Extended Abstracts of the 22nd (1990 International) Conference on Solid State Devices and Materials, Sendai, 1990, pp. 777-780 **S-B-5**

Invited

Monolithic Integrated Coherent Receivers

Kunishige OE

NTT Optoelectronics Laboratories
3-1, Morinosato Wakamiya, Atsugi-shi,
Kanagawa, 243-01, Japan

Monolithic integrated coherent receivers which incorporate a local oscillating laser, a 3 dB coupler, and pin photodetectors on a small single chip have been realized by the recent progress in the various technologies involved. The structure, current status and future prospects of the receiver are described.

1. Introduction

Recently there has been considerable interest in the monolithic integration of semiconductor optoelectronic devices including waveguides on a small single chip. The advantages of integrating optoelectronic devices have been recognized for a long time, but it has been difficult to demonstrate the merits of the integrated optical circuits in the past because of the immaturity of the technologies involved. Recent progress in crystal growth, single-mode waveguide and coupling techniques enable the development of monolithic integrated optical circuits with a clear demonstration of their functions. So far, many kinds of integrated optical circuits in various areas have been reported. The monolithic integrated coherent receiver, which includes a local oscillating (LO) laser, a 3 dB waveguide directional coupler, and pin photodetectors, has been one of the milestones of integrated optical circuits because the three different devices on the chip produce a clear function; optical heterodyne detection. The receiver has been successfully fabricated and operated without an optical isolator [1,2].

In this paper, the structure, current status, and future prospects of the integrated coherent receiver are described.

2. Structure and Fabrication Process

Figure 1 shows a photograph of the monolithic integrated coherent receiver we have fabricated. The size is small; 0.25 mm x 4.15 mm. It includes a wavelength-tunable multielectrode DFB laser as the LO laser, a 3 dB coupler for the mixing of light, and pin photodiodes for detection. Signal light is coupled into the integrated waveguide and led into the coupler along an S-bend waveguide. In the coupler, the signal light and the light from the LO laser are mixed and delivered equally to the two pin photodetectors. By controlling the wavelength of the LO laser, the signal can be detected as a beat signal with a intermediate frequency at the pin photodetectors.

The multielectrode DFB laser, invented

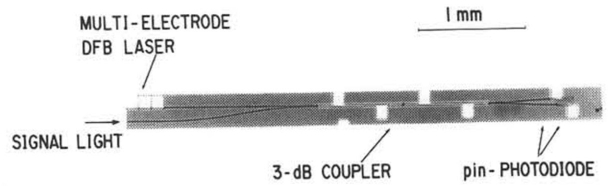

Fig. 1. The monolithic integrated coherent receiver

by NTT [3], is adopted as the LO laser, because it enables wavelength-tuning while keeping narrow spectral linewidth and has a simple structure.

Miniature strip-loaded single-mode waveguides with strong optical confinement[4] are used as waveguides and directional couplers in this integrated optical circuit.

The procedure used to fabricate the integrated device is shown in Fig. 2. It is basically a three-step MOVPE growth. First three undoped InGaAsP layers and an undoped InP layer are grown on an n-type InP substrate. Then the undoped InP layer is etched off except for the photodetector regions, and a first-order corrugation is formed in the DFB laser regions. All the grown layers are etched away, except in the laser and photodiode regions. After this, an undoped InGaAsP guiding layer and an InP layer are grown. In the third growth, p-InP and p+-InGaAsP cap layers are grown over the

