Design of a Wide Upstream-Bandwidth Optical Triplexer Using Three-Waveguide Interferometer

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***Abstract*—A novel planar lightwave circuit (PLC) triplexer is designed using a three-waveguide interferometer and Mach-Zehnder interferometers. We introduce a full-coupling scheme in the three-waveguide coupler for wide upstream-bandwidth characteristic. Transfer matrix forms for three-waveguide coupler and three-waveguide phase shifter are derived for numerical simulation. Simulation results show that the 1dB- and 3dB-bandwidth for the upstream channel are 115nm and 200nm, respectively. The proposed triplexer shows low insertion losses of less than 0.6dB and low crosstalks of less than -28dB for the two downstream bands, assuming that the waveguide width-error in the PLC fabrication is ±0.1μm.**

I. INTRODUCTION

Bi-directional optical triplexer is one of key components in the passive optical network (PON) system for FTTH (fiber-to-the-home) application, providing extra services like video or others in addition to the common service of data. It is required for the triplexer to demultiplex the two closely-spaced wavelength-bands of 1550±10nm and 1490±10nm in downstream and to multiplex the one far-off wavelength-band of 1310±50nm in upstream according to the standard of the International Telecommunication Union(ITU) T-983.3.

Recently, several studies have been made on planar lightwave circuit (PLC) triplexer [1], [2]. However, these have difficulties in satisfying the bandwidth requirement for the upstream channel. A triplexer composed of series of Mach-Zehnder interferometers (MZIs) is also proposed [3]. This type of triplexer must use at least two stages of MZIs for separating the three channels, because the MZI is only a two-port device in the input or output.

In this work, we propose a three-waveguide interferometer (TWI) for optical triplexer application. Trasfer matrix forms for three-waveguide coupler and three-waveguide phase shifter are derived. We introduce a full-coupling scheme for the far-off upstream channel (1310 nm) in the three-waveguide coupler of the TWI, and were able to design a compact low-loss PLC triplexer which has wide bandwidth in the upstream channel.

II. DESIGN AND SIMULATION

The proposed trixer consists of three parts as shown in Fig. 1: A three-waveguide interferometer (TWI), a demultiplexing Mach-Zehnder interferometer (D-MZI), and tuning MZIs (T-MZIs).

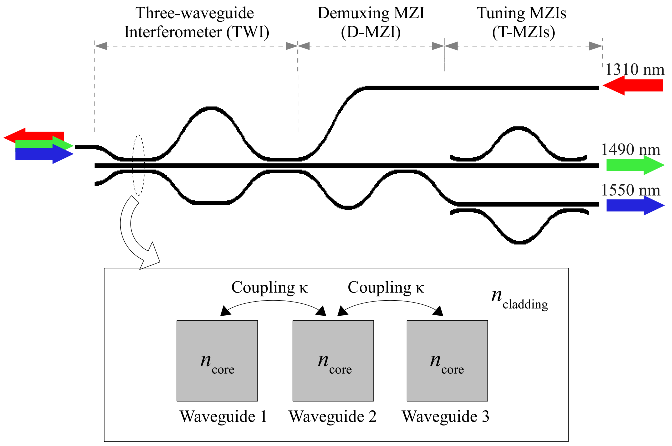

Fig. 1. Overall design of the triplexer and cross-sectional view of the three-waveguide coupler.

The TWI is designed to demultiplex the one far-off upstream channel (1310nm) and the two closely-spaced downstream channels (1490- and 1550-nm). From the coupled-mode equation, the transfer matrices of the three-waveguide coupler and phase shifter can be derived as follows

$$[M_{coupler}] = \begin{pmatrix} b+0.5 & a & b-0.5 \\ a & 2b & a \\ b-0.5 & a & b+0.5 \end{pmatrix} \tag{1}$$

$$[M_{ps}] = \begin{pmatrix} \exp(j\beta L_1) & 0 & 0 \\ 0 & \exp(j\beta L_2) & 0 \\ 0 & 0 & \exp(j\beta L_3) \end{pmatrix} \tag{2}$$

where, $a = -\frac{j}{\sqrt{2}}\sin(\sqrt{2}\kappa L_{cpl})$, $b = \frac{1}{2}\cos(\sqrt{2}\kappa L_{cpl})$, and L_{cpl} and L_i denotes the length of the coupler and the length of the ith waveguide in phase shifter. κ and β are the coupling constant and the propagation constant of the waveguide.

The transfer matrix form of the three-waveguide interferometer is then given by

$$[M_{TWI}] = [M_{coupler}]\,[M_{ps}]\,[M_{coupler}] \tag{3}$$

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In the TWI operation, the bandwidth for the upstream signal (λ_1=1310nm) must be as wide as 100nm while the band separation of 60nm between two downstream signals (λ_2=1490nm and λ_3=1550nm). However, when the TWI separates each wavelength by interference, the bandwidth for the upstream becomes narrower.

