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High power AlGaAs/GaAs lasers with improved optical degradation level

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Accurate numerical simulation of AlGaAs/GaAs SQW SCH lasers and MQW SCH lasers is presented. We discuss the performance of both types of lasers with regard to high power operation at 808 nm spectral band which is of interest for diode pumped Nd:YAG lasers. Design rules for above-mentioned lasers are formulated. From the analysis presented it follows that MQW SCH lasers are better suited for high power applications and exhibit a superior tolerance to inherent construction parameters variations, as well as to external operation parameters. We also test different waveguide designs. The most important conclusion is that broader waveguides are suitable for obtaining higher optical powers and generally result in higher COD (catastrophic optical degradation) level.

1. Introduction

Quantum well separate confinement heterostructure (QW SCH) lasers are usually designed with single quantum well (SQW) or multiple quantum well (MQW) active region. The multiple quantum well active region leads to an effective increase in the electrically pumped volume and thus allows for obtaining high powers which are attractive for such applications as diode pumped Nd:YAG lasers. The price one pays for higher power, however, is an increased threshold current density, since for reaching a necessary inversion level one has to fill with carriers a few quantum wells [1], [2]. Available experimental data show that also the other parameters of the laser depend on whether the active region is single or multiple quantum well [3], [4]. Theoretical works published so far reflected in general observed experimental trends [5]–[9]. Nonetheless, since they have used threshold analysis of the laser, based on the balance of gain and losses and employed a number of phenomenological parameters, in particular semi-empirical gain model and simplified band structure, they could not predict more sophisticated effects. It has to be also stressed that models in question were originally developed for double heterostructure lasers [10] and were subsequently used, with only minor modifications, for quantum well lasers where, however, they do not fully reflect physical complexity of involved phenomena. The reason for that was their simplicity and low computational requirements.

Given the technological importance of semiconductor lasers, it is crucial to be able to do predictive modelling of new device designs before devices are actually manufactured. Due to the advancement of computer techniques in last years it has been possible to develop more realistic laser modelling tools based on the drift diffusion equations augmented by a module for calculating optical field and a module for describing the interactions between carriers and optical field. The resulting set of non-linear differential equations is to be solved selfconsistently. Additionally, Schroedinger equation is used to calculate bound state energies and quantum well subbands in quantum size active region of the device. The software of this type of various degrees of sophistication is now commercially available. In this work we have used PICS3D simulation package from Crosslight Software Inc. [11]. It incorporates all the major physical models for modern semiconductor lasers, including strained quantum wells and valence band mixing effects [12].

2. Description of the structure

The devices modelled here consisted of quantum well active region embedded in waveguide region, formed by abrupt heterojunctions as in the majority of practical devices. The active region was either single quantum well or multiple quantum well, made of four wells separated by appropriate barriers. The notation used to identify structures described in this paper has the following syntax: sqw(mqw)_structure no._QW thickness_barrier thickness (for example, mqw_03_42_28). The GaAs quantum well thickness depends on desired application and varies from 15 to 40 ML (monolayers). The smallest QW thickness is required for 808 nm pumping lasers. Composition profile for the active region of a typical SQW SCH laser is shown in Fig. 1. The laser consists of active QW, waveguide made of $Al_xGa_{1-x}As$ ($x = 0.25$) and $Al_xGa_{1-x}As$ ($x = 0.4$) emitters. Typically, the thickness of waveguide regions equals to 0.12–0.15 μm on each side of QW. Such design, *i.e.*, single QW and narrow waveguide, leads to the low threshold. At the same time, however, the described design poses serious drawbacks; the operation of such lasers is limited to low powers and there are certain difficulties in achieving specified wavelengths of operation. The last

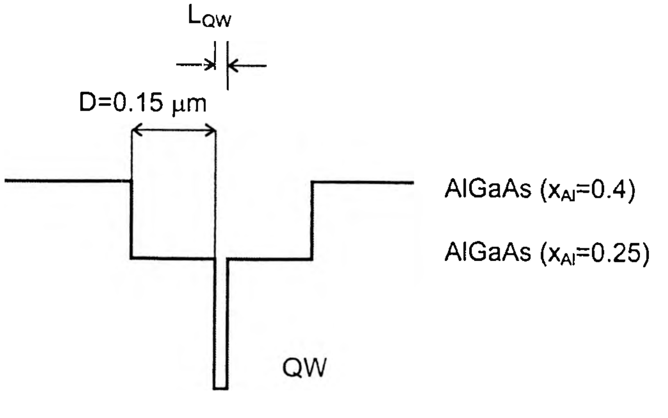

Fig. 1. Composition profile for the active region of standard SQW SCH laser.

