High-Speed and High-Power 1.3 μm InGaAsP/InP Selective Proton-Bombarded Buried Crescent Lasers with Optical Field Attenuation Regions

1999 Jpn. J. Appl. Phys. 38 6729

(http://iopscience.iop.org/1347-4065/38/12R/6729)

Jpn. J. Appl. Phys. Vol. 38 (1999) pp. 6729–6731
Part 1, No. 12A, December 1999

High-Speed and High-Power 1.3 μm InGaAsP/InP Selective Proton-Bombarded Buried Crescent Lasers with Optical Field Attenuation Regions

Baijun ZHANG, Maobin YI[1], Junfeng SONG[1], Dingsan GAO[1], Ninghua ZHU, Ronghan WU and Wei WANG
National Research Center for Optoelectronic Technology, Institute of Semiconductor, Chinese Academy of Sciences,
P. O. Box 912, Beijing, 100083, P. R. China
[1]*Department of Electronic Engineering and State Key Laboratory on Integrated Optoelectronics, Jilin University,*
119 Jiefang Road, Changchun, 130023, P. R. China

(Received May 20, 1999; revised manuscript received August 20, 1999; accepted for publication September 16, 1999)

High-speed and high-power InGaAsP/InP selective proton-bombarded buried crescent (SPB-BC) lasers with optical field attenuation regions were reported. The defect of proton bombardment can not affect the lifetime of the SPB-BC laser because the optical field attenuation region obstructs the growth and propagation of defects. A CW light output over 115 mW was achieved at room temperature using a 500 μm long cavity SPB-BC laser. The 3 dB bandwidth was 8.5 GHz, and the lifetime was about 8.5×10^5 h. The capacitance of four kinds of current blocking structures was first measured in our experiment, and the results shown that the capacitance of proton-bombarded *pnpn* structure was not only less than that of *pnpn* current blocking structure, but also less than that of semi-insulating Fe–InP structure.

KEYWORDS: semiconductor laser, heterostructure, proton bombardment, modulation bandwidth, MOCVD

1. Introduction

There is considerable interest in developing high-speed and high-power InGaAsP/InP semiconductor lasers for use in microwave fiber optic links, video analog applications, and digital lightwave communication systems. Conventional buried crescent lasers are attractive as light sources for optical fiber communication systems because of their high output power, low threshold current and good reliability.[1)] However, their small-signal modulation bandwidth is rather limited due to excess parasitic capacitance from the current blocking reverse-biased *p*-*n* junction. In order to improve the modulation bandwidth, various structures, therefore, have been developed, such as polyimide-based semi-insulating planar buried heterostructures,[2,3)] InGaAsP buried crescent injection lasers with semi-insulating current blocking layers,[4–6)] V-grooved inner-stripe lasers with semi-insulating current confinement structure on *p*-InP substrate,[7)] and so on.

In this paper, we proposed a novel high-speed and high-power laser structure, in which the resistance of the confinement layers was increased and the parasitic capacitance of the laser was reduced by using the selective proton bombardment technique, and the capacitance of four kinds of current blocking structures was measured. Comparing with those structures reported previously,[2–7)] it not only has a more convenient and economic procedure, but also exhibits better performances. In addition, unlike the proton-bombarded stripe-geometry laser, the defect of proton bombardment can not affect the lifetime of the selective proton-bombarded buried crescent (SPB-BC) laser because there is a 3.0 μm width unbombarded region as an optical field attenuation region to obstructing the growth and propagation of defects at each side of active region. With this structure, a CW light output over 115 mW was obtained, and the 3dB bandwidth of 8.5 GHz was presented.

