Interleaved Waveband MUX/DEMUX Developed on Single Arrayed-Waveguide Grating

S. Kakehashi 1, H. Hasegawa 1, K. Sato 1, and O. Moriwaki 2
1: Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8603 Japan, {hasegawa, sato}@meee.nagoya-u.ac.jp
2:NTT Photonics Laboratories, Morinosato-Wakamiya, Atsugi, Kanagawa, 243-0198 Japan

Abstract: We propose a novel interleaved waveband MUX/DEMUX developed on a single AWG. The device configuration is very simple and resolves the major difficulties raised by the previously proposed concatenated AWG arrangement.

©2008 Optical Society of America

OCIS codes: (230. 7408) Wavelength filtering devices; (230. 3120) Integrated optics devices

1. Introduction

Broadband access is rapidly penetrating the world. Significant traffic expansion is envisaged in the near future with the introduction of IP-TV and IP-based High-Definition (HD) and super-HD video services. In order to create cost-effective, bandwidth-abundant future networks, hierarchical optical path networks are recognized as playing a key role [1, 2]. They exploit grouping and routing wavelength paths as a bundle, the waveband [1, 2]. Wavebands have been proven to substantially reduce the size of optical cross-connect systems [2]. One of the key components in realizing the hierarchical optical path cross-connect is the waveband multi/demultiplexer (MUX/DEMUX). A dielectric multilayer filter has been fabricated that offers 8-skip-0 band operation at 100-GHz spacing [3], however, it requires 409 layers [3] and the manufacturing challenge is significant. Another band-filter that consists of two specially designed arrayed-waveguide gratings (AWG) has been reported [4]. The output/input ports of the two AWGs need to be connected with waveguides of exactly the same length and the level of precision required is high. A more recent proposal [5, 6] uses concatenated conventional AWGs to realize the waveband MUX/DEMUX. The key to the device is that it retains multi/demultiplexing granularity at the individual wavelength channel level. This means that conventional individual wavelength channel AWGs can be utilized. The salient feature of the waveband MUX/DEMUX is that it can accommodate multiple input fibers simultaneously, which makes it very effective in reducing the cost and size of the waveband cross-connect. Regarding waveband arrangements, two different configurations have been identified [5]: continuous and interleaved waveband arrangements. This paper proposes a novel interleaved waveband MUX/DEMUX. It is developed on a single conventional AWG, and as a result, it simultaneously eliminates the major two shortcomings seen in the previous development [5]. First, the proposed device can remove all the waveguide crossings that were used to connect the two AWGs. Second, the single AWG configuration substantially relaxes fabrication tolerance and increases yields, while the previous device demanded minimization of the performance variance between the two AWGs.

2. Comparison of continuous and interleaved waveband arrangements

The generic hierarchical optical cross-connect architecture is shown in Fig.1. It is divided into two parts; one part consists of a waveband MUX/DEMUX and waveband cross-connect (WBXC) for routing waveband paths, and the other part consists of a wavelength MUX/DEMUX and WXC for routing wavelength paths. Figures 2 and 3 depict two different waveband arrangements: continuous waveband arrangement and interleaved waveband arrangement. A continuous waveband accommodates continuous wavelength paths on the ITU-T grid. An interleaved waveband accommodates interleaved wavelength paths on the ITU-T grid. From the networking point of view, the waveband arrangement has virtually no effect on network OAM&P (Operation, Administration, Maintenance, and Provisioning). However, the wavelength MUX/DEMUX required depends on the arrangement selected. The channel spacing between wavelength paths is much wider for an interleaved waveband than for continuous waveband, so the wavelength path MUX/DEMUX required for an interleaved waveband can be realized with an AWG without any temperature control. The fabrication tolerance is also rather large and the integration of many wavelength MUX/DEMUX devices on a single chip becomes easier. Thus, the interleaved waveband arrangement can ease wavelength MUX/DEMUX fabrication.

The interleaved waveband MUX/DEMUX can use cyclic AWGs (FSR = channel spacing x # of wavebands). There is, however, one significant problem with cyclic AWGs. It is inherently difficult to precisely align the center frequency of each channel on the ITU-T grid among the multiple wavebands; the frequency deviation causes transmission signal distortion and large optical loss, particularly at or close to the edge channels of each waveband, and for wavebands near the edge of the total band (i.e. C or/and L-band). On the other hand, the previously proposed interleaved waveband MUX/DEMUX in [5] can be realized by using wide FSR AWGs (cyclic approach is not utilized). However the device still has two shortcomings; the substantial number of waveguide crossings needed between the two component AWGs, and the requirement that the characteristics of the two AWGs must be exactly matched. The proposed device explained below simultaneously eliminates these...
problems.

3. Formulation of AWG port connections for proposed interleaved waveband MUX/DEMUX

Here, in our assumed conventional AWGs, the output port number (# output port) corresponding to each pair of wavelength number (# wavelength) and input port number (# input port) is determined by equation (1).

\[
\text{# output port} = \text{# wavelength} - \text{# input port} + 1, \quad i \text{ is an integer.} \quad (1)
\]

There are several possible variations for the AWG used and waveguide connection pattern adopted, and only the most fundamental and effective ones are discussed hereafter. That is, variations that introduce extra AWG ports and increase un-used AWG ports are not considered here. Let \( L \) be the total number of wavelength paths per fiber, \( M \) the number of wavebands per fiber, and \( N \) the number of wavelength paths per waveband. Hence, the product of \( M \) and \( N \) equals \( L \).

