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THE INFLUENCE OF MBE GROWTH CONDITIONS ON OPTICAL PROPERTIES OF InAlGaAs/AlGaAs STRUCTURES

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ABSTRACT

Optical properties of compressively strained $In_{0.24}Al_{0.19}Ga_{0.57}As$ layers were investigated as a function of the MBE growth conditions. The optimum temperature of the crystal surface (T_s) for MBE growth of this quaternary layer as well as the optimal cooling down process necessary for achieving appropriate T_s for InAlGaAs were experimentally found.

1. Introduction

The potential application of the strained InAlGaAs layer as a lasing active material states the motivation of this work. Al content causes the blue shift of the laser line when compared to the wavelength region of InGaAs emission. The resulting wider range of wavelengths gives the possibility of operating below the wavelength corresponding to the bandgap energy in GaAs (λ_{GaAs} = 870 nm).

Indium containing alloys, however, are widely known as easily segregating this element during their crystallisation. We suppose that this can cause a risk of exceeding critical layer thickness in the case of high amount of InAs in the alloy. The In segregation effect is especially strongly pronounced in the case of materials containing Al [1–3]. Because of In high volatility, the upper limit of the temperature of the crystal surface has to be taken into account. On the other hand, it is widely known that relatively high optimum growth temperature is characteristic of Al containing alloys. This is partially due to low Al atoms surface mobility and because of necessity of oxygen contamination suppression. However, there is no clear published experimental data, finally solving or concerning the problem of InAlGaAs growth conditions playing the crucial role during the epitaxy of complex (for example optoelectronic device) structures. As an example, Qu et al. [4] have not described the way chosen by them for cooling down the crystal to the temperature necessary for the quaternary alloy deposition. They did not give any details of the method of the measurement of T_s (for example, whether it was performed by means of a pyrometer, a thermocouple or, by absorption band--edge spectroscopy).

In order to partially answer the question, optical properties of strained InAlGaAs containing structures were investigated as a function of their epitaxial growth conditions. The influence of crystal surface temperature was taken into account and the effect of interrupting the epitaxy process just before the InAlGaAs growth was investigated as an alternative for the continuous deposition.

2. Experimental

A set of test structures with quaternary alloy incorporated in a stack of (Al)GaAs layers was grown by Elemental Source MBE technique. Epilayers were deposited on (100)±0.1° oriented GaAs (n^+) crystalline substrates delivered by AXT. The sequence of layers for the investigated structures (presented in Table 1) is as follows: (i) 1 μm GaAs:Si buffer layer, n =1.5E+18 cm^{-3}, (ii) 1.2 μm $Al_{0.4}Ga_{0.6}As$:Si, n = 3E+17 cm^{-3}, (iii) 0.14 μm $Al_{0.25}Ga_{0.75}As$ undoped layer, (iv) indium containing quaternary layer forming the potential quantum well (QW) with the nominal composition of $In_{0.24}Al_{0.19}Ga_{0.57}As$ and the nominal thickness of 7.3 nm, (v) 0.14 μm $Al_{0.25}Ga_{0.75}As$ undoped layer (vi) 2.5 nm undoped GaAs cap layer.

Crystal surface temperature was 630°C and 690°C during the growth of GaAs and AlGaAs, respectively (see Table 1). The surface temperature during the growth of InAlGaAs (from the range of 505 ÷ 580°C for a set of structures) and the way of reaching it in a series of test structures (A-F) are presented in Table 2.

Table 1. The sequence of layers for InAlGaAs/ /AlGaAs/GaAs structures of the test set. The number of layer is given in the first column. The data concerning thickness, composition and doping are given in the next three columns. The values of temperature of the crystal surface (T_s) for the growth of the particular layers are enclosed.

