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FBG-based reconfigurable bidirectional OXC for 8 × 10 Gb/s DWDM transmission

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ABSTRACT

The paper presents a bidirectional high-speed, power-compensated, 3 × 3 reconfigurable and multi-wavelength optical cross-connect (RMB-OXC) for all-optical networks. RMB-OXC characteristics and its performance are experimentally verified in a bidirectional 8-channel × 10 Gb/s capacity system. The optical signal to noise ratio (OSNR) is achieved of 18.4 dB corresponds to a BER of 5×10^{-10}. The channel cross-connect function was demonstrated by incorporating RMB-OXC in an 50 km lightwave system. We have observed only ~0.5 dB power penalty in the bidirectional transmission in comparison to the uni-directional transmission. The proposed RMB-OXC has vast potential and it can be utilized in many applications in high-speed wavelength division multiplexed (WDM) networks.

1. Introduction

In recent years, a significant amount of efforts have gone into designing high-capacity, flexible and transparent multi-wavelength optical networks using cross-connect scheme [1,2]. Such networks have the ability to provide reconfigurable paths for signal routing in the optical layer, thus eliminating the need for complex and expensive digital switches, and offering more relaxed network management policies [3]. In high-speed optical networks the optical cross-connect (OXC) is one of the essential elements for wavelength routing, especially in the reconfigurable network topology. OXCs allow optical networks to be reconfigured on a wavelength-by-wavelength basis, thus providing routing function, facilitate the network growth, and enhancing the network survivability. OXCs also permits optimization of capacity allocation, management, and scalability of the network size. Conventional OXCs use a thin-film coating based one-to-*N* demultiplexer (DMUX) and *N*-to-one multiplexer (MUX) pair to separate and combine WDM channels. The ability for reconfiguration is introduced by including space division switches between the DMUX/MUX pair. Nowadays, most of the OXC is designed for unidirectional transmission because the commercial optical amplifiers are unidirectional. For the commercial array waveguide grating (AWG) based OXCs, the adjacent channel crosstalk is high when the channel spacing is down to 100 GHz. The larger crosstalk will degrade the system performance and restrict the applications of AWG in dense WDM systems for wavelength cross-connect. On the other hand, the fiber Bragg grating (FBG) with a low sideband loss, a high contrast ratio, and a low cost is an alternative candidate in high-speed OXC applications. In [4] we proposed a 2 × 2 FBG based reconfigurable, multi-wavelength OXC integrated optical switches (OSWs) and optical circulators (OCs) for the first time. Some structures for multi-wavelength OXC (MOXC) have been reported in recently. For examples; optical cross-connect system using planar device integration [5] and arrayed waveguide grating demultiplexer [6]. Another paper discuss the crosstalk issue using with different MZI techniques [7]. The bidirectional multiple OXC was realized by employing FBGs and OCs for the minimum loss [8]. However, the power compensation issue has not been addressed and the structure is still complex to implement. Previous work reported on OXCs only transmits information in one direction [9]. This approach limits the full functionality of OXC for optical routing in WDM networks. Recently, we presented the 3 × 3 reconfigurable, multiwavelength and bidirectional (RMB) OXC architecture [10] using the strain tunable FBGs (ST-FBGs) and four-port OCs. In this paper, we further discuss the power penalty impact from crosstalk, Rayleight back scattering and other issue. Bit error rate (BER) measurement to verify the RMB OXC performance in 50-km bidirectional optical network is also provided.

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2. Operational mechanism and experimental setup

Fig. 1(a) shows the structure of a conventional unidirectional 3 × 3 reconfigurable multiwavelength OXC. A multiple-input-multiple-output (MIMO) space-division switch is inserted between three WDM DMUX/MUX pairs to enable the selection, interchanging, and rearrangement of WDM channels. Three sets of WDM channels λ_i, λ'_i, and λ''_i ($1 \leq i \leq N$) are fed into the upper, middle, and lower input fiber branches, respectively. The channel assignment for an *N*-channel WDM system could be based on the International Telecommunication Union (ITU) proposal of 200 GHz (1.6 nm) or 100 GHz (0.8 nm) spacing. Signal power losses induced by the 3 × 3 OXC can be compensated by using optical amplifiers (OAs).

The operating mechanism of a ST-FBG relies on stress and strain. To suppress the residual signal power, the reflectivity of in-house built FBGs is made with the value above 99.9%. These FBGs are matched to the WDM channels, whereas the tunable ones can be tuned to offset the corresponding signal. The FBG Bragg wavelength is given by [11]:

