A CMOS Compatible On-Chip MMI based Wavelength Diplexer with 60 Gbit/s System Demonstration

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Abstract: An ultra-compact (41µm) 1310/1550 nm diplexer with an insertion loss < 1 dB and extinction ratio > 20 dB for both the wavelengths is demonstrated. Furthermore, experiments show clear eye diagrams at 60 Gbit/s signals. © 2022 The Author(s)

1. Introduction

Wavelength (de)multiplexers play a significant role with wavelength-division multiplexing (WDM) technology, especially in the deployment of fiber-to-the-home (FTTH) applications. Among FTTH wavelength (de)multiplexers, the dual-wavelength (de)multiplexer, also called diplexer, is a core optical filter in the WDM system, and simplifying it is of great interest. Designing wavelength diplexers on a silicon-on-insulator (SOI) platform is attractive owing to its CMOS compatibility and high integration density [1,2].

The SOI diplexers, which (de)multiplex O-band and C-band signals have been extensively demonstrated using diffractive gratings [3], microring resonators [4], directional couplers [5], and multimode interference (MMI) couplers [6-9]. An MMI-based diplexer solution stands out among SOI diplexers; it provides a relatively low insertion loss and broad bandwidth. Several groups have reported diplexers based on MMI couplers. However, the footprint of these devices is relatively large and is in the order of hundreds of microns [6,7]. In an MMI for demultiplexing operation, the device length must match several odd or even multiple beat lengths of both the wavelengths, causing an increased footprint. But for silicon photonics, compactness is one of the key features leading to high integration density. Subwavelength structures [8] and photonic crystals [9] have been integrated into the MMI to shrink the length. Nevertheless, these schemes reduce the reliability during fabrication when commercial 193 nm UV lithography is used. Moreover, many of these reports lack experimental validation [6-8]. Also, for passive FTTH networks, ITU-T G.983 recommends wide bandwidth for 1310 nm and 1550 nm wavelengths which is challenging to satisfy using previously reported devices [1,10].

Here we experimentally demonstrate a fully CMOS compatible MMI-based diplexer with a device length of only 41 µm. A low insertion loss (< 1 dB), high extinction ratio (> 20 dB) and wide 3dB bandwidth (100 nm) is measured for both the 1310 nm and 1550 nm wavelengths. An on-chip wavelength demultiplexing transmission experiment was also carried out with a non-return-to-zero (NRZ) on-off keying (OOK) signal modulated at 60 Gbit/s. The experimental results show clear eye diagrams for both the wavelengths channels. To the best of our knowledge, this is the first system demonstration of on-chip MMI based wavelength demultiplexer on an SOI platform.

2. Device Design and Methodology

A schematic of the proposed device is shown in Fig. 1. The device consists of three parts: an input channel, an MMI coupler, and two S-bent output channels, in which one is bar-port, and the other is cross-port. The waveguide design parameters used are as follows: the refractive index of silicon (Si) and oxide (SiO_2) are 3.445 and 1.445, respectively. The diplexer is fabricated on an SOI platform with a 220 nm thick silicon layer, a 2.2 µm thick oxide cladding, and 2 µm thick box oxide.

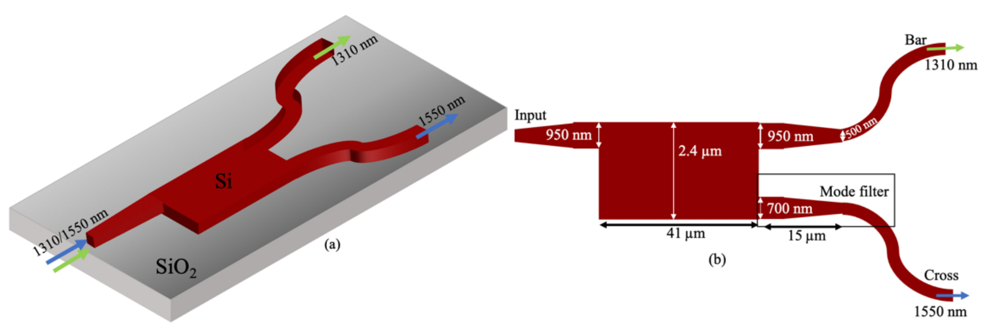

Fig. 1. (a) 3D view and (b) 2D view of the Proposed diplexer.

