WDM devices in InP/InGaAsP

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Abstract:

This paper reviews the state-of-the-art of monolithic integration on InP of components for wavelength multiplexed networks. Key components such as multiwavelength lasers and wavelength demultiplexers are reviewed in terms of their performance and ease of fabrication. In addition, the crucial issue of the wavelength precision of these devices is addressed.

Introduction:

Multiwavelength optical networks are gaining interest due to their potential of creating all-optical routed, rearrangeable, scaleable and transparent networks [1]. Essential ingredients for such networks are wavelength division multiplexing, the use of wavelength for routing purposes, and wavelength translation at network nodes. Multiwavelength transmitter and WDM-receiver arrays are key components for the realization of these functions. Monolithic integration of these devices increases reliability and reduces packaging costs. The present paper reviews the state-of-the art of integration of these devices.

Multiwavelength lasers:

Starting with a DFB (or DBR) conventional single wavelength laser, the most straightforward way to realize a multiwavelength laser is by fabrication of an array of DFB lasers with variable grating period. Twenty-wavelength DFB laser arrays with 3 and 7 nm channel spacing have been demonstrated [2,3]. Typically a wavelength accuracy of 0.3 nm (relative deviation) can be achieved with this approach. In order to reduce packaging costs the individual laser signals should be recombined on-chip into one output. Planar star coupler recombiners have been integrated with 16-channel DBR [4] and 21-channel DFB laser arrays [5]. The inherent power splitting loss incurred by the recombiner may be reduced by integration with a semiconductor amplifier or, in the future , by replacing it with a wavelength multiplexer.

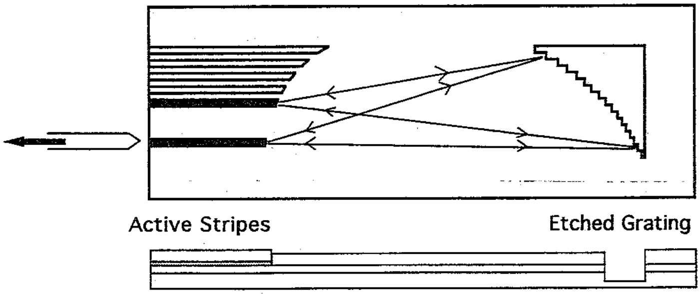

Fig. 1: Schematic representation of the MAGIC laser [6].

An alternative approach for the realization of multiwavelength lasers is to integrate an array of gain blocks with a cavity incorporating a wavelength demultiplexer. Bellcore's MAGIC (multistripe array grating integrated cavity laser) was the first example of such a device [6].
More recently a similar device was reported by AT&T using a phased-array demultiplexer (see below) as the wavelength selective element [7]. Due to the precisely defined wavelength spacing of the demultiplexer, the relative wavelength position can be accurately controlled. Relative wavelength variations of 0.023 nm have been reported for the MAGIC laser.
The long cavity length however limits the direct modulation speed. Therefore external modulation will be required to achieve high bit rates. In addition, the threshold current of these lasers has been relatively high due to the loss of the wavelength demultiplexer.

WDM receiver arrays:

Monolithic wavelength demultiplexers employing a curved reflection grating as the dispersive element have proven accurate demultiplexing of a high number of closely-spaced wavelength channels [8,9,10] and have also been integrated with photodetector arrays [11,12] (see table 1). However, due to the critical vertical mirror etching required, the insertion loss of these devices was relatively high.

Reference	*year*	*channels*	$\Delta\lambda$ *[nm]*	*loss [dB]*	*crosstalk [dB]*	*size [mm^2]*	$\Delta\lambda_{pol}$ *[nm]*
Reflection gratings:							
[8]	91	35	4	10-17	< -25	2.5 × 3.2	0.4
[11]*	92	35	4	10-17	< -15	4.7×3.5	2.5
[9]	91	78	1	16	< -19	12×2	0.2
[12]*	93	65	1	13-20	< -7	12×2	1.7
[10]	94	8	3.6	9.7	< -30	13×3	4.8
Phased arrays:							
[15]	92	15	0.7	2-7	< -18	10×10	4.7
[21]	93	7	0.7	5	< -20	6×9	0
[16]	93	4	1.7	2.5-3.5	< -23	2.5×2.3	4.8
[17]*	93	4	1.7	4-5	< -25	3.0×2.3	4.2
[19]	94	16	1.8	11-12	< -9	33.5×4.2	0.48
[22]	94	4	1	5	< -14	3.3 × 5.1	0.15
[24]	94	8	2.0	5	< -25	2.6×2.3	0

Table 1: Comparison of wavelength demultiplexers on InP-substrate. The * indicates that the device has been integrated with photodetectors.

