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High-power pulsed laser diodes emitting in the range 1.5–1.6 μm

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Abstract. **This paper examines approaches for increasing the output pulse power of laser diodes based on MOVPE InGaAs/AlGaInAs/InP heterostructures and emitting in the range 1.5–1.6 μm. We demonstrate that optimising waveguide layer parameters may ensure an increase in the quantum efficiency of the laser diodes and a reduction in their internal optical loss. Characterisation results are presented for laser diodes based on the proposed heterostructures.**

Keywords: *metal-organic vapour phase epitaxy, laser diode, spectral range 1.5–1.6 μm.*

1. Introduction

The ability to obtain high output powers of laser diodes (LDs) in the spectral range 1.5–1.6 μm depends on the heterostructure (HS) geometry and is a challenging problem. The material system InGaAsP–InP, widely used in this spectral range, has a relatively low barrier height for electrons in a quantum well (QW), which leads to a rather low characteristic temperature of devices based on HS's of this system [1, 2]. As a result, LDs produced from this type of HS are characterised by increased temperature sensitivity and, accordingly, by a reduced slope of their light power–current ($L-I$) characteristic at high pump currents.

AlGaInAs/InP HS's ensure better electron confinement than do InGaAsP HS's, which is essential for high-power LDs and is evidenced by the higher characteristic temperatures achieved for LDs based on AlGaInAs/InP HS's [3, 4]. The level of output characteristics of laser HS's is highly dependent not only on HS material but also on active-region design, in particular on waveguide layer width and QW depth. Advantages of devices based on broad-waveguide HS's over narrow-waveguide structures have been demonstrated in several studies [5–10]. The use of broad-waveguide HS's allows one to employ longer gain elements, which ensures higher output powers owing to reduction in losses.

Many reports have examined the effect of the band gap of the waveguide layer on output device parameters [11, 12]. Better electron confinement determines both electron retention in the QW, preventing electron ejection to the waveguide layer, and the influence of various nonradiative recombination mechanisms. The contribution of Auger recombination to light power–current curve saturation is an essential factor that reduces the efficiency of long-wavelength LDs [13]. For this reason, the degree of carrier confinement in QWs, determined by the band gap of the waveguide, has a direct effect on output characteristics of devices based on AlGaInAs/InP HS's. By analogy with short-wavelength devices [14], increasing the band gap of the waveguide layer at a given QW composition is expected to reduce the effects of nonradiative recombination and electron ejection from the QW, thereby enabling an increase in quantum efficiency at high pump currents.

The purpose of this work is to obtain a high output pulse power of AlGaInAs/InP separate confinement double HS LDs. We examine the effects of waveguide layer width and electron confinement in QWs on the output parameters of LDs emitting in the range 1.5–1.6 μm.

2. Experimental

Epitaxial InGaAs/AlGaInAs/InP HS's for laser emitters were grown by low-pressure metal-organic vapour phase epitaxy in a horizontal slit reactor on (001)-oriented InP substrates in a hydrogen atmosphere. The principal growth parameters (temperature, pressure and deposition rate) were optimised so as to obtain good characteristics of the material.

Samples for this investigation had the form of separate confinement double HS's with a quantum well active region. Their waveguide layers were confined between InP emitter layers gradient-doped with silicon and zinc. The main parameters of the waveguide layers are listed in Table 1.

The HS's were used to fabricate single LDs with a mesa stripe width of 100 μm and a varied cavity length. The LD samples were mounted, with their epitaxial side down, on a copper heat sink. Pulsed output characteristics of the devices were measured using LDs with cleaved facets as mirrors and with 95% and 5% reflecting coatings. Power characteristics

Table 1. Main parameters of InGaAs/AlGaInAs/InP HS's.

Sample no.	Waveguide width/μm	Waveguide band gap/eV
1	0.3	1.0
2	1.5	1.0
3	1.5	1.12

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were studied at room temperature, a pulse duration of 100 ns and a pulse repetition rate of 5 kHz.

3. Results and discussion

Increasing the waveguide width proved to be an effective approach for reducing the internal optical loss in creating LDs of increased power in the ranges 0.8–1.1 and 1.7–1.8 μm [8, 10, 15–17]. This approach was also used in producing high-power LDs emitting in the range 1.5–1.6 μm. We fabricated three types of HS's, differing in active-region design (Table 1), and investigated LDs based on them.

