Phased-array wavelength demultiplexer with flattened wavelength response

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the band 4.5-9.2GHz are shown in Table 2. As expected, very good output balance performances are obtained. As predicted by the theory, a second frequency where the coupler is perfectly matched exists near 8.8GHz.

Table 2: Coupler measured performances in frequency range 4.5 - 9.2GHz

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Electrical definition</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return loss</td>
<td>mag(s)</td>
<td>&lt;-10dB</td>
</tr>
<tr>
<td>Transmission when fed to H-port</td>
<td>mag(Sm), mag(Sm)</td>
<td>4.3 ± 0.3 dB</td>
</tr>
<tr>
<td>Transmission when fed to E-port</td>
<td>mag(Sm), mag(Sm)</td>
<td>4.3 ± 0.3 dB</td>
</tr>
<tr>
<td>Output magnitude balance when fed to H-port</td>
<td>mag(Sm/Sm)</td>
<td>0.3 ± 0.05 dB</td>
</tr>
<tr>
<td>Output phase balance when fed to H-port</td>
<td>phase(Sm/Sm)</td>
<td>0° ± 4°</td>
</tr>
<tr>
<td>Output magnitude balance when fed to E-port</td>
<td>mag(Sm/Sm)</td>
<td>0.4 ± 0.25 dB</td>
</tr>
<tr>
<td>Output phase balance when fed to E-port</td>
<td>phase(Sm/Sm)</td>
<td>180° ± 4°</td>
</tr>
<tr>
<td>Isolation</td>
<td>mag(Sm), mag(Sm)</td>
<td>&lt;-23 dB</td>
</tr>
</tbody>
</table>

Conclusion: We have presented a new small size, wideband hybrid ring coupler. Its circumference is only 0.67λ, which is to our knowledge the smallest size ever attained by a 180° ring hybrid. All the coupler ports are fed by coplanar waveguides. The coupler demonstrated a band slightly larger than one octave. Excellent output magnitude and phase balance is achieved. The design simplicity and the absence of any transition make the coupler suitable for monolithic integration.

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References


Phased-array wavelength demultiplexer with flattened wavelength response


Indexing terms: Optical waveguides, Integrated optics, Wavelength division multiplexing

A four-channel phased-array wavelength demultiplexer with a flattened wavelength response has been realised for the first time in InP/InGaAsP at 1.34μm by employing multime output waveguides. The device has 2μm channel spacing and a flat response (within 1dB) of 17nm.

Introduction: Optical phased array wavelength demultiplexers combine low loss with excellent spectral resolution [1-3]. However the parabolic shape of the spectral output characteristics of those demultiplexers requires accurate matching of the laser wavelength to the transmission maximum of the demultiplexer. In this Letter we report the realisation of a phased-array demultiplexer with a flattened wavelength response. This has been achieved by using wide multimode output waveguides.

Fig. 1 Schematic representation of phased-array demultiplexer

- monomode waveguide
- multimode waveguide

Design: A phasor demultiplexer consists of two star couplers, connected by a dispersive waveguide array (see Fig. 1). The electrical field distribution of the input waveguide is reproduced in the image plane of the demultiplexer with a lateral displacement dependent on the input wavelength, thus allowing for the spatial separation of different wavelengths, as described by Smit [4]. The shape of the spectral response curve is determined by the overlap of the field distribution in the image plane with the eigenmode(s) of the output waveguide. In the phasor demultiplexers reported to date, monomode input and output waveguides were used with identical dimensions, giving a parabolic-like spectral response. To flatten this response, we applied relatively wide multimode output waveguides, which is a common technique in bulk-optic demulti-
plexers [5]. Within a certain wavelength range, the focused spot in the image plane (Fig. 2) will couple efficiently to the output waveguide. Although the power distribution between these modes strongly depends on the relative position of the image, the total coupling efficiency will be close to 100%, as long as the image is not too close to the edge of the output waveguide.

Fig. 2 Representation of image plane of demultiplexer

Use of wide multimode output waveguides will flatten the spectral response of the demultiplexer. Owing to the multimode excitation of the output waveguide, the demultiplexer outputs cannot be coupled efficiently to monomode output fibres. If they are however coupled to detectors, the advantage of the flattened response can be fully exploited.

A four-channel demultiplexer with 2 nm wavelength spacing at 1.54µm has been designed. The array has 46 waveguides with a path length difference of 59 µm between adjacent arms. The radius of curvature in the array varies from 500 to 8050 µm. The width of the input waveguides is 2 µm. At the output, 6 µm wide multimode output waveguides separated by a 3 µm gap are used. Calculations predict a 1 dB transmission bandwidth of 1.12 nm, taking into account that the highest order mode of the multimode output waveguide will be radiated out of the bend. A diffraction loss of 2 dB was allowed for the outermost receiver waveguides. Calculations predict a TE-TM shift of 4.1 nm due to waveguide birefringence. The total device size is 3.3 x 3.9 mm² including the input and output branches.

Fabrication: The demultiplexer is realised on InP substrate for integration with photodetectors. A double-heterostructure waveguide structure was grown by LP-MOVPE: a 1.5 µm InP buffer layer, a 0.666 µm InGaAsP(1.3) waveguide core and a 0.32 µm InP top cladding. The demultiplexer was fabricated by etching 0.4 µm deep waveguide ridges using CH₄/He IRIE with an SiO₂ etching mask. In a second step the output waveguides were etched another 60 nm to reduce the radiation loss of the bends. Finally the sample was cleaved and AR-coated by evaporation of an SiO₂ layer onto the waveguide facets.

