Extended Abstracts of the 22nd (1990 International) Conference on Solid State Devices and Materials, Sendai, 1990, pp. 773-776

S-B-4

Invited

Photonic Integrated Circuits for Telecommunication —Present Status and Future Trends—

U. Koren, T.L. Koch

AT&T Bell Laboratories

Holmdel N.J. 07733 U.S.A

We describe recent progress in photonic integrated circuits which employ passive waveguide interconnects between optical devices integrated on a single InP substrate. We describe some applications where lasers and optical amplifiers are integrated and also devices designed for multi-channel and coherent telecommunications systems.

Photonic integrated circuits (PIC's) are a subset of OEIC's where several optical devices are integrated on a single semiconductor chip, with passive waveguides interconnecting these devices on the same chip. Modern PIC's will have the waveguide directional coupling capabilities of classical integrated optics plus the additional capabilities of using active devices such as lasers,optical amplifiers and detectors. One *reason D'etre* for PIC's is the substantial cost reduction for complex optical systems once mechanical optical alignments are eliminated due to on-chip integration.

For optical switching applications, integration of optical switches with passive waveguides on InP substrates has been demonstrated [1] and recently, the integration of an optical amplifier within the switch element was reported [1-3]. Laser based elements such as tunable DBR lasers [4-5] and lasers-modulators [6,7] can be considered as PIC's since the issue of coupling between active and passive waveguides is of critical importance for these devices [8,9]. Previously [9], we have described a process where the epitaxial growth steps for a regular lasers are used for PIC devices containing active and passive waveguides. This approach was based on growing a base wafer which contains the passive and active layers followed by selectively etching away the active layers in the passive waveguide sections. Using this method for active-passive coupling, high coupling efficiency, and very low back reflections are possible. To demonstrate, Fig.1. shows the longitudinal cross section of an integrated DBR laser-amplifier PIC operating at 1.3 micron wavelength [10].

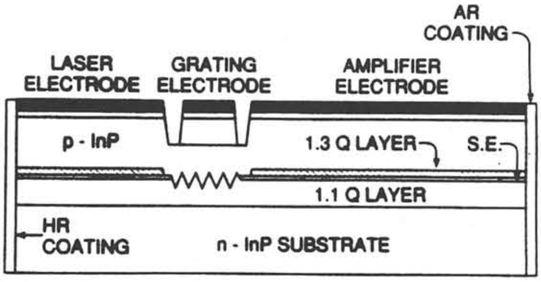

Fig.1 Schematic structure of an integrated laser amplifier

The measured differential current transfer efficiency (photocurrent increase at the amplifier at zero bias per increase of input laser current) was as high as 33% , and the laser light-current slope efficiency was higher than 2 mW/ma. These results demonstrate the high component and coupling efficiencies that can be obtained with this technique. The amplifier section in this device can be used for digital switching [11] , or as a booster for an already modulated laser signal.

Wavelength division multiplexing (WDM) is one application where PIC's can play an important role. Fig.2. shows a WDM transmitter PIC which combines four lasers with 30Å wavelength spacings into a single waveguide. The output is then fed into an optical amplifier which acts as a power booster compensating for some of the combiner and coupling losses. Fig. 3. shows the spectrum of the transmitted signal using this PIC at 2Gbit/sec/channel. At a total capacity of 8 Gbit/sec over 36 km of optical fiber a small (< 2 dB) penalty for cross talk in receiver sensitivity was measured [12].

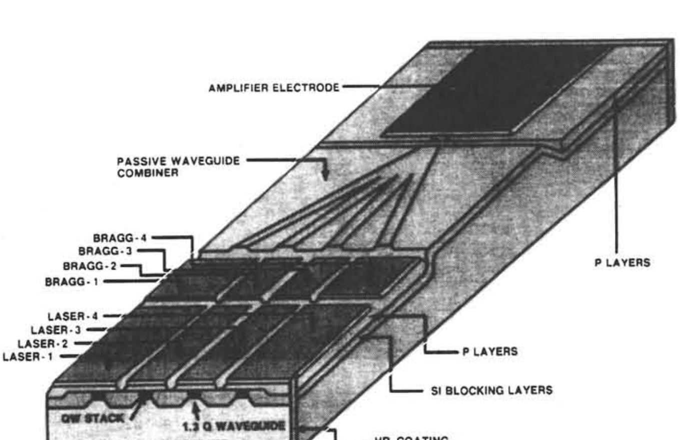

Fig.2. A four channel WDM transmitter

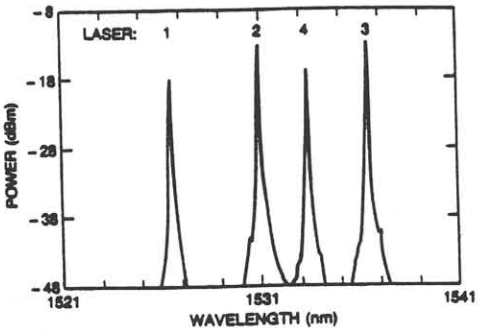

Fig.3. .Spectrum of the modulated signal

In this PIC the loss-gain product is only about 0.3, meaning that the combiner loss is not entirely compensated by the amplifier gain. Under these conditions, the back reflections are small enough so that the linewidth of the lasers does not change as the optical amplifier is operated.