Figure 1 shows the $L-I$ curves of the LDs. The curve of sample 1, which had a narrow waveguide, showed saturation at a low current: increasing the pump current to above 15 A led to saturation at a power level of ~2.2 W. Increasing the waveguide width allowed us to increase the slope of the $L-I$ curve. Sample 2 reached a higher power at an increased cavity length owing to the lower optical loss in it. At the same time, increasing the waveguide layer width may lead to the generation of additional modes. To avoid this, the quantum well active region was displaced towards the emitter, which reduced the gain for high-order modes [8, 15]. The use of a broad waveguide enabled the output pulse power to be increased by a factor of ~1.5 (to ~4 W at a pump current of 13 A) compared to sample 1 (Fig. 1a). At pump currents in the range from 13 to 30 A, the output power of sample 2 increased steadily, reaching 6 W at a current of 30 A.

The lasers made from the HS's in which the waveguide layers differed in band gap E_g (Table 1, samples 2, 3) were compared with the aim of assessing the effect of electron confinement in QWs on their output characteristics. Increasing the band gap of the waveguide layer was expected to increase the degree of electron confinement in the QWs, thereby influencing the internal quantum efficiency of the LDs. Assuming sufficient electron confinement in the QWs and sufficient optical confinement on the InP side, we determined the optimal band gap of the waveguide to be 1.12 eV. Unfortunately, the use of Al-rich AlGaInAs leads to undesirable incorporation of residual oxygen from the process atmosphere during epitaxial growth, which places limitations on the possible increase in QW barrier height [18]. In particular, the use of an AlGaInAs waveguide layer with E_g = 1.24 eV did not help us to obtain reliable devices. Such LDs rapidly degraded, so their characteristics were not considered in this study.

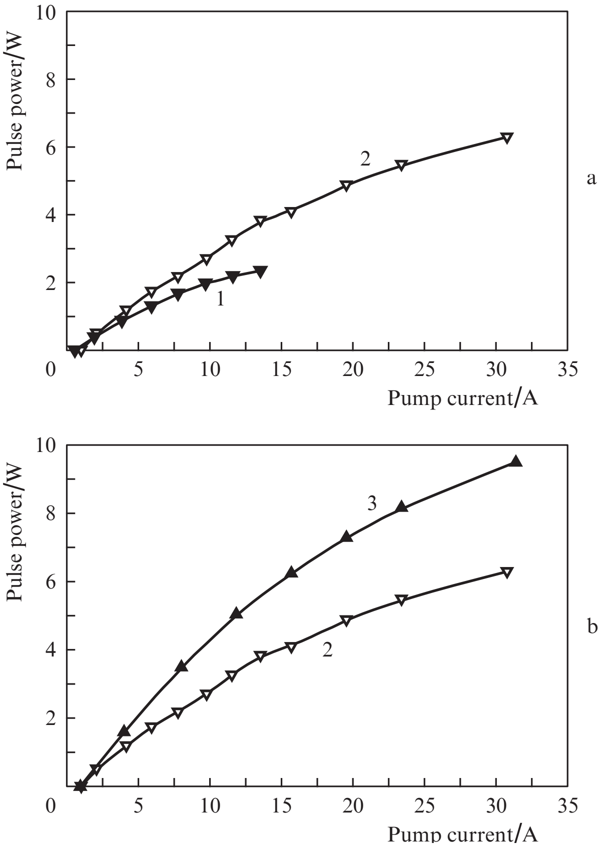

Figure 1. Light power–current curves of LDs based on AlGaInAs/InP HS's (1–3).

Comparison of the $L-I$ curves of samples 2 and 3 (Fig. 1b) demonstrates that the curve of the LDs made from the HS with the increased band gap of the waveguide region and, accordingly, with an increased barrier height for electrons in QWs has a higher slope. At a current of 30 A, the laser diode based on the HS with an increased waveguide width and a waveguide band gap of 1.12 eV (sample 3) had an output power of 9.5 W. Further increasing the pump current led to power saturation.

Thus, the present results indicate that optimisation of the waveguide layer geometry in InGaAs/AlGaInAs/InP HS's has a strong effect on characteristics of LDs emitting in the range 1.5–1.6 μm. The highest output pulse power was offered by the samples with the increased waveguide width and increased band gap. The output pulse power of sample 3 was three to four times that of sample 1, which was based on an HS of standard design.

In this paper, we examined approaches for raising the power of laser emitters in the range 1.5–1.6 μm by optimising the design and growth conditions of the waveguide layer of HS's. The LDs based on an HS with an increased waveguide layer width had a higher quantum efficiency. Owing to a reduction in internal optical loss, the peak pulse power reached ~6 W, whereas output power of lasers based on an HS of standard design was ~2 W. Increasing the E_g of the waveguide and optimising growth conditions allowed us to further raise the output power to 9.5 W owing to better electron confinement.

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