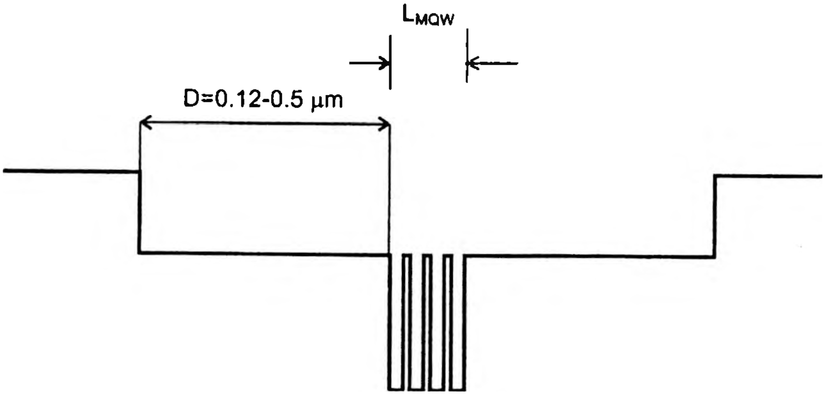

Fig. 2. Composition profile for the active region of broad waveguide MQW SCH laser.

being of primary importance for pumping lasers. To avoid those problems we have studied, both theoretically and experimentally, the new recently proposed design for the high power lasers, *i.e.*, broad waveguide, MQW SCH laser [13]. Composition profile for the active region of MQW SCH with broad waveguide is shown in Fig. 2. The basic difference between the standard laser and the one shown in Fig. 2 is in the thickness of optical waveguide, which can reach 0.5 μm on each side of MQW region.

3. Simulation of basic characteristics of SQW SCH and MQW SCH AlGaAs/GaAs lasers

Simulation of basic characteristics of both SQW SCH and broad waveguide MQW SCH lasers have been performed using PICS 3D Crosslight Software simulation package, which allows for self-consistent calculation *P–I* (light-current) and spectral characteristics for arbitrary designed lasers. The main laser parameters which are compared here are threshold current density J_{th}, wavelength of emission and total amount of optical power which can be drawn from the laser.

Band diagram and Fermi level positions through a typical separate confinement multi quantum well heterostructure laser biased at near threshold are shown in Fig. 3. The comparison of *P–I* characteristics for standard SQW SCH and broad waveguide MQW SCH laser optimized for 808 nm is shown in Fig. 4. It can be seen that an increase in the number of QWs, as well as an increase in waveguide thickness, results in the increase of threshold current, which could be expected. On the other hand, however, one can notice that differential efficiency of the laser does not deteriorate and, consequently, the wall-plug-efficiency, for currents high above the threshold, which is true measure of the device performance, is only slightly lower than for standard SQW SCH lasers. Additionally, in a broad waveguide laser, due to substantial increase in the waveguide volume the average density of the optical power on the mirrors decreases up to 10 times which should result in the increased level of COD level.

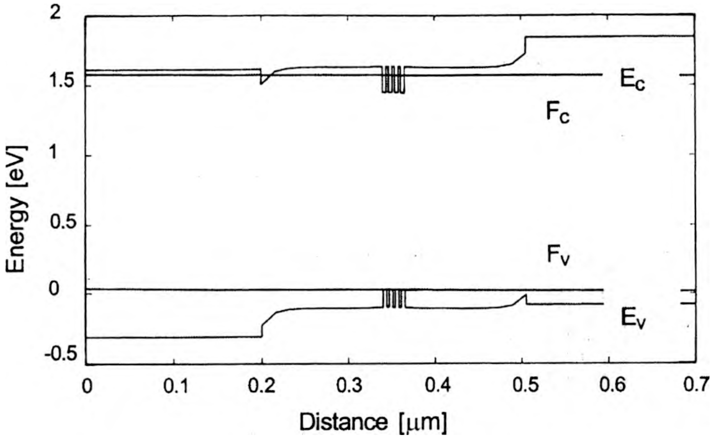

Fig. 3. Calculated band diagram and quasi-Fermi level positions through a typical separate confinement MQW heterostructure laser biased near threshold (structure with 80 A QWs and 40 A barriers – mqw_01_80_40).

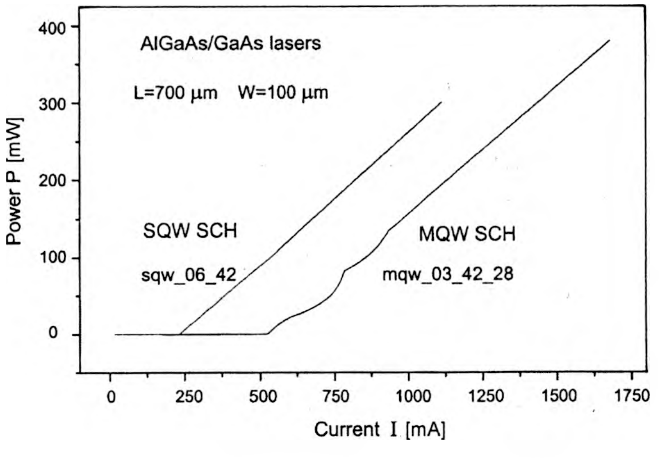

Fig. 4. Comparison of calculated P–I characteristics for standard SQW SCH and broad waveguide MQW SCH lasers optimized for 808 nm. QW thickness in both cases is equal to 42 A and barrier thickness in MQW laser is equal to 28 A.