To solve this problem, we set the coupling length L_{cpl} of the three-waveguide coupler to be integer times of the full-coupling length, which is expressed by

$$L_{cpl} = \frac{m\pi}{\sqrt{2}\kappa(\lambda_1)}, \quad (m = 1, 2, 3, \cdots) \tag{4}$$

On the other hands, the λ_2 and λ_3 signals are distributed into the three waveguides of the phase shifter and interfere in the second coupler. There is a simple analytic solution for λ_3 signal to go to the output port 3, which is given by

$$\kappa(\lambda_3)L_{cpl} = (m + \tfrac{1}{2})\tfrac{\pi}{\sqrt{2}} \tag{5}$$

$$\cos(\beta\Delta L_{12}) = \cos(\beta\Delta L_{23}) = \cos(\beta\Delta L_{31}) = 1 \tag{6}$$

where, ΔL_{ij} denotes the path length difference between the ith and jth waveguides in the phase shifter.

However, there is no analytic solution for λ_2 to be 1 in output port 2. Therefore, we numerically searched for the optimum parameters such as κ, L_{cpl}, ΔL_{12}, and ΔL_{23} for the separation of λ_2 and λ_3 into the output port 2 and 3, respectively.

In this work, ΔL_{12} and ΔL_{23} are determined to be 26.69μm and -12.85μm, respectively. The coupling length L_{cpl} and the distance between adjacent waveguides in the coupler are determined to be 664μm and 1μm, respectively, from Eq. (4) and Eq. (5).

An additional demultiplexing device is combined to the output port 2 and 3 of the TWI to improve the insertion loss characteristic of downstream channels as shown in Fig. 1. Here, the device is a single-stage MZI, called demuxing MZI (D-MZI). We numerically searched for the optimized design parameters such as coupling length and path-length difference for the D-MZI to have the maximum at the wavelength of λ_2 and λ_3 in the output port 2 and 3, respectively. Also, tuning MZIs (T-MZIs) are concatenated after the D-MZI for further enhancement of the performances such as fabrication tolerance and polarization dependence. They consist of two directional couplers and a phase shifter. The T-MZIs at the output port 2 and port 3 are designed to have constructive interference for λ_2 and λ_3, respectively, and destructive interference for λ_3 and λ_2, respectively.

The spectral response of the proposed triplexer simulated by the transfer matrix method is shown in Fig. 2. The crosstalk dependence and the insertion-loss dependence on polarization and width-error of the waveguide are shown in Fig. 3. Assuming the waveguide width-error is less than ±0.1μm, the insertion losses and the crosstalks of the proposed triplexer are maintained to be less than 0.6dB and -28dB at the center wavelength of each wavelength band. The tolerance ±0.1μm of the waveguide width-error can be commonly achieved using standard lithographic processes in silicon electronics industry.

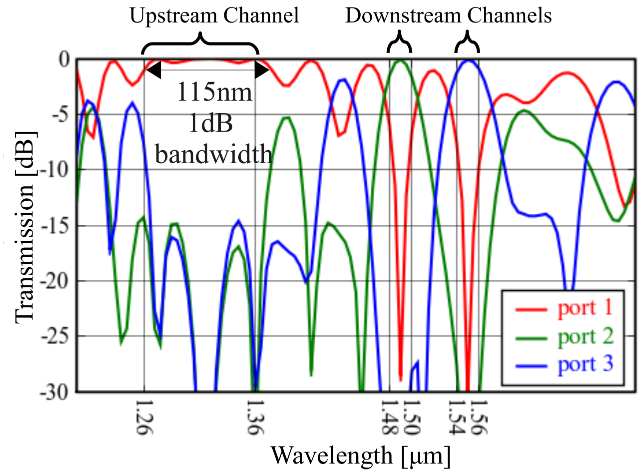

Fig. 2. Spectral response of the proposed triplexer.

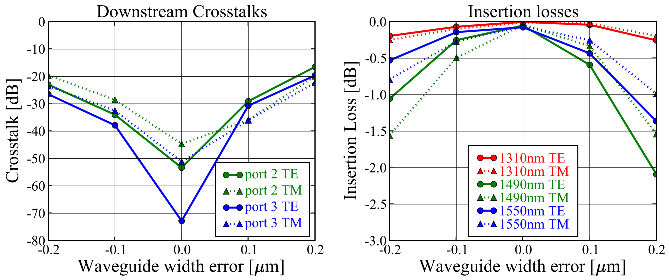

Fig. 3. Effects of polarization and waveguide width-error of the triplexer.

III. CONCLUSION

We proposed a PLC-type triplexer which consists of TWI and MZIs. Simulation and optimization for the proposed triplexer are performed by using the transfer matrix method. For wide-bandwidth operation for the upstream channel, full-coupling scheme was introduced. Simulation results show that 1dB- and 3dB-bandwidth of the upstream channel are 115nm and 200nm, respectively.

To improve the performances of the triplexer, we combined a demultiplexing MZI and tuning MZIs to the downstream ports of the TWI. The insertion losses and crosstalks are maintained to be less than 0.6dB and -28dB, respectively, at the center wavelength of each wavelength band, assuming the waveguide width-error of ±0.1μm.

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