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Heterostructure design features for 975 nm high-power laser diodes

E.V. Ershov [1] ✉, A.V. Fomin [1], M.V. Lupachev [1], O.A. Rogachkov [1], A.A. Naidin [1]

[1] Russian Federal Nuclear Center - Zababakhin All - Russia Research Institute of technical Physics, Snezhinsk, Chelyabinsk region, Russia

✉ sneg.ershov@mail.ru

Abstract. The heterostructure design has been optimized to achieve high radiation output power and high conversion efficiency of 970–980 nm laser diodes. The influence of active layer geometry and waveguide layer doping on the output electrical and optical LD chip parameters has been studied. As a result of the optimization, operating LD output of 11.6 W has been achieved at a current of 12 A. The maximum conversion efficiency was 65% at a pump current of 5A.

Keywords: laser diode, laser cavity, heterostructure, quantum well

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Материалы конференции
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Особенности конструкции гетероструктур для мощных лазерных диодов спектрального диапазона 975 нм

Е.В. Ершов [1] ✉, А.В. Фомин [1], М.В. Лупачев [1], О.А. Рогачков [1], А.А. Найдин [1]

[1] Российский Федеральный Ядерный Центр – Всероссийский научно-исследовательский институт технической физики им. академ. Е.И. Забабахина,
г. Снежинск, Челябинская обл., Россия

✉ sneg.ershov@mail.ru

Аннотация. С целью достижения высокой выходной мощности излучения и КПД лазерных диодов спектрального диапазона 970–980 нм проведена оптимизация конструкции гетероструктуры. При оптимизации исследовано влияние геометрических параметров слоев активной области, а также легирования волноводных слоев гетероструктуры на выходные электрооптические характеристики чипов ЛД. Проведенная оптимизация позволила достичь рабочую выходную мощность излучения лазерных диодов 11,6 Вт при токе 12 А. Максимальный КПД при этом составил 65%, при токе накачки лазера 5 А.

Ключевые слова: лазерный диод, резонатор, гетероструктура, квантовая яма

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Introduction

Laser diodes (LDs) based on InGaAs/AlGaAs/GaAs with radiation wavelength λ_{rad} = 975 nm are widely used for fiber laser pumping. Specific requirements to heterostructure (HS) design are imposed by high optical output and operation modes of such lasers. The ways to improve LD output are intensively investigated by domestic and foreign scientific communities [1–3] while heterostructure design is constantly refined. Thus, output power is increased by 1) optimizing quantum well (QW) parameters, and 2) doping profile of HS waveguide layers. Therefore, the research aimed at optimizing the HS design with an extended waveguide is of high interest since it allows achieving high optical output and high conversion efficiency of LD chips.

Materials and Methods

For the research, InGaAs/GaAs/AlGaAs HSs were grown by MOCVD. The HS design for samples 1–8 is presented in Table.

Table

Design and composition of HS layers

Layer	Composition	Thickness
n-substrate	GaAs(001)	625±25 μm
buffer	GaAs:Si	1–2 μm
n-cladding	$Al_{1.75\cdot x}Ga_{(1.75\cdot x)-1}As$:Si	1.5 μm
waveguide	$Al_xGa_{1-x}As$	1.2 μm
active region	$In_yGa_{1-y}As$/(Al)GaAs	5–9 nm /10 nm
waveguide	$Al_xGa_{1-x}As$	0.5 μm
p-cladding	$Al_{1.75\cdot x}Ga_{(1.75\cdot x)-1}As$:Zn	1.0 μm
contact p-layer	GaAs:Zn	0.15–0.20 μm

The samples 1–8 were used to manufacture LDs with a cavity length of 4 mm and an emitting stripe width of 100 μm using the developed planar technology. The LD chips end facets were anti-reflective and reflective coated. The LD chips were soldered p-side down on a heat-conducting submount with vacuum Au-Sn eutectic solder coating. Light-current and voltage-current characteristics of LD chips were measured using the equipment for electrical and optical measurements in CW laser generation mode at the currents from 0 A to 12 A.

Results and Discussion

At the first stage of the work, the effect of QW thickness, d, and QW number on the LD chip output power, P_{max}, was investigated. Heterostructures with a single QW were grown with varying QW thickness from 5 nm to 9 nm. In those experiments with varying QW thickness, In molar fraction was selected so that the peak photoluminescence (PL) wavelength for a heterostructure would be 955 ± 2 nm at normal conditions. The above PL wavelength allows obtaining the radiation wavelength λ_{rad} = 975 ± 1 nm for LD chips in CW laser generation mode at the currents of 10–12 A. The dependencies of P_{max} on QW thickness and QW number are shown in Figure 1.

