Rev. Cub. Física vol. 27 No. 1 (2010) p.42-44
ISSN: 0253-9268. Original paper

TECNOLASER
2009

Revista Cubana de Física
Calle I No. 302 e/ 15 y 17
Vedado, La Habana. CP 10400
www.fisica.uh.cu/biblioteca/revcubfi/index.htm

Single-longitudinal-mode InGaAsSb/AlGaAsSb lasers for gas sensing

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Recibido el 15/04/2009. Aprobado en versión final el 18/02/2010.

Abstract. Regrowth-free gain-coupled GaSb-based DFB lasers suitable for gas sensing were fabricated. Threshold currents for 2.4µm emission of 400µm-long DFB devices were 45mA with a total output power of nearly 11mW in CW operation at 20°C.

Resumen. Se reporta sobre la fabricación de lásers de semiconductor de retroalimentación distribuida (Distributed feedback lasers o DFB) para el monitoreo de gases. El material de los lásers fue desarrollado sobre cristales de GaSb. Se empleo un método novedoso de fabricación para lograr el acomplamiento por ganancia, lo cual elimina la necesidad de re-crecimiento epitaxial. Lásers de 400µm de longitud, que emiten a una longitud de onda de 2.4µm, presentaron una corriente de umbral de 45mA y una potencia de salida de 11mW en operación en corriente continua (CC) a una temperatura de 20°C.

Palabras clave. Semiconductor lasers, 42.55.Px, Gas sensors, 07.07.Df.

1 Introduction

Ever-increasing global concerns over such issues as pollution, health, workplace safety, and industrial process control are requiring intensified research on gas sensors. Fortunately, semiconductor lasers emitting in the 2-5µm spectral region, where many gaseous byproducts of industrial processes have strong absorption features, can be used to monitor gas emissions using tunable diode laser absorption spectroscopy (TDLAS)[1].

In the case of GaSb-based laser diodes, the development of these systems has been hindered by the complexities of epitaxial regrowth and the use of aluminum containing compounds in the cladding layers. We have circumvented this problem by employing a material-independent, regrowth-free process that could be used to fabricate gain-coupled single frequency lasers regardless of the substrate and epilayer materials[2]. This process also has the advantage that facet coatings are not needed for single mode operation.

In this work, we describe device processing and optical characterization of Sb-based tunable distributed feedback lasers (DFBs) with emission near 2.4µm.

2 Growth

The laser structures were grown on GaSb substrates by molecular beam epitaxy in a custom V90 system using conventional group-III effusion cells and valved cracker cells for As_2 and Sb_2. The laser structure consists of 2µm-thick Te- and Be-doped $Al_{0.6}Ga_{0.4}As_{0.0516}Sb_{0.9484}$ cladding layers lattice-matched to the GaSb substrate. Uniform doping of $2x10^{18}$ cm^{-3} was used throughout the n-cladding, while the p-cladding doping was carefully graded close to the waveguide to reduce optical losses. The active region contains three 94.2Å The active region contains three $In_{0.4}Ga_{0.6}As_{0.14}Sb_{0.86}$ quantum wells separated by 300Å $Al_{0.24}Ga_{0.76}As_{0.021}Sb_{0.979}$ barriers, embedded in an $Al_{0.24}Ga_{0.76}As_{0.021}Sb_{0.979}$ waveguide with a total thickness of 0.53μm. This structure was designed using the approach of Ref. [3] which uses a broader optical waveguide mode in order to reduce the fast-axis beam divergence.

3 Fabrication

Fabrication of single-mode distributed feedback lasers (DFBs) followed, in essence, the method outlined in Ref. [2] which involves the deposition of lateral metal gratings on either side of a narrow ridge waveguide to provide evanescent coupling to the optical mode. Twin-channel ridges were fabricated using inductively-coupled plasma reactive ion etching (ICP-RIE) with BCl_3/Ar chemistry. The etch process was tailored to produce waveguides with both, smooth sidewalls to reduce optical scattering losses, and slanted sidewalls, 12º from the vertical to allow for uniform resist coating across waveguides. A JEOL 6000 e-beam lithography tool with fine-pitch control was used to write a grating lift-off pattern across the ridges using ZEP resist. First-order Cr gratings with a 50% duty cycle and a thickness of 40nm were deposited using e-beam evaporation. A first sacrificial planarization step was used in conjunction with a Cl_2-O_2 etch in an ICP-RIE for removal of the Cr around the top of the ridge. This step is necessary to electrically isolate the top p-contact from the Cr grating, see Fig. 1(a). A 150nm SiO_2-PECVD layer was then deposited across the entire sample. The oxide on top of the ridges was removed by patterning windows on the ridges and etching the oxide in an RIE with CHF_3-O_2 chemistry.

