Design of a 785 nm/1850 nm wavelength (de)multiplexer based on multimode interference coupler

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Abstract

Aluminium oxide material (Al_2O_3) is a promising material for integrated photonics with a very wide transparency window (200 – 5500 nm). Channel waveguides fabricated by RF reactive sputtering have shown losses lower than 0.1 dB/cm at 1550 nm[1]. *Compared with other silicon-based photonic material platforms, Al_2O_3 has higher trivalent rare earth solubility*[2]. *Amplification and lasing can be achieved by Tm^{3+} doped Al_2O_3 in the wavelength range of ~1.8-1.9 µm*[3]. *After being amplified, the pump laser (~785 nm) and the signal laser (~1850 nm) need to be demultiplexed.*

*In this work, a demultiplexer operating at 785 nm and 1850 nm wavelengths in a 550 nm thick Al_2O_3 platform was designed based on the MMI principle. The optimized MMI demultiplexer has a multimode region with a size of 14.65 µm * 3150 µm. For 785 nm and 1.85 µm wavelengths, the simulated extinction ratio (ER) is 37.75 dB and 23.47 dB respectively, and the simulated insertion loss (IL) is lower than 0.1 dB in both wavelength.*

Introduction

Al_2O_3 is a promising integrated optical material, which is reported in the previous literature as a very suitable rare earth doped host material[2]. Thulium-doped Al_2O_3 can be used to make amplifiers work at 1850 nm wavelength[3]. For the on-chip amplifier, an optical wavelength splitter can be used to combine/separate the pump and signal laser before/after amplification.

Several approaches have been reported to implement (de)multiplexer in integrated photonics, including directional couplers[4], Mach-Zehnder interferometers[5] and multimode interferometers (MMI)[6]. Among them, MMI has as advantages of ease of fabrication, low excess loss, compact size, and large fabrication tolerance errors[6].

In this work, an MMI-based 785 nm/1850 nm wavelength (de)multiplexer is designed and simulated in a 550 nm thick Al_2O_3 platform. An additional taper is added between the output taper and MMI region to achieve low insertion loss at dual wavelengths, which will be described in detail in the design section below. The results obtained by simulation show excellent optical characteristics, with insertion loss below 0.1 dB at both pump and signal wavelengths.

Design

The cross section of the Al_2O_3 platform is shown in Fig. 1 (a). It consists of a 550 nm thick Al_2O_3 strip waveguide on 8 µm SiO_2 layer and covered with 6 µm SiO_2 cladding layer. Fig. 1 (b) shows the layout of a basic MMI-based 1x2 (de)multiplexer. According to the MMI principle[7], the input/output tapers are placed at the position corresponding to ±W/6 from the centerline of the MMI region, where W is the width of the MMI. In order to achieve that both the 785 nm and 1850 nm light can be input from the same port of the MMI, but output from different output ports, the length of the MMI needs to satisfy the following equations[6], [7]:

$$L_{\pi,\lambda} = \frac{\pi}{\beta_0 - \beta_1} \cong \frac{4n_{eff}W^2}{3\lambda} \qquad Eq.1$$

$$L_{MMI} = n \times L_{\pi,785} = (n+m) \times L_{\pi,1850} \qquad Eq.2$$

where, $L_{\pi,\lambda}$ is the beat length for the wavelength λ, β_0 and β_1 are propagation constants of mode 0 and mode 1 of the multimode region respectively, n_{eff} is the effective index of the fundamental mode, W is the width of the MMI region, L_{MMI} is its length, $L_{\pi,785}$ and $L_{\pi,1850}$ are beat lengths for 785 nm and 1850 nm respectively, n is integer number and m is odd number.

