HOMOGENEOUS BURIED RIDGE STRIPE SEMICONDUCTOR OPTICAL AMPLIFIER WITH NEAR POLARIZATION INDEPENDENCE

C. Deguet[(1)], D. Delprat[(1)], G. Crouzel[(1)], N.J. Traynor[(1)], P. Maigné[(1)], T.Pearsall[(1)], C. Lerminiaux[(1)], N. Andreakis[(2)], C. Caneau[(2)], F. Favire[(2)], R. Bhat[(2)], and C.E.Zah[(2)].

[(1)] Corning S.A., Centre Européen de Recherche de Fontainebleau, 7bis, Avenue de Valvins, 77210 Avon, France.
(traynorn@cerf.corning.com).
[(2)] Corning Incorporated, Science and Technology, Sullivan Park, Corning, NY, 14831-0001.

Abstract: We have developed a 1.55 μm semiconductor optical amplifier with high gain, low polarisation dependence and low gain ripple using simple and non-critical fabrication techniques. This device lends itself well to integration in photonic devices without the need for precise fabrication control.

Introduction

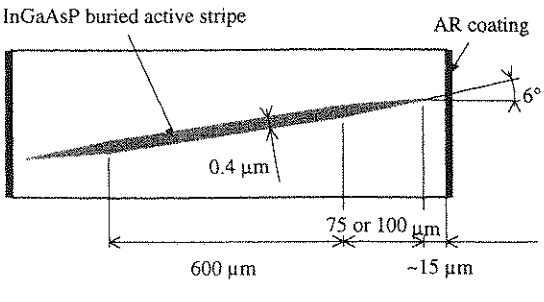
As optical networks grow in size and complexity, the need for high functionality photonic integrated circuits (PIC) will grow accordingly. Consequently there is intense interest in technologies that will enable fabrication of such PICs. Semiconductor optical amplifiers (SOA) are emerging as a key technology in this area.

Realization of SOA devices has been achieved using both bulk and multiple quantum well structures. Devices based on MQW material have shown impressive performance with high gain, high saturation output power and low noise figures /1,2/. From a practical point of view, however, there are drawbacks to these devices – achievement of polarization insensitivity requires very precise fabrication control which may have implications in production of high-yield, low-cost devices that can be incorporated into PICs. In this paper we show that it is possible to achieve state of the art performance in a bulk square waveguide structure which employs uncritical fabrication technology, and has excellent potential for monolithic integration into active and passive waveguide devices.

Device structure

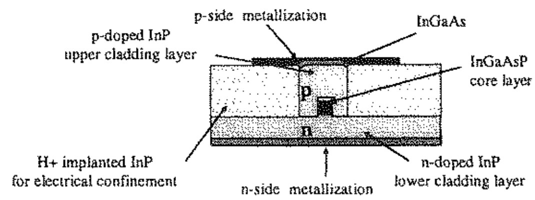
The layers for the SOA device were grown by MOCVD on a (001) oriented n-doped InP substrate. The InGaAsP active region was patterned to a width of 1.5 μm using

Figure 1 : Top view of the active waveguide section employing tapered and tilted waveguides in a buried window structure



optical photolithography, and 0.4 μm square waveguides were formed using controlled undercut during the wet etching process. The design we use incorporates tilted and tapered waveguides in a buried InP window structure /2,3/, which is shown in Figure 1. After formation waveguides are overgrown with p-doped InP followed by a p-doped InGaAs contact layer. The waveguides are electrically confined using proton implantation, after which they are contacted and separated for testing. A cross-section of the finished device is shown schematically in Figure 2.

Figure 2 : Cross-section of the finished device structure



The presence of the taper allows us to increase the output mode size of the SOA and reduce the far-field divergence, thus increasing the coupling efficiency to external optics /3/. The mode, being strongly confined in the active waveguide section (confinement factor, Γ=0.45), experiences less confinement in the tapered section and expands accordingly. For our devices the mode field diameter increases from 0.8 μm in the square waveguide to 2.4 μm at the facet. With this structure we achieve a fiber coupling loss of 3 dB.

Referring to figure 1, it can be seen that the active waveguide is tilted 6° away from the [001] direction. This, together with the antireflection coating and buried window structure, serves to minimize Fabry-Perot effects in the cavity. From gain ripple measurements we estimate an overall residual cavity reflectivity of 5.10^{-5}.

