High power 2-μm room-temperature continuous-wave operation of GaSb-based strained quantum-well lasers*

Xu Yun(徐 云), Wang Yong-Bin(王永宾), Zhang Yu(张 宇), Song Guo-Feng(宋国峰)†, and Chen Liang-Hui(陈良惠)

Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, *China*

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A high power GaSb-based laser diode with lasing wavelength at 2 μm was fabricated and optimized. With the optimized epitaxial laser structure, the internal loss and the threshold current density decreased and the internal quantum efficiency increased. For uncoated broad-area lasers, the threshold current density was as low as 144 A/cm^2 (72 A/cm^2 per quantum well), and the slope efficiency was 0.2 W/A. The internal loss was 11 cm^{-1} and the internal quantum efficiency was 27.1%. The maximum output power of 357 mW under continuous-wave operation at room temperature was achieved. The electrical and optical properties of the laser diode were improved.

Keywords: GaIn(As)Sb/AlGaAsSb diode lasers, threshold current density, output power

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1. Introduction

GaSb-based quantum-well (QW) strained diode lasers emitting around 2 μm have been intensively developed in recent years because they have potential applications in a wide variety of areas such as atmospheric pollution monitoring, laser surgery, and optical pump sources for solid state or fiber lasers.[1–3] A continuous-wave (CW) output power of 1.96 W from a 150-μm-wide aperture with wavelength of 2 μm was reported at 290 K.[4] A high power 2 μm diode laser with a broadened waveguide achieved a threshold current density of 115 A/cm^2 for a cavity length of 3 mm.[5] In our previous publication, we demonstrated that a 2-μm diode laser with a 8-μm-wide aperture had a continuous-wave output power of about 80 mW at room temperature.[6] However, there are still some remaining problems, including the huge threshold current density, large internal loss, and small internal differential efficiency.

In this paper, we investigate the optimized growth conditions and laser structures to improve the electrical and optical properties. The threshold current density is as low as 144 A/cm^2 (72 A/cm^2 per QW) for the optimized 2 μm laser with a 90-μm-wide output aperture. The maximum output power of 357 mW under CW operation at room temperature (RT, 300 K) is achieved for devices without coated mirrors. Varying the In concentration of the GaIn(As)Sb/AlGaAsSb QWs, three different ridge waveguide diode lasers emitting between 1.9 μm and 2.1 μm are presented.

2. Experiments

Laser heterostructures were grown by solid-source molecular beam epitaxy (MBE) on tellurium-doped GaSb substrates using a VG80-H system equipped with valved crackers for both As and Sb. The laser device structure consisted of a 300-nm-thick n-type GaSb buffer layer (1×10^{18} cm^{-3}, Te), a 1.5-μm $Al_{0.6}Ga_{0.4}As_{0.02}Sb_{0.98}$ n-type (4×10^{17} cm^{-3}, Te) cladding layer, an undoped active zone consisting of two 10-nm compressively strained QWs of $In_{0.18}Ga_{0.82}Sb$ separated by a 20-nm $Al_{0.35}Ga_{0.65}As_{0.02}Sb_{0.98}$ barrier and enclosed between two 300-nm $Al_{0.35}Ga_{0.4}As_{0.02}Sb_{0.98}$ waveguide layers and topped by a 1.5-μm p-type $Al_{0.6}Ga_{0.4}As_{0.02}Sb_{0.98}$ (5×10^{18} cm^{-3}, Be) cladding layer and a 0.3-μm p-type $Al_{0.6}Ga_{0.4}As_{0.02}Sb_{0.98}$ cap (2×10^{19} cm^{-3}, Be), as shown in Fig. 1. Compared with our previous laser structure,[6] the waveguide layer width of the optimized laser structure has been extended from 200 nm to 300 nm, and the number of QWs has been reduced to two from three. Instead of the $Ga_{0.82}In_{0.18}Sb$ QWs used for 2 μm diode lasers, $Ga_{0.84}In_{0.16}Sb$ and $Ga_{0.8}In_{0.2}As_{0.02}Sb_{0.98}$ QWs were used for the shorter and the longer wavelength devices at 1.9 μm and 2.1 μm, respectively. More details of the growth conditions have been given previously.

Ridge waveguide layers with stripe widths between 8 μm and 90 μm were fabricated, the cavity lengths of which were 800 μm and 1000 μm, respectively. Metal contacts were defined using the standard photolithography. The n-side of the wafer was thinned to a thickness of about 120 μm by a combined mechanical and chemical method. Ti–Pt–Au and AuGe(80%)–Ni(20%) contacts were evaporated as the top and the bottom contacts, respectively. The structures were

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†Corresponding author. E-mail: sgf@semi.ac.cn

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mounted epi-side down onto copper heat sinks, and the facets were kept uncoated. All measurements were taken at room temperature on a temperature-controlled heat sink.