The new design of the lasers has been verified experimentally. The standard structures and the structures with broad optical waveguide were grown by molecular beam epitaxy and subsequently processed into broad contact, ridge waveguide (in lateral direction) lasers. We have used Schottky isolation technique and standard metallization technology. The lasers were tested for threshold characteristics, spectral properties as well as near and far field patterns. The theoretical predictions have been confirmed by the experiment. The broad waveguide lasers, as expected, exhibited substantially higher COD levels. Some of them could be drown up to 16 A and 8 W

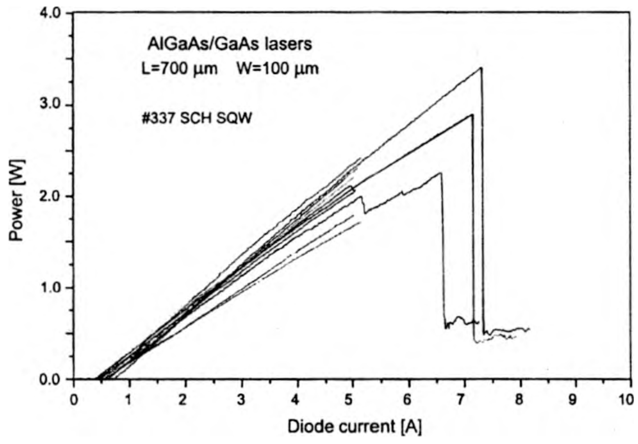

Fig. 5. Experimental *P–I* characteristics of standard SQW SCH lasers (pulse driven with filing factor ff = 0.1%).

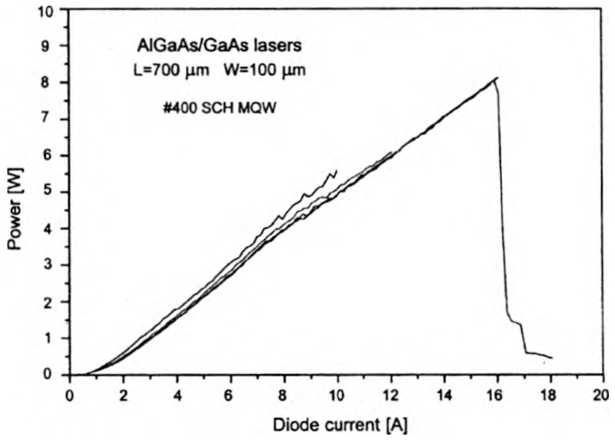

Fig. 6. Experimental *P–I* characteristics of broad waveguide MQW SCH lasers (pulse driven with filing factor ff = 0.1%).

pulse power (for broad waveguide MQW SCH devices), whereas standard waveguide SQW SCH devices reached only 3.5 W pulse power (for filling factor 0.1%; 200 ns pulse with 5 kHz repetition) at 7 A current. Above that power mirrors were irreversibly damaged by high density optical power in the resonator. The experimental characteristics of standard waveguide SQW SCH lasers are shown in Fig. 5, whereas those of broad waveguide MQW SCH lasers are shown in Fig. 6. In both cases the lasers were fabricated from one wafer. Some of them were driven to the high currents and consequently damaged. This manifests itself in a sudden drop of the optical power, in contrast to thermal roll-over of the *P–I* characteristic which is a reversible process. It has to be also mentioned that measurements, for the speed of evaluation of different lots of devices, were done on laser chips assembled on the copper submounts. The final processing of the high power lasers includes mounting lasers on suitable heat sink and encapsulation, which due to the more efficient heat dissipation should further increase COD level and amount of power which can be delivered by the laser in a stable way.

4. Conclusion

Numerical simulation of standard AlGaAs/GaAs SQW SCH lasers and broad waveguide MQW SCH lasers have been performed. We have analyzed the performance of both types of lasers with regard to high power operation at 808 nm spectral band which is of interest for diode pumped Nd:YAG lasers. Design rules for above-mentioned lasers are formulated. From the analysis presented it follows that broad MQW SCH lasers are better suited for high power applications and exhibit a superior tolerance to both inherent construction parameters variations and to external operation parameters. The most important conclusion is that broader waveguides are suitable for obtaining higher optical powers and generally result in higher COD level. This happens on the expense of higher threshold current but differential quantum efficiency remains the same and the wall-plug-efficiency, for currents high above threshold, deteriorates only slightly.

The new design of the lasers has been verified experimentally. The broad waveguide MQW SCH lasers, as expected, exhibited substantially higher COD levels. Some of them could be drown up to 16 A and 8 W pulse power, whereas standard SQW SCH reached only 3.5 W pulse power (for filling factor 0.1%; 200 ns pulse with 5 kHz repetition). Above that power mirrors were irreversibly damaged by high density optical power in the resonator.

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