Published in Electronics Letters 31, issue 12, 980-982, 1995
which should be used for any reference to this work

Ridge waveguide DBR laser with nonabsorbing grating and transparent integrated waveguide

D. Hofstetter, H.P. Zappe and J.E. Epler

Indexing terms: Distributed Bragg reflector lasers, Semiconductor quantum wells

A ridge waveguide GaAs/AlGaAs DBR laser with a nonabsorbing grating section and a monolithically integrated transparent waveguide has been fabricated by the use of vacancy-enhanced quantum well disordering (VED). This technique allows the definition of absorbing and transparent regions, and requires only a single growth step. No VED-enhanced degradation of the laser quality was noted. The optical output power was 5 mW from both the cleaved facet and the grating reflector, threshold currents were 25 mA and the slope efficiencies were 0.2W/A.

Introduction: Monolithic photonic integrated circuits (PICs) often require coherent light sources without cleaved laser facets. Distributed Bragg reflector (DBR) lasers are ideally suited to this application. Furthermore, a method is needed to produce absorbing and nonabsorbing regions on the same substrate without degrading laser performance. Pumped laser sections and photodetectors need to absorb at the operating wavelength, whereas the waveguides and the grating section of the DBR laser must be transparent. DBR lasers with a transparent grating section fabricated by vacancy-enhanced disordering (VED) [1] and DBR lasers evanescently coupled with a transparent waveguide [2] have been reported. The first of these approaches demonstrated that the VED process can shift the energy bandgap, albeit at the cost of a very high laser threshold current, whereas the latter required extended regrowth technology.

In this Letter, we demonstrate the use of the VED process to fabricate a low threshold DBR laser with a nonabsorbing grating section, monolithically integrated with a 700μm long transparent waveguide. The device demonstrates the utility of postgrowth processing for achieving spatially-defined transparency in a PIC. VED selectively alters the shape of the quantum well (QW) in the active region, using lift-off patterned SrF_2 and SiO_2 surface dielectrics to define the transparent and absorbing regions and a high temperature rapid thermal anneal to accomplish disordering [3].

Device fabrication: An MOVPE layer structure grown on an *n*-type, Si-doped, ($10^{18}cm^{-3}$) GaAs substrate was used to fabricate the device. An undoped 165nm thick $Al_{0.3}Ga_{0.7}As$ core containing a single 7nm wide GaAs quantum well was grown between a 1.1μm thick $Al_{0.8}Ga_{0.2}As$ lower cladding layer (*n*-doped $1.5 \times 10^{18}cm^{-3}$ Si) and a 0.8μm thick $Al_{0.8}Ga_{0.2}As$ upper cladding layer (*p*-doped $10^{18}cm^{-3}$ Mg). The upper cladding was covered with a 100 nm thick highly *p*-doped ($8 \times 10^{18}cm^{-3}$Zn) GaAs cap layer. The VED process started with a 200 nm thick e-beam evaporated SiO_2 layer, patterned by standard photolithography and reactive ion etching (RIE) in a CF_4 plasma. Using a selfaligned process, a 250nm thick SrF_2 layer was subsequently evaporated, and removed from the underlying SiO_2 by liftoff. The final wafer surface was nearly planar and completely covered with either SiO_2 or SrF_2. The selective bandgap-shift was then accomplished using a rapid thermal anneal in an N_2 ambient at 960°C for 24s.

During thermal annealing, the group-III vacancies generated under the SiO_2-capped regions diffuse through the upper cladding into the waveguide core. These vacancies promote intermixing of the Ga in the GaAs QW and the Al of the adjacent $Al_{0.3}Ga_{0.7}As$ waveguide core, increasing the effective Al content of the QW.

