A novel DWDM interleaver scheme based on phased-array wavelength demultiplexer with multimode interference couplers

Si Lu (陆 思), Yingbai Yan (严瑛白), and Guofan Jin (金国藩)

State Key Laboratory of Precision Measurement Technology and Instruments, Tsinghua University, Beijing 100084

Received January 5, 2004

A novel integrated dense wavelength division multiplexing interleaver scheme is presented based on phased-array (PHASAR) wavelength demultiplexer with multimode interference (MMI) couplers. MMI-PHASAR interleaver with simple structure and compact size can realize narrow channel spacing through simple design procedure. And it is convenient for integration with integrated planar waveguide multiplexer/demultiplexers. A 25/50-GHz MMI-PHASAR interleaver is designed and the transmission characteristic is investigated by beam propagation method.

OCIS codes: 060.1810, 130.3120.

The ever increasing demand of networks with large transmission capacity leads to an urgent need for narrow channel spacing and large channel number multiplexer/demultiplexer for dense wavelength division multiplexing (DWDM) systems. The mainly used multiplexer/demultiplexers, such as thin film filter (TFF), fiber Bragg grating (FBG), and arrayed waveguide grating (AWG), are difficult to implement for channel spacing less than 100 GHz. DWDM interleaver is an effective solution to double the channel number and halve the channel spacing. Interleaver schemes have been developed, mainly including Mach-Zehnder interferometer, polarization interferometer, Michelson interferometer, FBG, and AWG[1,2]. In this letter, a novel DWDM interleaver scheme based on phased-array (PHASAR) wavelength demultiplexer with multimode interference (MMI) couplers is presented.

The schematic diagram of MMI-PHASAR interleaver is shown in Fig. 1. Two MMI couplers are connected by a two-path PHASAR. It can be directly integrated with planar waveguide multiplexer/demultiplexers. The simple structure allows relaxed fabrication tolerances.

The MMI couplers are designed based on self-imaging phenomena[3−6]. The input MMI coupler is a uniform 1×2 power splitter with the input access guide at the center. The length L' is given by

$$L' = \frac{3L_c}{8}, \tag{1}$$

where L_c is the coupling length between the two lowest

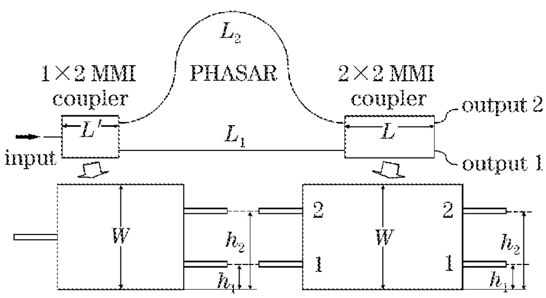

Fig. 1. Schematic diagram of MMI-PHASAR interleaver.

order modes of the slab waveguide, defined as

$$L_c = \frac{\pi}{\beta_0 - \beta_1}, \tag{2}$$

where β_0 and β_1 are the propagation constants of the fundamental and first-order modes, respectively. The output MMI coupler is a 2×2 power combiner. The length L is given by

$$L = \frac{3L_c}{2}. \tag{3}$$

The transverse positions of PHASAR guides and output access guides are

$$h_1 = \frac{W}{4}, \quad h_2 = \frac{3W}{4}, \tag{4}$$

where W is the width of the couplers.

The travelling paths through the 1×2 MMI power splitter remain fixed for all outputs of the demultiplexer. Therefore, the path length difference between L_1 and L_2 of PHASAR is determined by the phase transfer relation of the 2×2 MMI power combiner to achieve phase matchings for wavelength λ_0 (named central wavelength) at output 1 and $\lambda_0 + \Delta\lambda$ ($\Delta\lambda$ denotes channel spacing) at output 2, simultaneously. The length difference between L_1 and L_2 should be

$$L_2 - L_1 = \left\{ \text{round}\left[\frac{\lambda_0(\lambda_0 + \Delta\lambda)}{2\Delta\lambda\left(n_{g0} - \lambda_0 \frac{\mathrm{d}n_g}{\mathrm{d}\lambda}\right)} \frac{n_{g0}}{\lambda_0} + \frac{\varphi_{1,2} - \varphi_{1,1}}{\pi} \right] + \frac{\varphi_{1,2} - \varphi_{1,1}}{\pi} \right\} \frac{\lambda_0}{n_{g0}}, \tag{5}$$

where n_g denotes the effective index of the mode of an array guide and n_{g0} is the value of n_g at the central wavelength λ_0, $\varphi_{1,j}$ $(j = 1, 2)$ is the phase transfer associated with input 1 and output j of the 2×2 MMI power combiner,

$$\varphi_{1,1} = -\beta_0 \frac{3L_c}{2} - \frac{\pi}{4}, \quad \varphi_{1,2} = -\beta_0 \frac{3L_c}{2} + \frac{\pi}{4}. \tag{6}$$

