

# J-Rib Waveguide as a Mode-Division Demultiplexer

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**Abstract:** A rib waveguide with unequal slab thicknesses, called J-rib waveguide, is proposed as a mode-division demultiplexer. 3D FDTD simulation of the proposed device is performed. Low insertion loss, low crosstalk, and wide bandwidth are achieved.

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## 1. INTRODUCTION

The increasing bandwidth of the future parallel chip multiprocessor to meet up with the current demand in high transmission rate has been promising with the emergence of optical interconnect [1]. Many multiplexing techniques have been used to increase the capacity of systems [2, 3]. Space-Division Multiplexing (SDM) technique increases capacity but it is unsuitable for on-chip applications since it increases footprint due to the fact that each signal has its own path [4]. Wavelength-Division Multiplexing (WDM) technique, that increases capacity without increasing footprint, seems better for on-chip application [5]. The problem of complexity and increase in cost that arises from the use of multiple laser sources for different wavelengths makes WDM also unsuitable for on-chip applications. In Mode-Division Multiplexing (MDM) techniques, each mode of a multimode waveguide is considered as an independent channel that carries data. MDM techniques can increase capacity and reduce footprint. They have shown to be more suitable for on-chip applications [6].

In an MDM system, a mode multiplexer/demultiplexer is one of the important component, as it combines/retrieve data from each modes. Many mode (de)multiplexer have been presented in literature. Dai *et al.* have demonstrated experimentally a small silicon mode (de)multiplexer with cascaded asymmetrical directional coupler [7]. Gui *et al.* have fabricated an on-chip two-mode multiplexer/demultiplexer using a tapered asymmetrical grating-assisted contra-directional coupler-based [8]. Dorin and Ye have presented a design and fabrication of a two-mode SOI ring resonator for MDM systems [9]. Shalaby has presented a simple mode-division (de)multiplexer using a bi-directional coupler supported with a Bragg grating [10].

Here, we propose a simple mode-division demultiplexer using only one waveguide, called J-rib. The structure can demultiplex 3 modes with only one waveguide. That is, the structure is simple and compact in size. In addition, we show that the device has low insertion loss and low crosstalk over a wide bandwidth.

## 2. PROPOSED SYSTEM MODEL

Figure 1 shows the structure of the proposed J-rib waveguide. The length of the device is denoted by  $L$ . The thicknesses

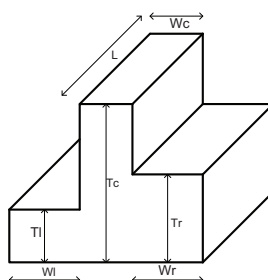


Fig. 1. Structure of J-Rib waveguide.

of the center, right, and left regions are denoted by  $T_c$ ,  $T_r$ , and  $T_l$ , respectively. The widths of the center, right, and left regions are denoted by  $W_c$ ,  $W_r$ , and  $W_l$ , respectively. The concept of our demultiplexer is to keep the fundamental mode in the center region, couple the first-order mode to the right region, and couple the second-order mode to the left region. We developed a theoretical analysis of the proposed demultiplexer by extending the theory of large rib single-mode condition [11, 12]. Using the developed theory, we are able to get the correct conditions for the dimensions of the J-rib waveguide as  $0.5 < T_r/T_c < 1$  and  $0.33 < T_l/T_c < 0.5$ . This would ensure that in the vertical direction only  $HE_{n0}$  and  $EH_{n0}$ ,  $n \in \{0, 1, 2, \dots\}$ , are allowed to propagate in the center, while  $HE_{n1}$  and  $EH_{n1}$  and subsequently  $HE_{n2}$  and  $EH_{n2}$  are allowed to propagate in the right and left regions, respectively. Finally,  $W_c < 2.75 \mu\text{m}$  would ensure that the fundamental mode stays in the center region. Sweeps of both  $W_r$  and  $W_l$  are done to get the best widths that would ensure first- and second-order modes coupling to right and left regions, respectively.

### 3. FDTD SIMULATIONS AND RESULTS

In this section, we study the performance of the proposed concept for practical use as MDM. We start by designing a multimode strip input waveguide with three TM-like modes, next we design three single-mode output waveguides that are attached to the output of the MDM to collect the three modes concurrently. The input waveguide has a thickness of  $1.4 \mu\text{m}$  and a width of  $0.25 \mu\text{m}$  to support 3 modes only. The J-rib parameters are as follows:  $T_c = 1.4 \mu\text{m}$ ,  $T_r = 0.85 \mu\text{m}$ ,  $T_l = 0.49 \mu\text{m}$ ,  $W_c = 0.25 \mu\text{m}$ ,  $W_r = 0.4 \mu\text{m}$ ,  $W_l = 0.4 \mu\text{m}$ ,  $L = 15 \mu\text{m}$ . A 3D FDTD simulation was performed and the results are plotted in Fig. 2. Figures 2(a), 2(b), and 2(c) show the resulting crosstalks and insertion losses versus