N°	Thick-ness	Composition	Doping [cm^{-3}]	T_s [°C]
(vi)	2.5 nm	GaAs	undoped	630
(v)	0.14 μm	$Al_{0.25}Ga_{0.75}As$	undoped	690
(iv)	7.3 nm	$In_{0.24}Al_{0.19}Ga_{0.57}As$ (QW)	undoped	505-580
(iii)	0.14 μm	$Al_{0.25}Ga_{0.75}As$	undoped	690
(ii)	1.2 μm	$Al_{0.40}Ga_{0.60}As$:Si	$n = 3\cdot10^{17}$	690
(i)	1 μm	GaAs:Si (Buffer)	$n = 1.5\cdot10^{18}$	630
	400 μm	GaAs:Si (Substrate)	$n = 2\cdot10^{18}$	

Table 2. Intensities of PL signal from InAlGaAs QW (I_{PL}) and full widths at half maximum (FWHM) in a series of A-F test structures. Values obtained in room-temperature. Also given the surface temperature (T_s) during InAlGaAs growth and the way of reaching it.

Struct.	T_s [°C]	T_s reaching	I_{PL} [a.u.]	FWHM [nm]
A	580	Temperature ramping	1	26.6
B	560	Growth interrupting	1.8	26.6
C	550	Growth interrupting	2.4	24.7
D	520	Temperature ramping	0.9	43.7
E	510	Growth interrupting	3	28.5
F	505	Growth interrupting	1.6	34.2

The required temperature of 580°C, and lower, was achieved either by interrupting the epitaxy for a time necessary for cooling down process (just before the InAlGaAs growth), or alternatively by ramping down the temperature during the period of few minutes of continuous $Al_{0.25}Ga_{0.75}As$ (iii) deposition. After the quaternary layer growth, the epitaxy process was always continued without any interrupting. The high crystal temperature, which is appropriate for $Al_{0.25}Ga_{0.75}As$ (v) layer deposition, was attained during few minutes by ramping it up. To achieve the appropriate for InAlGaAs growth high As/III flux ratio, As flux was gradually enhanced during crystal temperature ramping or alternatively during deposition interval. As flux adequate for $Al_{0.25}Ga_{0.75}As$ (v) layer deposition was gradually reduced during crystal temperature ramping up.

GaAs, $Al_{0.25}Ga_{0.75}As$, $Al_{0.40}Ga_{0.60}As$ and $In_{0.24}Al_{0.19}Ga_{0.57}As$ layers were grown with nominal rates of 0.75 μm/h, 1 μm/h, 1.25 μm/h, 1.32 μm/h, respectively. The As_4/III flux ratio was set 5, 3 and 10 during GaAs, AlGaAs and InAlGaAs deposition, respectively. Surface reconstruction during epitaxy binary, ternary and quaternary layers was kept 2×4, 3×1 and 1×1, respectively.

Epitaxy of the structures was realised in the Riber 32P machine, equipped with ABN 135L evaporation cells and As_4 source. Crystal surface temperature was measured by pyrometer (IRCON Modline Plus). The crystal automatic heating control was enabled by thermocouple measurement. The material growth rate was determined by means of RHEED oscillations. Bayard-Alpert gauge, mounted on the sample manipulator, let us fix the elemental fluxes. The state of the crystal surface was monitored by use of RHEED system, with 10 keV electron gun.

Test structures were optically characterised by means of photoluminescence measurements. PL spectra were obtained in the same conditions for all samples of the test series and in particular in room temperature with excitation line of 514 nm obtained from Ar laser, and with 50 mW excitation power.

3. Results and discussion

The resulting photoluminescence spectra for A-F series are presented in Fig. 1. Signals from quantum well regions are found in the wavelength range of 800 ÷ 850 nm. Peaks at about 720 nm are related to $Al_{0.25}Ga_{0.75}As$ layers.

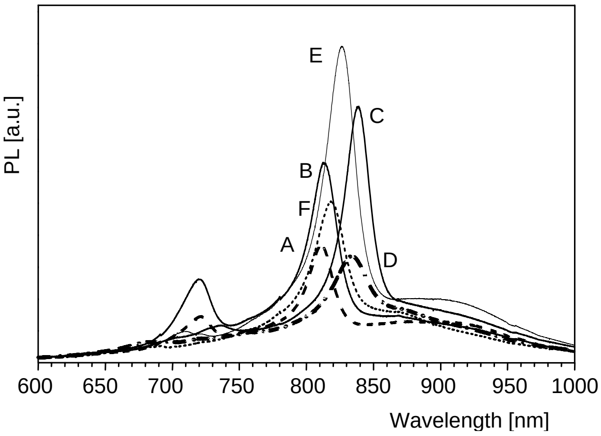

Fig. 1. Room-temperature photoluminescence spectra of a set of InAlGaAs/AlGaAs/GaAs test structures. Letter symbols of structures are placed near the QW peaks.

