



An on-chip silicon compact triplexer based on cascaded tilted multimode interference couplers

Jingye Chen, Penghao Liu, Yaocheng Shi *

Center for Optical and Electromagnetic Research, State Key Laboratory for Modern Optical Instrumentation, Zhejiang University, Zijingang Campus, Hangzhou 310058, China

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ABSTRACT

An on-chip triplexer based on cascaded tilted multimode interference (MMI) couplers has been demonstrated to separate the 1310 nm wavelength band into one port and 1490 nm and 1550 nm wavelength bands into the other two ports respectively. By utilizing the dispersive self-imaging and pseudo self-imaging, the device length is not critically determined by the common multiple of beat lengths for different wavelengths. The total device size can be reduced to $\sim 450 \mu\text{m}$, which is half of the butterfly structure reported. The whole device, fabricated with only one fully-etching step, is characterized with < -15 dB low crosstalk (CT) and ~ 1 dB insertion loss (IL).

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1. Introduction

With the urgent demand of the big data and optical communication, the fiber to the home (FTTH) is one of the typical solutions for broadband services. Triplexer is one of the most important components in the broadband optical access networks, e.g. fiber to the home (FTTH) systems, which are used for broadband services. For passive FTTH networks, ITU-T G.983 recommends three wavelengths bands, commonly 1310, 1490 and 1550 nm, which are utilized for upstream voice data, downstream voice data and dedicated wavelength for RF digital/analog video, respectively. The triplexers realized by a combination of film filters [1] or diffraction gratings [2], or Mach–Zehnder interferometers (MZI) [3] are bulky and complex to be fabricated. Bragg grating assisted directional coupler (DC) [4] and Photonic Crystal (PhC) [5] based triplexers have also been reported. However, the bandwidth of the above triplexers is not large enough, especially the one for 1310 nm band (generally < 100 nm). For the Bragg grating assisted structures shown in [6,7], complex steps with shallow etching step (hard to control the etching depth actually) are required for fabricating the grating reflector. Cascaded multimode interference (MMI) couplers have also been utilized to realize the triplexers [8,9]. Especially for the two close wavelength bands (1490 nm/1550 nm bands), the length of the MMI section should be chosen as a common multiple of the beat lengths. Thus, the devices size will still be quite large. An ultra-compact triplexer based on topology optimization method is reported [10]. However, the designed device with irregular shapes is difficult to be fabricated. In

recent years, a kind of tilted MMI couplers utilizing dispersive self-imaging mechanism have been proposed [11] and utilized to realize various devices [12–16]. The device size can be dramatically reduced by using such type of tilted MMIs.

In this paper, a compact triplexer has been designed and experimentally demonstrated based on cascaded tilted MMI couplers. With the first MMI coupler, the 1310 nm wavelength band is (de-)multiplexed to one port and the other two wavelengths bands (1490 nm/1550 nm) to the other port by using the pseudo self-imaging principle [17]. Then, the two wavelength bands (1490 nm and 1550 nm) are separated by a MMI coupler with tilted output ports. The three wavelength bands are all well separated without satisfying the common multiple of the beat length. Thus, the size of the present triplexer is dramatically reduced to $\sim 450 \mu\text{m}$ and half of the cascaded one based on butterfly MMI couplers, which has been designed to reduce the device length compared to the common ones [8].

2. Design and analysis

The schematic diagram of the proposed triplexer is shown in Fig. 1. The SOI platform with 220 nm-thick silicon layer and a $2 \mu\text{m}$ -thick buried oxide is considered in our work. The present triplexer is designed for operating at TE polarization.

The proposed triplexer consists of two MMI couplers sections. The first one is a common 1×2 MMI coupler based on general interference, and the second is the tilted MMI coupler. In the first MMI section, the

* Corresponding author.

E-mail address: yaocheng@zju.edu.cn (Y. Shi).

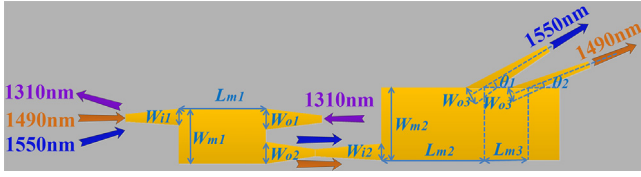
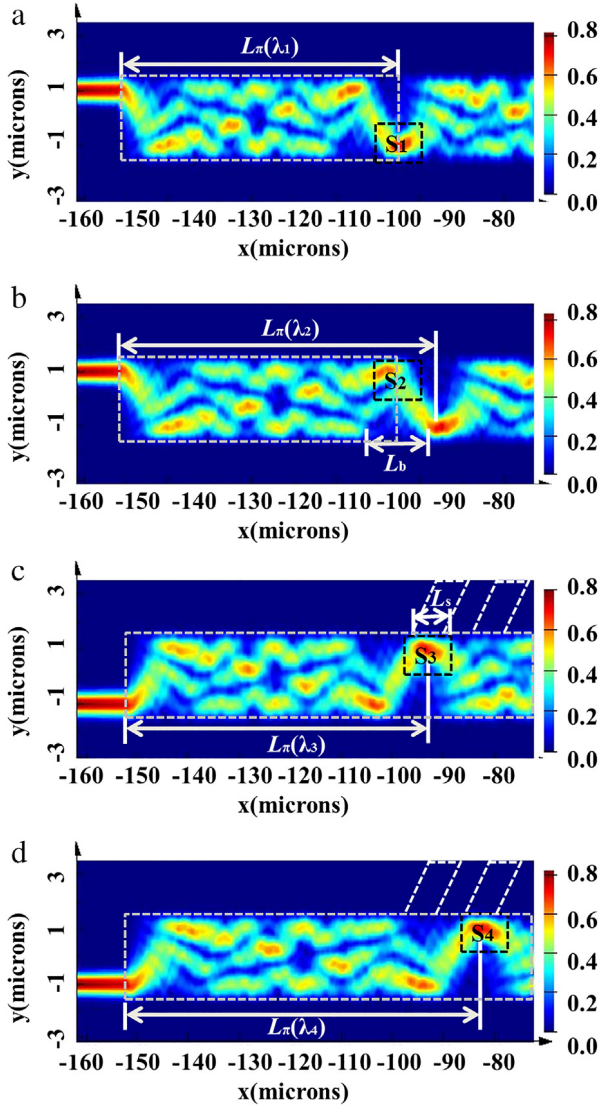