2. Device Structure and Fabrication Process

Figure 1 shows schematic and scanning electron micrograph (SEM) views of cross section of 1.3 μm InGaAsP/InP SPB-BC laser. The laser was fabricated by hybrid epitaxial growth technique. A *pnp* blocking structure was first grown on a *p*-InP substrate by metalorganic chemical vapor deposition (MOCVD) described previously.[6)] Arrowhead-shaped channels with a width of 2.0 μm were etched along the [011] direction on the MOCVD grown wafer. The etched arrowheads have to extend just below the n_1-InP layer. A double heterostructure consisting of a p_2-InP lower cladding layer (Zn-doped, 1×10^{18} cm^{-3}), an undoped InGaAsP active layer ($\lambda = 1.3\,\mu$m), an n_2-InP upper cladding layer (Sn-doped, 1×10^{18} cm^{-3}), and an n^+-InGaAsP (Te-doped, 3×10^{18} cm^{-3} $\lambda = 1.1\,\mu$m) contact layer were successively grown on the grooved wafer by LPE. The crescent-shaped active region was located above the junction between the *n*-blocking and *p*-blocking layers to minimize the leakage current and the parasitic capacitance. After the metallization process, a deep proton bombardment (3.8 μm) using the multi-energy and dose was carried out on both sides of the active channel using a special tiny frame with the tungsten filament as mask reported previously.[8)] The diameter of tungsten filament is 8.0 μm. Finally, the wafer was cleaved into individual lasers and mounted on copper heatsinks with the junction-down configuration using In-Sn solders without small bonding pads.

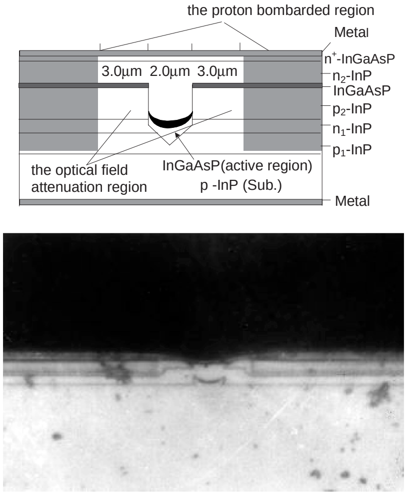

Fig. 1. Schematic and SEM views of cross section of 1.3 μm InGaAsP/InP SPB-BC laser, (a) Schematic cross section SPB-BC laser, (b) SEM of SPB-BC laser.

3. Results and Discussions

Unlike conventional *pnpn* current blocking structure, the thyristor effect of proton-bombarded *pnpn* structure will vanish if the depth of proton bombardment is deep enough because the proton bombardment increases the resistivity of InP material.[9] The proton-bombarded *pnpn* structure has far superior endurance against high voltage compared to conventional *pnpn* structure. Therefore, high performance of the SPB-BC laser has been realized. Figure 2 shows the CW light-current characteristics for a SPB-BC laser. The maximum output power is over 115 mW at 300 mA for 500 μm cavity length with 5 and 95% reflectivity of the front and rear facets, respectively. The linear output power is larger than 90 mW, and the threshold current is about 25 mA.

There are mainly four kinds of current blocking structures for high-speed and high-power InGaAsP/InP semiconductor lasers; i.e. *pnpn* structure, semi-insulating Fe–InP structure, polyimide structure, and proton-bombarded *pnpn* structure. In our experiment, the capacitance of these kinds of current blocking structures was first measured in the range of 50 MHz to 10 GHz using an HP8720D network analyzer and a calibrated microwave probe. The thickness of semi-insulating Fe–InP layer and polyimide insulating layer is the same as the depth of proton bombardment, and the proton-bombarded depth is 3.8 μm. The measured area of these kinds of current blocking structures is $250 \times 300\,\mu\text{m}^2$. The measured results were shown in Fig. 3. The capacitance of proton-bombarded *pnpn* current blocking structure is the smallest in these structures except polyimide structure. So the SPB-BC lasers showed good high-frequency modulation characteristics.

The modulation response was measured at room temperature using an HP network analyzer and a 20.0 GHz bandwidth GaInAs p-i-p detector. The small-signal frequency response of SPB-BC lasers at various bias currents is shown in Fig. 4. The 3 dB modulation bandwidth of 8.5 GHz is achieved at room temperature and a CW bias current of 100 mA even though the measured laser has a 500-μm-long cavity and full area electrodes ($500 \times 300\,\mu\text{m}^2$). The modulation bandwidth will be increased if a smaller bonding pad was used.

