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High-performance 980-nm strained-layer InGaAs/GaAs quantum-well lasers

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The paper reports fabrication of strained-layer InGaAs/GaAs separate-confinement -heterostructure single-quantum-well (SCH SQW) lasers operating in the wavelength range of 980 nm. Design process of the devices involved simulation of their above-threshold operation including all relevant physical phenomena. The lasers were characterized at room temperature in the pulsed operation regime at frequency $\nu = 5$ kHz and pulse length $\tau = 200$ ns. Threshold current densities of the order $J_{th} = 280$ A/cm^2 and differential efficiency $\eta = 0.40$ W/A were obtained for devices with cavities of 700 μm in length and broad contacts of 100 μm in width.

1. Introduction

Semiconductor lasers with strained InGaAs/GaAs active region are currently an object of intensive research due to the well established applications for 980-nm pump sources for erbium doped fiber amplifiers used in communication systems. All practical 980-nm lasers are based on the ternary AlGaAs and InGaAs alloys. The excellent lattice match, refractive index contrast, and thermal conductivity of AlGaAs give a freedom to optimize the vertical laser structure, while a single pseudomorphic InGaAs quantum-well active region produces sufficient gain and good electrical confinement leading to low-threshold current and high quantum efficiency [1]. In this paper, we provide details concerning design, fabrication and operation of 980-nm strained-layer InGaAs/GaAs separate-confinement-heterostucture single-quantum-well (SCH SQW) lasers fabricated at the Institute of Electron Technology, Warsaw.

2. Design considerations

The laser structure is shown in Fig. 1. It consists of n-type GaAs buffer layer grown on a conductive (100) GaAs substrate, 1.5 μm $Al_{0.3}Ga_{0.7}As$ n-type cladding layer, undoped active 80 Å $In_{0.21}Ga_{0.79}As$ quantum-well (QW) layer enclosed by 0.3 μm GaAs waveguide layers, 1.5 μm $Al_{0.3}Ga_{0.7}As$ p-type cladding layer, and p$^+$-type 0.25 μm GaAs subcontact layer. The design process of the laser is based on the simulation of its above-threshold operation. We have used laser modelling procedures based on the drift diffusion equations augmented by appropriate modules for calculating optical field and for describing the interactions between optical field and

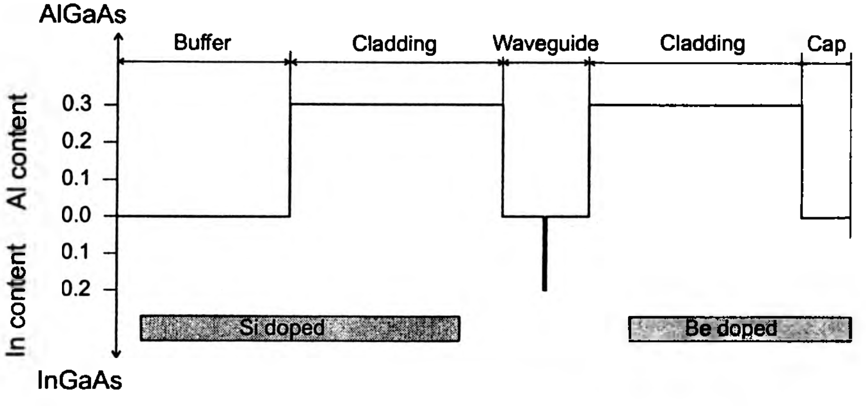

Fig. 1. InGaAs/GaAs quantum-well laser structure.

carriers. In addition, Schrödinger equation has been used to calculate bound state energies and quantum-well sub-bands in the active region of the device. All these calculations have been performed by using PICS3D simulation package [2]. It involves all the major physical models for modern semiconductor lasers, including strained quantum well and valence band mixing. Figure 2 illustrates typical light-current (P-I) characteristics obtained for lasers with stripe width $W = 100$ μm and resonator length $L = 700$ μm. Calculated threshold current densities are equal to 197 A/cm^2 and 208 A/cm^2 for QW indium content of 21% and 20%, respectively. In Figure 3, one can see relevant spectra of longitudinal modes belonging to the fundamental transverse and lateral mode. Due to the discrete nature of quantum-well thickness variations