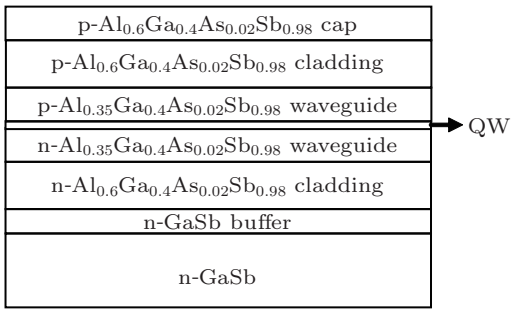


Fig. 1. Schematic diagram of the GaSb-based QW laser diode structure.

3. Results and discussion

Figure 2 shows the measured CW output powers of 2 μm diode lasers with stripe widths of 8 μm for both the optimized and the previous structures. The maximum single facet output power is increased to 109 mW at the drive current of 0.8 A. The inset illustrates the threshold current density as a function of the reciprocal cavity length for both structures. In the CW mode, the threshold current density at infinite cavity length is reduced from 2293 A/cm^2 to 350 A/cm^2 of the optimized structure (150 A/cm^2 per QW). To determine the internal loss α_i and the internal quantum efficiency η_i, we have plotted the reciprocal differential quantum efficiency $1/\eta_D$ as a function of the cavity length L. From the intercept and the slope of the straight line fitted to the data in Fig. 3, the internal loss is 11 cm^{-1} and the internal quantum efficiency is 27.1%.

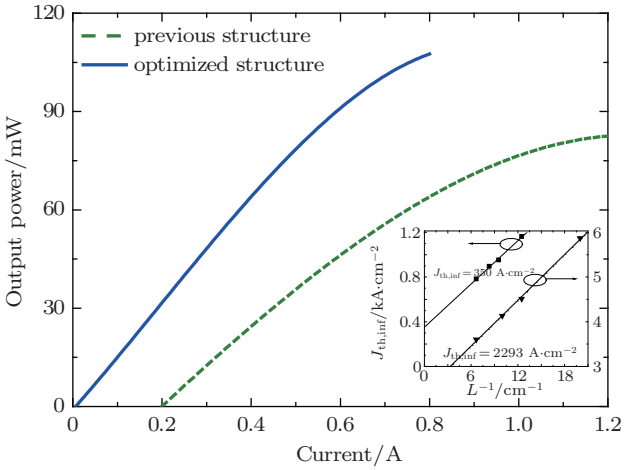


Fig. 2. (color online) CW output power characteristics measured at 300 K for both previous and optimized structures with 8 μm stripe width. Inset shows the threshold current density as a function of the reciprocal cavity length for both structures.

The improved laser properties, relative to the previously described structure,[6] are attributed to the increased waveguide width and the decreased number of QWs. The optical coupling between the active region and the laser mode increases gradually with a widening of the waveguide core.[7] Due to the reduced modal volume, the modal leakage into both the high-index GaSb substrate and the high-doping p-type cladding would decrease, so the internal loss and the threshold current density decrease correspondingly. The effect of the QW number on the performance of GaSb-based lasers has been theoretically analyzed.[8,9] Reducing the QW number decreases α_i significantly, and it is beneficial to η_i as well. For diode lasers with a cavity length of 800 μm, the optimum QW number for the lowest threshold current density is two, which is consistent with our experimental results.

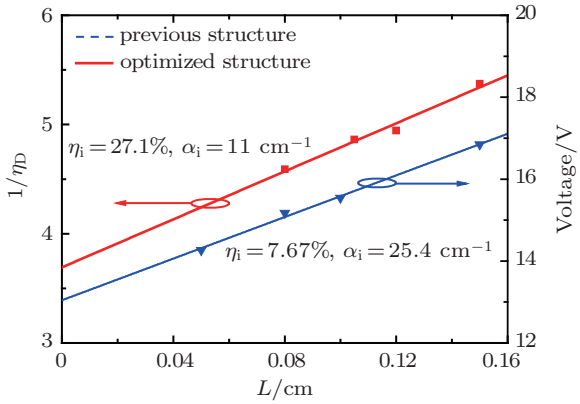


Fig. 3. (color online) The reciprocal differential quantum efficiency as a function of the cavity length for both previous and optimized structures with 8 μm stripe width.

With this optimized structure, broad-area diode lasers with a stripe width of 90 μm were examined to obtain high output power. The power versus current and the voltage versus current characteristics of 2 μm lasers under CW operation are shown in Fig. 4. The broad-area device with the optimized design exhibits a low threshold current of 130 mA, equivalent to a threshold current density of 144 A/cm^2 (72 A/cm^2 per QW), and a slope efficiency of 0.2 W/A. The maximum output power of 357 mW is limited by thermal pump saturation for a 1-mm-long, 90-μm-wide cavity with uncoated mirrors.