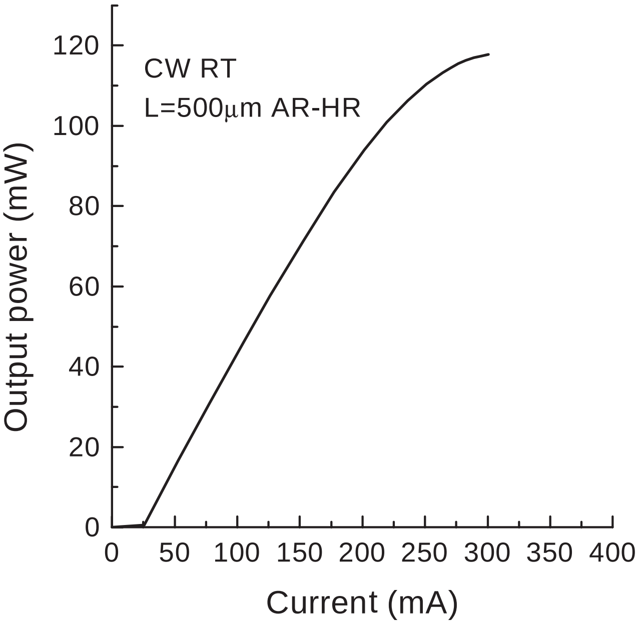

Fig. 2. CW light-current characteristics of the SPB-BC lasers.

High reliability, as well as high performance, is required for the fiber optic communication systems. It is well known that the proton-bombarded stripe-geometry lasers have a poor reliability. The lifetime is about 10^3–10^4 h.[10,11] The main reason is that the optical field will induce the growth and propagation of the proton-bombarded dark-line-defects (DLDs) during lasers operating. The experiment of optically induced degradation in InGaAsP/InP DH laser material have been reported previously.[12] The optical degradation was observed after10 min at 10^5 W/cm^2, and the product of the excitation intensity and exposure time is a constant, so the threshold of optical degradation (E_a) is $\sim 1.6 \times 10^4$ W/m^2. For SPB-BC lasers, however, there is an unbombarded region at each side of active region as an optical field attenuation region. The intensity of optical field becomes very weak when the optical field reaches the edge of bombarded region, so it cannot induce the growth and propagation of the proton-bombarded defects. If we assume that the growth and propagation of the proton-bombarded defects is only induced by the optical field of laser, the minimum width of optical field attenuation region can be calculated by using the mode theory and the value of E_a. The calculated result is shown in Fig. 5. There is an inset graph in Fig. 5, in which the distance is from 1.78 to 2.52 μm. When the intensity of optical field is attenuated to the same value E_a, the distance from the center of active region is 1.82, 1.94, 2.0, 2.05 and 2.1 μm for the different output power of 3, 10, 30, 50 and 70 mW, respectively. Besides the optical

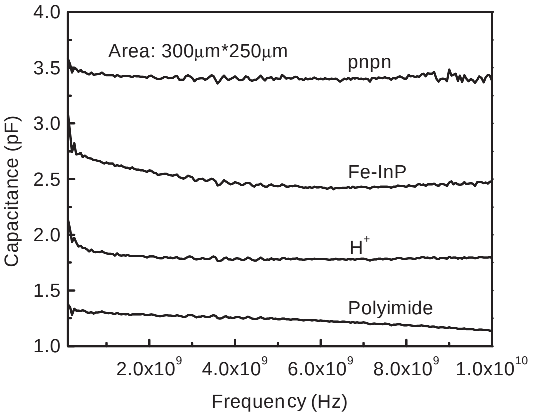

Fig. 3. Capacitance of four kinds of current blocking structures.

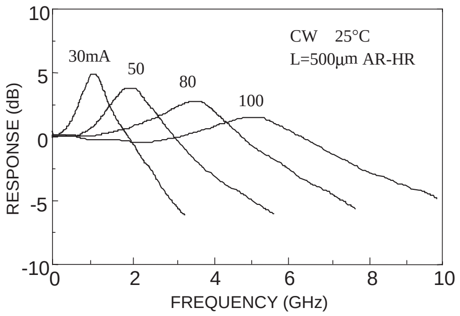

Fig. 4. Small-signal modulation characteristics of a 500-μm-long SPB-BC laser.