Table 1. Values of Design Parameters of the 25/50-GHz MMI-PHASAR Interleaver

Parameter	Value
Central Wavelength	1550 nm
Wavelength Channel Spacing	0.2 nm
Free Spectral Range	0.4 nm
Width of MMI Couplers	18 μm
Spacing of PHASAR	9 μm
Spacing of Output Waveguides	9 μm
Length of 1×2 MMI Input Coupler	192.04 μm
Length of 2×2 MMI Output Coupler	768.15 μm
Effective Index of Channel Waveguide	1.4718
Length Difference between Paths of PHASAR	4060.73 μm
Chip Size	9×4 mm^2

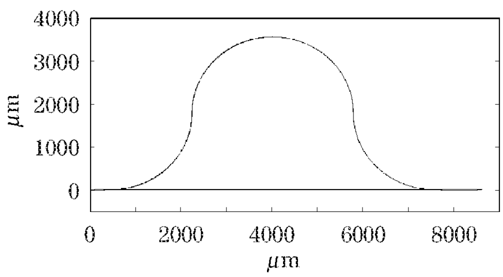

Fig. 2. Layout of the 25/50-GHz MMI-PHASAR interleaver.

A 25/50-GHz MMI-PHASAR interleaver is designed on silica-based waveguide system. The single-mode channel waveguide for PHASAR and input/output access guides have a core size of 3×3 mm^2 with refractive index contrast of Δ=1.86%. The values of the design parameters are listed in Table 1. The high Δ permits low-loss bend of PHASAR with radius as small as 1.8 mm. The path waveguides of PHASAR are tapered at both joints with MMI couplers. The actual layout of the device drawn in Fig. 2 shows its simple and compact structure. Beam propagation method (BPM) is adopted to perform the transmission spectra simulation as shown in Fig. 3.

A novel DWDM interleaver based on MMI-PHASAR is presented. Narrow channel spacing can be achieved through simple design procedure. The simple, compact, and integrated structure makes the approach easy to implement.

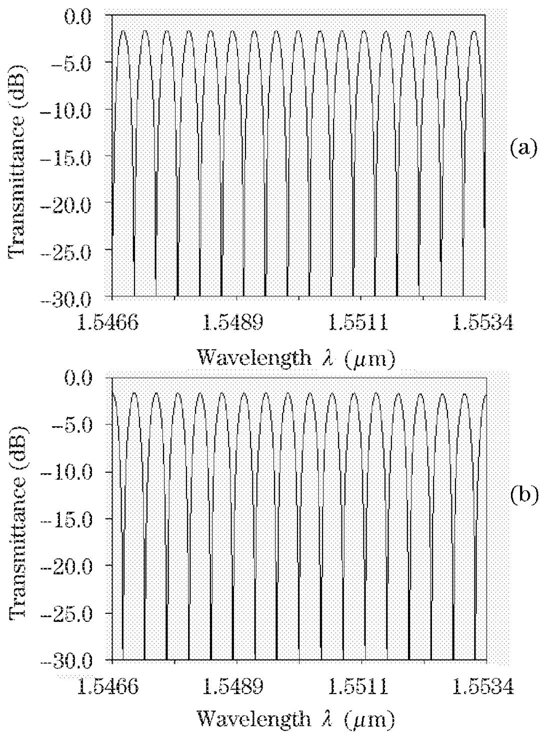

Fig. 3. Transmission spectra of output 1 (a) and output 2 (b).

This work was supported by the National Natural Science Foundation of China (No. 69990540). S. Lu's e-mail address is lusi99@mails.tsinghua.edu.cn.

References

1. M. Abe, Y. Hibino, T. Tanaka, M. Itoh, A. Himeno, and Y. Ohmori, Electron. Lett. **37,** 376 (2001).
2. D. W. Huang, T. H. Chiu, and Y. Lai, in *Proceedings of OFC 2001* **3,** WDD80-1 (2001).
3. M. Bachmann, P. A. Besse, and H. Melchior, Appl. Opt. **33,** 3905 (1994).
4. M. R. Paiam, P. A. Besse, and H. Melchior, Appl. Opt. **34,** 6898 (1995).
5. M. R. Paiam and R. I. MacDonald, Appl. Opt. **36,** 5079 (1997).
6. X. Q. Jiang, H. L. Ma, H. L. Mao, and M. H. Wang, Chin. J. Lasers (in Chinese) **29,** 253 (2002).