PIC's can also be very useful for coherent communications [13,14]. Fig. 4. shows a schematic description of a balanced receiver PIC with a MQW tunable DBR laser used as a local oscillator. The two balanced waveguide detectors employ the same MQW active region as the laser for the absorption layers. The passive waveguides are entirely buried rib, using a stop etch layer to define the rib size. The 3 dB coupler is a zero gap directional coupler optical switch with current injection to the two sides of the coupling region. The estimated excess noise due to coupling,bending and propagation loss was as low as 4.2 dB for this PIC.

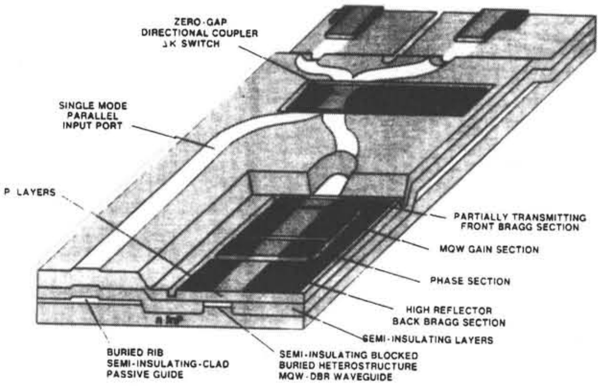

Fig.4. Heterodyne balanced receiver

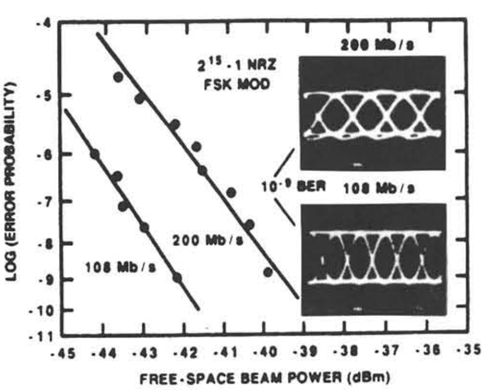

Fig. 5. Receiver characteristics.

The receiver bit error rate (BER) as a function of input power as well as the eye diagrams at 10^{-9} BER at 108 and 200 Mbit/sec are shown in Fig.5. The receiver sensitivities are -42.3 and -39.8 dBm at these bit rates respectively.These results represent the highest sensitivities reported for any OEIC receiver. Projection of these results with improved coupling into the chip and improved RF amplification scheme shows that receiver sensitivities within 8 dB of the quantum shot noise limit for the in-fiber optical power are feasible

In conclusion, we describe the technology used for fabrication of photonic integrated circuits for telecommunications and demonstrate some applications in multi-channel transmission and in coherent communication systems.

REFERENCES

1. H.Inoue, T. Kirihara, Y.Sasaki, K. Ishida. OSA Integrated Photonic Research conf. Paper ME5, Hilton Head, South Carolina (1990).

2. D.A.H. Mace, M.J. Adams, J. Singh, M.A. Fisher, I,D. Henning, W.J. Duncan. Electronics Lett. 25,987 (1989).

3. S. Oku, K.Yoshino, M. Ikeda,M.Okamoto,T. Kawakami. Photonic Switching Conf. Paper 13C-17, Kobe Japan (1990).

4. S. Murata,I. Mito, K. Kobayashi, Electronics Lett. 23, 325, (1987).

5. T.L.Koch, U. Koren, R.P. Gnall,C.A. Burrus, B.I. Miller, Electronics Lett. 24, 1431, (1988).

6. H. Soda, M. Furutsu, K. Sato, M. Matsuda, H. Ishikawa, Electronics Lett. 25 334, (1989).

7. M. Suzuki, H, Tanaka, M. Usami, H. Taga, Y. Matsushima. IOOC Conf. Paper 20PDB-3. Kobe Japan, (1989).

8. H. Takeuchi, K. Kasaya, K. Oe, IOOC Conf. Paper 20B1-8, Kobe Japan,(1989).

9. U. Koren, T.L. Koch, B.I. Miller, A. Shahar, IGWO Conf. Paper MDD2 Houston Texas, (1989).

10. U. Koren, M. Oron, M.G. Young, G. Raybon, T.L. Koch, B.I. Miller. CLEO Conf. Paper CThE5, Anaheim California, (1990).

11. G. Eisenstein, U. Koren, T.L. Koch, G. Raybon. R.S. Tucker, B.I. Miller, IOOC Conf. Paper 19C2-3, Kobe, Japan , (1989).

12. A.H. Gnauck, U.Koren, T.L. Koch, F.S. Choa, G. Raybon, C.A. Burrus, G. Eisenstein. OFC Conf. Paper PD-26, San-Fransisco California, (1990).

13. H. Takeuchi, K. Kasaya, Y. Kondo, H. Yasaka, K. Oe, Y. Imamura, IEEE Photonic Tech Lett., 398, (1989).

14. T.L. Koch, F.S.Choa, U. Koren, R.P.Gnall, F. Hernandez-Gil, C.A. Burrus, M.G. Young, M.Oron,B.I. Miller. OSA Integrated Photonic Research Conf. Paper PD5, Hilton Head, South Carolina,(1990).