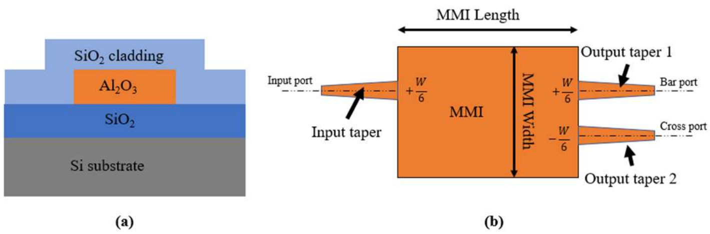

Fig. 1 (a) Cross section of the Al_2O_3 platform. (b) The schematic of the MMI based 1x2 (de)multiplexer.

Fig. 2 (a) shows the simulated intensity near the input port of the MMI. The intensity of the field at the corner of input port is very low. Therefore, the corner area does not affect the working of the MMI[8]. The maximum angle of laser entering MMI from the input waveguide is [8]:

$$\theta_C = cos^{-1}\frac{n_{cl}}{n_{co}} \qquad Eq.3$$

where n_{cl} and n_{co} are the effective refractive indices of cladding and core respectively at the wavelength of interest. The effective refractive indices of cladding and core used in this work are obtained via Lumerical Mode simulation.

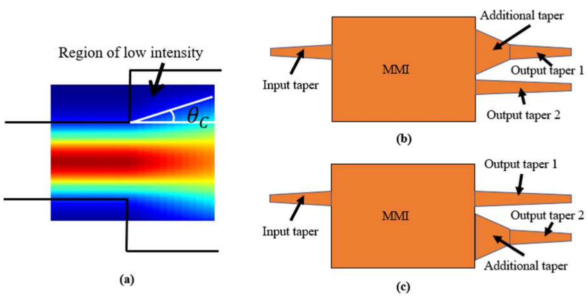

Fig. 2 (a) Field pattern near the input port of MMI chamber. (b) and (c) Optimized MMI shape. An additional taper is added before the output port 1 or output port 2.

Therefore, an additional taper added between the output taper and MMI chamber, like shown in Fig. 2 (b) and (c), will not intersect the outermost ray as long as the following condition is satisfied[8]:

$$\frac{L_{at}}{\frac{W_{at}}{2}} \leq \cot(\theta_C) \qquad Eq.4$$

where L_{at} is the length of the additional taper, W_{at} is the width of the additional taper at the interface with the MMI region.

Optimized design

In this work, the FDE solver in Lumerical is used to simulate the MMI effective indices of different MMI widths. From the simulation, the beat length at 785 nm and 1850 nm for different MMI widths is calculated according to Eq. 1 and shown in Fig. 3 (a). And the beat length ratio between $L_{\pi,785}/L_{\pi,1850}$ is shown in Fig 3 (b). In order to fulfill Eq. 2, one possible solution is $n = 5$, $m = 7$, Which leads to a beat length ratio of 2.4. As seen in Fig. 3 (b), the corresponding MMI width is 14.65 µm.

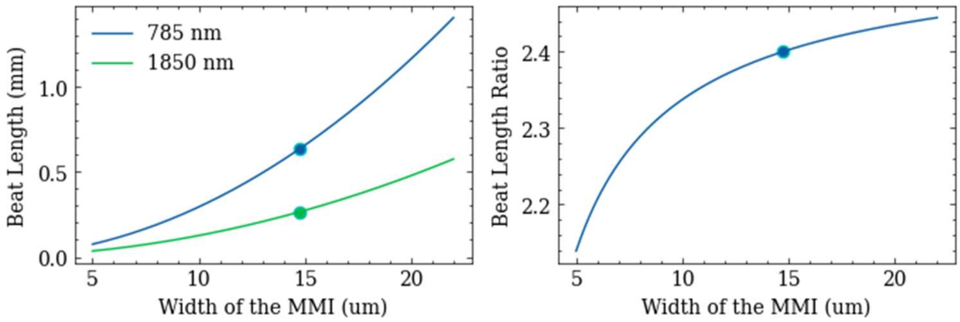

Fig. 3. (a) Beat length of different MMI widths. (b) Beath length ratio of different MMI widths.