Table 2 and Fig. 2 bring into relationship the QW photoluminescence properties and epitaxy conditions. It is seen that higher intensities and narrower PL lines are characteristic of structures grown with deposition interruptions. This is perhaps because of better quality of $Al_{0.25}Ga_{0.75}As$ (iii) layer obtained in the case when it is fully deposited in optimum conditions (high

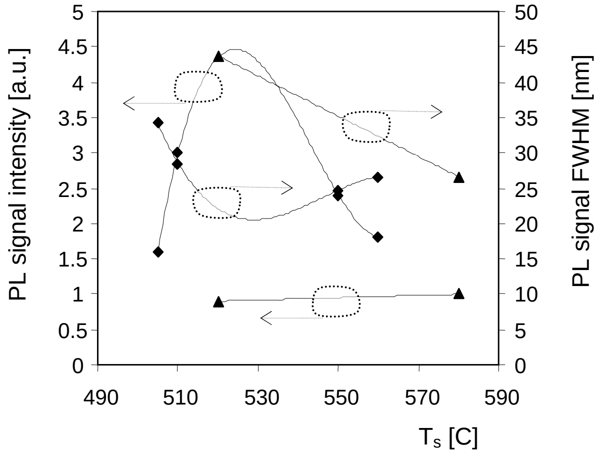

Fig. 2. Room-temperature QW photoluminescence signal intensities (full symbols) and widths (open symbols) for a set of InAlGaAs/AlGaAs/GaAs structures, as a function of crystal surface temperature during growth of quaternary layer. Squares – subseries of epitaxy processes with crystal growth interrupting just before the InAlGaAs deposition, triangles – subseries of runs with temperature ramping (see in the text). Experimental points are connected with the sixth order trend lines.

temperature, stable As/III flux ratio). The non-radiative recombination centres in AlGaAs (for example oxygen, though the mass spectrometer indicated its absence in the growth chamber during epitaxy process) as well as the rough AlGaAs surface, resulting in the rough InAlGaAs/AlGaAs interface (and hence the enhanced QW region thickness fluctuations) should be taken into account. The last hypothesis is confirmed by the large FWHM of QW signals observable for structures grown with temperature ramping. What is more, in this case, signal FWHM is the wider the deeper temperature ramping was applied.

The best QW photoluminescence signal intensity – corresponding with quite good FWHM – is experimentally found for T_s of 510°C. As we observed, the lower as well as the higher T_s resulted in poorer optical properties of compressively strained InAlGaAs QWs.

However, we do not have any data for T_s from the range of 510 ÷ 550°C (for runs with the growth interrupting). Additional experiments are needed in this area, particularly if we pay heed to data published by Jensen et al. [5]. The T_s reported by these authors is 530°C, as being used for growing the $In_x(Al_{0.17}Ga_{0.83})_{1-x}As/(Al)GaAs$ MQW structure, where $0.05 < x < 0.25$. The method of temperature measurement is not disclosed in this paper. On the other hand Qu et al. have reported [4] considerably higher T_s for quaternary alloy deposition (680°C) in the high-power $In_{0.1}Al_{0.17}Ga_{0.73}As/(Al)GaAs$ laser arrays emitting at 808 nm. Temperature determination method, however, was also not revealed.

4. Summary

Optical properties of compressively strained $In_{0.24}Al_{0.19}Ga_{0.57}As$ containing structures were investigated as a function of their epitaxial growth conditions. It was experimentally found that the optimum crystal temperature for this quaternary MBE growth is about 510°C. However, the T_s range from 510°C to 550°C should be carefully examined. The crucial role plays the type of cooling down process being necessary for achieving appropriate T_s for InAlGaAs. We stated that indispensable is interrupting the epitaxy process just before the InAlGaAs growth, as an alternative for the continuous deposition.

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