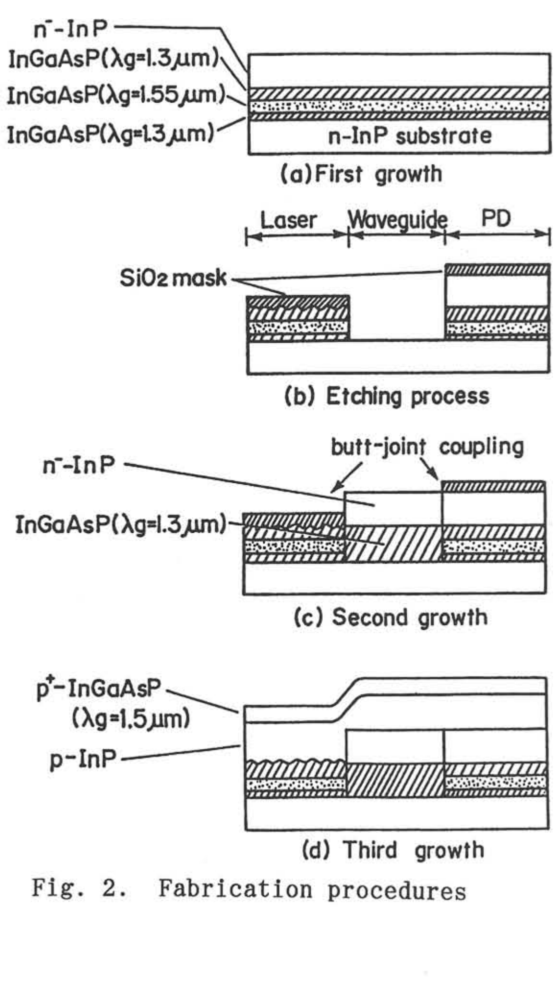

Fig. 2. Fabrication procedures

wafer. Butt-joint coupling using selective epitaxy is adopted to connect the devices because theoretically it appears to be the best method. A maximum coupling efficiency of 90 % is obtained using this technique [5]. A low preassure MOVPE enables us to obtain high quality selectively regrown layers. The salient point in this procedure is that the InGaAsP layer, which acts as the guiding layer in the laser portion, prevents hole trapping at the heterojunction interface in the photodiode portion. After growth is completed, a strip-loaded structure is fabricated to produce lateral optical confinement. Electrical isolation between the laser and the coupler, and between the coupler and the photodetectors is achieved by etching grooves down to the undoped InP layer.

3. Device Characteristics

The relation of the photocurrents of the two photodetectors at zero bias voltage on the injection current to the LO laser is shown in Fig. 3. It can be seen that the threshold current of the multielectrode DFB laser with strip-loaded structure is 55 mA. The photocurrents of the two detectors are nearly equal to each other at any injection current to the LO laser. This proves that the waveguide directional coupler works as a 3 dB coupler as designed without any bias adjustment to the coupler electrodes. The photocurrents are nearly 1 mA when the injection current to the LO laser is 100 mA. The photocurrents generated by the light coupled into the receiver from another DFB laser are 30 - 75 μA. These values are consistent with the estimation that the quantum efficiency of the photodetector is 100 %.

The 3 dB down bandwidth of the detector was 2.2 GHz at zero voltage and 2.6 GHz at

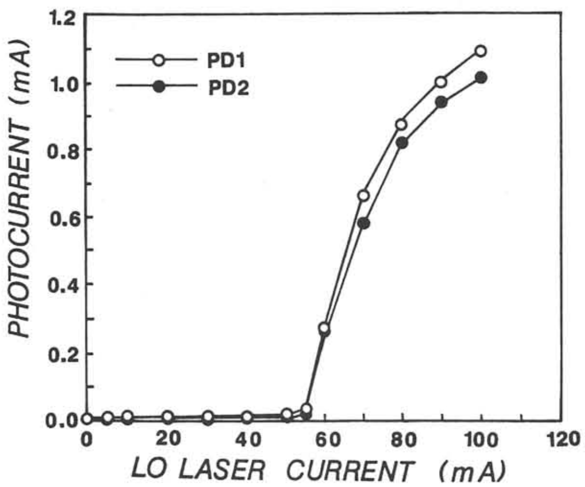

Fig. 3. Photocurrents of the two photodetectors at zero bias voltage versus injection current to the LO laser.

-2 V reverse voltage. These values are fairly high and reflect the effect of inserting the InGaAsP transition layer. The bandwidth limitation comes from parasitic capacitance of the pad electrodes on the n-type substrate.

In monolithic integrated optical circuits, an optical isolator cannot be included. It is thus extremely important to suppress reflected light effect at the coupling portion through efficient optical coupling. Figure 4 shows the integrated LO laser linewidth dependence on the lasing wavelength. If some reflection of the LO laser occures at the waveguide/ detector joint portion, periodic variation of the linewidth with every 0.9 A is expected. However the linewidth stays constant in the range of experimental accuracy. This shows that the light reflection at the jointed portion is negligibly small in our integrated coherent receiver.

The performance of the monolithic integrated coherent receiver was examined by optical heterodyne detection. The wavelength of the integrated LO laser is controlled with respect to that of the coupled signal light to keep the frequency separation of the two lasers constant by electrical feedback. FM sidebands are observed at 500 MHz apart from the main beat spectrum when the frequency of the signal light is modulated at 500 MHz. This is a clear demonstration of successful optical heterodyne detection using the integrated coherent receiver.