Figure 1 shows that P_{max} = 8.7 W was reached for the LD chips with a QW thickness of 6.0 nm. The radiation output decreased with varying the QW thickness. Note that the obtained optimal QW thickness agrees with the data in [4] where the dependency of internal quantum HS photoluminescence output on QW thickness was studied. The radiation output decreased from 8.6 W down to 8.0 W with double quantum well 6 nm thick due to the increase in the threshold current density, J_{th}, from 125 A/cm^2 up to 180 A/cm^2. Therefore, the HS design should contain a single QW with a thickness of ~ 6 nm to achieve high radiation output.

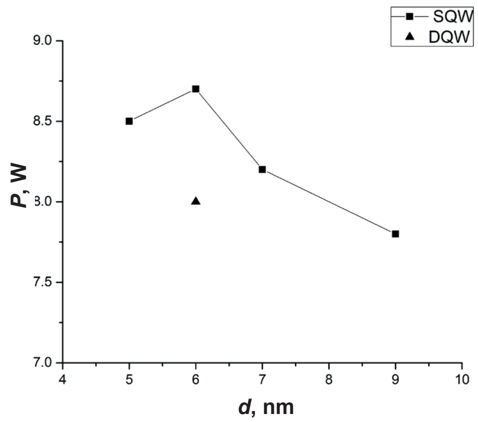

Fig. 1. Optical absorption spectra before and after etching of soda-lime glass after vacuum thermal poling and silver-for-sodium ion exchange

At the second stage, the effect of QW energy depth on the LD output characteristics was studied. For this, HS samples with an extended undoped waveguide were grown with varying Al molar fraction in $(Al_x)Ga_{1-x}As$ barrier layers from 0% to 20%. Those were grown with a single QW 6 nm thick to maintain high radiation output.

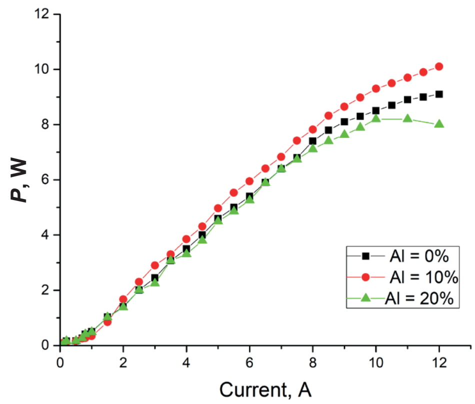

Fig. 2. Light-current characteristics of the LD chips from HSs with different Al molar fractions in $InGaAs/(Al_x)Ga_{1-x}As$ barrier layers of the active region

The measured light-current characteristics (Fig. 2) show that P_{max} of 10.1 W was achieved for the LD chips with Al molar fraction of 10% at a current of 12 A. Besides, saturation of light-current characteristics was observed for all LDs preventing radiation output from growing further. At that, the operating voltage, U, was 1.88 V at a current of 12 A. Saturation of light-current characteristics and high values of voltage-current characteristics are typical for LD chips with an extended undoped waveguide. Such waveguide design enables reducing internal optical loss, thus, increasing differential quantum efficiency, and allows using lasers with an extended cavity length. Moreover, HSs with an extended waveguide induce the decrease in laser radiation density on the cavity mirrors while shifting down the threshold of critical optical degradation of the mirrors. However, the extended undoped waveguide increases both thermal and electrical series resistance of the structure, thus, resulting in the increase in heat release, which affects laser conversion efficiency and constrains their maximum achievable output [5].

Additionally, the influence of doping HS waveguide layers on LD light-current and voltage-current characteristics was investigated to reduce thermal and electrical series resistance. For this, HS samples with $Al_{0.1}Ga_{0.9}As$ barrier layers were grown where the waveguide regions adjacent to n-cladding and p-cladding were doped with Si and Zn, respectively. The waveguide region adjacent to the quantum well remained undoped to keep the optical loss below 1 cm^{-1}. The zone energy diagram of such an HS is given in Figure 3.