The MMI coupler length is chosen as the first beat length corresponding to 1550 nm wavelength for a 2.4 µm wide multimode waveguide to make the device ultra-compact. Such selection results in optimal imaging of 1550 nm wavelength at the cross port but poor extinction ratio (ER) for 1310 nm light. As shown in Fig. 2(a), higher-order ripples can be seen with 1310 nm wavelength as input. For improving the performance, the cross-port width is reduced to filter higher-order mode power when O-band light is injected, increasing the extinction ratio. Additionally, S-bends are further added to cut off the higher-order excitations completely. All device parameters need to be carefully optimized as reducing the output port width increases the insertion loss (IL). Figure 2 (b) shows the beam propagation of the final optimized device.

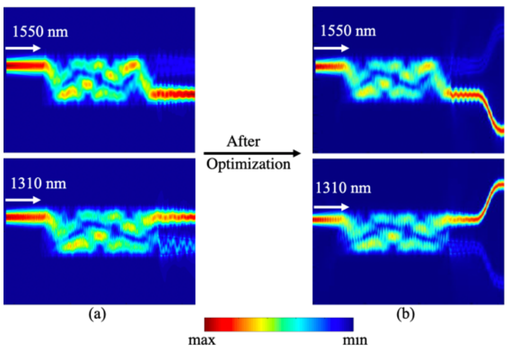

Fig. 2. Simulated field evolution at 1550/1310 nm wavelengths (a) without higher order mode filtering (b) after optimization.

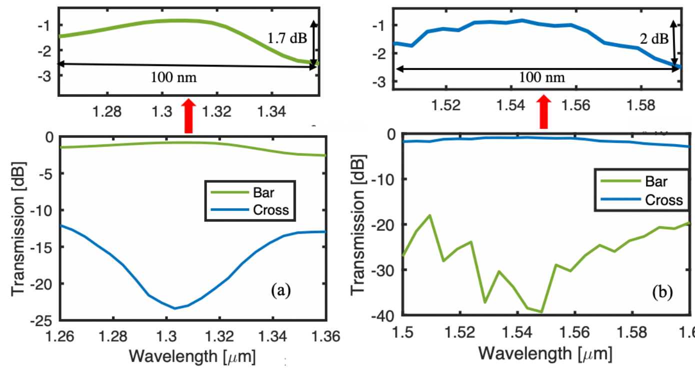

Fig. 3. Power transmission at Bar and Cross ports (a) O-band (b) C-band.

The overall performance of the diplexer is evaluated by 3D FDTD simulations performed over a broadband wavelength range (Fig. 3). At 1310 nm wavelength, the IL and ER are 0.8 dB and 24 dB, respectively. For 1550 nm, the IL is still 0.8 dB, but the ER is 41 dB due to perfect imaging. Furthermore, the 3dB bandwidth covers 100 nm near center wavelengths of both O- and C-bands.

3. Fabrication and Measurements

The proposed diplexer is fabricated using the NanoSOI process by Applied Nanotools Inc., based on direct-write 100 KeV electron beam lithography technology. Scanning electron microscope (SEM) micrographs of the fabricated device are shown in Fig. 4. Edge couplers are used to couple light to the Silicon chip using lensed fibers. Two tunable Keysight 8100B laser sources (C-band and O-band lasers) and Keysight N7744A optical detector sensors are used to characterize the optical transmission responses. The measured IL is 0.9 dB for both 1310 nm and 1550 nm wavelengths. The ER of 1310 nm wavelength measures 20.5 dB, while the ER of 1550 nm is 38 dB. The discrepancy in ERs from the simulations can be attributed to limited polarization extinction between the TE and TM mode of the input fibers. This can be improved with the use of grating couplers instead of edge couplers.

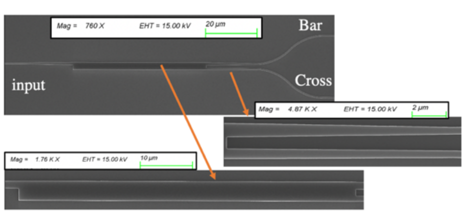

Fig. 4. SEM of fabricated diplexer.

