Optica Applicata, Vol. XXXV, No. 3, 2005

Some problems of molecular beam epitaxy growth of epitaxial structures of semiconductor lasers for a 980 nm band

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The paper deals with selected problems of molecular beam epitaxy (MBE) technology of fabrication of 980-nm strained InGaAs quantum-well (QW) lasers. Special attention has been paid to the growth of active region of such lasers. Therefore, a certain method of optimisation of the growth process is presented. It consists of two steps. First, the layer temperature is measured during the growth of the active region of the laser in several test processes. From the experimental data the optimum temperature profile of the MBE process is found. Then, a sequence of test structures are grown in different growth conditions in QWs (the temperature and the As_4/InGa flux ratio are changed) and on the basis of photoluminescence measurements the best regulation parameters for the actual MBE processes are selected. The optimisation has been confirmed by fabrication and characterisation of entire semiconductor laser devices.

Keywords: InGaAs quantum-well lasers, molecular beam epitaxy, optical pyrometry.

1. Introduction

Semiconductor strained InGaAs quantum-well (QW) lasers for a 980 nm band have attracted much attention in recent years because of their application in telecommunication [1]. However, despite many efforts, the problem of optimisation of molecular beam epitaxy (MBE) technology of fabrication of such lasers is still open [2–4]. This is due to the fact that the design of the quantum well separate confinement heterostructure (QW SCH) laser needs proper tuning of many different optical parameters of such a structure. The procedure of designing the MBE process for growing the laser structure should take into account two classes of problems. The first one is connected with growing materials of high quality for all parts of the structure. This optimisation concerns GaAs, GaAs:Si, GaAs:Be, AlGaAs:Si, AlGaAs:Be, and InGaAs compounds. The second group of problems concerns the precise fabrication of the active region of the laser and especially the InGaAs QW. As the wavelength and intensity of stimulated radiation depend on both the composition and the thickness of QW, regulation of the MBE process in this region should be especially precise.

A crucial parameter of any MBE process is the growth temperature. It determines the quality of the material, its transport and optical properties and, to some extent, the growth rate. Therefore, in what follows, we shall first concentrate on the problems of thermal regulation of the MBE process. Then, after establishing an adequate procedure of thermal regulation, we optimise the remaining parameters of growth (V/III flux ratios for different compounds, composition and thickness of QW, and the mean value of temperature in the QW).

2. Design and growth of the structures

The growth processes reported in this study have been performed by the elemental source MBE technique on the RIBER 32P machine equipped with ABN 135L effusion cells. The molecular fluxes were measured by a Bayard–Alpert gauge mounted on the sample manipulator. The manipulator could be rotated so as to place the Bayard–Alpert gauge at the standard position of the substrate. Thus, the gauge could measure the beam equivalent pressure (BEP) of the As_4, Ga, Al and In beams. The substrate temperature

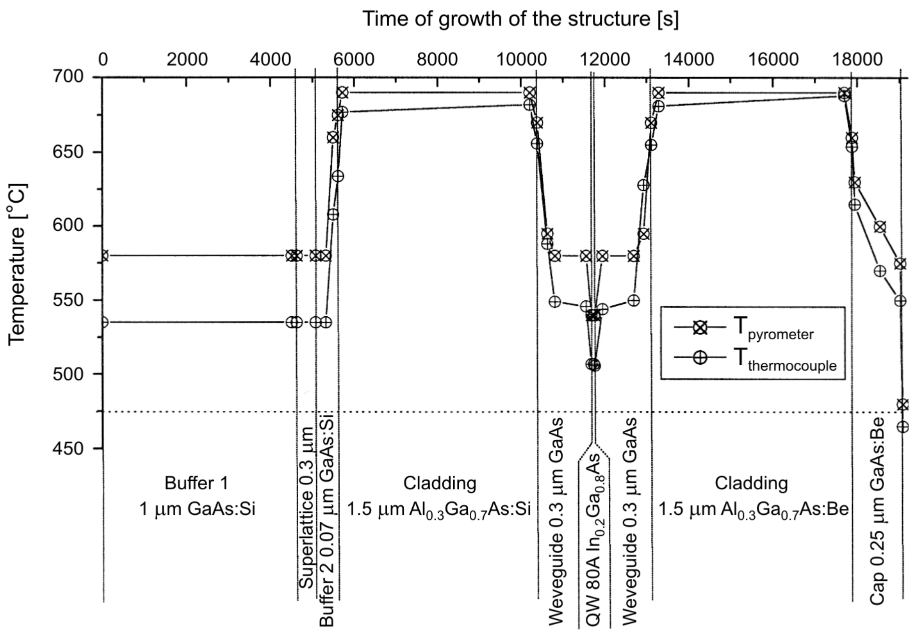

Fig. 1. Scheme of the structure of the semiconductor laser for a 980 nm band and the assumed growth temperatures measured by a thermocouple (+) and by a pyrometer (×).

