Chapter 5

LPE-Grown GaAs-GaAlAs Single Quantum Well Lasers

5.1 Introduction

Single quantum well (SQW) is a finite segment of a superlattice which is one-dimensional structure consisting of a very thin layer of material A (well) embedded between two thick layers of material B, where B (barrier) has the larger bandgap than A. If the characteristic well layer thickness (d) normal to the layer sequence has a dimension such that d is shorter than the charge carrier mean free path and thin enough compared to the de Broglie wavelength of electron in the material, the energy levels become discrete that effects not typical of bulk material known as quantum size effects. At present, the activities on semiconductor quantum well lasers have expanded rapidly, partly because of many superior characteristics compared to the conventional lasers, e.g. low threshold current density, high quantum efficiency, higher T_o, higher modulation frequency limited, etc. The most commonly employed techniques for producing quantum well lasers are molecular beam epitaxy (MBE) and metalorganic vapor phase epitaxy (MOVPE), etc. On the other hand, liquid phase epitaxy (LPE) is extensively used for the growth of most conventional lasers that are commercially avaliable. But LPE is usually not considered suitable for QW structure. Therefore, a potentially efficient scheme to develope QW lasers, an alternative to those based on MBE and OMVPE techniques, would be the growth of QW lasers by LPE. Recently, LPE has been succesfully applied for the InGaAsP/InP devices with submicron layer thickness. In addition, GaAlAs/GaAs quantum well structures have also been prepared by LPE.

The purpose of this chapter is to desbribe an experimental application of combined techniques of two-phase solution and supercooling to fabricate GaAs-GaAlAs single quantum well lasers by liquid phase epitaxy. The characteristics of LPE-Grown GaAs-GaAlAs single quantum well lasers are also presented in this chapter.

5.2 Fabrication Consideration for SQW Structures

The requirements for the SQW structures growth are a) low growth rate for very thin active layer and very thin waveguide but high epilayer quality, b) high growth rate for the other passive layers such as buffer layer, cladding layer, cap-layer, and waveguide layer with smooth surface. Earlier works have been reported on the growth of very thin layer by two-phase solution [30], the growth at low temperature range [31], using dummy substrate [32], and using the vertical gradient temperature to reduce the gradient of supersaturation [29]. These techniques have the feature of growing very thin layers, however they are not suitable for producing few-micron thick doped epitaxial layers with high crystal quality that needed for the device fabrication. These techniques can neither minimize the diffusion problem nor avoid the melt carryover [33]. Besides, these techniques give rough interface.

A combined technique of two-phase solution and supercooling is used as the key technology to fabricate SQW lasers by LPE method. The merits of two-phase solution are the constant growth rate, the growth rate dependence on cooling rate and low growth rate at any growth temperature. But the two-phase solution still gives the rough interface and nonuniform thickness. To improve the flatness, the two-phase solution where a GaAs wafer floate on the top of Ga melts was applied. This technique offers the advantages of a) to smooth out the motion of the melt for flat surface, b) to induce the vertical temperature gradient of the melt in order to reduce the gradient of supercooling. The supercooling technique offers the merit of high initial growth rate which minimizes the diffusion problem.

5.3 Experimental Procedure

GaAs-GaAlAs single quantum well (SQW) lasers are grown by LPE using a combined technique of the two-phase solution to grow (very) thin layers and the supercooling technique to grow thick layers with fast growth rate for minimizing the diffusion problem. The starting substrates are (100)-oriented n-type (Si-doped, $N_d=1x10^{18}$ cm^{-3}) GaAs substrate. In this growth run, the constant cooling rate of 0.2°C/min. is used. The solution of melts is saturated at 800 °C. The growth is done at temperture range of 797-793 °C and GaAs active layers are grown at 0.2-0.3°C below 795 °C for <1 sec [34]. The schematic diagram of SCH-SQW structure is shown in Fig.5.1. A 25 μm stripe width is defined by an opening of SiO_2 window. Then, Au-Ge/Ni/Au and AuZn/Au ohmic contacts are formed on n- and p-side, respectively. Substrate are cleaved with uncoated facets to give laser chips with the different cavity lengths from 200 to 700 μm.