Device performance

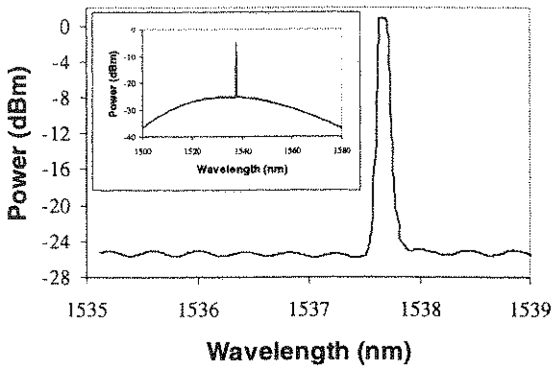
The parameters of the device performance are summarized in Table 1 :

Table 1 : Summary of performance characteristics of the SOA device

Internal Gain (dB)	31
Coupling Loss (dB)	3
Fiber to fiber gain (dB)	25
Polarization sensitivity (dB)	0.12
Driving current (mA)	130
3 dB gain bandwidth (nm)	38
Saturation output power (dBm)	8
Gain ripple (dB)	0.5
Internal (F to F) noise figure (dB)	5.8 (8.8)

Gain measurements were made from fiber to fiber using a dual input power meter. The coupling loss was estimated by measuring the output power from the SOA on a large area photodiode directly after the device and subsequently after optimum coupling into a SELFOC lensed fiber. Figure 3 shows the output spectrum obtained from the SOA with a – 20 dBm input signal at 1537.7 nm; the inset figure shows the broad-band output spectrum of the device.

Figure 3 : Output spectrum from the SOA with an input power of – 20 dBm, showing 0.5 dB gain ripple and (inset) the broadband output spectrum.



The magnitude of the oscillation on the ASE spectrum gives a direct measurement of the gain ripple, which we estimate to be 0.5 ± 0.1 from figure 3. The 3 dB gain bandwidth (Figure 3, inset) is 38 nm. To estimate the noise figure of the amplifier we use the standard noise formula:

$$NF = \frac{N_{out} - N_{in}.G}{h\upsilon B_w G} + \frac{1}{G}$$

where $N_{out,in}$ are the output and input noise levels respectively, G is the amplifier gain, ν is the optical frequency and B_w is the resolution bandwidth of the optical spectrum analyzer. From this formula we estimate an intrinsic noise figure for our device of 5.8 ± 0.3 dB, and taking into account the coupling loss we obtain a user noise figure /4/ of 8.8 ± 0.3 dB. This represents an impressive intrinsic noise figure for a bulk device. Indeed it is close to the performance obtained by SOAs employing MQWs /1,2/ which have intrinsically lower noise figures because their quantised density of states allows more complete population inversion. We believe that the user noise figure can be improved significantly by employing optimum coupling optics.

The polarization sensitivity (defined as the difference in gain between TE and TM modes) of 0.12 dB for this device is exceptionally low, significantly lower than for any SOA device reported to date. The gain of our device is comparable to the best performance reported to date, but we achieve this at a significantly lower driving current.

Conclusions

In summary, we have fabricated SOAs using simple and uncritical growth and photolithography techniques to produce an SOA with an overall performance comparable to current state of the art devices. In particular our device achieves exceptionally good polarization insensitivity which is critical for implementation in photonic integration. We see this device as an ideal building block for applications such as wavelength conversion, all-optical regeneration and ultra-fast switching devices.

References

/1/ L.F. Tiemeijer, P.J.A. Thijs, T. van Dongen, J.J.M. Binsma and E.J. Jansen, IEEE Photon. Technol. Lett., vol. 8, pp. 873-873, July 1996.

/2/ A.E. Kelly, I.F. Lealman, L.J. Rivers, S.D. Perrin and M. Silver, Electron. Lett., vol. 33, pp. 536-538, March 1997.

/3/ P. Doussiere, P. Garbedian, C. Graver, D. Bonnevie, T.Fillon, E. Derouin, M. Monnot, J.G Provost, D. Leclerc and M. Klenk, IEEE Photon. Technol. Lett., vol. 6, pp. 170-172, February 1994.

/4/ J-C. Simon, P. Doussiere, L. Pophillat and B. Fernier, Electron. Lett., vol. 25, pp. 434-436, March 1989.