As an alternative, wavelength demultiplexers employing a phased array of curved waveguides [13,14] as the dispersive element have become increasingly popular [15,16]. Due to the elimination of the reflective mirror these devices can be fabricated with simple and tolerant technology. Experimental results appear to be close to the theoretical limits. Figure 2b shows the spectral response of a 4-channel demultiplexer integrated with a photodetector array [17,18]. The device combines excellent spectral resolution with low-loss operation.
Due to the birefringence of conventional InGaAsP/InP waveguides, these demultiplexers may exhibit a significant TE/TM-shift (see table 1). Different approaches have been used to eliminate this effect. By reducing the refractive index contrast between waveguide core and cladding this shift can be reduced significantly. However, this occurs at the expense of higher loss or increased device size [19].

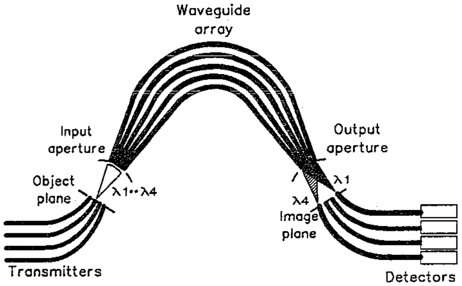

Fig. 2a: Schematic representation of a phasar demultiplexer.

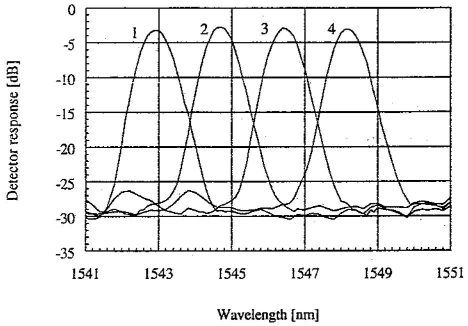

Fig 2b: Spectral response of a phasar demultiplexer integrated with a detector array [18].

An alternative approach has been to design the demultiplexer free spectral range equal to the TE/TM shift of the waveguide [14,20,21,22]. This limits, however, the operation range of the demultiplexer to only a few nanometers. A λ/2 waveplate inserted in the middle of the glass waveguides demultiplexers [23] yields a fundamentally polarization independent performance through 90° polarization rotation halfway the symmetrical design. The application of this concept to monolithic demultiplexers is, however, not straightforward. So far, the only broadband polarization insensitive demultiplexer on InP has been realized by employing non-birefringent raised stripe waveguides. A first prototype of such a device [24] has shown polarization independent demultiplexing of 8 wavelength channels at 2 nm spacing, with 5 dB on-chip loss and less than 1 dB coupling loss to a lensed fiber.

Recently an electronically tunable wavelength demultiplexer has been reported [25]. Tuning over more than 2 nm was obtained by injecting current into the arms of the phased-array through electrodes with a linearly increasing length, thus causing a current-dependent phase front tilting at the end of the array.

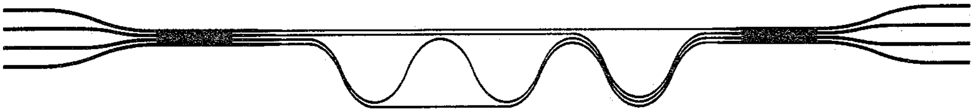

Fig. 3: Layout of a novel 4x4 waveguide array demultiplexer with MMI-couplers [26]. The device size is 2.8×0.11 mm^2.

