Phased-array wavelength demultiplexer with flattened wavelength response

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I. Zaquine

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Phased-array wavelength demultiplexer

with flattened wavelength response

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M.K. Smit, P. Demeester, J.J.G.M. van der Tol and
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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 multimode output
waveguides. The device has 2mm 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 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-

Fig. 3 Coupler reflection loss

(i) H-port (mag(\(S_{H}\)));
(ii) E-port (mag(\(S_{E}\)));
(iii) output port 1 (mag(\(S_{1}\)))

the band 4.5-9.2GHz are shown in Table 2. As expected, very

good output balance performances are obtained. As predicted by
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_h)</td>
<td>-10dB</td>
</tr>
<tr>
<td>Transmission when fed to H-port</td>
<td>mag(S_h), mag(S_m)</td>
<td>4.3 ± 0.3dB</td>
</tr>
<tr>
<td>Transmission when fed to E-port</td>
<td>mag(S_e), mag(S_m)</td>
<td>4.3 ± 0.3dB</td>
</tr>
<tr>
<td>Output magnitude balance when fed to H-port</td>
<td>mag(S_m / S_m)</td>
<td>0.3 ± 0.05dB</td>
</tr>
<tr>
<td>Output phase balance when fed to H-port</td>
<td>phase(S_m / S_m)</td>
<td>0° ± 4°</td>
</tr>
<tr>
<td>Output magnitude balance when fed to E-port</td>
<td>mag(S_e / S_m)</td>
<td>0.4 ± 0.25dB</td>
</tr>
<tr>
<td>Output phase balance when fed to E-port</td>
<td>phase(S_e / S_m)</td>
<td>180° ± 4°</td>
</tr>
<tr>
<td>Isolation</td>
<td>mag(S_e), mag(S_m)</td>
<td>-23dB</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 sim-
plicity and the absence of any transition make the coupler suitable
for monolithic integration.

Acknowledgment: The authors wish to thank A. Bouloard from
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Fig. 2 Schematic representation of phased-array demultiplexer
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](image)

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 1.54 μm 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 805 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 μm, 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 μm 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 0.66 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 CH₃/He RIE 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 an 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 mm. For the TM polarisation the spectrum is blue shifted by 4.0 nm due to waveguide birefringence.

**Discussion:** The insertion loss of this device is comparable to demultiplexers in InP that we realised before [5]. 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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20Gbit/s, 1.55\,\mu m strained-InGaAsP MQW modulator integrated DFB laser module

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Indexing terms: Integrated optoelectronics, Electroabsorption modulators, Distributed feedback lasers

The high-speed (20Gbit/s) and highly efficient (2V peak to peak for a 22dB on/off ratio) operation of an MQW integrated electroabsorption modulator/DFB laser module is demonstrated. Output power from the module is over +3dBm in the gigahertz singlemode fibre. To the authors' knowledge, this is the first report of 20Gbit/s operation with a monolithically integrated light source.

Introduction: For long-haul optical fibre transmission over 100km, at a wavelength of 1.55\,\mu m, 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) of their highly efficient electroabsorption [4,5,9], we reported the first successful 15Gbit/s operation with a monolithically integrated light source.

Module design: Optical transmitter modules for 10Gbit/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 optical 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\,\Omega was mounted close to the modulator chip. This matching circuit has a return loss of more than 10dB from 0 to 10GHz. 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\,\mu m diameter and one with a 2.0mm diameter were placed in a confocal arrangement to accommodate the optical isolator. The minimum coupling loss of this lens system was 4.0dB, 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.

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