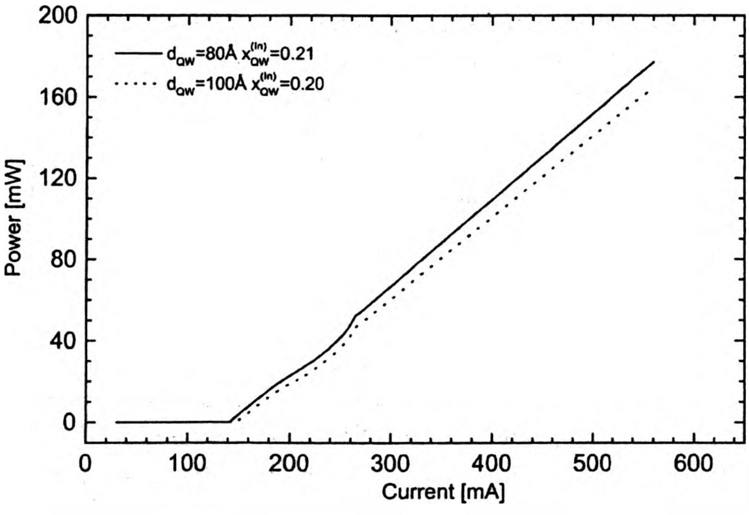

Fig. 2. Calculated light-current characteristics of the InGaAs/GaAs lasers with different combination of the thickness and indium content of the QW layer: d_{QW} = 80 Å and $x_{QW}^{(In)} = 0.21$ (solid line), d_{QW} = 100 Å and $x_{QW}^{(In)} = 0.20$ (dashed line). The waveguide layer thickness d_w = 0.3 μm.

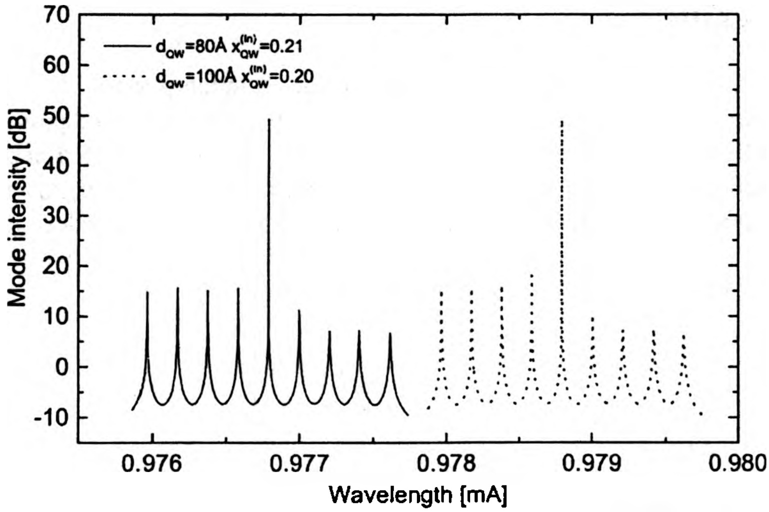

Fig. 3. Calculated spectral characteristics of the InGaAs/GaAs lasers with different combination of the thickness and indium content of the QW layer: d_{QW} = 80 Å and $x_{QW}^{(In)}$ = 0.21 (solid line), d_{QW} = 100 Å and $x_{QW}^{(In)}$ = 0.20 (dashed line). The waveguide layer thickness d_w = 0.3 μm.

which are expressed as multiples of monolayers (1 ML = 2.83 Å), thickness and indium composition of the QW layer have to be varied simultaneously in order to get the required emission wavelength. The calculated threshold current densities have to be treated as a bottom limit. In actual devices one should expect higher values due to unavoidable technological and processing faults and inaccuracies.

Our calculations revealed that the thresholds can be significantly decreased by application of narrower waveguiding layers on each side of the quantum well. For example, 0.1 μm waveguiding layers enable a decrease of the threshold current by about 25%. However, the optical power density in the resonator is then three times higher, which may lead to a faster degradation of lasers, in particular to the lowering of COD threshold level. Since our primary concern was the laser durability, the former design was chosen, although the penalty of slightly higher thresholds had to be paid.

3. Device fabrication

The laser heterostructures were fabricated by molecular beam epitaxy in a Riber 32P solid source reactor. The contact stripes of 100 μm width were fabricated using conventional photolithography and ion-beam etching techniques. The AuGeNi/Au contact with additional thick Au layer was deposited on the n-side of the device, whereas p-contact consisted of consecutive layers: Cr (50 nm), Pt (200 nm), Cr (50 nm) and Pt (150 nm). The individual lasers were In-soldered p-side down on copper blocks. Some of them had antireflection (AR) and high-reflectivity (HR) coatings deposited on the front and rear facets, respectively. Single SiO_2 layer was used as an AR coating, whereas HR coating was formed by a Si/SiO_2 multilayer system.