Fig. 1. Schematic diagram of the proposed silicon triplexer.

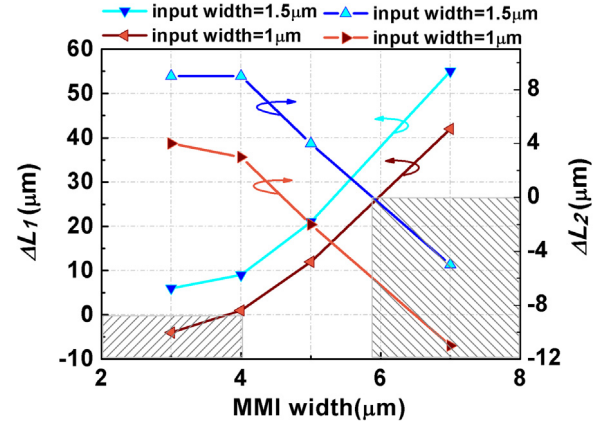
Fig. 2. Calculated optical field distributions of the MMI couplers at four different wavelengths. The first MMI: (a) $\lambda_1 = 1520$ nm, (b) $\lambda_2 = 1310$ nm, and the second MMI: (c) $\lambda_3 = 1550$ nm, and (d) $\lambda_4 = 1490$ nm.

1310 nm band and 1490 nm/1550 nm band are separated, while the cascaded tilted MMI is utilized to demultiplex 1490 nm and 1550 nm further.

The self-image will be reproduced at the integer multiple of the beating length for two lowest modes. The beating length L_π is defined by the following formula [18]:

$$L_\pi(\lambda) = 4n_r W_e^2 / 3\lambda \quad (1)$$

where n_r , W_e , and λ represent the effective index of the MMI section, the effective MMI width, and the wavelength in the free space, respectively.

Fig. 3. Length differences (ΔL_1 and ΔL_2) vary with the widths of the MMI couplers and the widths of the input port waveguides.

Two different methods are utilized for separating different two wavelength bands i.e., “1310 nm and 1490 nm/1550 nm”, and “1490 nm and 1550 nm” respectively in our work. Fig. 2 shows the calculated optical field distribution of the MMI couplers at different wavelengths. To separate the two different wavelengths band of 1490 nm/1550 nm and 1310 nm, the pseudo self-image for 1310 nm wavelength is formed at the corner of the MMI, which is labeled as “S₂” in Fig. 2(b). Thus, we use the first self-image (“S₁”) for one wavelength band and the pseudo self-image (“S₂”) for the other wavelength band. By properly choosing the width of the MMI section, self-image can be formed for one wavelength at one output port while pseudo-image can be formed for the other wavelength at the other output port as shown in Fig. 2(a) and (b). The self-image for one wavelength (λ_1) band should be at the dark zone (“L_b”) of the other wavelength (λ_2) band. Since the 1490 nm and 1550 nm signals are too close to each other, dispersive self-imaging principle is utilized to separate these two nearby wavelength bands. By properly choosing the parameters of the MMI section, two different self-images for the two wavelength bands can be formed at the tilted output ports, which are labeled as “S₃” and “S₄” in Fig. 2(c) and (d) respectively. To avoid crosstalk between the two wavelength bands, the two self-images (“L_s”) should be at a certain distance from each other. One should note that, there is no need to satisfy the common multiple of the beat length with these two methods.

The most challenging part for the triplexer design is the large bandwidth requirement, especially for the 1310 nm band. As shown in Fig. 2, we define two parameters, i.e., dark zone length and self-image size, which are labeled as “L_b” and “L_s” respectively. The length differences (ΔL_1 and ΔL_2) are defined as follows:

$$\Delta L_1 = \Delta L_\pi(1310-1550) - L_b \quad (2)$$

$$\Delta L_2 = L_s - \Delta L_\pi(1490-1550) \quad (3)$$

where $\Delta L_\pi(1310-1550)$ and $\Delta L_\pi(1490-1550)$ are the difference of beating length between 1310/1550 nm and the difference between 1490/1550 nm, respectively.

The first MMI is used to separate the 1310 nm and 1490 nm/1550 nm bands. As shown in Fig. 2(b), the optical field distribute in the MMI section with a dark zone “L_b” at one wavelength (1310 nm). When the input wavelength changes to be 1550 nm, the self-imaging “S₁” can be at the dark zone with a proper design. The widths of the MMI coupler and the input waveguide are optimized for a large wavelength separation. Fig. 3 shows the length differences vary with the widths of the MMI coupler and the input waveguide. The length difference $\Delta L_1 < 0$ represents that the 1490 nm/1550 nm band wavelengths can be localized in the dark zone (L_b) of the 1310 nm band.

According to the above analysis of ΔL_1 , the widths of the first MMI W_{m1} and the input waveguide are chosen to be 3 μ m and 1 μ m,

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