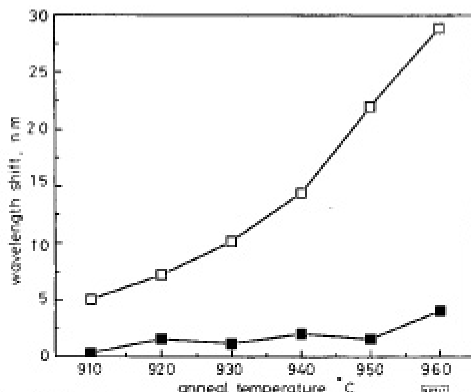

Fig. 1 *Photoluminescence wavelength shift of SiO_2-capped and SrF_2-capped material after 30s rapid thermal anneal at various temperatures*

—□— SiO_2 cap
—■— SrF_2 cap

The resulting larger bandgap blue-shifts the photoluminescence (PL) spectrum and thus the lasing wavelength. SrF_2, on the other hand, suppresses the generation of these group-III vacancies and no blue shift occurs during thermal annealing. As seen in Fig. 1, the amount of blue shift under the SiO_2 cap can be varied between 5 and 28nm with the anneal temperature, while on the same wafer under the same anneal conditions, the blue shift under the SrF_2 cap is only 1 – 5nm. The anneal time is held constant at 30s in both cases. During RTA, a GaAs proximity cap prevents surface damage of the sample due to As outdiffusion [4].

After RTA, SrF_2 and SiO_2 were removed with diluted HCl (HCl/H_2O 1:9, 20s) and by RIE in CF_4, respectively. Lasers were then fabricated by dry etching ridge waveguides, deposition of 250nm Si_3N_4 as an electrical isolation layer and Ti/Pt/Au *p*-contact metallisation. The holographically-defined third-order grating (Λ = 380nm) was fabricated in a grating recess as described in [5]. DBR lasers with ridge widths of 2,3 and 4μm, a constant pumped length of 500μm and six different grating section lengths (50 to 150μm) were made and comparatively characterised. The lasers and gratings were integrated with a 700μm long transparent waveguide.

Results: As seen in Fig. 2, DBR laser threshold currents were typically 25mA on devices witha 4μm stripe width and a 500μm pumped length, corresponding to a threshold current density of $1.25kA/cm^2$. The ripples in the L-I curve for optical output from the cleaved facet are reproducible and without hysteresis when increasing and decreasing the injection current. They indicate that the laser has to optimise its internal stored energy under changing phase conditions due to carrier and temperature induced refractive index changes. The ripples in the L-I curve were less pronounced for emission from the grating side of the laser than from the cleaved facet. We believe that this results from a trade-off between the grating transmission and the internal laser stored energy. A decrease in grating reflectivity induces a simultaneous decrease of the internal power and since the output power is the product of internal power and mirror transmission, nearly constant laser output power is expected.

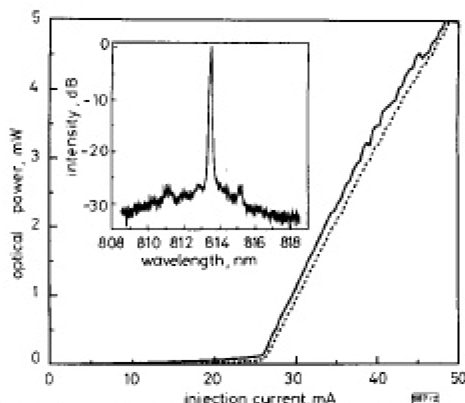

Fig. 2 *L-I curves of emission from the cleaved facet and the grating plus the transparent waveguide*

——— P_{opt} (cleaved facet)
- - - - P_{opt}' (grating side facet)
Inset: optical spectrum

The optical output power was 5mW from both the cleaved facet and the grating side of the DBR laser at $I = 2I_{th}$ and the slope efficiencies were 0.21W/A at the cleaved facet and 0.19W/A at the grating. This balance is due to the low grating reflectivity (< 30%) and the transparency of the waveguide. The optical emission spectrum, shown in the inset of Fig. 2, shows a primary emission peak at λ = 814nm and an SMSR of 25dB. No mode hops were seen as the temperature was varied from 7 to 25°C; the temperature tuning coefficient was 0.05nm/°C.

