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Non-Pseudomorphic Strained-Layer Multiple Quantum Wells for Device Applications

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Highly-strained $In_xGa_{1-x}As/GaAs$ ($0.25 \leq x \leq 0.28$) multiple quantum wells (MQWs) have been grown on GaAs substrates by molecular beam epitaxy, and investigated for optoelectronic device applications. A strained-layer buffer was interposed between the QW and the GaAs substrate, and it is found that the buffer can filter dislocations created at the buffer/substrate interface. Such lattice relaxation consequently provides a balanced strain in the QW region, making possible the growth of the QW structures exceeding the critical layer thickness limit. Well-designed $In_xGa_{1-x}As/GaAs$ MQW structures were stable against the rapid thermal annealing process up to 650°C.

1. INTRODUCTION

Strained-layer heterojunctions and quantum wells (QWs) are of considerable interest for device applications because they provide more flexible device design and material choice, however only pseudomorphic structures have been primarily considered for device applications. In this work, strained-layer $In_xGa_{1-x}As/GaAs$ MQW structures exceeding the pseudomorphic limit have been grown by molecular beam epitaxy (MBE), and investigated for spatial light modulator applications. Strained-layer $In_xGa_{1-x}As/GaAs$ MQW structures are important, and have been extensively investigated for such applications because of the availability of various coherent light sources[1)-4)]. The emphasis is placed on the development of the techniques which make possible the growth of large-period strained-layer MQWs without having propagating dislocations into the active QW layer, and on the engineering of the lattice constant of the epitaxial layer in order to provide optimum strain conditions. Thermodynamic stability of these MQWs is important for device applications and will be also discussed.

2. GROWTH AND CHARACTERIZATION

Thirty-period $In_xGa_{1-x}As(100Å)/GaAs(100Å)$ MQWs ($0.25<x<0.28$) have been grown on (100)-oriented GaAs substrates at 500-530°C with a 0.5μm-thick $In_yGa_{1-y}As$ or $In_yAl_{1-y}As$ ($0 \leq y \leq 0.28$) buffer interposed between the QW layer and the substrate. Detailed sample structures and optical properties are shown in Table 1. Only the MQWs with y close to the average InAs mole fraction of the QW layer exhibited good crystalline quality, implying the strain is well-balanced between the GaAs and $In_{0.28}Ga_{0.72}As$ layer. The condition of strain in such MQWs in comparison with the pseudomorphic case is shown in Fig. 1. Only the $In_xGa_{1-x}As$ layer is deformed in the pseudomorphic case, while both GaAs and $In_xGa_{1-x}As$ are deformed with the magnitude of strain presumably half of that in the pseudomorphic case. It has been theoretically predicted[5), 6)] that an alternating strained-layer structure whose weighted strains equal but opposite remains commensurate if each layer is below critical layer limit. X-ray rocking curves for the (400) reflection obtained from sample 1-5 are shown in Fig. 2. Only sample 2-4 show well-ordered periodic

Table 1 Details of the growth parameters and optical characteristics

Sample#	1	2	3	4	5	6	7
Alloy Buffer							
Material	InGaAs	InGaAs	InGaAs	InGaAs	InGaAs	InAlAs	InGaAs
In Content, y	0	0.1	0.14	0.18	0.28	0.17	0.13
QW							
In content	0.28	0.28	0.28	0.28	0.28	0.28	0.25
PL							
FWHM (meV)	-	11.9	14.1	16.5	-		
Energy (eV)	-	1.2049	1.2152	1.2049	-		

structures in good accord with the photoluminescence results. Transmission electron microscopic investigations of sample 7 suggested that dislocations are created at the substrate/buffer interface, however they are confined near the interface. Therefore, the active QW region is dislocation free. EA spectra obtained from sample 7 are shown in Fig. 3. A distinct exciton peak and clear quantum confined Stark effects indicate possible practical device applications.

