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A novel optical waveguide LP_{01}/LP_{02} mode converter

Dongya Shen [a], Changhui Wang [a], Chuan Ma [a], Hakim Mellah [b], Xiupu Zhang [a,b,*], Hong Yuan [a], Wenping Ren [a]

[a] Yunnan Provincial Engineering Lab. of Cloud Wireless Access & Heterogeneous Networks, Yunnan University, Kunming, Yunnan, 650500, China

[b] iPhotonics Laboratories, Department of Electrical and Computer Engineering, Concordia University, Montreal, Quebec, H3G 1M8, Canada

A R T I C L E I N F O

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A B S T R A C T

A novel optical waveguide LP_{01} /LP_{02} mode converter is proposed using combination of bicone structure based on the coupled-mode theory. It is composed of a cladding, a tapered core and combined bicone structure. It is found that this mode converter can have operating bandwidth of 1350–1700 nm, i.e. 350 nm, with a conversion efficiency of ~90% (~0.5 dB) and low crosstalk from other modes

1. Introduction

In the past few decades, the communication infrastructure of connecting the data center servers and personal mobiles and internet of things continues to grow. From the early 1990s to 2000, wavelength-division multiplexing (WDM) optical networks almost met the growing demand for network traffics [1]. However, with the evolution of communication demands and the emergence of new business explosions, such as big data, social networks, real-time games, high-definition audio/video data, artificial intelligence and other high data bandwidth requirements from other applications, requires further higher capacity transmission. The existing WDM optical transmission capacity based on single mode fiber has been exhausted [2,3], and the Shannon limit has been reached [3,4].

To further explore higher transmission capacity, space division multiplexing (SDM) could be an effective way to solve the current optical network capacity shortage [4–6]. Mode division Multiplexing (MDM), a class of SDM, is based on the use of independent (orthogonal) spatial fiber modes to carry parallel signals. These modes are individually excited or converted from other modes, and then multiplexed on the same waveguide or fiber. There are three main ways of space division multiplexing: mode division multiplexing (MDM), core multiplexing [7, 8], and orbital angular momentum (OAM) [9,10]. It is achieved by multiplexing different modes (fundamental and high order modes) of a single core fiber/waveguide, each mode carrying and independent signal. However, mode converters are required and are key devices in the MDM. These converters are necessary to obtain higher order modes from the fundamental mode.

Since 2014, mode converters have been widely studied for MDM. Mode conversion can be achieved either by means of free-space optics or waveguides. Free-space based mode converters match the profile of an input mode to an output mode using phase mask or spatial light modulator [11]. These types of converters are insensitive to wavelengths; therefore, they provide a wide bandwidth operation, but they suffer from high insertion loss in addition to the fact that they are bulky.

Waveguide based mode converters achieve mode conversion by inducing some changes in the characteristics of the waveguide to convert from one mode to another. These changes can be achieved using different techniques, such as periodic fiber grating [12–14], photonic crystal structures [15,16], multimode interference [17], directional coupling [18,19] Y-junctions, lanterns and tapering [20–25]. This type of converters provides high conversion efficiency (i.e., low insertion loss) and are small in size, however, their performances may depend on the working wavelength and therefore some designs only operate in a narrow bandwidth.

Tapered core structures have been widely investigated for mode conversion. Such structures can excite high-order modes from a low order mode (the fundamental mode) by adiabatically changing the cross section of the waveguide (the radius in case of circular waveguide).

In this paper, a structure of multiple bicones is proposed to realize $LP_{01} \rightarrow LP_{02}$ mode conversion. The conversion efficiency and the bandwidth are analyzed. A comparison with the previous similar works is also given.

* Correspondence to: School of information Science and Engineering, Yunnan University, Kunming, Yunnan, 650500, China.
E-mail address: xzhang@ece.concordia.ca (X. Zhang).

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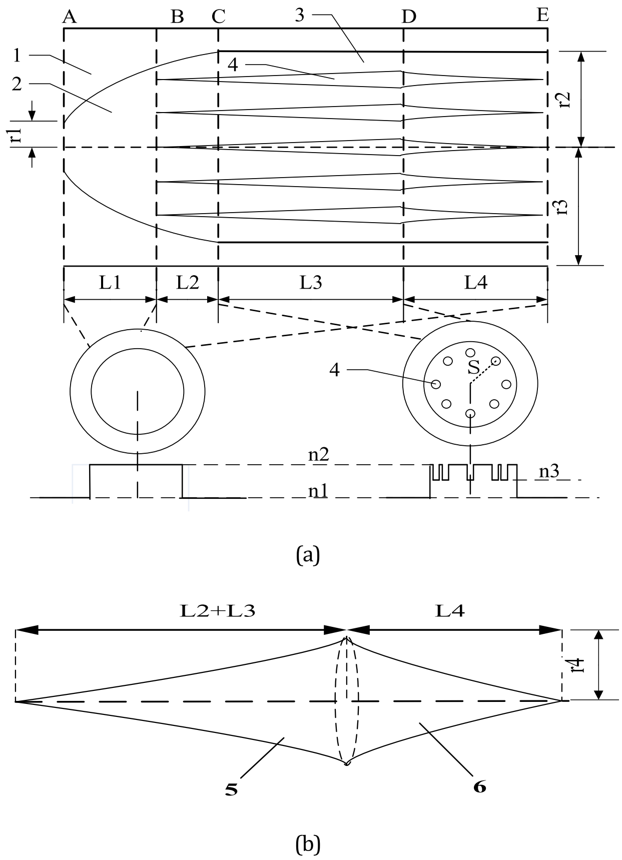

Fig. 1. (a) Longitudinal and transverse views of LP_{01}/LP_{02} mode converter, and (b) longitudinal view of bicone structure.

