Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 128-130

D-2-4

Realization of Tensile Strain on GaAs Substrates with Non-Pseudomorphic Grid Layer

Yuen-Chuen CHAN, Tetsurou MORIMOTO and Kunio TADA

Department of Electronic Engineering
University of Tokyo
Hongo 7-3-1, Bunkyo-ku, Tokyo 113, Japan

To realize tensile strain on GaAs substrates, a novel structure consisting of a thick non-pseudomorphic InAlAs grid layer and InGaAs-GaAs strained-layer superlattice dislocation filter is proposed. The combined structure is examined by photoluminescence, Nomarski etch-pit microscopy and double crystal x-ray diffraction and found to be effective in incorporating tensile strain in devices grown on the GaAs substrate.

1. INTRODUCTION

Strained quantum wells are presently attracting a lot of attention because it is possible to accomplish bandgap engineering with elastic strain[1)] as well as achieve drastic improvements in device performance[2)]. Moreover, devices operating at wavelengths which are not achievable with any existing unstrained semiconductor material systems could now be realized with the effect of elastic strain[3)]. For bandgap engineering, tensile strain is especially favorable as the relative positions of the heavy and light hole quantum energy levels can be adjusted at will[4)]. However, a simple study of the lattice constants of the GaAs-AlAs-InAs material system will reveal that only compressive strain could be realized by coherent epitaxial growth on GaAs substrates. In this paper, we devised a scheme for realizing tensile strain with the GaAs substrate and examined the structure with photoluminescence, Nomarski etch-pit microscopy and double crystal x-ray diffraction.

2. STRUCTURE

To realize tensile strain on GaAs substrates, it is necessary to lay down a grid layer with a much larger lattice constant. This can be accomplished by growing a thick non-pseudomorphic InGaAs or InAlAs layer so that the lattice constant at the surface relaxes back to its bulk value. Subsequent growth of layers with a lattice constant smaller than that of the grid will result in tensile stress. However, allowing the thick grid layer to relax back to its bulk lattice constant also means the generation of misfit dislocations. In order to obtain good crystal quality at the surface, these dislocations must be filtered, by bending them to the sides of the sample through the interfaces of a strained-layer superlattice structure, so that they do not thread up[5)]. In addition, the strained-layer superlattice structure should be designed in such a way, shown in Fig. 1, that its average lattice constant matches that of the grid so that the structure itself does not introduce any new dislocations.

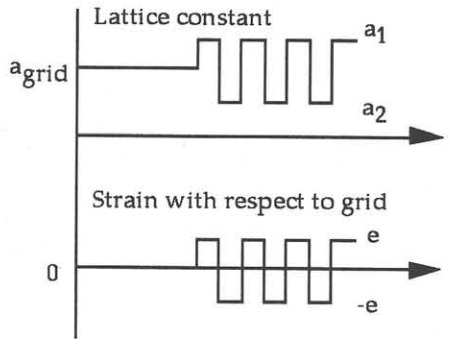

Fig. 1 Design concept for a balanced superlattice structure on top of grid layer.

3. EXPERIMENT AND EVALUATION

To examine the feasibility of such an approach, two samples each with 5 sets of 62Å-wide GaAs-AlAs quantum wells were prepared. One sample has a 1μm-thick $In_{0.06}Al_{0.94}As$ grid with a strained-layer superlattice dislocation filter structure, made up of 30 sets of $In_{0.16}Ga_{0.84}As$-GaAs quantum wells with layer thicknesses

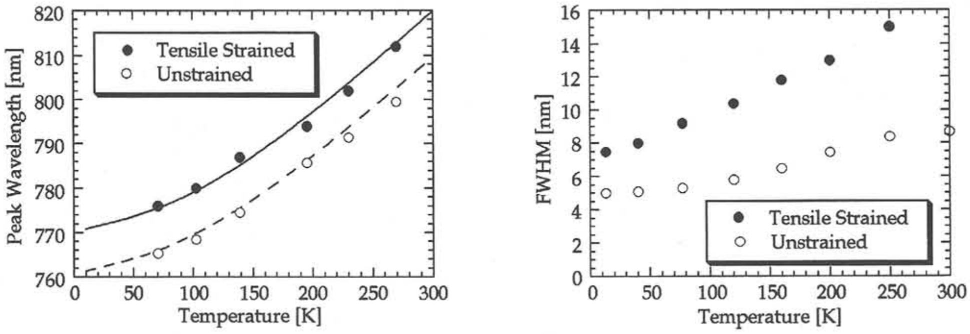

Fig. 2 Photoluminescence peak wavelength and its FWHM for tensile-strained and unstrained GaAs-AlAs quantum wells.

of 23Å, in between. On the other hand, the other sample has no grid layer and hence is totally unstrained. The temperature dependence of the photoluminescence peak wavelength and its FWHM are shown in Fig. 2. Solid and broken lines are the theoretical values based on quantum well energy level calculations taking into account excitonic and strain effects. Good agreement between the experimental and calculated results is obtained and the tensile-strained sample's peak is shifted by 10nm to the longer wavelength. Moreover, the FWHM obtained by both samples are roughly of the same order, indicating reasonably good crystal quality.

The effectiveness of the superlattice dislocation filter structure in reducing the amount of threading dislocations up to the quantum well structures was also examined by Nomarski etch-pit microscopy. The samples were prepared by selective etching with molten KOH to reveal etch pits on the {100} surface. Figure 3 shows the micrographs for samples without the superlattice structure (left) and that with 10 periods of $In_{0.20}Ga_{0.80}As$-GaAs superlattices (right), examined under a Nomarski phase contrast microscope. The diamond shape of the etch pits confirms its dislocation-related origin[6]. The etch-pit densities for both samples come up to approximately $1x10^6 cm^{-2}$ and $3x10^5 cm^{-2}$, respectively. This means that the strained-layer superlattice structure greatly reduces the number of dislocations propagating up from the non-pseudomorphic layer.