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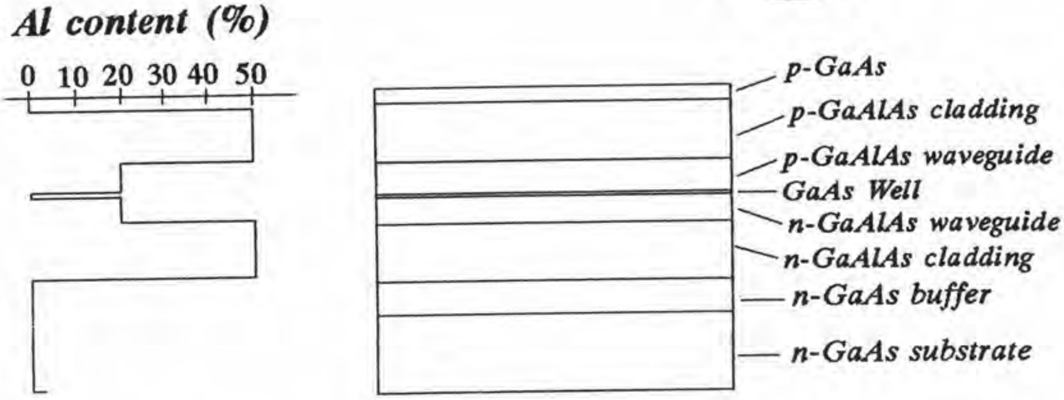


Fig.5.1 The schematic structure of SQW-SCH

5.4 Characteristics of GaAlAs-GaAs Single Quantum Well Lasers

Fig. 5.2 shows the SEM photograph of cleaved and etched cross section of SQW-SCH GaAs-GaAlAs structure. The active layer of GaAs well is less than 300 Å.

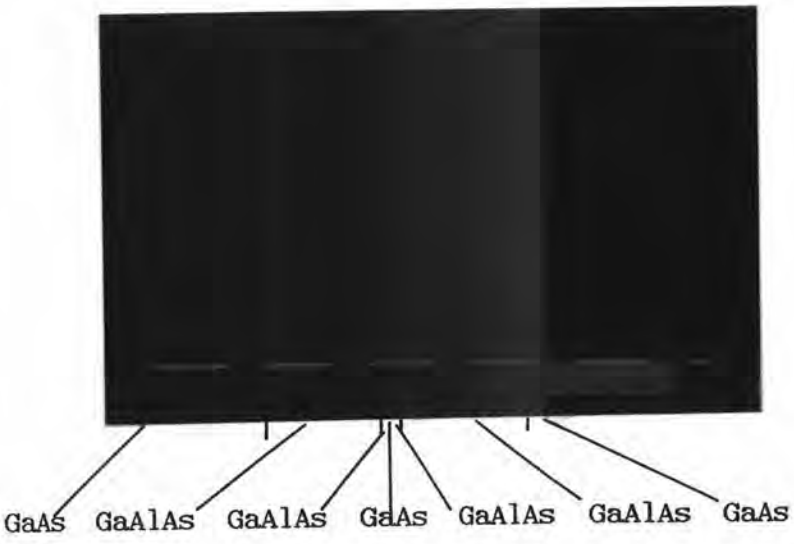
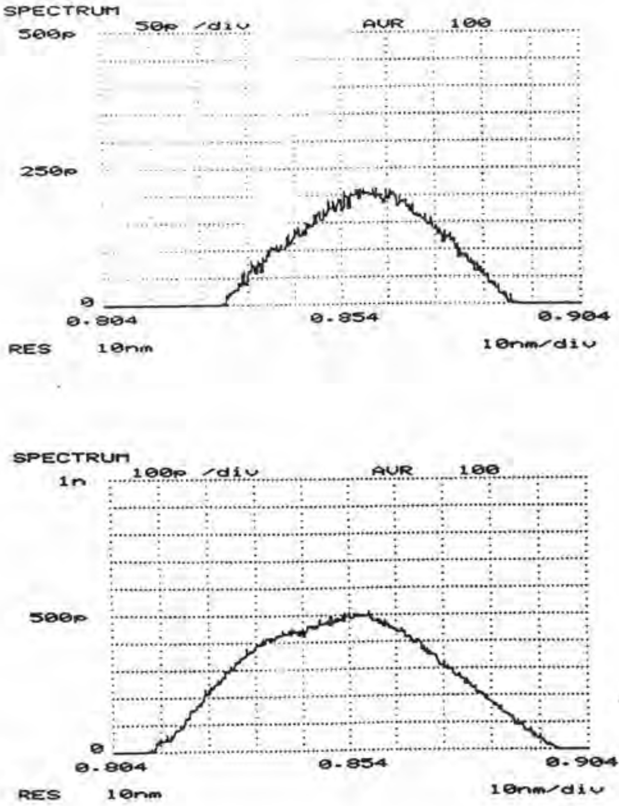


Fig.5.2 SEM image of LPE grown of GaAs-GaAlAs SQW-SCH structure. Marker represents 1 μm.