Due to beat length from Eq. 1 is an approximation of the period of light change in the MMI[7]. In order to get the accurate MMI length, simulations of MMI length sweep are done in Lumerical EME solver. The results shows 3150 µm and 3155 µm are the length of MMI chamber to give the best insertion loss for 1850 nm and 785 nm respectively.

Therefore, the final design selected Fig. 2 (c), the MMI length is set to 3150 µm. And an additional taper with 5 µm length, 7.7 µm width is added at the 785 nm output port.

Results and discussion

The simulation was accomplished by the EME solver in Lumerical software.

Fig. 4 shows the simulated intensity pattern of the optimized (de)multiplexer when working at 785 nm (right) and 1850 nm (left). The 785 nm output power focus at the cross port, while the 1850 nm output power focus at the bar port.

The performances of the wavelength demultiplexer are characterized by the extinction ratio (ER) and the insertion loss (IL), which are defined as:

$$ER = 10\log\left(\frac{P_d}{P_u}\right) \qquad Eq.5$$

$$IL = 10\log\left(\frac{P_d}{P_i}\right) \qquad Eq.6$$

where, P_d, and P_u are the intensities in the desired and undesired output waveguides respectively, and P_i is the input optical power at input waveguide.

The simulated insertion loss are 0.094 dB and 0.095 dB for 785 nm and 1850 nm respectively. The extinction ratio are 37.75 dB and 23.47 dB respectively. Fig. 5 shows the additional insertion loss caused by MMI length variations and wavelength variations, which represent the fabrication tolerance error and bandwidth of MMI respectively. With a requirement of 1 dB insertion loss, the fabrication tolerance of the MMI length is about ±12 µm, the bandwidth of the MMI is 5.6 nm and 16.4 nm for pump and signal wavelength respectively.

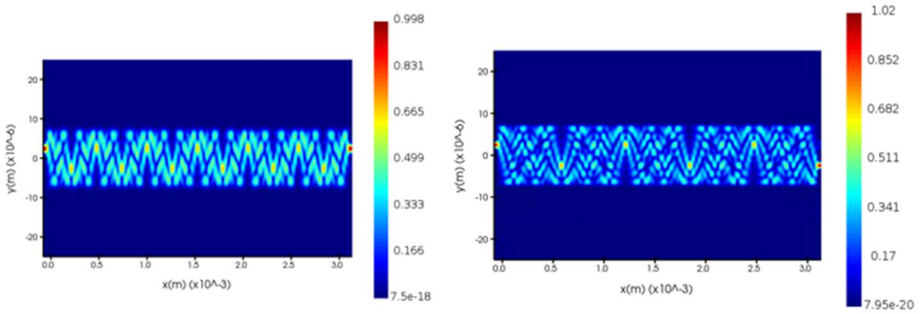

Fig. 4. Simulated intensity pattern of the demultiplexer at (a) 1850 nm wavelength (b) 785 nm wavelength.

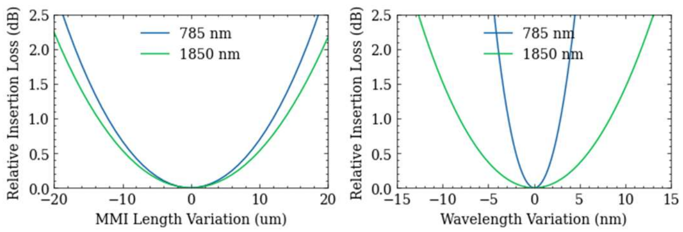

Fig. 5. Relative insertion loss caused by variation of (a) MMI length and (b) Wavelength.

Conclusion

This paper proposes a (de)multiplexer operating at 785 nm and 1850 nm wavelengths in a 550 nm thick Al_2O_3 platform. Simulation results showed that the insertion losses are below 0.1 dB for both wavelengths, extinction ratio is 37.75 dB for 785 nm and 23.47 dB for 1850 nm. The size of the demultiplexer MMI region is 14.65 µm * 3150 µm.

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