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# AlGaInAs/InP semiconductor lasers with an increased electron barrier

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***Abstract.*** **This paper presents an experimental study of AlGaInAs/InP semiconductor lasers with different barrier layers. The use of strained layers with an increased band gap as blocking barriers limiting carrier leakage is shown to increase the output power of the lasers at a given pump current.**

***Keywords:*** *semiconductor laser, heterostructure, AlGaInAs/InP, electron barrier.*

## 1. Introduction

AlGaInAs/InP heterostructure lasers emitting in the range 1.3–1.55 μm are widely used in information transfer systems utilising fibre-optic communication links. One well-known problem that limits further improvements of output characteristics of such lasers is the insufficient energy depth of their quantum wells. As the pump current is raised, some of the charge carriers may leave the active region to form leakage channels to the emitter layers. The approaches proposed to prevent this unwanted effect are to increase the energy depth of quantum wells or use barrier layers in the waveguide in order to block charge carriers ejected from quantum wells. Quantum wells with an increased depth can be produced by using a strain compensated active region in which the quantum wells and barriers are subject to stresses having opposite signs [1–3]. Candidate barriers are AlInAs [4–6] and GaInP [7] layers or a short-period GaInAs/AlInAs superlattice [8]. Note that layers used as barriers are usually lattice-matched to the substrate. The lattice matching requirement sets the barrier composition and band gap $E_g$. The potential barrier height can be raised using compositions that ensure an increase in band gap, but this impairs the barrier–substrate lattice match. In this context, it is of considerable interest to examine potential applications of strained layers with an increased band gap as blocking barriers limiting carrier leakage.

## 2. Experimental

AlGaInAs/InP separate-confinement laser heterostructures were grown by metal-organic vapour phase epitaxy. The active region of the heterostructures was formed by six strain compensated ($\varepsilon_{\text{total}} = +0.6\%$) GaInAs quantum wells located in the centre of an AlGaInAs/InP waveguide ($E_g = 1.08$ eV). The waveguide was confined between InP emitter layers. To reduce leakages, an AlInAs blocking barrier layer was placed on the waveguide–emitter interface. We grew two types of heterostructures: with and without lattice match between the AlInAs layer and substrate. Note that the band gap of the lattice-mismatched barrier ($E_g = 2.3$ eV) exceeded that of the lattice-matched layer (1.48 eV). From the heterostructures, we fabricated single-mode semiconductor lasers, and their characteristics were studied in continuous mode at room temperature.

## 3. Results and discussion

In a conventional AlGaInAs/InP laser heterostructure configuration, an AlInAs barrier layer is often placed on the waveguide–emitter interface [4–6, 9]. Since the conduction and valence band edges differ in position, it allows one to produce an energy barrier to electrons between the waveguide and emitter (Fig. 1a), which blocks current leakages to the emitter and helps to raise the differential quantum efficiency of lasing and the optical output power [10]. As a rule, this layer is lattice-matched to the InP substrate, which determines its band gap and, hence, the energy barrier height. Clearly, barrier effectiveness can be improved by using wider band gap layers. In the case of an AlInAs ternary solid solution, this will entail changes in lattice parameter and tensile stress build-up in such layers. In this approach (Fig. 1b), the permissible layer thickness is related to the limiting lattice mismatch at which there is still no generation of misfit dislocations. This condition imposes limitations on the increase in the band gap of the barrier layer of required thickness. In this situation, use can be made of strain compensation, a method that proved effective in producing the quantum confinement emitting region of AlGaInAs/InP lasers [1–3] and whose principle is that a wider band gap layer under tension is placed at the interface with the waveguide to improve electron confinement and a narrower band gap, compensating layer subject to stress of opposite sign is shifted closer to the emitter (Fig. 1c). To enhance the compensation effect, a few combinations of such layers can be used.

To find barrier layer parameters permissible from the viewpoint of the generation of misfit dislocations, we studied the photoluminescence of the active region of a laser. We examined the effect of variations in parameters of a wide-band-gap barrier placed on the waveguide–p-emitter interface to limit electron leakages.

We determined the geometry and growth conditions of barrier layers capable of raising the photoluminescence inten-

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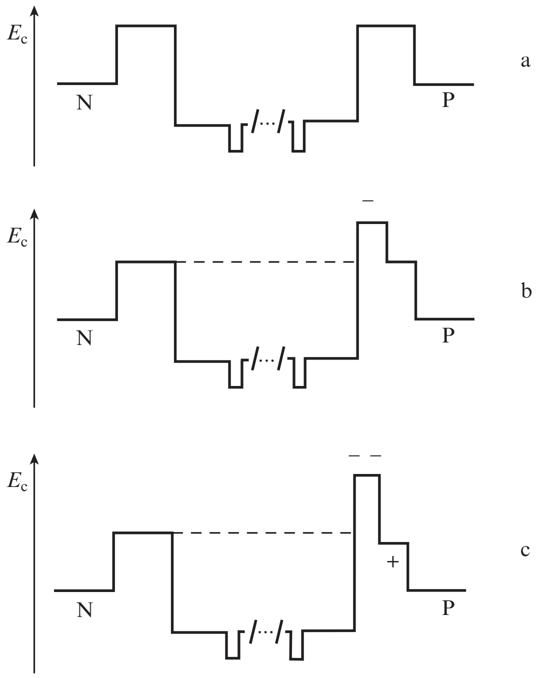