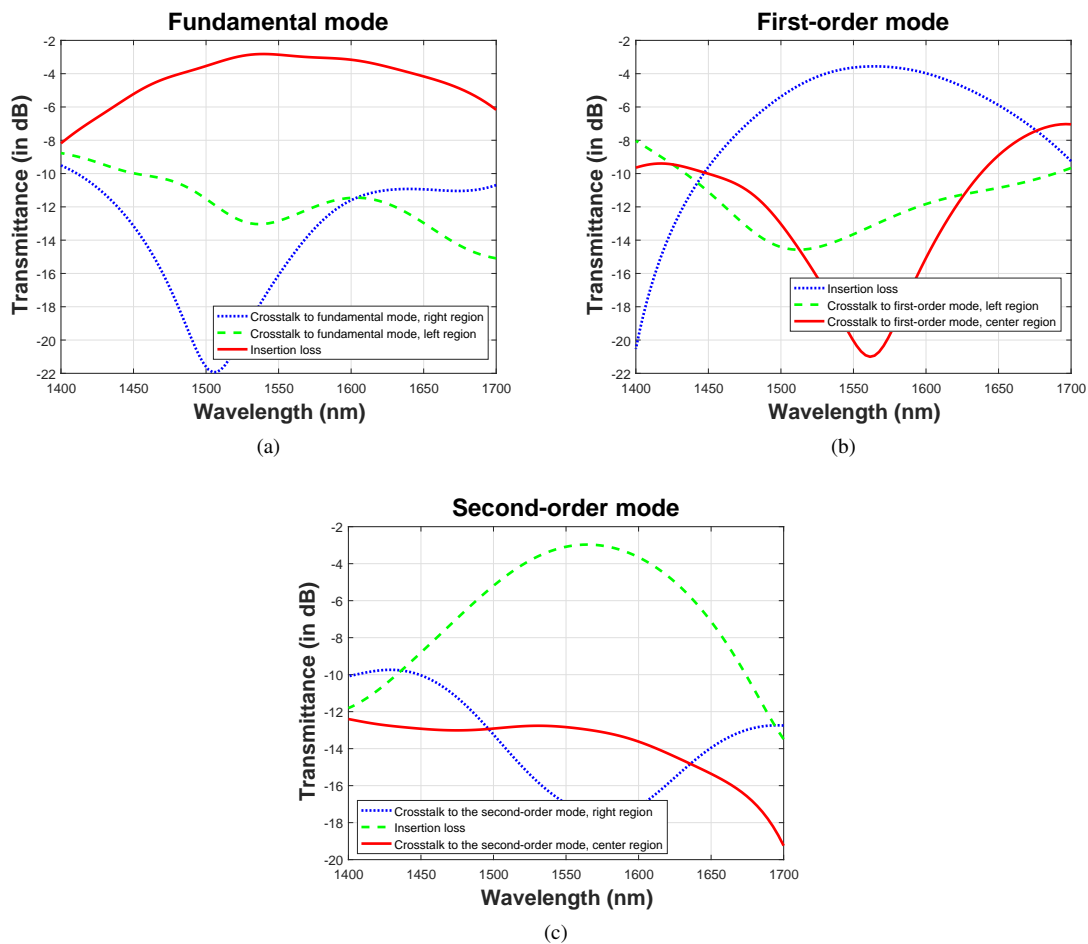


Fig. 2. FDTD simulation of crosstalk and insertion loss versus wavelength of proposed J-rib waveguide.

wavelength when exciting the demultiplexer with the fundamental, first-order, and second-order modes, respectively. It is clear from the figures that the three modes are separated at the three different regions with suitable values of crosstalks among other different modes. Specifically, at a wavelength of 1550 nm, the crosstalk is below  $-12.9$  dB,  $-13.6$  dB, and  $-12.9$  dB, when the J-rib is excited by fundamental, first-order, and second-order mode, respectively. The insertion loss is about  $-2.8$  dB,  $-3.5$  dB, and  $-2.9$  dB for fundamental, first-order, and second-order modes, respectively. The MDM has a good performance over a wide bandwidth of about 100 nm

#### 4. CONCLUSIONS

A rib waveguide with unequal slab thicknesses, called J-rib waveguide, has been proposed as an MDM. The device can demultiplex 3 modes with only one waveguide. The device has a very simple structure with compact size. Its length is about 15 nm. The input waveguide is multimode while the output waveguides are single-mode tapered waveguides. The fundamental mode is kept in the center region of the J-rib and is collected by the center output waveguide. The first- and second-order modes are coupled to the right and left regions of the J-rib, respectively, and are collected by the right and left output waveguides, respectively. Theoretical analysis of the device has been developed as an extension to that of the large-rib single mode conditions. FDTD simulation of the proposed device has been performed to prove the validity of the proposed concept. Our results show that by proper selection of the design parameters of proposed demultiplexer, suitable values of both insertion losses and crosstalks are achievable over a wide bandwidth.

#### 5. REFERENCES

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