A comparison of Fabry-Perot lasers fabricated from the annealed but unshifted (SrF_2 capped) and as-grown (unannealed) material provided a further demonstration that high-quality lasers can be fabricated using VED. The former devices operated with a threshold current of 14mA (J_{th} = 700A/cm²), slope efficiency of 0.36W/A per facet at an emission wavelength of λ = 825nm with *SMSR* = 20dB. In as-grown material, the same laser structures yielded a threshold current of 12mA (J_{th} = 600A/cm²) and a slope efficiency of 0.52W/A per facet at an emission wavelength of λ = 827nm with *SMSR* = 20dB, demonstrating that devices produced in high temperature annealed material are of comparable quality to those produced in as-grown material. In contrast to results published in [6], we could not see any dopant diffusion or a drift of the *pn*-junction by inspecting the stained facet in the scanning electron microscope. These data also helped to explain the somewhat high threshold current density of the DBR lasers, owing to the mismatch between the Bragg peak of the grating (814nm) and the laser gain peak (825nm).

Conclusions: Low threshold DBR lasers monolithically integrated with a transparent waveguide have been fabricated using selective vacancy-enhanced disordering. The performance of the laser was not adversely affected by the high temperature anneal required for VED, demonstrating the utility of this process for PIC fabrication.

Acknowledgments: The authors are grateful to M. Moser and H.P. Schweizer for crystal growth, P. Riel, A. Vonlanthen and D. Jeggle for processing assistance, J. Söchtig for helpful discussions and H.W. Lehmann, M.T. Gale and R. Dändliker (IMT, University of Neuchâtel) for their generous support.

D. Hofstetter, H.P. Zappe and J.E. Epler (*Paul Scherrer Institut Zürich, Badenerstrasse 569, CH-8048 Zürich, Switzerland*)

References

1 AYLING, S.G., BEAUVAIS, J., and MARSH, J.H.: 'A DBR laser using dielectric cap disordering and strontium fluoride masking', *Proc. ECIO*, 1993, **1993**, pp. 7-10–7-11

2 DERI, R.J., DOLDISSEN, W., HAWKINS, R.J., BHAT, R., SOOLE, J.B.D., SCHIAVONE, L.M., SETO, M., ANDREADAKIS, N., SILBERBERG, Y., and KOZA, M.A.: 'Efficient vertical coupling of photodiodes to InGaAsP rib waveguides', *Appl. Phys. Lett.*, 1991, **71**, pp. 2749–2751

3 BEAUVAIS, J., MARSH, J.H., KEAN, A.H., BRYCE, A.C., and BUTTON, C.: 'Suppression of bandgap shifts in GaAs/AlGaAs quantum wells using strontium fluoride caps', *Electron. Lett.*, 1992, **28**, pp. 1670–1672

4 GUIDO, L.J., HOLONYAK, N., HSIEH, K.C., KALISKI, R.W., PLANO, W.E., BURNHAM, R.D., THORNTON, R.L., EPLER, J.E., and PAOLI, T.L.: 'Effects of dielectric encapsulation and As overpressure on Al-Ga interdiffusion in $Al_xGa_{1-x}As$/GaAs quantum well heterostructures', *J. Appl. Phys.*, 1987, **61**, pp. 1372–1379

5 HOFSTETTER, D., ZAPPE, H.P., EPLER, J.E., and SÖCHTIG, J.: 'Single-growth-step GaAs/AlGaAs distributed Bragg-reflector lasers with holographically-defined recessed gratings', *Electron. Lett.*, 1994, **30**, pp. 1858–1859

6 AYLING, S.G., BRYCE, A.C., GONTIJO, I., MARSH, J.H., and ROBERTS, J.S.: 'A comparison of carbon and zinc doping in GaAs/AlGaAs lasers band-gap tuned by impurity-free vacancy disordering', *Semicond. Sci. Technol.*, 1994, **9**, pp. 2149–2151