2. Proposed mode converter

The proposed structure of optical waveguide mode converter with combination of bicone structures is shown in Fig. 1(a), which mainly comprises of three parts: cladding (1) with refractive index n_1, tapered core (2 & 3) with refractive index n_2, and a combination of bicone structures with annular distribution (4). It is seen that there is a tapered core of AC segment, a cylindrical core of CE section, and annularly distributed eight bicones (4). The tapered bicone is shown in Fig. 1(b) with refractive index of n_3.

The specific structural parameters are defined as follows:

(1) Cladding

The structure of the cladding (1) is the same as the conventional step fiber cladding structure. It is a cylindrical structure with a refractive index of n_1, a radius of r_3 and a length of $L_1 + L_2 + L_3 + L_4$.

(2) Conical core

The conical core (2) consists of two parts, the tapered core of the AC segment and the cylindrical core of the CE section. The refractive index of the two parts is the same (i.e. n_2). The radius of the cone at A and C is r_1 and r_2, respectively, and the AC segment has a length of $L_1 + L_2$. The cylindrical core structure of the CE section has a radius r_2 and a length of $L_3 + L_4$.

(3) Combined bicone structure

The circularly distributed structure consists of eight cones with refractive index n_3. The eight cones are distributed circularly in a radius of S. As shown in Fig. 1(b), the two ends of the cones are zero in radius, and the radius at the connection of the cones is r_4. The left/right cone's length is $L_2 + L_3/L_4$. All taper profiles follow an exponential function. Table 1 shows the parameters for the mode converter.

Table 1
Parameters of the mode converter.

Symbol	Values
r_1	3.9 μm
r_2	28.5 μm
r_3	40 μm
r_4	2.06 μm
L_1	510 μm
L_2	350 μm
L_3	1120 μm
L_4	450 μm
n_1	1.495
n_2	1.5
n_3	1.45
S	19 μm

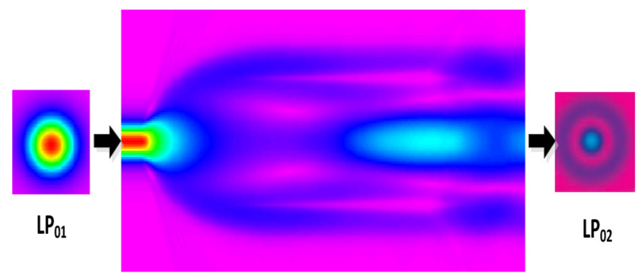

Fig. 2. Electric field evolution of LP_{01}/LP_{02} mode converter.

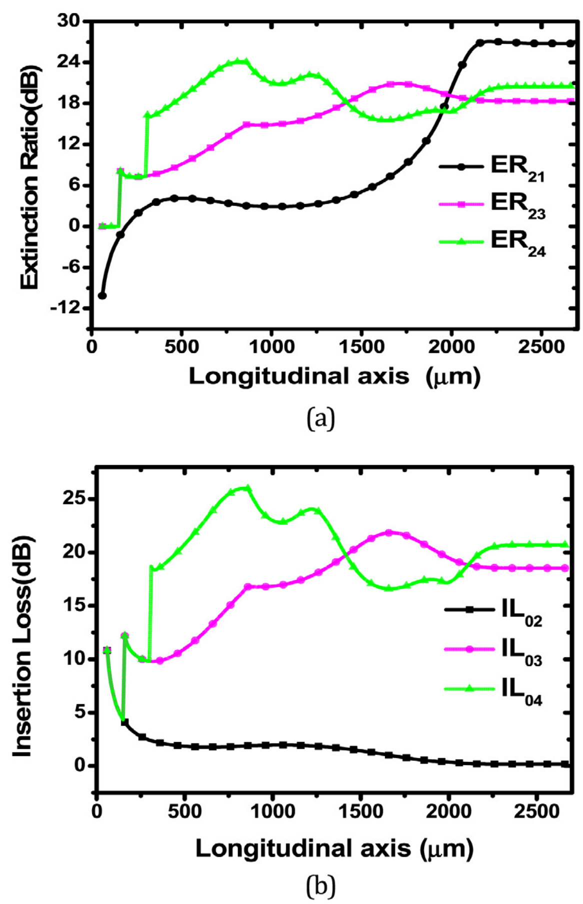

Fig. 3. (a) Extinction ratio and (b) insertion loss along transmission axis.