The emission spectrum measurement is performed at room temperauture with 200 nS pulses at a 10 KHz repetition rate. The spontaneous emission characteristics are detected from nonlasing chips and lasing chips under condition of biasing below threshold current at the different bias currents. Typical spontaneuos emission characteristics are shown in Fig.5.3. The spontaneous emission spectrum shows that the optical gain spectrum broadens and the gain peak wavelength shifts to shorter wavelength with higher current injection. The spectrum shift with a quantum well current density by band filling is due to the staircase-shape density of a quantum well and is more pronounced for a single well [35].



a) I=500 mA

b) I=1000 mA

Fig.5.3 Spontaneous emission spectrum at differnt bias currents of LPE grown GaAs-GaAlAs SQW-SCH structure.

An example of current-light output characteristics and its lasing spectrum are shown in Fig. 5.4. The threshold current density is in the range of 1.8-8.0 KA/cm^2 and differential quantum efficiency is in the range of 40-65% for the cavity lengths of 200-700 µm.

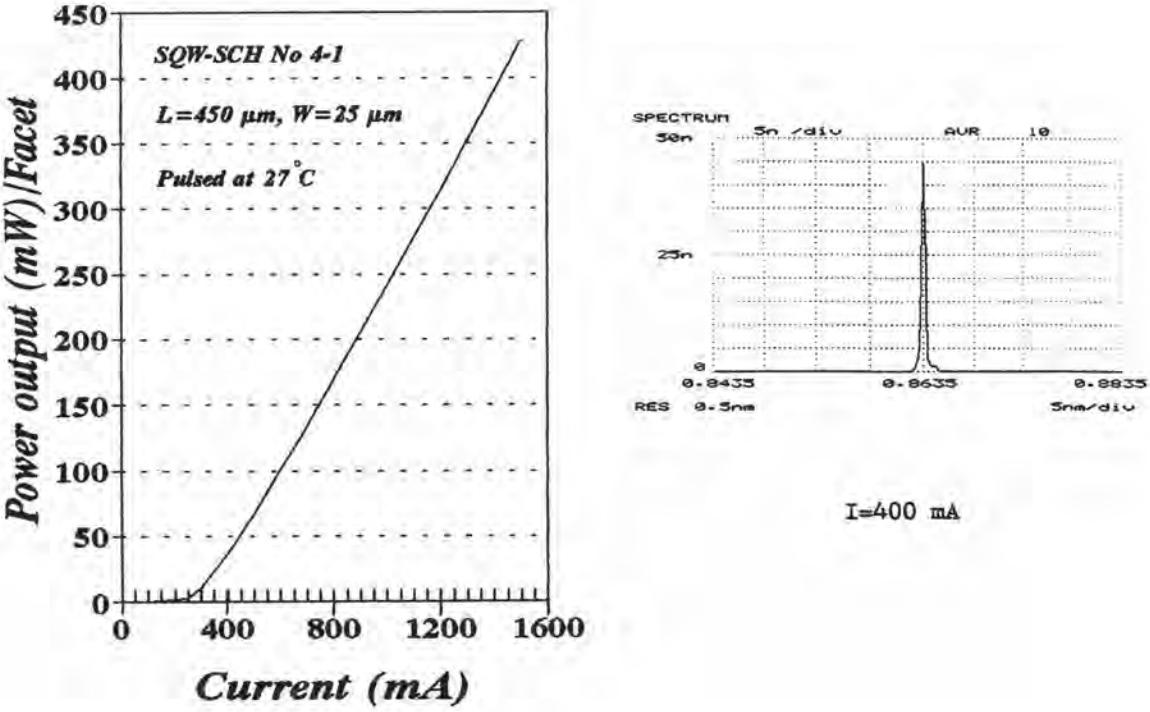


Fig.5.4 I-L characteristics of LPE grown GaAs-GaAlAs SQW-SCH lasers and its lasing spectrum.

The threshold current density and lasing wavelength versus cavity length are shown in fig. 5.5. The threshold current density decreases superlinearly from 8.0 KA/cm^2 to 1.8 KA/cm^2 and the lasing wavelength increases from 830 nm to 872 nm as cavity length increases from 200 µm to 700 µm. The threshold current density is relatively high becuase the optical confinement factor is very small and the injected current is spreading in SiO$_2$ stripe-geometry [36].

The shift of lasing wavelength is caused by decreasing of the bandgap shrinkage effect and by gain spectrum broadening when the carrier density increases [35], [37].