4. Future Prospects

Application of this device seems to be quite favorable based on successful initial results. At present, however, this receiver is based on an n-type substrate and has three disadvantages. One is that two photodetectors cannot be implemented in a balanced mixer configuration. Also, receiver signal reception will not be possible in the gigabit regime due to the parasitic capacitance of the photodetectors on the n-type substrates. The third disadvantage is that propagation loss of the waveguide on an n-type substrate is much higher than that on a semi-insulating substrate. Thus Figure 5 shows the configuration we are really aiming for; a device that integrates the components on a

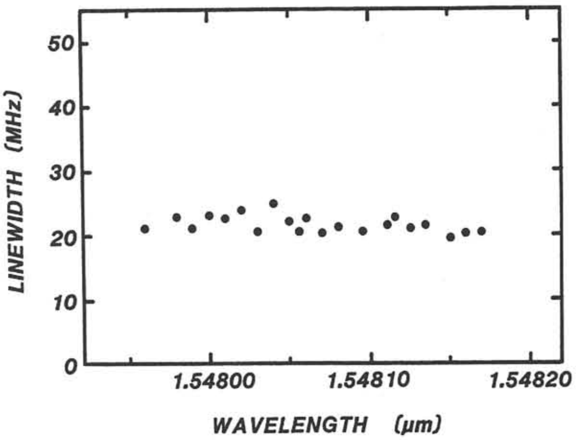

Fig. 4 Relation between lasing wavelength and spectral linewidth of the integrated LO multielectrode DFB laser

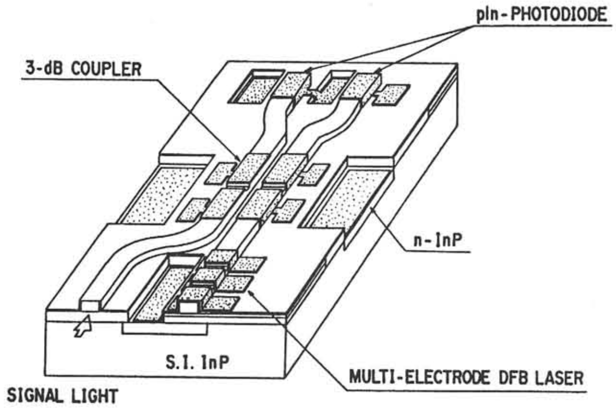

Fig. 5. Configuration of planned integrated balanced mixer coherent receiver

semi-insulating substrate. In this device, two pin photodetectors that are electrically separated from each other can be connected in series. A balanced mixer coherent receiver can thus be realized in an integrated optical circuit. The balanced mixer receiver on a semi-insulating substrate is inherently superior to the hybrid systems used now in high- bit-rate signal reception[6]. It also has the advantages of compactness and mechanical stability. In the fiber couplers used in hybrid systems, the lengths between the coupler and detectors are not equal to each other, which results in phase deviation of the intermediate frequency beat signals, especially at high frequency. In integrated circuits, the lengths are determined exactly by photo-lithographic processes, where the length difference can be minimized to less than a few microns. Another outstanding feature is that the waveguide-type detector in the integrated circuit can annihilate the inherent thickness trade-off between efficiency and speed in conventional photodetectors. Consequently, the monolithic integrated coherent receiver seems to be feasible for handling higher signal at, for instance, values greater than 10 GHz.

5. Summary

The compactness and mechanical stability of the monolithic integrated coherent receiver are outstanding compared with hybrid systems. In addition it has inherent advantages for high-bit-rate signal reception. Prospects for applying the device seem to be quite favorable based on successful initial results. At present, a balanced mixer receiver is still beyond reach because of the relative immaturity of the technologies involved. These technologies will undoubtedly mature, however, in the near future.

Acknowledgment

The author thanks H. Takeuchi, K. Kasaya and F. Kano for their valuable discussions. He also wishes to thank Y. Imamura, K. Kurumada and T. Ikegami for their continuous encouragement.

References

1) H.Takeuchi, K.Kasaya, Y.Kondo, H.Yasaka, K.Oe and Y.Imamura, Digest of papers, IOOC'89, Kobe(1989) 20PDB-6.
2) T.L.Koch, U.Koren, R.P.Gnall, F.S.Choa, F.Hernandez-Gil, C.A.Burrus, M.G.Young, M.Oron, and B.I.Miller, Digest of papers, LEOS annual Meeting, Orland(1989) PD-1.
3) Y.Yoshikuni and G.Motosugi, Summary of papers, OFC'86, Houston(1986) TUH-3.
4) H.Takeuchi and K.Oe, J. Lightwave Technol 7(1989)1044.
5) H.Takeuchi, K.Kasaya and K.Oe, Trans. IEICE, E73(1990)53.
6) K.Oe and K.Kurumada, Digest of papers, Integrated Photonics Research, Hilton Head(1990) ME-1.