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High-power AlGaAs/GaAs broad-area lasers grown by MBE

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Abstract

A new broad area (BA) structure laser has been designed with a weak lateral index waveguide, an optical coupling layer and nonabsorbing windows to improve the light output properties of BA lasers. The wafer has been grown successfully by MBE and the BA stripe has been obtained mainly by an impurity-free vacancy diffusion (IFVD) technique. The prepared devices have been measured with a maximum output power of 3.2 W. A satisfactory far field ($\theta_{\parallel}$) output property is also obtained. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

High-power semiconductor lasers have great potential applications in a wide variety of fields such as printing, pumping of solid state lasers, illumination, medical diagnosis, surgery, spectroscopy and material processing [1,2]. Broad area (BA) stripe is fundamental for many kinds of high-power LDs or LD arrays, and design of the lasing stripe is very important for output characteristics of the prepared LD devices. Most studies [3,4] related to high-power LD devices have simply taken an electrically insulating stripe process for the fabrication of carrier injection region, while some window structures were made to restrain possible optical absorption in the vicinity of cavity facets for certain fundamental transverse mode devices. In this paper, we will present some considerations for design of BA LD structures by the idea of window structure, main fabricating process by MBE and detail performances of the specially prepared high-power LDs.

2. Structural considerations for BA lasers

The maximum output power of semiconductor lasers is generally limited by either thermal rollover or Catastrophic optical mirror damage (COMD). Thermally limited power saturation can be eliminated mainly by designing laser structures to have high total power conversion efficiencies, which is relevant to threshold current density, characteristics temperature and external differential quantum efficiency. COMD power limitation, mainly due to waveguiding parameters,

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interface optical absorption and carrier combination, can be improved mostly by cavity facet coating, enlarging of optical cavity and nonabsorption window structures. In our fabrication of high-power BA lasers, some considerations have been made as follows:

(a) SQW SCH structure is adopted as the basic structure for low-threshold current density of LD;
(b) Coupling waveguiding design is taken to enlarge thickness of optical cavity, so a large optical spot size can be obtained with little penalty in threshold current density by optimizing structural parameters;
(c) Impurity-free vacancy diffusion (IFVD) technology is used to form nonabsorption window;
(d) IFVD technology is used to form lateral index waveguide to improve stability of transverse modes in BA lasers. Fig. 1 gives the schematic epitaxial structure, in which two 100 nm coupling waveguiding layers are separately inserted into upper and lower cladding layers. According to waveguiding theoretical calculations, a drop of 40% of optical confinement factor (Γ) can be obtained by adopting coupling waveguiding layers in QW SCH lasers, while a good carrier confinement characteristics of the LD structure remains. Window nonabsorbing region and lateral index waveguide are made by a one-step IFVD process. Fig. 2 shows a schematic diagram of BA stripe LD devices. The width of the stripe is 150 μm.

3. Fabrication process and LD performance

The LD structure has been grown by MBE in a V80 H system. The substrate is a Si-doped n^+-GaAs (1 0 0) wafer tilted about 2–3° toward (1 1 1)A with an etch pit density of less than $500\,cm^{-2}$. Strict outgasing process must be guaranteed to have a clean surface before growth. The growth rate is kept constant at 1.0 μm/h for GaAs during the entire structure epitaxial process, and the V/III ratio varies from 10 to 20 according to different AlGaAs alloy ingredients. Growth temperature for GaAs is 600°C, and AlGaAs layers are grown at a constant temperature of 700°C. The growth temperature damps during the growth of AlGaAs layers in the vicinity of heterojunction interface; no growth interruption is used during the entire epitaxial process. The main epitaxial process is as follows: First, a 0.5 μm n-GaAs buffer layer is grown, then the lower cladding layer of 1.5 μm thick N-$Al_{0.55}Ga_{0.45}As$ is followed with an inserted 100 nm $Al_{0.15}Ga_{0.85}As$ optical coupling layer which is located 500 nm under the top surface of the lower cladding layer. After that, a 70 nm undoped $Al_xGa_{1-x}As$ ($x = 0.55 \rightarrow 0.30$) composition-graded waveguiding layer and a 7 nm undoped $Al_{0.07}Ga_{0.93}As$ QW active layer are subsequently grown. Then an upper waveguiding structure (symmetrical to the lower waveguide, doped with p-type) is brought to growth successively. A heavily doped p-GaAs layer ($1\text{–}2 \times 10^{19}\,cm^{-3}$, 0.1 μm thick) is used for ohmic contact.

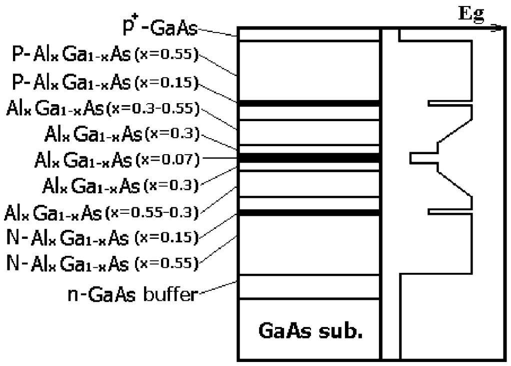

Fig. 1. Epitaxial structure of the designed BA lasers.