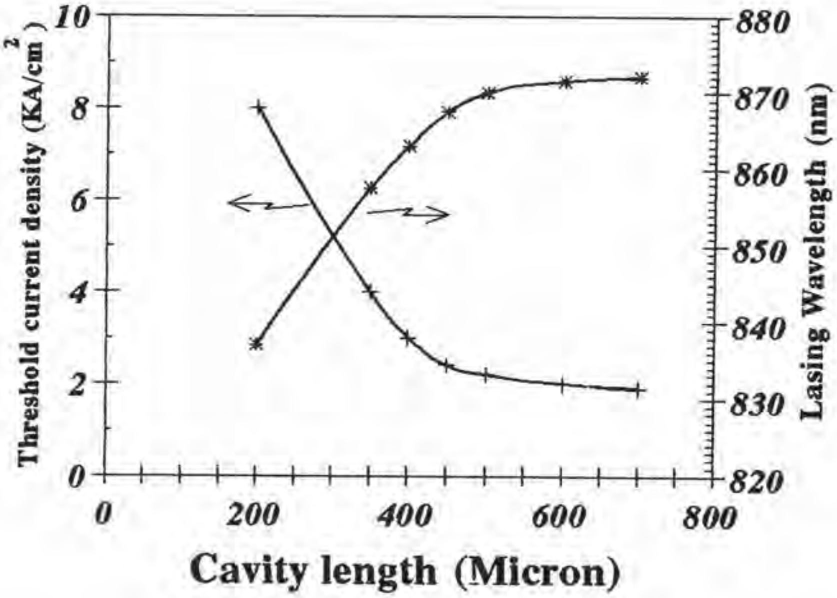
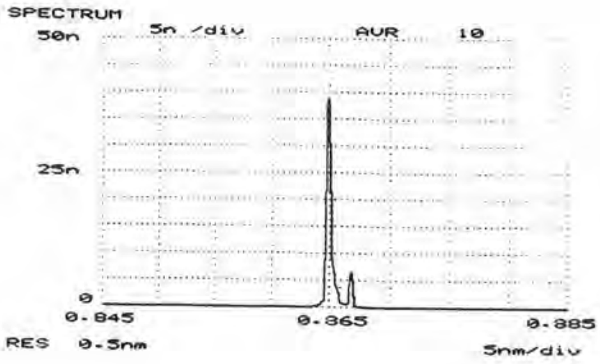
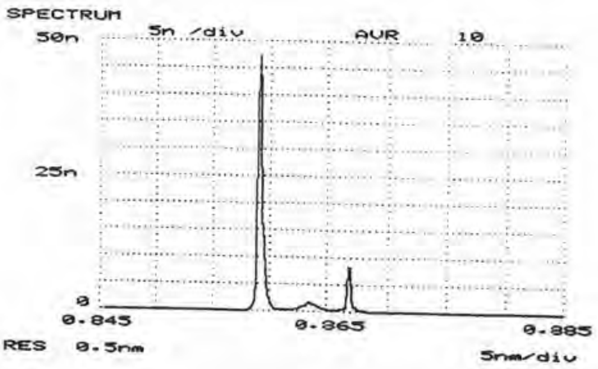


Fig.5.5 The dependence of threshold current density and lasing wavelength on cavity length.

The variation of lasing wavelength at different bias currents is monitored at room temperature under pulsed condition. The result shows the blue shift when the current is increased as shown in Fig. 5.6. At the low bias current of 400 mA, the lasing wavelength is 865 nm. As bias current is increased up to 600 mA, the lasing wavelength shifts to 859 nm. The spectrum shift at the high injection current corresponds to the transition from the first quantized state to the second quantized state [35], [37], [38].



a) I=400 mA



b) I=600 mA

Fig.5.6 Lasing spectrum at different bias currents of LPE grown GaAs-GaAlAs SQW-SCH laser.

5.5 Photoluminescence Measurement

The photoluminescence (PL) measurements are performed on the cleaved egdes of QW samples at room temperature using a He-Ne laser (6328 Å) with power density of 50 mW/cm^2. Fig. 5.7 shows spectrum of the quantum well structure. A peak characteristic of energy-level distribution appears at 863 nm together with a subpeak at 835 nm. It predicts that E_{1h} should be 1.437 eV (863 nm) and E_{2h} should be 48.23 meV above E_{1h}. To compare these results with the calculation data by Mukai, et al. [39], the well thickness and grading length of our SQW sample correspond to (approximately) 20 nm and 2.7 nm, respectively.