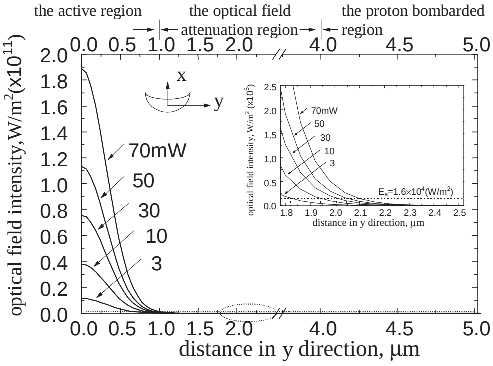

Fig. 5. The distribution of optical field in y direction. Inset: distance shown is from 1.78 to 2.52 μm, and minimum width of optical field attenuation region is 0.82, 0.94, 1.0, 1.05 and 1.1 μm for the different output power of 3, 10, 30, 50 and 70 mW, respectively.

field of laser, electrical injection and high temperature also can induce the growth and propagation of defects. To obstruct the growth and propagation of the proton-bombarded defects, 3.0-μm-width optical field attenuation region was adopted in the SPB-BC laser. The reliability of the SPB-BC lasers was measured. The median lifetimes at the 65°C–3 mW and 80°C–3 mW aging conditions were estimated to be 1.1×10^4 h and 2.8×10^3 h, respectively. The extrapolated lifetime of the lasers at room temperature is $\sim 8.5 \times 10^5$ h. The result shows that the proton-bombarded defects does not induce the rapid degradation in SPB-BC lasers.

4. Conclusions

High-speed and high-power 1.3 μm InGaAsP SPB-BC lasers have been developed. The current blocking structure of the SPB-BC laser has a high resistivity and a low parasitic capacitance. A CW maximum power of 115 mW is obtained. A 3 dB modulation bandwidth of 8.5 GHz for 500 μm cavity length is presented, and the lifetime of lasers at room temperature is about 8.5×10^5 h. The SPB-BC laser is an ideal high-speed, high-power and long lifetime laser structure. The selective proton-bombarded technique is suited for not only BC lasers but also all kinds of buried stripe-structure laser.

1) Y. Sakakibara, H. Horikawa, E. Oomura, Y. Nakajim, Y. Yamamoto, K. Goto, H. Namizaki, K. Ikeda and W. Susaki: J. Lightwave Technol. **3** (1985) 978.
2) J. E. Bowers, U. Koren, B. I. Miller, C. Soccolich and W. Y. Jan: Electron. Lett. **23** (1987) 1263.
3) I. E. Berishev, A. Yu.gorbachev and V. A. Mishournyi: Appl. Phys. Lett. **68** (1996) 1186.
4) W. H. Cheng, C. B. Su, K. D. Buehring, S. Y. Huang, J. Pooladdej, D. Wolf, D. Perrachione and D. Renner: Appl. Phys. Lett. **51** (1987) 1783.
5) H. Horikawa, H. Wada, Y. Matsui, T. Yamada, Y. Ogawa and Y. Kawai: Appl. Phys. Lett. **54** (1989) 1077.
6) R. T. Huang, S. Keo, W. H. Cheng, D. Wolf, K. D. Buehring, R. Agarwal, C. L. Jiang and D. Renner: J. Appl. Phys. **71** (1992) 1061.
7) H. Wada, H. Horikawa, Y. Matsui, Y. Ogawa and Y. Kawai: Appl. Phys. Lett. **55** (1989) 723.
8) B. J. Zhang, M. B. Yi, J. F. Song, D. H. Li, D. M. Zhang and D. S. Gao: Electron. Lett. **34** (1998) 88.
9) J. P. Donnely and C. E. Hurwitz: Solid-State Electron. **21** (1978) 475.
10) C. C. Chen, J. J. Hsieh and T. A. Lind: Appl. Phys. Lett. **30** (1977) 353.
11) T. Yamamoto, K. Sakai and S. Akiba: IEEE J. Quantum Electron. **15** (1979) 684.
12) W. D. Johnston, Jr., G. Y. Epps, R. E. Nahory and M. A. Pollack: Appl. Phys. Lett. **33** (1978) 992.