samples were chemically bevelled, then thinned from the substrate to allow transmission microscopic observations. Figure 1 shows an optical image of such a bevel: the InGaAs/GaAs multilayer was chemically stained.

Fig. 1: Chemical bevel showing 10 periods of alternating layers GaInAs/GaAs (optical view X50)

Sample a (Fig.2) shows a high density of dislocations located mostly at the first interface but also within the multilayer. In sample b, the GaAs layers were twice as thick. It resulted in no dislocation in the multilayer (as observed using STEM) and a low density of 1/2 (110) dislocations located at the first interface (Fig.3). The typical distance between dislocations is a few microns.
Fig. 2: High density of dislocations observed at the first interface of sample a (TEM image)

In sample c, the 1000 Å InGaAs layer induced a higher density of dislocations as sample b (Fig. 4), still confined at first interface. This 1000 Å layer simulates a thicker multilayer as far as strain is concerned. So the multilayer thickness in sample b is close to its critical value, whereas it is beyond that value in sample c.

Fig. 3: Very low dislocation density observed at the first interface of sample b (TEM image)

Fig. 4: High density of dislocations confined at first interface in sample c.

**X ray double diffraction**

Double diffraction was performed using the (400) symmetric reflection with InP as a first crystal. The periodical set of peaks (Fig. 5) is typical of the different reflection orders of a superlattice. Fig. 5 is a profile obtained on sample b: Similar profiles were obtained from samples showing a good morphology. Samples showing a high density of dislocations did not exhibit these satellite peaks. The superlattice periodicity can be determined with high accuracy from the X ray profile: 318 Å in this case.
Photoluminescence and absorption.

Absorption measurements are useful here because the contribution of the InGaAs wells is separated from absorption due to the GaAs substrate. Low temperature absorption performed on sample b (Fig 6a) shows a strong excitonic contribution. This result is important because single thick InGaAs layers did not show such contribution, due to their poor purity. We believe that 2D excitons contribute efficiently to absorption.

Fig. 5: Double X ray diffraction profile obtained on sample b.

Fig. 6. Absorption and photoluminescence spectra obtained on sample b at 4K.
Photoluminescence at the same temperature (Fig.6b) occurs at the same energy; excitonic recombinations are probably involved also in this emission. Photoluminescence was performed on sample b along the bevel (Fig.7), on the GaAs buffer layer (1) and on top of the superlattice (2). The striking result is that In_{0.1}Ga_{0.9}As shows a luminescence efficiency far larger than the GaAs buffer layer taken as a reference Fig.7.

At 77°K, there is a two orders of magnitude ratio between the InGaAs emission at $\hbar \nu = 1.372 \text{ eV}$ and the GaAs at 1.50 eV. This clearly shows that minority induced carriers diffuse and recombine very efficiently in the InGaAs wells. On sample c, a comparison was made with emission from the 1000 Å thick InGaAs layer. We did not observe a significant wavelength shift of the InGaAs peak between that layer and the superlattice. But the difference in energy gap between InGaAs and GaAs is relatively small (0.13 eV) and a quantification effect in the energy wells, would probably not be noticeable in that case.

CONCLUSION

Strain superlattice $\text{In}_{0.1}\text{Ga}_{0.9}\text{As/GaAs}$ have been successfully grown by MBE. They show good morphological qualities (from X ray diffraction) and very exciting optical properties, relatively high luminescent efficiency and strong excitonic absorption at low temperature.

This proves that it is possible to obtain very high quality material far from lattice matching to the substrate.
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