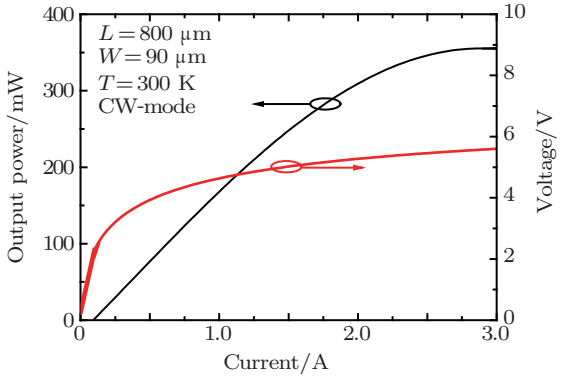


Fig. 4. (color online) CW output power characteristics measured at 300 K for the optimized structure with 90 μm stripe width.

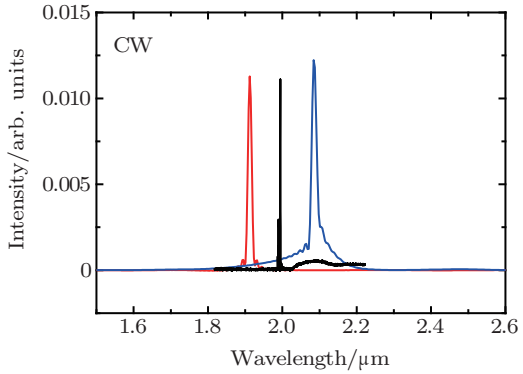


Fig. 5. (color online) Laser spectra of GaIn(As)Sb/AlGaAsSb quantum-well diode lasers emitting between 1.9 μm and 2.1 μm measured at room temperature.

Besides 2 μm lasers, lasers with two other emission wavelengths were obtained by adjusting the In concentration of the GaIn(As)Sb/AlGaAsSb QWs. The emission wavelength is proportional to the In compositional value.[10] Thus $Ga_{0.84}In_{0.16}Sb$ QWs and $Ga_{0.8}In_{0.2}As_{0.02}Sb_{0.98}$ QWs were used for devices emitting at 1.9 μm and 2.1 μm, respectively. It should be noted that As was introduced into the QWs to maintain the optimum compressive strain for the longer wavelength devices. The As level was maintained at a very low value and was not intentionally varied during the MBE growth. The composition and strain of $GaIn_{0.6}AsSb$/AlGaAsSb QWs are beneficial for GaInAsSb compounds to operate in a region outside the miscibility gap.[11,12] Figure 5 illustrates the lasing emission spectra of diode lasers emitting between 1.9 μm and 2.1 μm.

4. Conclusion

In summary, GaSb-based diode lasers with optimized growth conditions and laser structures grown by MBE have been fabricated. Varying the In concentration of the GaIn(As)Sb/AlGaAsSb QWs, three different ridge waveguide diode lasers emitting between 1.9 μm and 2.1 μm were presented. For uncoated broad-area lasers with emission wavelength at 2 μm, the threshold current density was as low as 144 A/cm^2 (72 A/cm^2 per QW), and the slope efficiency was 0.2 W/A. A maximum output power of 357 mW under CW operation at room temperature was achieved.

References

[1] Choi H K and Eglash S J 1992 *Appl. Phys. Lett.* **61** 1154
[2] Kelemen M T, Gilly J, Ahlert S, Kissel H, Biesenbach J, Rattunde M and Wagner J 2009 *Proc. SPIE* **7483** 74830C
[3] Chen J F, Kipshidze G D and Shterengas L 2010 *IEEE J. Quant. Electron.* **46** 1464
[4] Rattunde M, Schmitz J, Kaufel G, Kelemen M, Weber J and Wagner J 2006 *Appl. Phys. Lett.* **88** 081115
[5] Garbuzov D Z, Martinelli R U, Lee H, Menna R J, York P K, DiMarco L A, Harvey M G, Matarese R J, Narayan S and Connolly J C 1997 *Appl. Phys. Lett.* **70** 2931
[6] Zhang Y, Wang Y B, Xu Y Q, Xu Y, Niu Z C and Song G F 2012 *J. Semicond.* **33** 044006
[7] Botez D 1999 *Appl. Phys. Lett.* **74** 3102
[8] Rouillard Y, Angellier J, Salhi A, Grech P and Chevrier F 2005 *Proc. SPIE* **5738** 120
[9] Salhi A and Al-Muhanna A A 2009 *IEEE J. Sel. Top. Quant. Electron.* **15** 918
[10] Lin C, Grau M, Dier O and Amann M C 2004 *Appl. Phys. Lett.* **84** 5088
[11] Garbuzov D Z, Lee H, Khalfin V, Martinelli R, Connolly J C and Belenky G L 1999 *IEEE Photon. Technol. Lett.* **11** 794
[12] DeLong M C, Mowbray D J, Hogg R A, Skolnick M S, Hopkinson M, David J P R, Taylor P C, Kurtz S R and Olson J M 1993 *J. Appl.Phys.* **73** 5163