$$\lambda_B = 2n\Lambda \tag{1}$$

where Λ (in nm) is the grating pitch and n is the effective index of the optical fiber. The criterion of wavelength-shift value depends on the stop-band bandwidth of ST-FBG and the channel spacing of the WDM system. With no strain applied to the FBG, the input signal with its wavelength matching the FBG Bragg wavelength will be reflected. With strain, the Bragg wavelength of an ST-FBG can be tuned to a longer or shorter wavelength by stretching or compressing the ST-FBG, respectively. The signal will then pass through the corresponding ST-FBG. The functionality of RBM-OXC is demonstrated using the experimental setup shown in Fig. 1(b). Without the loss of generality, channels λ_1 (1547.76 nm), λ_2 (1549.68 nm) and λ_3 (1551.16 nm) are used for the downstream channels and channels λ_4 (1548.44 nm), λ_5 (1550.80 nm) and λ_6 (1551.84 nm) are used for upstream channels for the feasible study. The launched power is 0 dBm at each channel. In order to observe the inter-channel crosstalk within the co-propagation signals, the downstream wavelength set including λ_1, λ_2 and λ_3 are different to those of the upstream wavelength set of λ_4, λ_5 and λ_6. Three pieces of EDFs each of 3 m length share a total of 65 mW pumping power to compensate for fiber losses. Practically, TFBGs could be inscribed into EDF or use FBGs on either side of the EDF unit within the RMB-OXC module. For the four-port OC device the inter-port isolation and the inter-port insertion loss are 45 dB and ~0.7 dB, respectively. The in-house fabricated FBGs have a 3-dB bandwidth of ~0.15 nm, and 10-, 20-, and 30- dB bandwidths of 0.20, 0.35, and 0.60 nm, respectively. Each FBG module is glued onto two translation stages. The transmission dips for all six FBGs are around −30.0 dB, i.e. 99.9% of reflectivity. FBG may change its wavelength in case strain/stress has applied to have signal pass through. Although the noise figure (NF) may not be good enough using a low-gain EDF, the SNR values could be improved by increasing the lengths of EDFs or increasing the pumping power. Nevertheless, the gain of EDF is large enough to compensate for the insertion loss of the RMB-OXC.

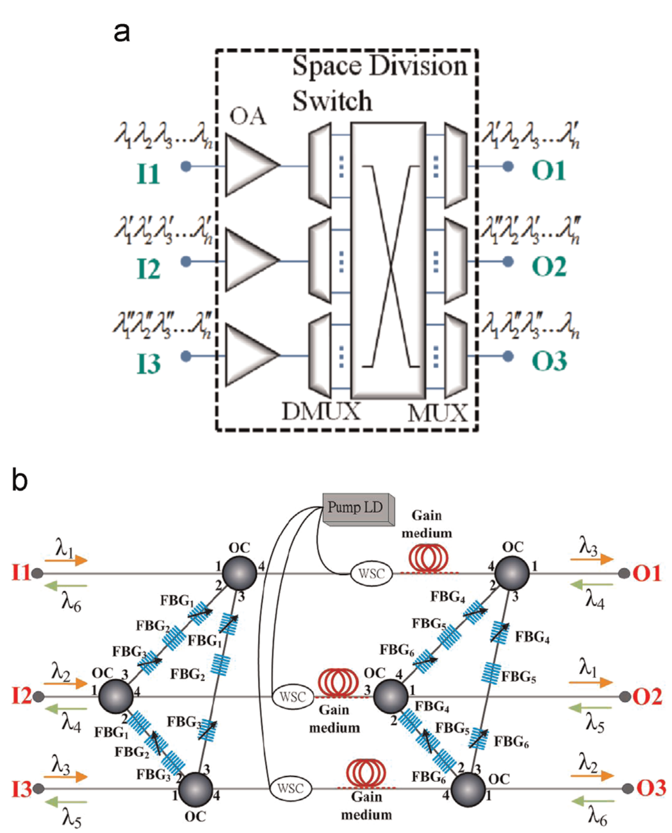

Fig. 1. (a). Schematic diagrams of: the conventional 3 × 3 B-MOXC. (b) Experimental setup of the proposed 3 × 3 RMB-OXC for optical measurement.

3. Theoretical and experimental studies of possible impacts in system

3.1. System setup and spectra

For assessing the RMB-OXC performance, a transmission system using RMB-OXC, see Fig. 2, was put together. The output of eight-channel distributed feedback (DFB) lasers array with a channel spacing of 0.8 nm is divided into two groups for bidirectional transmission in downstream and upstream directions, respectively. The downstream wavelengths used are 1545.38 nm, 1546.98 nm, 1548.58 nm and 1550.18 nm, and the upstream wavelengths are 1546.18 nm, 1547.78 nm, 1549.38 nm and 1550.98 nm. All signals are externally modulated using a 10 Gb/s electro-optical modulator (EOM). An InGaAs avalanche photodiodes (APD) with a sensitivity of −21.0 dBm at a BER of 10^{-9} is used as a low-noise receiver. In this experiment, the operation is symmetrical for both signals in downstream and upstream directions.

The pseudo random bit sequence (PRBS) data stream of length $2^{31}-1$ in the non-return-to-zero (NRZ) format is used. Each group is combined using an AWG. The RMB-OXC is sandwiched between two 25 km single-mode fiber (SMF) spools used as the transmission link. The same AWG is located at the receiving side to select a certain channel for detection. OCs connected to SMF spools were used to separate the upstream and downstream signals.

The superposed output spectra of DFB lasers array are depicted in Fig. 3, with −10 dBm power for each channel. Where Ch 1, Ch3, Ch5 and Ch7 are on the left-hand side being launched into the I1 via 25-km SMF spool; and Ch 2, Ch 4, Ch 6 and Ch 8 are on the right hand side being launched into the O2 via another 25-km SMF

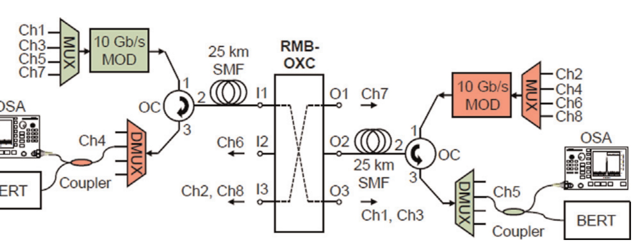

Fig. 2. RMB-OXC in 50 km lightwave system for BER measurement.