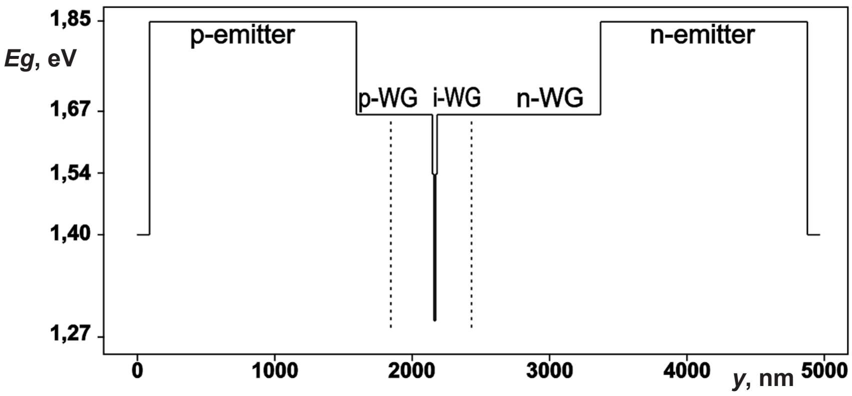

Fig. 3. Zone diagram of a doped-waveguide heterostructure

The measured light-current characteristics (Fig. 4, *a*) for the LD chips manufactured from doped-waveguide HSs showed the increase in the output power, P_{max}, up to 11.6 W at an operating current of 12 A. No saturation of light-current characteristics within an operating current range from 1 A to 12 A was observed. The voltage-current characteristics (Fig. 4, *b*) showed the decrease in the operating voltage, *U*, from 1.88 V down to 1.74 V at an operating current of 12 A for doped-waveguide chips. The LD chip conversion efficiency was 56% at an operating pump current of 12 A. The maximum conversion efficiency of 65% for the LD chips manufactured from doped-waveguide HSs was achieved at 5 A.

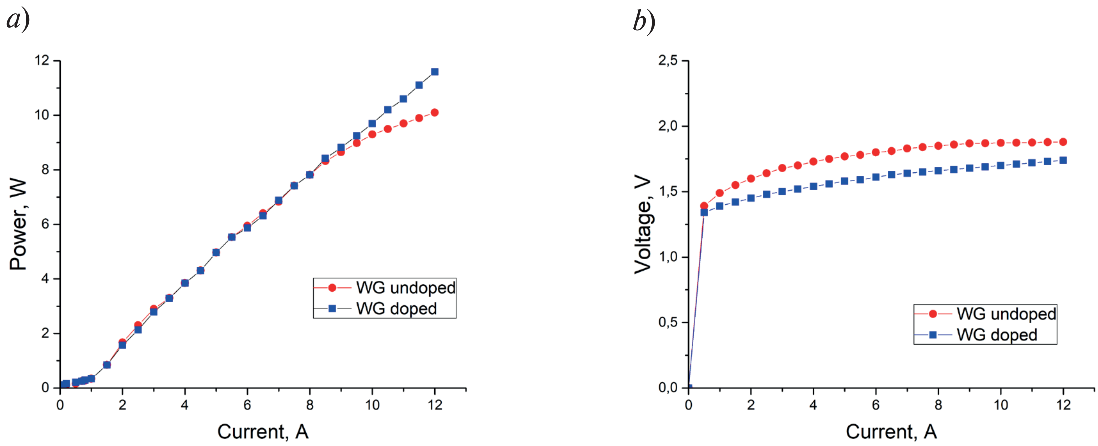

Fig. 4. Light-current and voltage-current LD chip characteristics manufactured from HS with doped and undoped waveguide layers

Conclusion

The HS design with an extended asymmetric waveguide has been optimized to obtain high radiation output power and high conversion efficiency of 970–980 nm LD chips. The influence of HS layer doping and the geometry of active-region layers on electrical and optical LD output characteristics has been investigated. As a result, the LD operating output power of 11.6 W at a current of 12 A. The maximum conversion efficiency of 65% have been achieved at a current of 5 A. It should be noted that authors of [5] achieved maximum conversion efficiency of 70–72% due to doping and decreased molar fraction of aluminum in AlGaAs waveguide layers.

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THE AUTHORS

ERSHOV Evgenii V.
sneg.ershov@mail.ru

FOMIN Aleksei V.
a.v.fomin@vniitf.ru

LUPACHEV Maksim V.
Dep5@vniitf.ru

ROGACHKOV Oleg A.
roa_jr@mail.ru

NAIDIN Andrei A.
naydin_andrey@mail.ru

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