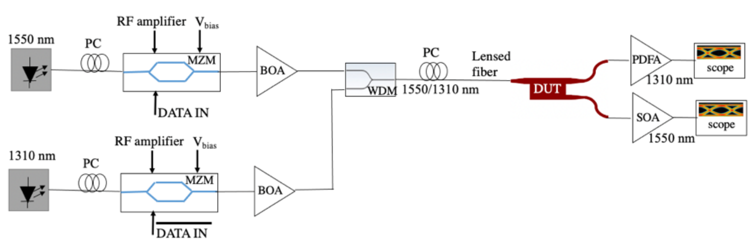

Fig. 5. Experimental setup for on-chip wavelength division demultiplexing.

Figure 5 shows the transmission test experimental setup. The C-band tunable laser source centered at 1550 nm is connected to a polarization controller. It is then modulated at 60 Gbit/s in the NRZ-OOK scheme with a known random binary pattern of 2^{31}-1 generated from Keysight 64 Gbaud pattern generator M8045A. The modulation is performed with Thorlabs LN05S 40 GHz intensity Mach-Zehnder modulator. The optical signal is then pre-amplified with a polarization-maintaining booster optical amplifier (Thorlabs S9FC1004P). The exact configuration is implemented for the O-band tunable laser centered at 1310 nm, modulated with IxBlue Mx1300-LN-40 40GHz intensity modulator. The optical signal is pre-amplified with a polarization-maintaining booster optical amplifier (Thorlabs S9FC1132P). The measured eye diagrams for the pre-amplified 1550 nm and 1310 nm optical signals are shown in Fig.6 (a) and.6 (b), respectively. Both signals are then multiplexed with a commercial fiber-based WDM into one single fiber connected to a polarization controller and coupled to the proposed silicon diplexer (DUT) with a lensed fiber. The eye diagram of multiplexed 1550 nm/1310 nm is shown in Fig 6(c). This diplexer acts as an on-chip demultiplexer with the 1550 nm signal directed to the cross-port and the 1310 nm wavelength to the bar-port. Each output of the DUT is amplified with a polarization-insensitive semiconductor optical amplifier Thorlabs (S7FC1013S) and a single-mode Praseodymium-doped fiber amplifier (PDFA100) at 1550 nm and 1310 nm wavelength, respectively. Due to the high extinction ratio, the corresponding demultiplexed signals exhibit clear eye diagrams, as shown in Figures 6(d) and 6(e). A Keysight Infinium DCA-X 86100D wide-bandwidth oscilloscope is used to capture the eye diagrams and confirm the bit rate in our setup.

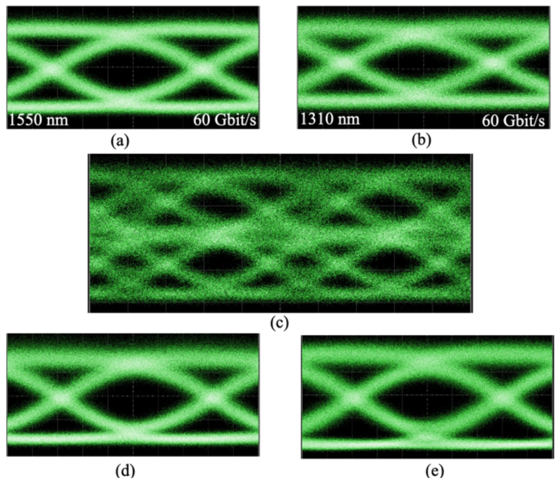

Fig. 6. Measured eye-diagrams of the pre amplified optical signal (a) 1550 nm (b) 1310 nm. (c) Measured eye-diagram of multiplexed optical signal. Measured eye-diagrams of the demultiplexed signal at (d) cross-port (1550 nm) and (e) bar-port (1310 nm).

4. Conclusion

An ultra-compact (41 µm) 1310/1550 nm wavelength MMI-based diplexer is demonstrated on the SOI platform. The minimum critical dimension of the device is fully compatible with 193 nm UV lithography. A compact footprint is achieved by designing and optimizing the MMI at the first beat length of 1550 nm wavelength. Measurement shows a low IL (< 1 dB) and high ER (> 20 dB) for both the wavelengths. System experiments have been carried out for on-chip wavelength demultiplexing application at 60 Gbit/s, showing clear eye diagrams for demultiplexed channels.

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