Another novel development is the realization of a phased-array demultiplexer based on MMI-couplers [26], as shown in Figure 3. These demultiplexers apply Multi Mode Interference (MMI) couplers instead of star couplers at both sides of the waveguide array. The demultiplexers tend to be more compact than conventional phased-arrays and have potentially lower insertion loss for waveguides with a high lateral refractive index contrast. A disadvantage is the reduced low-crosstalk bandwidth as compared to the classical design. The width ~~of the passband~~ is comparable. Although we do not expect this novel demultiplexer to replace the classical phased-array, it may be advantageous in applications where compactness is very important.

Wavelength accuracy:

An important issue for WDM components that, until recently, received little attention is the wavelength precision and stability that can be realized for individual components. Especially if a number of WDM components are to be cascaded both the absolute wavelength and the channel spacing have to be controlled accurately. Soole *et. al.* measured a run to run reproducibility of about +/- 0.5 nm (see Figure 4) for reflection grating demultiplexers [27]. This would require a temperature tuning < 6°C (~0.11 nm/°C) to line up the wavelengths of the individual devices. Channel spacing deviations were found to be less than 0.03 nm and may therefore be neglected.

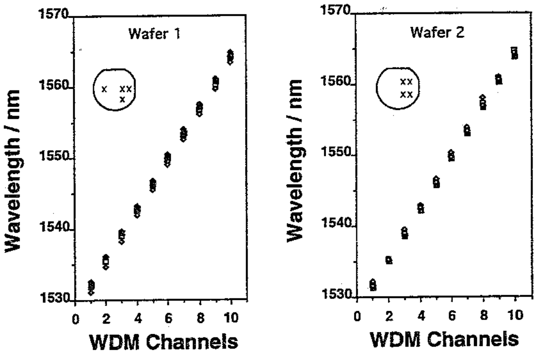

Fig. 4: Wavelengths of 8 demultiplexer devices formed from two 2" MOCVD-grown wafers [27].

Since the absolute wavelength of InP-based devices is fundamentally temperature dependent, temperature control will be necessary to keep the device operating at the right wavelength.

In addition, it may be desirable to provide passband flattening of the demultiplexer to correct for potential deviation of the laser source wavelength from the design value. A 4-channel spectrally flattened arrayed waveguide demultiplexer has been realized on InP by using relatively wide multimode output waveguides [28]. This device shows a 1-dB passband of 1.0 nm at 2.0 nm wavelength spacing (see Figure 5). Owing to the multimode excitation of the output waveguides, the demultiplexer outputs cannot be coupled efficiently to monomode fibers. If they are coupled to photodetectors, however, the advantage of the passband flattening can be fully exploited.

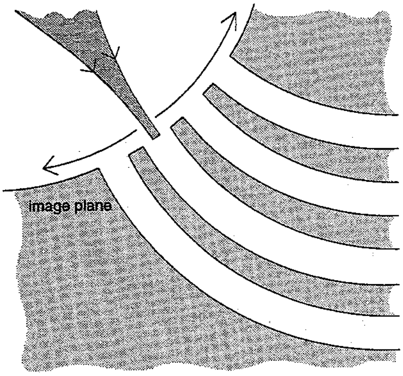

Fig 5a: Schematic representation of the focused spot in the image plane of a spectrally flattened demultiplexer.

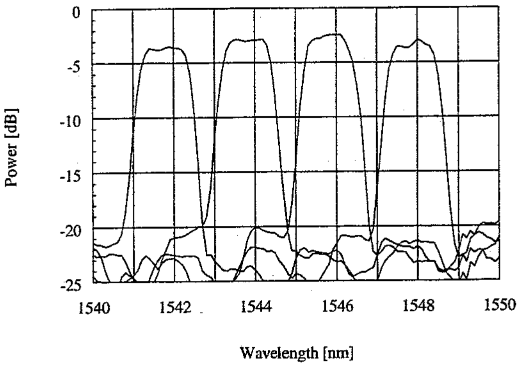

Fig. 5b: Spectral response of a passband flattened phasar demultiplexer on InP [18].

Conclusion:

In the last few years significant progress has been made on the monolithic integration of multiwavelength sources and detectors for WDM systems. Developments in the field of passband flattening and polarization independent operation are promising but still need further elaboration.
The channel spacings of the WDM-devices recently reported are sufficiently accurate for many applications. Temperature control will be necessary to stabilize the absolute wavelength of InP-based devices. The results obtained so far are sufficiently promising to support development of novel network concepts based on WDM.

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