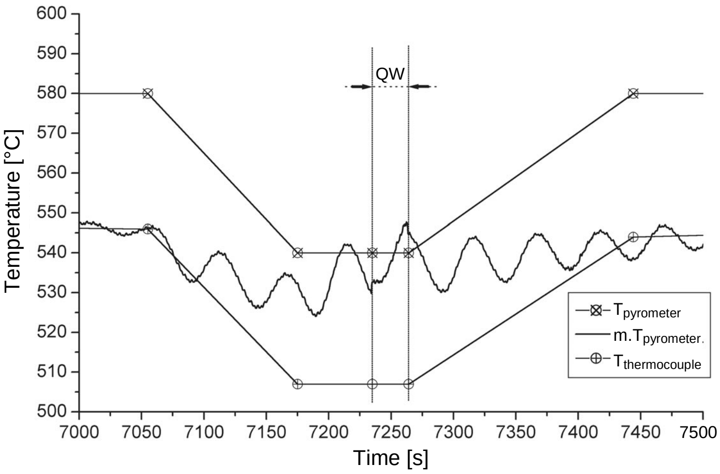

Fig. 2. Substrate temperatures during the growth process of the active region of the semiconductor laser for a 980 nm band. (+) and (×) are assumed temperatures measured by a thermocouple and by a pyrometer, respectively. Solid line without marks is the real temperature registered by a pyrometer. The process has not been optimised.

was measured with a thermocouple and simultaneously with the IRCON Modline Plus pyrometer. This particular model of pyrometer is specially designed to measure the A_3B_5 surface temperatures that are of interest for MBE (400–750°C). More details of the configuration of the MBE machine can be found in [5, 7] and the pyrometric system used for the temperature measurements is described in detail in [6].

A schematic laser structure is presented in Fig. 1. The individual layers belonging to the structure should be grown at different temperatures. Because we want to perform the whole process without interruption, we must introduce a rather complicated profile of temperature as a function of time. The figure presents the assumed growth temperature (as should be measured by the pyrometer) and, corresponding to it, the temperature shown by the thermocouple. (The values shown by the thermocouple are used for automatic regulation of MBE process.) The whole process has been divided into stages (intervals) marked in the scheme by crosses. In the process of optimisation we change positions of the marks, thereby we change the length of the stages and the slope of the ramps.

In any real process the temperature profile differs substantially from the assumed one (see Fig. 2). This effect is especially destructive in the active region: large fluctuations of temperature result in low quality of InGaAs material and in fluctuations of its composition. Thus, we must optimise the project so as to obtain good coincidence between the assumed and the registered temperature profiles in the active region. At the same time we have to maintain the assumed values of temperature in the buffer, in the cladding layers and in the contact.

3. In situ measurements and post growth characterisation

In a number of MBE processes we have established the optimum temperature profile for the MBE process. The test structures consisted of reduced cladding layers, waveguides and QWs. During any process both the temperature shown by the pyrometer and that shown by the thermocouple were registered. An example of a non optimised process is shown in Fig. 2. It is evident that the temperature is not stable in the QW and its oscillation is very large (more than 10°C).

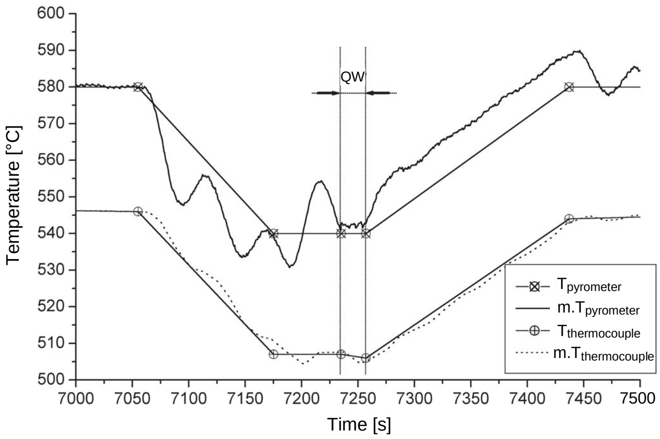

Fig. 3. Effect of optimisation of the growth process of the semiconductor laser for a 980 nm band – the real temperature in the QW is almost constant. (+) and (×) are assumed temperatures measured by a thermocouple and by a pyrometer, respectively. Solid line without marks is the real temperature registered by a pyrometer, while the dashed one represents the temperature measured by a thermocouple.

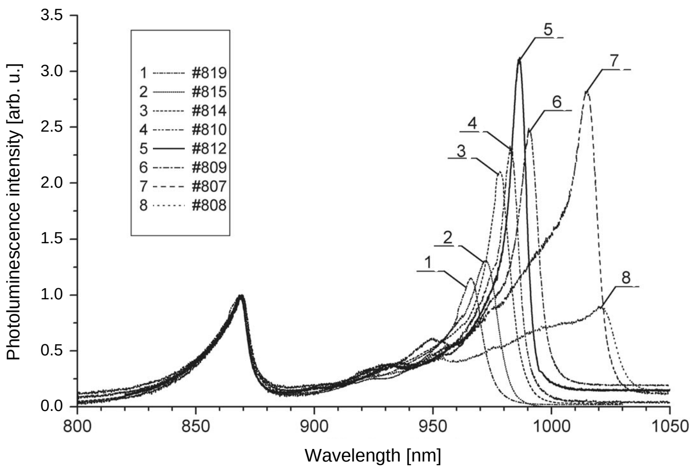

Fig. 4. Photoluminescence spectra from the laser test structures grown in different growth conditions.

