Wavelength Combiner based on Silicon Platform

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Abstract A wavelength combiner based on a silicon-on-insulator (SOI) multimode interferometer (MMI) coupler and a Mach-Zehnder interferometer (MZI) was designed, fabricated and tested. It has 0.1dB spectral full-width of 18nm around 1440nm and 22nm around 1560nm.

Introduction

SOI photonics is of much interest due to the potential for low cost integration of multiple functions on a chip. SOI wafers can be used to make compact low-loss (<0.1dB/cm) waveguide devices [1] including variable optical attenuators [2], waveguide autocorrelators [3], polarization beam splitter (PBS) [4], and polarization-mode converters [5]. Stimulated Raman scattering (SRS) in SOI waveguide [6-8] is a candidate for integrated optical amplifiers in future planar light circuit (PLC). Raman amplification in silicon requires a wavelength combiner to combine a pump wavelength that is separated by 15.6THz from the signal wavelength (e.g. 1440nm pump for gain at 1556nm). Another potential application for wavelength combiners lies in the passive optical networks (PON). Current implementations of PON transceivers use thin film filters but the multiple optical alignment and hermetic packaging requirements of such transceivers may make it attractive to explore potentially lower cost approaches involving non-hermetic integrated triplexers and diplexers. Here we report the design, simulation, and measurement results of a SOI wavelength combiner for possible use in an integrated silicon optical amplifier [7, 8]. The device is simple, passive and has potential for hybrid integration with pump lasers, and can be shrunk to small size for low cost manufacture when compared to the earlier work based on silica waveguides [9]. The wavelength combiner has a 0.1dB spectral full-width of 18nm around 1440nm and 22nm around 1560nm. The spectral width is wide enough to provide wavelength tolerance for the use of low cost uncooled lasers in PON.

Design and Simulation

The proposed wavelength combiner is based on an asymmetrical MZI SOI rib waveguide, as shown in inset of Fig. 1. The MMI couplers act as 3dB splitters. In the wavelength combiner, the required conditions for the length difference between the two arms of MZI (ΔL) are

\[
\Delta L = \frac{(2m+1)\lambda_1}{2n_{eff_1}} \quad (1)
\]

\[
\Delta L = \frac{2m'\lambda_2}{2n_{eff_2}} \quad (2)
\]

where \(m\) and \(m'\) are integers, \(n_{eff_1}\) and \(n_{eff_2}\) are effective indices at \(\lambda_1\) and \(\lambda_2\), respectively. In our design the \(\Delta L\) for the lowest order wavelength combiner is 2.68µm. In principle the shorter the length difference, the wider will be the passband for the wavelength combiner. In order to increase the width of the passband, we choose the shortest \(\Delta L\) possible that allowed the desired wavelengths to fall within the passbands of the wavelength combiner rather than using a \(\Delta L\) which gave a nominally exact match in passband center wavelengths with the desired wavelengths. The inputs, outputs, and delay lines for the device have waveguide widths of 4µm.

Fig. 1  Cosine curve model of the normalized output power at PortD for different wavelengths input at PortA (solid line) and PortB (desh line). Inset: schematic layout of the wavelength combiner.

The cosine curve model of the MZI wavelength combiner based on the calculated \(\Delta L\) for the wavelengths 1440nm and 1560nm is plotted in Fig. 1. These theoretical plots show that the MZI has a designed 0.1dB spectral full-width of 21nm around 1440nm and 24.9nm around 1560nm when \(\Delta L=2.68\mu m\). Even allowing for a large 0.5µm tolerance in etch depth, the designed target wavelengths can fall within the 0.1dB band of the wavelength combiner. We used beam propagation method (BPM) to simulate the performance of the wavelength combiner. Different wavelength input signals (1440nm and 1560nm) were launched into PortA and PortB respectively. Results of the BPM simulations of the wavelength combiner are shown in Fig. 2. We can see that separate inputs of 1440nm and 1560nm from PortA [Fig. 2(a)] and PortB [Fig. 2(b)] respectively combine at the same output PortD.
Experiment, Results and Discussion

The device was characterized by using a tunable laser (scanning from 1440nm to 1570nm), which was end-fire coupled into the waveguide via an optical fiber. The output light was collected by a cleaved single mode fiber and measured by a PIN photodiode connected to a 500 MHz digital sampling oscilloscope. Fig. 3 shows the output power at PortD for different wavelength scan from PortA and PortB respectively. The wavelength combiner has a 0.1dB spectral full-width of 18nm around 1440nm and 22nm around 1560nm, which agree well with the theoretical plots in Fig.1. The wavelength selectivity of the combiner was measured by launching a CW signal into PortA and comparing the output optical powers at PortD and PortC. The output powers from PortD and PortC for 1560nm CW signal input at PortB were also measured. The output ports had 17dB and 20dB wavelength selectivity for 1440nm and 1560nm wavelength inputs respectively. The polarization dependence wavelength (PDA) measurements were also performed by having different wavelength scan of TE and TM polarization from input PortA and PortB to PortD. The polarization insensitive wavelength is at 1453nm and 1556nm. The maximum polarization dependence is 0.35 dB at wavelength of 1510nm. The PDA of the Mach Zehnder was measured to be about 3nm. This is somewhat larger than the predicted value of about 1nm obtained from the calculated effective indices for TE and TM, and may be due to the observed non-uniformity of the etch depth in the fabricated device. The ripples on the curves in Fig. 3 may be due to the beating between evanescent substrate modes and guided modes in SOI waveguide. The fiber to fiber insertion loss of the uncoated device was about 9dB (the linear loss is about 0.1dB/cm), which includes input and output fiber-waveguide coupling losses, 3dB Fresnel reflection loss from the two uncoated facets of the device and the losses in the two MMI and any waveguide losses. The insertion loss may be significantly reduced with the use of improved mode-matching between the waveguide and the input and output optical fibers (for example via the use of tapers and AR coatings on the waveguide facets).

Conclusion

We described the design, simulation, fabrication and measurement results of a SOI wavelength combiner. The device may be a potential candidate for use in an integrated silicon optical amplifier [7, 8] and PON. The proposed device is simple, integratable and has potential to be shrunk into small size. The PDA and insertion loss were also measured.

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References