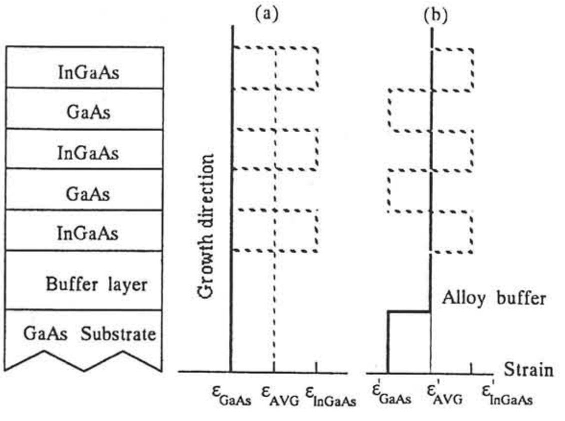
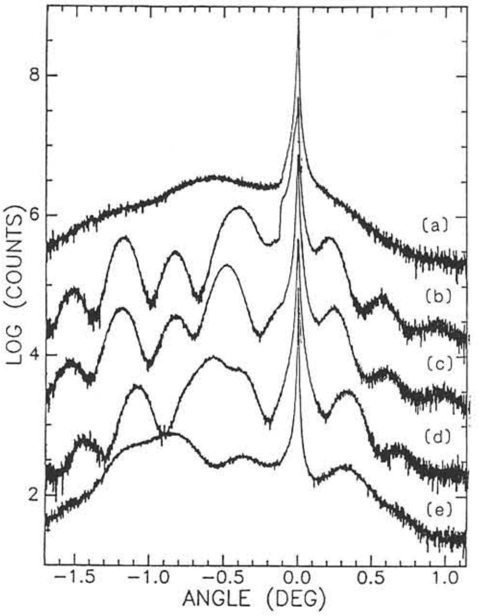


Fig. 1 Schematic representation of the magnitude of strain in an $In_xGa_{1-x}As/GaAs$ multiple quantum well. (a) pseudomorphic to GaAs (b) oscillating compressive and tensile strain. Dotted lines indicate the oscillating strain components. Solid lines show the position in which the strain is equal to zero.



(a) y=0, (b) y=0.10, (c) y=0.14, (d) y=0.18, (e) y=0.28

Fig. 2 X-ray rocking curves for (400) reflection obtained from Saple 1-5. (a)-(e) correspond to sample 1-5, respectively.

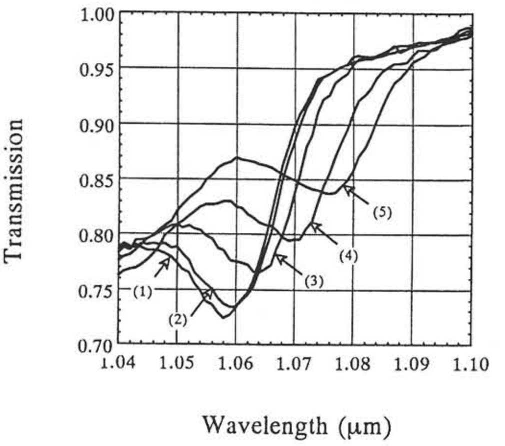


Fig. 3 Electroabsorption spectra of sample 7. (1)-(5) correspond to 0, 22, 44, 67, 89 kV/cm, respectively.

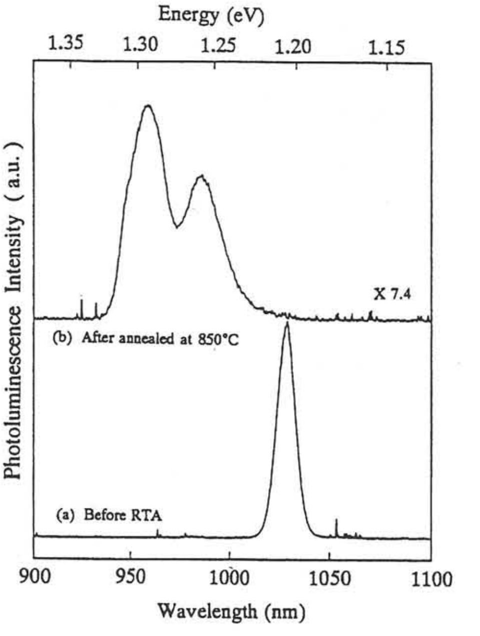


Fig. 4 Photoluminescence spectra obtained from sample 2 before and after RTA at 850°C for 5 seconds.

3. ANNEALING EFFECTS

These samples were annealed by means of rapid thermal annealing (RTA) at 650-850°C for 5 seconds. The effects of annealing have been examined by low temperature photoluminescence (PL) spectroscopy at 2K. Preliminary results exhibited that, in sample 2, an excitonic emission due to the ground-state electron-heavy hole is blue-shifted when annealed at 750°C, and then two distinct peaks appear at 850°C. PL spectra obtained from sample 2 before and after the RTA at 850°C are shown in Fig. 4 (a) and (b), respectively. Similar results were observed from sample 3 and 4. This may be attributed to the interdiffusion of In atoms at the $In_xGa_{1-x}As/GaAs$ interface and (or) structural disorder induced by plastic deformation during the RTA process.

4. REFERENCES

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