T a b l e. Growth conditions for the active regions and entire semiconductor laser structures for a 980 nm band. The processes #817 and #824 correspond to the optimum growth conditions.

Number of process	As_4/InGa flux ratio	Time of growth of QW [s]	Growth temperature of QW [°C]	Ramp of temperature in QW [°C]	Type of structure
#807	8.5	22	550	3	test
#808	9.3	20	550	3	test
#809	8.3	22	545	3	test
#810	9.3	20	555	2.5	test
#812	8.3	22	555	3	test
#814	8.3	22	545	3	test
#815	8.3	22	540	3	test
#817	8.3	22	555	3	laser
#819	8.3	22	570	3	test
#823	8.1	22	580	3	laser
#824	8.3	22	555	3	laser
#834	7.2	22	545	3	laser

After finishing the process of optimisation described in the previous section, we obtain the stable temperature in the QW and the required temperature in the cladding layers (Fig. 3). The real temperature in the QW coincides with the assumed one and its oscillation is less than 3°C.

The second part of optimisation process consisted in growing a sequence of structures in different growth conditions. The following parameters were subjected to changes: the mean temperature and the ramp of temperature in QW, the time of growth of QW and the As_4/InGa flux ratio. We retained the optimised temperature profile everywhere except two points determining the temperature in the QW. In the Table, the growth conditions for test structures and for entire laser structures are presented.

The best regulation parameters for the real MBE processes were selected on the basis of photoluminescence measurements. Figure 4 contains photoluminescence spectra from the laser test structures grown in the conditions presented in the Table. All plots have been normalised to unity for the peaks corresponding to the interband transitions in GaAs. We assume that the highest intensity of luminescence corresponds to the optimum growth conditions. So, the optimum growth conditions are those applied in the process #812 (*cf.* the Table).

4. Conclusions

The optimisation of the MBE processes has been confirmed by growing entire semiconductor laser structures in different growth conditions (processes #817, #823, #824, and #234 in the Table) and fabrication semiconductor laser devices. Then, the basic characteristics of those lasers have been measured. As our goal was to

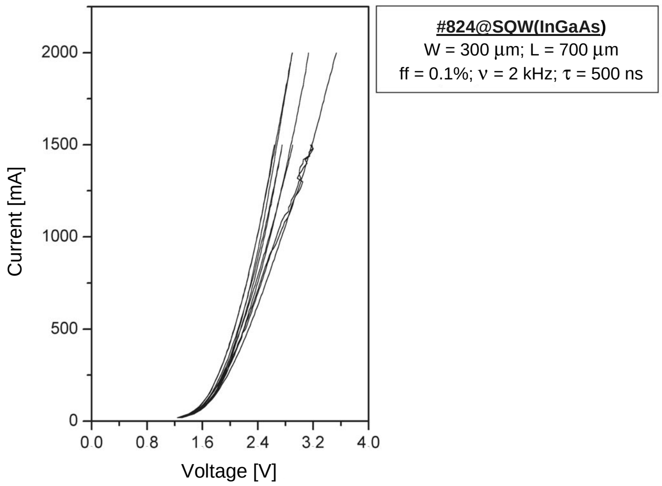

Fig. 5. Current–voltage characteristic of the semiconductor laser grown in the optimum growth conditions.

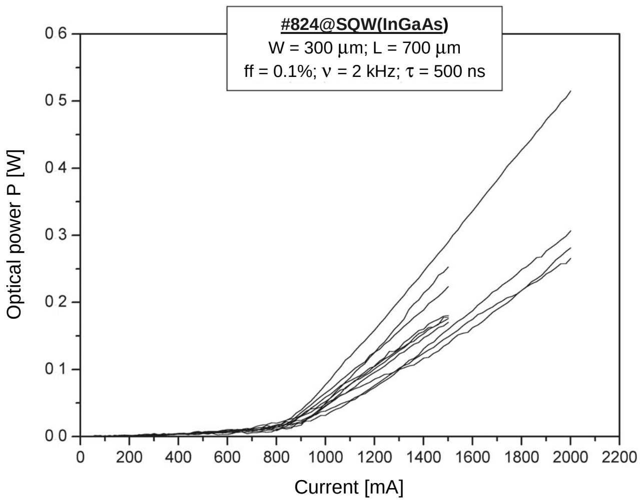

Fig. 6. Light–current characteristic of the semiconductor laser grown in the optimum growth conditions.

compare different laser devices, only simplified processing has been performed. It consisted merely in thinning the wafer, making contacts and cleaving the structure. The characterisation of the lasers confirms the fact that the lasers grown in the optimum growth conditions (process #824 in the Table) exhibit the best current–voltage and light–current characteristics. Examples of those characteristics are presented in Figs. 5 and 6.

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Received June 6, 2005