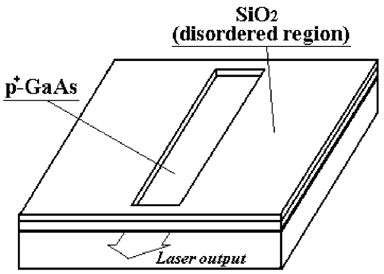

Fig. 2. Schematic diagram of BA lasers specially designed.

Measuring under pulse condition has been done; the main results of the grown wafer are as follows: the typical threshold current density is 240 A/cm^2, and the slope efficiency is about 0.7 W/A per-facet, the value of the internal loss coefficient is about 3.8 cm^{-1} calculated from the relation between the external differential quantum efficiency η_d and cavity length L, indicating the high quality of the epitaxial material.

An IFVD process is used to intermix the SCH SQW structure including the quantum well layer in the region near the cavity facet and outside the lasing stripe, with a 250 nm-thick SiO_2 capping film prepared by sputtering. IFVD is perhaps the simplest method to alter material properties (both energy gap and optical index). The mechanism which is responsible for material property altering is that when a suitable dielectric film is used as a cap annealing the sample at high temperature will enhance interdiffusion of some ingredients in the sample; thus properties of the annealing structure will be altered. A series of annealing conditions has been tested to optimize the IFVD process in a rapid thermal annealing (RTA) system. Finally, the temperature for RTA is chosen to be 950 °C experientially, and the annealing time is 40 s. The wafer is protected from heat damage by covering GaAs substrate during the RTA process. A standard photolithography technique is used to form the SiO_2 window stripe for the designed BA lasers. AuZn and AuGeNi are used as p- and n-type ohmic contact electrodes by a thermal evaporation. In order to reduce the contact resistance due to Be diffusion in contact layer in the annealing process, an additional shallow Zn diffusion is carried out before the evaporation of AuZn alloy. After annealing for ohmic contact at 420°C, a carefully cleaving process is done to satisfy the size of nonabsorbing window region which has a length of 30 μm and the cavity length of the BA lasers is 1.2 mm. Finally, two facets are coated with AR/HR films, respectively, to prepare a low-reflectivity (5%) front facet and a high-reflectivity (⩾90%) rear facet. Then the diced chips are mounted p-side down on copper heat sinks with evaporated Indium solder.

The threshold current of the prepared laser diodes is about 400 mA, and the slope efficiency is about 1.2 W/A. A typical light output curve versus DC current of the tested lasers is shown in Fig. 3. The maximum light output power is up to 3.2 W which increases by 60% compared with conventional lasers with the same stripe width; higher power output of the LD is possible under higher driving level. Fig. 4 gives a measuring curve of the far field ($\theta_{\parallel}$) of the BA lasers at different driving levels. It is found that the far field in the direction parallel to PN junction is more stable and smooth with the increasing of injected current than the conventional BA lasers. Improvement in far field properties is possibly a result of the considerations

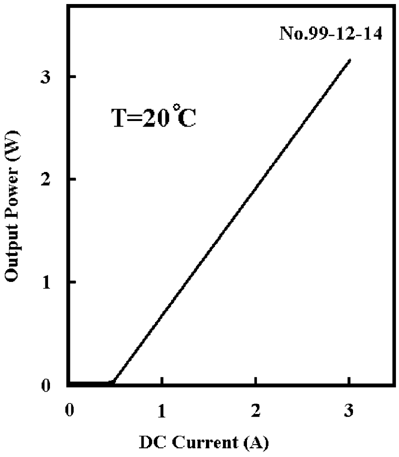

Fig. 3. P–I characteristics of a measured BA laser diode.

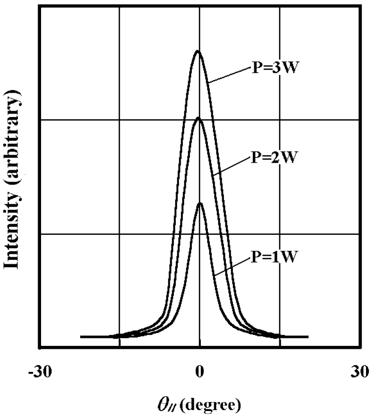

Fig. 4. Farfield ($\theta_{\parallel}$) properties with different output powers.

for the prepared BA lasers. First, IFVD process within lateral region out of the stripe has built up an index waveguiding mechanism which tends to a more stable transverse mode than a gain waveguide. Second, design of coupling waveguide layers has enlarged the optical field across the QW layer, which weakens the tendency of waveguide alternating due to optical field factors. Third, nonabsorbing window structure near cavity facets has reduced the optical absorption, which has an advantage to keep the facets stable.

4. Conclusions

A new BA laser structure has been designed with a weak lateral index waveguide, an optical coupling layer and nonabsorbing windows to improve the light output properties of BA lasers. The designed BA LD devices grown by MBE have been fabricated mainly by an IFVD technique. The prepared devices have been measured with satisfactory results including light power output and light beam profile, which has been analyzed, respectively.

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