**Figure 1.** Diagrams of the conduction band of AlGaInAs/InP laser heterostructures with a (a) lattice-matched AlInAs barrier layer, (b) strained AlInAs barrier layer and (c) strain compensated AlInAs barrier layer. The symbol + denotes compressive stress and the symbol – denotes tensile stress. The number of symbols corresponds to the stress level.

sity. In our experiments, luminescence characteristics of samples with a lattice-matched barrier were compared to those of samples with a strain compensated barrier ($\varepsilon_{\text{total}} = -1.4\%$) consisting of two pairs of layers. Figure 2 shows typical photoluminescence spectra of the samples. It is seen that, even under optical pumping, the peak photoluminescence intensity of the heterostructure with the wider band gap barrier is more than twice that of the heterostructure with the lattice-matched barrier.

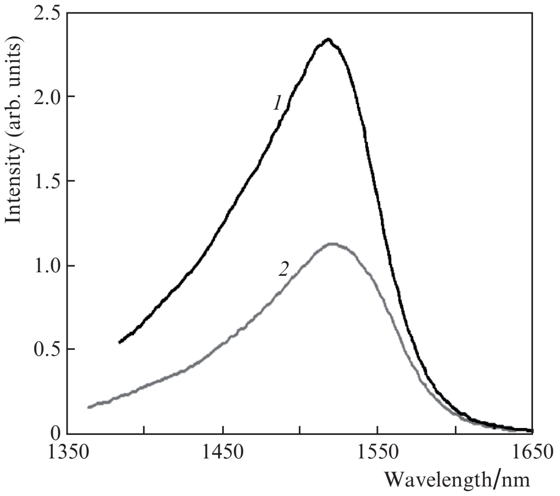

**Figure 2.** Photoluminescence spectra of AlGaInAs/InP quantum well heterostructures with a (*1*) strain compensated AlInAs barrier layer and (*2*) lattice-matched AlInAs barrier layer.

Laser heterostructures with such active regions were used to produce single-mode laser diodes [11]. The mesa stripe contact width was 2 μm and the cavity length was 200 μm. In assembling the diodes, the active region was located over a copper submount. Measurements were performed in continuous mode, without producing reflective or antireflective coatings on the cavity facets.

The slope of the light–current characteristic of the semiconductor lasers based on the heterostructure with the wider band gap barrier was found to be 10% to 20% higher than that in the case of the lasers with the conventional (lattice-matched) AlInAs barrier (Fig. 3a). In addition, there was a slight reduction in threshold current, but the presence of an additional barrier had a negative effect on the current–voltage characteristic (Fig. 3b). Thus, the lasers with the wide band gap barrier had a higher output power, confirming that the approach used here is effective in reducing leakage currents to the p-emitter.

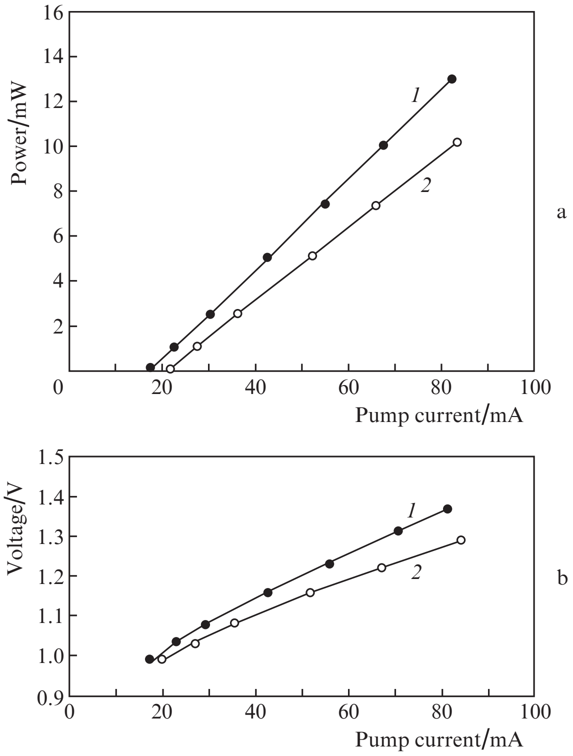

**Figure 3.** (a) Light–current and (b) current–voltage characteristics of the AlGaInAs/InP semiconductor lasers with (*1*) a strain compensated and (*2*) a lattice-matched barrier.

Producing dielectric coatings (with reflectivities of 15% and 80%) by sputter deposition allowed the slope of the light–current curve to be increased to 0.34–0.36 W $A^{-1}$. Despite the increased operating voltage of the lasers with the wide-band-gap electron barrier, operating life tests confirmed reliability of such devices.

The present results demonstrate that blocking the carrier leakage in the active region of a semiconductor laser helps to raise its output power. In particular, increasing the band gap of the barrier on the waveguide–p-emitter interface proved to be effective in the case of lasers emitting in the spectral range 1.3–1.55 μm.

## 4. Conclusions

AlGaInAs/InP semiconductor lasers have been studied experimentally using strain compensated AlInAs layers with an increased band gap as blocking barriers. The presence of wider band gap AlInAs layers improves electron confinement in the active region and reduces the carrier leakage to the emitter layers. This has an advantageous effect on the output characteristics of the lasers, in particular, raising their output power at a given pump current.

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