Multiple quantum well structures grown on top of the non-pseudomorphic grid layer and strained-layer superlattice were studied with double crystal x-ray diffraction. The primary x-ray beam from the Cu target is diffracted by the [400] diffraction of the GaAs (100) crystal monochromator, and the diffracted beam then falls incident on the sample. Figure 4 shows the x-ray rocking curve for a grown sample of GaAs-InAlAs quantum wells on the prepared InAlAs grid layer. Peaks related to the substrate and InAlAs grid can be seen together with the satellite peaks, which are attributable to the superlattice structure. The satellite peaks are rather weak for this sample as it has a 1μm-thick layer of InAlAs clad and 600Å of InGaAs cap on top of the multiple quantum well layer. Together with photoluminescence results, the indium content of the InAlAs layers is determined to be 5.1% and

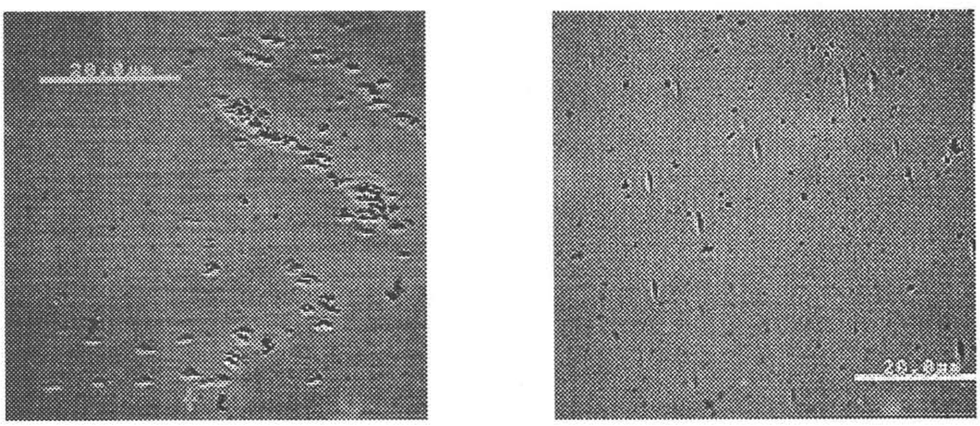

Fig. 3 Micrographs of etch pits obtained by etching in molten KOH of a thick relaxed InAlAs layer and InGaAs cap on a GaAs substrate (left) and a thick relaxed InAlAs layer, an InGaAs-GaAs strained-layer superlattice structure and InGaAs cap on a GaAs substrate (right).

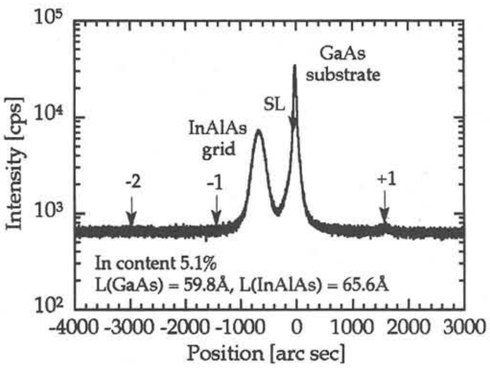

Fig. 4 Double crystal x-ray rocking curve for grown sample. The denotations of '*SL*' and integers *m* represent the main superlattice (0th-order) and *m*th-order satellite peaks of the multiple quantum well structure on top of the grid layer.

the thicknesses of the tensile-strained GaAs wells and unstrained InAlAs barriers to be 59.8Å and 65.6Å. This sample is fabricated as a planar waveguide device and has in fact demonstrated polarization independent optical modulation[7], which means that tensile strain is effectively introduced into the GaAs wells.

4. CONCLUSIONS

A novel structure, comprising a thick non-pseudomorphic InAlAs grid layer and InGaAs-GaAs strained-layer superlattice dislocation filter, is proposed for realizing tensile strain on GaAs substrates. The feasibility of such a scheme is demonstrated by photoluminescence, Nomarski etch-pit microscopy and double crystal x-ray diffraction, and the structure proves effective in introducing tensile strain in devices grown on GaAs substrates.

ACKNOWLEDGEMENT

The authors would like to thank Mr. Wu-Yih Uen of Nishinaga Laboratory, Dept. of Electronic Engineering, University of Tokyo for the assistance in the etch-contrast microscopy experiments.

REFERENCES

1. G. C. Osbourn; Phys. Rev. B **27** (1983) 5126.
2. E. Yablonovitch and E. O. Kane; J. Lightwave Technol. **LT-4** (1986) 504.
3. M. Okayasu, M. Fukuda, T. Takeshita and S. Uehara; IEEE Photon. Technol. Lett. **2** (1990) 689.
4. G. P. Kothiyal, S. Hong, N. Debbar, P. K. Bhattacharya and J. Singh; Appl. Phys. Lett. **51** (1987) 1091.
5. P. L. Gourley, T. J. Drummond and B. L. Doyle; Appl. Phys. Lett. **49** (1986) 1101.
6. T. Takenaka, H. Hayashi, K. Murata and T. Inoguchi; Jpn. J. Appl. Phys. **17** (1978) 1145.
7. Y. C. Chan and K. Tada; Tech. Digest of Topical Meeting of Photonics in Switching, PMB2 (1993) 21.