Channel planarization was carried out with Polyimide, PI2562, which was baked at 240ºC under controlled temperature ramping, and cooled down to room temperature. A second layer of Polyimide was spun on the samples to improve planarization following the same temperature treatment. Polyimide was finally cured at 400ºC for 6 min in N_2 atmosphere. Surface morphology was further smoothened by spinning Futurrex planarizing coating PC3-1500 on the samples. Top of the ridges were cleared of planarizing coating and polyimide with a dry-etch in O_2 atmosphere.

Prior to top contact metallization, native oxide removal was accomplished by immersing the samples in 10 H_2O: 1 HCl for 30sec, followed by a 30sec rinse in de-ionized water. A TiPtAu p-contact stack was deposited immediately on top of the ridges. After wafer thinning, and sample encapsulation with PMMA, NiGeAu was deposited by e-beam evaporation on the backside of the samples for n-contact metallization. Samples were subsequently cleaved in bars or individual chips for electrical and optical characterization. See Fig. 1(b).

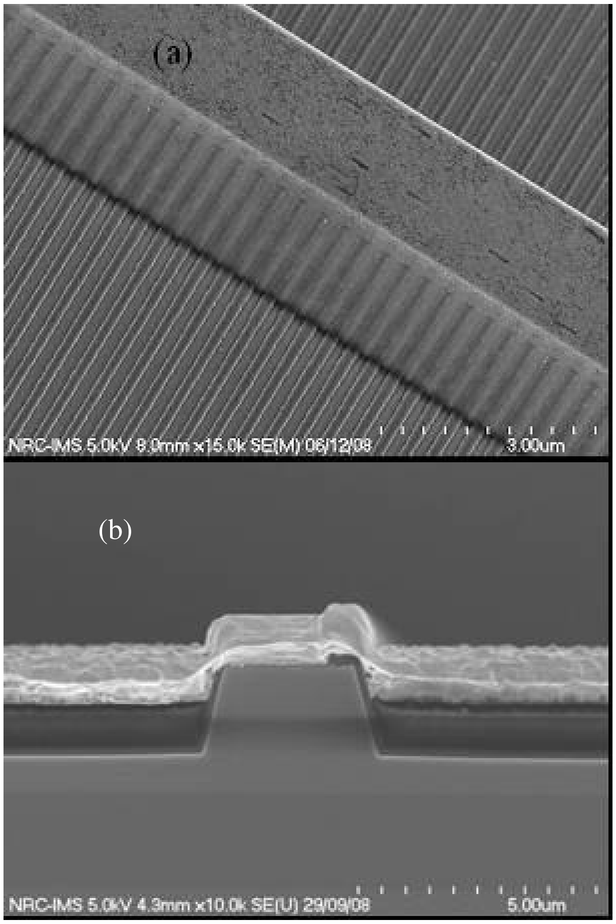

Figure 1. (a) Slanted SEM view of ridge waveguide after Cr deposition and lift-off which also shows the Cr etch around top of waveguide, (b) SEM cross-section of finished DFB laser.

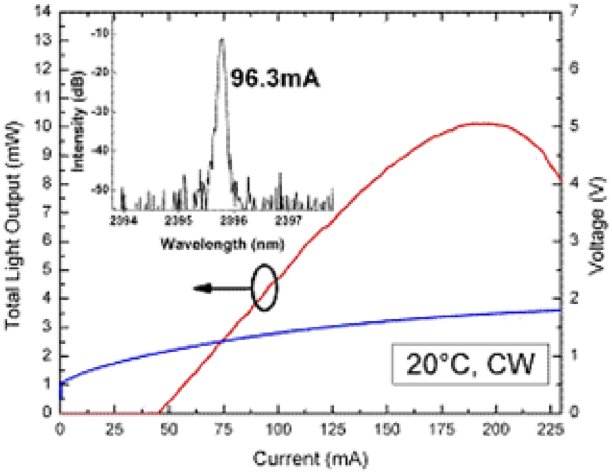

Figure 2. Output power characteristics of 4μm x 400μm DFB laser operating CW at a temperature of 20°C. Facets were not coated. Gain coupling was obtained with a 1st-order Cr grating with 50% duty cycle. Inset shows single mode emission at 2395.8nm.