4. Experimental results

The InGaAs/GaAs laser structures have been characterized at room temperature in the pulsed operation regime with filling factor of 0.1% at frequency $\nu = 5$ kHz and pulse length $\tau = 200$ ns. The measurements have been carried out on both uncoated and coated devices with cavities of 700 μm in length and broad contacts of 100 μm in width. For the best uncoated devices, threshold current density of an order of

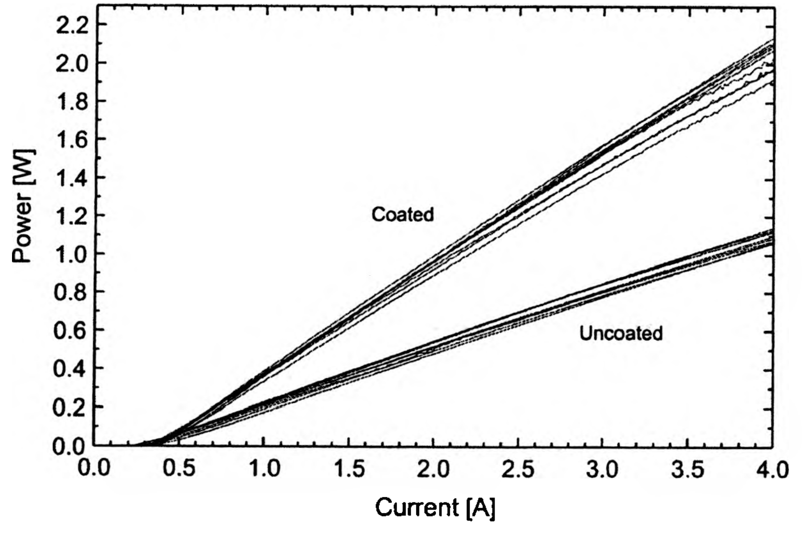

Fig. 4. Typical pulsed light-current characteristics of the InGaAs/GaAs lasers.

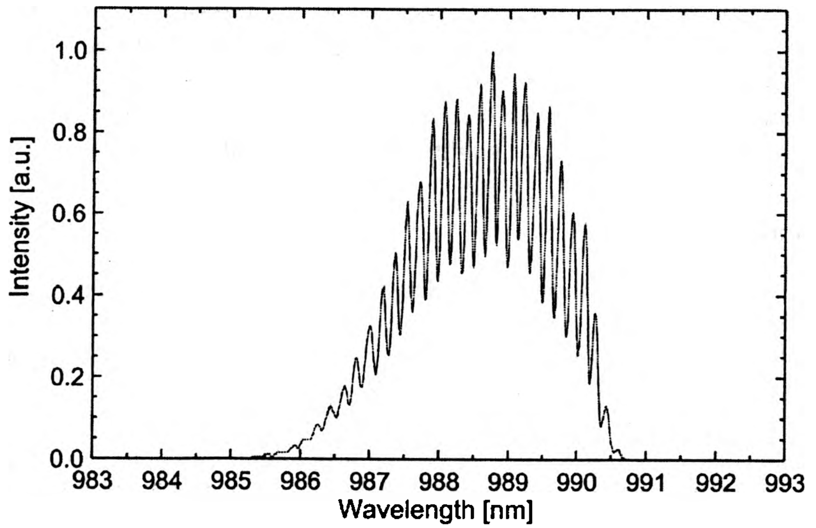

Fig. 5. Typical emission spectrum of the InGaAs/GaAs laser.

280 A/cm^2 and differential quantum efficiency η = 0.4 W/A were obtained. The wall-plug efficiency of the lasers was 38%. Threshold current of lasers with AR/HR coatings is similar, but differential quantum efficiency is roughly twice that of uncoated devices (see Fig. 4). The typical emission spectrum of the laser is presented in Fig. 5. It shows many longitudinal modes, with the halfwidth of the band less than 3 nm. One of the greatest concerns of the fabricated lasers was their reliability. Preliminary studies revealed that the uncoated devices did not show any appreciable degradation after 1000 hours of CW operation with 50 mW emitted power. These results are in good agreement with the similar studies for the state-of-the-art InGaAs/GaAs lasers [3]. The yield of the final devices was also satisfactory (40% lasers with good parameters).

5. Conclusions

We have developed a technology of strained-layer InGaAs/GaAs SCH SQW lasers operating in the 980-nm wavelength band. The threshold current density of an order of 280 A/cm^2 and differential quantum efficiency η = 0.4 W/A were obtained. The wall-plug efficiency of the lasers was 38%. Preliminary results show that the laser reliability is commercially acceptable for many practical applications.

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References

[1] LARSSON A., FOROUHAR S., CODY J., *et al.*, IEEE Photon. Technol. Lett. **2** (1990), 540.
[2] PICS3D is a trademark of Crosslight Software Inc., P.O. Box 27102, Gloucester, Ontario Canada K1J 9L9.
[3] HORIE H., OHTA H., FUJIMORI T., IEEE J. Select. Topics Quantum Electron. **5** (1999), 832.

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