Results: Light from an HP 8168A tunable laser source was end-fire coupled into the input waveguide using a NA = 0.65 microscope objective. The light emanating from the multimode output waveguide was imaged onto a Ge photodiode. The attenuation of 2 µm wide straight reference waveguides was found to be 2 dB/cm for both polarisations by Fabry-Perot contrast ratio measurements on uncoated waveguides. Fig. 3 shows the output power of the four receiver channels for TE polarised light. Measurements are calibrated against straight reference waveguides. The excess loss of the device is 3.5 - 4.5 dB with a crosstalk level below -18 dB. On-chip losses are estimated to be 4 - 5 dB by adding the loss of a straight reference waveguide. The average 1 dB bandwidth is 1.05 nm. For the TM polarisation the spectrum is blue shifted 4.0 nm due to waveguide birefringence.

Discussion: The insertion loss of this device is comparable to demultiplexers in InP that we realised before [3]. The measured 1 dB bandwidth agrees quite well with theoretical calculations. The crosstalk level is ~5 dB higher than for previous demultiplexers. This is mainly attributed to the wider output waveguides, that will pick up more of the incoherent background radiation that is due to local variations in the propagation constant in the array.

The realised 1 dB bandwidth in excess of 1 nm will relax the matching requirements for the laser source wavelength with respect to the transmission maximum of the demultiplexer. In addition this flattened wavelength response can be used for polarisation independent demultiplexers [6, 7] based on a TE-TM shift equal to the demultiplexer periodicity. In that case the flattened wavelength response will relax the required tight control of the TE-TM shift of such a device.

Conclusions: A four-channel phased-array demultiplexer has been realised on InP substrate with a 1 dB bandwidth of 1 nm at 2 nm wavelength spacing. The on-chip loss of the device is 4 - 5 dB with a crosstalk level below -18 dB. The flattened wavelength response will alleviate several tuning and trimming problems in WDM applications.

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References
Introduction: For long-haul optical fibre transmission over 100 km at a wavelength of 1.55 μm, chipless or low-chip light sources are required. An electroabsorption intensity modulator monolithically integrated with a DFB or DBR laser is the most promising light source. Since an external modulator and a DFB laser diode (LD) were first integrated [1], many structures have been reported [2-9].

In lightwave systems with greater than 10 Gb/s capacity, the modulation voltage must be reduced to produce a drive voltage in high-speed IC drivers. Multiquantum well (MQW) structures based on the quantum-confined Stark effect are promising [3-9], because they exhibit polarization independence, high modulation efficiency, small drive voltage, and high speed. We reported the first successful 15 Gb/s operation with a monolithically integrated light source. To the authors' knowledge, this is the first report of 20 Gb/s operation with a monolithically integrated light source.

Module design: Optical transmitter modules for 10 Gb/s systems have been developed using a Franz-Keldysh electroabsorption modulator integrated light source [11]. In the module in this Letter, we reduced parasitic reactance caused by the assembly for high-speed modulation, introduced an efficient optical coupling scheme for high output power, and used an efficient compact opto-electrical isolator for low noise operation. Moreover, temperature controllability and a hermetically sealed package improve stability and reliability. To reduce the impedance mismatch between the monolithic chip and the transmission line, a thin film resistor of 50 Ω was mounted close to the modulator chip. This matching circuit has a return loss of more than 10 dB from 0 to 10 GHz. The bonding wire between the chip and the line is designed as short as possible.

For efficient optical coupling of the chip to a singlemode fibre, we used an optical coupling scheme where a spherical lens with a 600 μm diameter and one with a 2.0 mm diameter were placed in a confocal arrangement to accommodate the optical isolator. The minimum coupling loss of this lens system was 4.0 dB, including isolator loss.

To stabilize operation, we introduced a thermoelectric cooler. The module can be operated from 0 to 50 °C with a stable item temperature of 25 ± 0.01 °C. All elements except the isolator were permanently fixed by YAG laser welding.

Module performance: The output power from the module as a function of applied voltages is shown in Fig. 1. The average output power of the chip was +3 dBm in the singlemode fibre. The threshold current of the DFB laser was 0.7 A under 20 Gb/s modulation and injection current of 88 mA.

Emitting wavelength is 1.546 μm

Module performance: The output power from the module as a function of applied voltages is shown in Fig. 1. The average output power of the chip was +3 dBm in the singlemode fibre. The threshold current of the DFB laser was 15 mA.

The small signal frequency response is shown in Fig. 2. The injection current was 80 mA and the DC applied voltage for the modulator was -0.4 V. The 3 dB electrical bandwidth of the transmitter module was more than 15 GHz which was consistent with the measured capacitance. Large signal measurements were performed at 20 Gb/s for a pseudorandom sequence 2⁵−1 pulses long with 2 V non-return-to-zero (NRZ) modulation. The centre oscillation wavelengths and the full widths at 20 dB down with and without modulation were 1.5466 and 1.5468 μm, and 0.22 mm and 0.42 mm, respectively. Sidelobe suppression ratio of more than 40 dB was obtained. The output power of the module was -0.7 dBm under 20 Gb/s modulation and injection current of 88 mA.

Injection current for laser diode is 80 mA, and applied voltage for modulator is -0.4 V.

Fig. 3 shows the eye pattern for 20 Gb/s modulation driven by a 2 V peak to peak electrical signal. A clear eye opening was