\( \lambda_k \) and \( \lambda_1 \) represent wavelength path 1 in fiber A and waveband 1 in fiber A, respectively. Input side AWG is denoted as AWG X and output side AWG as AWG Y, respectively. Input AWG X consists of \( z \) input fibers and \( z \) output ports. Thus, the maximum number of output ports \( z \) that can be outputted from any input fiber \( i \) is determined by equation (2), where \( j \) is a positive integer.

\[
\text{# X out} = 2Mj + M \quad \text{or} \quad 2Mj + M + 3 \quad (1 \leq \text{# X out} \leq S) \quad (2)
\]

The size of AWG X and Y, \( S \times S \), depends on the number of input fibers and wavelength paths per fiber. In Fig. 4, the MUX/DEMUX can accommodate 16 wavelength paths per fiber and 4 input fibers (each fiber carries 4 interleaved wavebands each consists of 4 wavelength paths) and parameter \( i \) is set at 15. This MUX/DEMUX requires two AWGs and the waveguide crossings between the two AWGs cannot be eliminated. Further, the characteristics of the two AWGs must be exactly the same; any deviation can degrade the performance of the waveband MUX/DEMUX. One of the important characteristics of the MUX/DEMUX is crosstalk. In an AWG, the output signal slightly couples into the neighboring output ports when the output waveguides of AWG are very closely spaced. This results in optical crosstalk between wavelength paths. However, this crosstalk at each output port of waveband MUX is reduced by passing through the waveband MUX after the optical switch (see Fig. 1) [6]; in waveband optical cross-connect, waveband MUX and DEMUX are used as a pair.

3.2 Newly proposed interleaved waveband MUX/DEMUX

Figure 5 shows an example of our newly proposed interleaved waveband MUX/DEMUX using a single AWG X. Suppose that we have AWG X of \( S \times S \). In this case, the MUX/DEMUX is realized by connecting output ports of AWG X (the right side ports of AWG X) as shown in equation (4).

\[
\text{# X out} = M(2 \cdot \text{# X out} - 1) / M + 1 \quad (1 \leq \text{# X out} \leq S) \quad (4)
\]

Input fiber connection ports to AWG X can be determined by equation (3). The necessary size of AWG X, \( S \times S \), depends on the number of input fibers and wavelength paths per fiber. In the left of Fig. 5, the MUX/DEMUX can accommodate 16 wavelength paths per fiber and 4 input fibers (each fiber carries 4 interleaved wavebands each consists of 4 wavelength paths) and parameter \( i \) is set at 15. As seen in Fig. 5, this MUX/DEMUX can be realized using one AWG and the waveguides connecting output ports do not cross. Therefore, the newly proposed interleaved waveband MUX/DEMUX will greatly ease monolithic implementation. Please note that the MUX/DEMUX on the left of Fig. 5 requires optical circulators at some ports (\( x4, x7, x12, x15 \)) because some wavebands (\( WB_{A,B,C,D} \)) are output from ports to which input fibers are connected. The waveband MUX/DEMUX that can remove this restriction (use of circulators) is presented on the right of Fig. 5. With this arrangement, the number of input fibers accommodated is two, instead of four. Thus, the port utilization efficiency declines, however, band crosstalk can be decreased because there are no neighboring output ports.
4. Experiments

The proposed device will be realized monolithically using silica PLC technology. To confirm device feasibility we constructed a prototype of the interleaved waveband MUX/DEMUX. In the experiment, a 32 x 32 uniform-loss and cyclic frequency (ULCF) AWG was used, and each two of the 32 output ports were connected using 16 optical fibers. The device can accommodate 32 100-GHz spaced C-band channels (192.1 ~ 195.2 THz) on the ITU-T grid per fiber and 4 input fibers simultaneously. Each fiber carries 4 interleaved wavebands with 8 channels. Figure 6 shows an example of a measured output spectrum for the device at one output port. The solid and dotted traces correspond to the output spectrum when 4 input fibers and 3 input fibers were connected, respectively; that is, the dotted trace corresponds to crosstalk. Outputs from other waveband output ports were also measured and the routing capability of the prototype device was confirmed to be accurate. The measured worst coherent crosstalk was -34 dB. The average 3 dB transmission bandwidth was 38 GHz. The loss of this prototype device was large (more than 10 dB) since we simply used a ULCF AWG on hand to verify the routing capability. The expected loss of a monolithically fabricated proposed waveband MUX/DEMUX is better than 3.8 dB, since this value has been attained by a previously proposed device that used two concatenated AWGs [6].

5. Conclusions

We proposed a novel interleaved waveband MUX/DEMUX using a single AWG. It can accommodate multiple input fibers simultaneously. Input and output port connection rules were formulated and experimentally confirmed. The device simultaneously eliminates the two major shortcomings seen in the previously developed device; elimination of all waveguide crossings between AWGs, and removal of the requirement to exactly match the characteristics of the two AWGs. This proposal will be effective in driving down device cost.

Acknowledgment

This work was supported by JST (Japan Science and Technology Agency).

Reference