The effect of lhigh reflection (HR) and anti-reflection (AR) coatings was also investigated and compared to as-cleaved (CL) facets. The HR mirror stack was set at 99% reflectivity and the AR at 0.1%.

4 Characterization

The threshold current for a 400µm-long DFB device was 45mA with a total output power of nearly 11mW in CW operation at 20°C. See Fig. 2. The emission spectra are single-mode throughout the entire range of operation, indicating a strong grating coupling, even for a rather short cavity length.

The effect of facet coatings was evident on the power output and the slope efficiency. Power output increased by 25% with an HR-CL combination, and by 50% with an HR-AR combination. Similarly, slope efficiency increased from 27mW/A for a CL-CL laser bar, to 35mW/A for an HR-CL, to 53mW/A for an HR-AR combination.

The current tuning was well-described by a second-order polynomial, and at the target wavelength of 2395.8nm the tuning was 0.062nm/mA. See Fig. 3. Adjustment of the heatsink temperature results in a tuning coefficient of 0.2nm/K. The DFB wavelength can also be readily adjusted by varying the grating pitch, Λ, e.g. the wavelength was shifted from 2396nm to 2376nm by varying Λ from 339.6nm to 336.65nm. This provides a means of monitoring many gases using lasers from a single epi-wafer by adjusting the grating pitch, operating temperature and current of individual emitters.

Conclusions

We have fabricated regrowth-free tunable DFB lasers emitting at 2.4µm on GaSb-based material. Threshold currents of 400µm-long DFB devices were around 45mA with a total output power of nearly 11mW in CW operation at 20°C. We can envision using these lasers in portable gas detectors, as well as, in line-of-sight gas sensing applications.

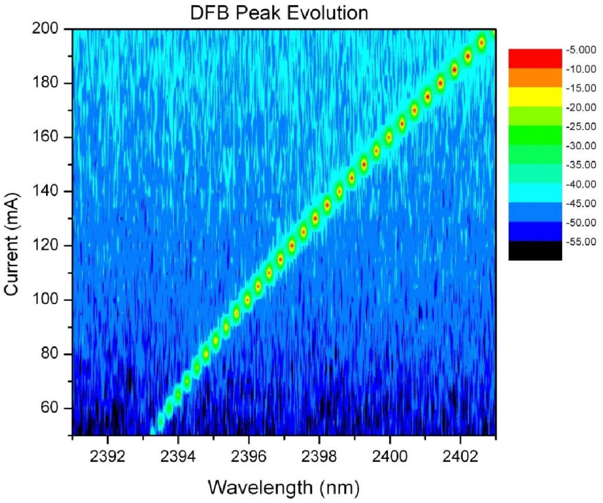

Figure 3. Single-mode tuning with applied injection current

Acknowledgments

The authors would like to thank Phillip Chow-Chong, Hue-Tran, and Mark Malloy for their assistance with laser processing.

References

1. Y.K. Sin, R.N. Bicknell-Tassius, R.E. Muller, S. Forouhar, “Fabrication of laterally coupled InGaAsSb-GaSb-AlGaAsSb DFB laser structures,” in International Conference On Environmental Systems, 00ICES-141, (society of automotive engineers) , Toulouse, France, July 2000

2. M. Kamp, J. Hofmann, F. Schäfer, M. Reinhard, M. Fischer, T. Bleuel, J.P. Reithmaier and A. Forchel, “Lateral coupling – a material independet way to complex coupled DFB lasers,” *Opt. Mater.* **17**, 19 (2001).

3. M. Rattunde, J. Schmitz, G. Kaufel, M. Kelemen, J. Weber and J. Wagner, “GaSb-based 2.X µm quantum-well diode lasers with low beam divergence and high output power,” Appl. Phys. Lett. 88, 081115 (2006).