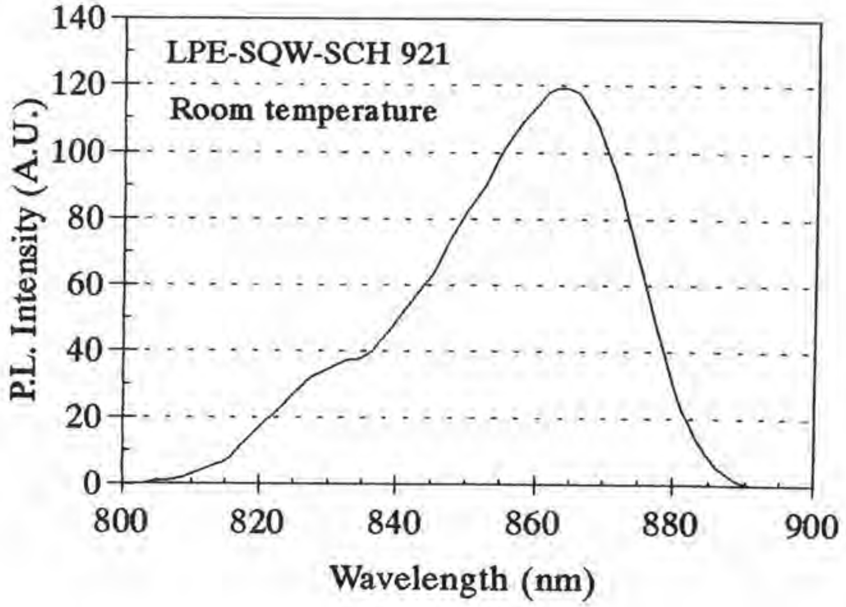


Fig.5.7 The photoluminescence (PL) spectrum of GaAs-GaAlAs SQW-SCH.

5.6 Broad Area Structure Results

The broad area GaAs-GaAlAs SQW-SCH LDs are fabricated under the same growth condition and using a 100 μm wide SiO_2 stripe-geometry. An example of I-L characteristic from the sample with the lowest threshold current density of 500 A/cm^2 is shown in Fig. 5.8. The threshold current density of the broad area GaAs-GaAlAs SQW-SCH LDs is in the range of 500-900 A/cm^2 for the cavity lengths of 400-700 μm.

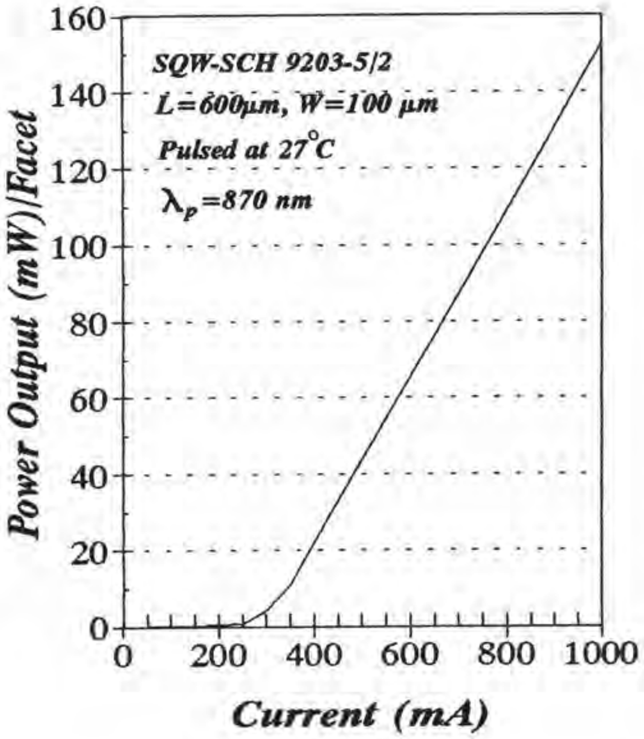


Fig.5.8 I-L characteristic of LPE grown GaAs-GaAlAs SQW-SCH with 100-μm wide SiO_2 stripe-geometry.

5.7 Summary

The feasibility of LPE-grown GaAs-GaAlAs single quantum well lasers has been demonstrated using a combined techniques of two-phase solution and supercooling. The characteristics of SQW LDs give shorter lasing wavelength than those obtained from the conventional bulk type lasers. In addition to blue shift of lasing wavelength, the broadening of spontaneuos emission spectral is also observed in this work. The low threshold current density as low as 500 A/cm^2 is obtained from the SQW-SCH LDs fabricated by LPE technique.