Design of an Integrated Optical Circuit for Generation of Optical Vortex

Mihai Kusko[1], **Rebeca Tudor**[1], **Stefan Caramizoiu**[1], **Cristian Kusko**[1]
[1] National Institute for R&D in Microtechnologies IMT-Bucharest, 126A Erou Iancu Nicolae Str., Voluntari, 077190, Romania
e-mail: mihai.kusko@imt.ro

ABSTRACT

We present the results of design studies on an integrated optical circuit able to generate optical vortex by superposition of the two first order modes on the horizontal and vertical direction, respectively. The vertical first order mode has been excited by a discontinuity on the vertical direction, the separation of this mode by the remaining fundamental mode has been obtain via a directional coupler. Another very short directional coupler has been employed to transfer the fundamental mode into a first order mode of a larger waveguide. The vertical and horizontal first order modes has been recombined in order to produce an optical vortex.

Keywords: optical vortex, integrated optical circuits, BPM simulations

1. INTRODUCTION

The integrated optical circuits (IOCs) are used for fulfilling various functions as coupling, filtering, splitting, modulation, etc. for a variety of applications in optical signal processing. The IOCs based components are more competitive over their micro optical counterparts in the terms of size, cost, operation flexibility as well as the possibility of integration of optical circuits with various functionalities on a chip. In this context, there is a growing interest in considering IOCs for generation of beams with helical wavefronts presenting orbital angular momentum (OAM), beams which are also known as optical vortices. The beams carrying OAM are mainly employed in communications applications due to the possibility to propagate on the same optical path beams with distinctive OAM states, increasing in this way the overall capacity of the communication channel [1]. Even if the standard method of generation of light carrying OAM is based on micro optic components such as spiral phase plates, the IOCs based devices offer the flexibility, robustness, and miniaturization required for applications. A category of IOCs used for optical vortex generations is based on micro ring resonators with gratings which are emitting the radiation on a direction perpendicular on the IOCs chip [2]. A different approach is based on the generation of the optical vortices with OAM= ±1 inside the waveguides by combining the first excited high order modes with a phase delay between them of $\pm\pi/2$. This approach has been proposed in [3] and [4] for generation of OAM radiation in dielectric waveguides.

In this work we present the results of design studies for optical vortex generation using an integrated optical circuit. Unlike the layout presented in [4] which consists in two types of vertically integrated waveguides situated at different height levels implying a higher level of technological complexity, here we present a configuration based on a single type of waveguide which can be fabricated using a single fabrication process.

2. RESULTS

The configuration of the integrated optical circuit is illustrated in Fig. 1 where the graphical representation of the layout is given by the OptiBPM software 3D viewer [5]. For clarity purposes we partition the layout in three distinctive zones. We consider silicon nitride waveguides (n = 2) embedded in silicon dioxide (n= 1.46). In zone A, there is the input waveguide having a rectangular shape 400 nm thick and 400 nm wide such that it allows only three modes to operate at 635 nm wavelength - the fundamental mode, the first order mode on the vertical direction and the first order mode on the horizontal direction. One can notice that the input waveguide presents a a height discontinuity of 220 nm in order to excite the first order mode on the vertical direction.

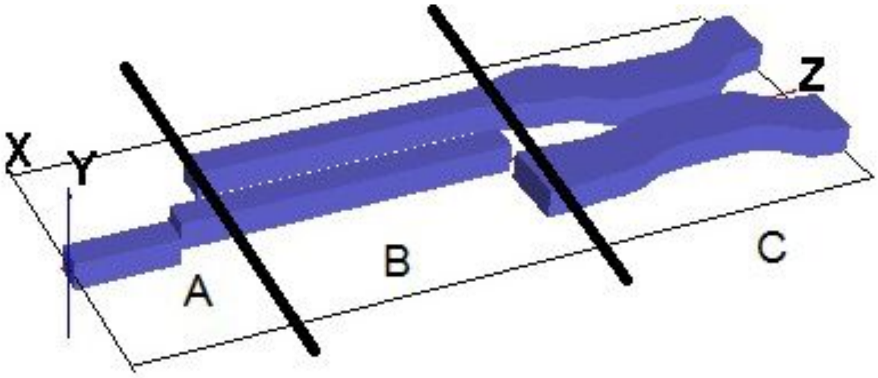

Figure 1. 3D view of the simulation layout.

The radiation propagating in the input waveguide as the fundamental mode is equally split into the vertical mode and the fundamental mode by the discontinuity 220 nm high. The two modes generated in zone "A" (see Fig. 1) are separated in the zone "B" via a symmetrical directional coupler with its length and separation distance adjusted such the vertical order is completely transferred in the lateral left waveguide, while the fundamental mode remains in the input waveguide. The fundamental mode remained in the input waveguide is laterally coupled in a large waveguide as the horizontal first order using matching of fundamental mode of the input waveguide with horizontal first order mode of the larger waveguide. The excitation of the first order mode at the discontinuity is presented in Fig. 2, while the excitation of the two first order modes on two distinct waveguides is shown in Fig 3. The separation of the two modes has the advantage of independently tuning their phase difference such one can obtain a vortex at the end of the integrated optical circuit.

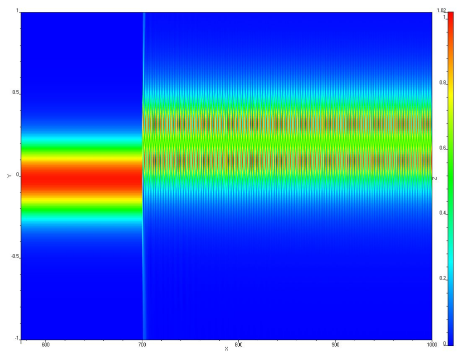

Figure 2. Excitation of the vertical first order mode by the discontinuity present in the input waveguide (lateral view)

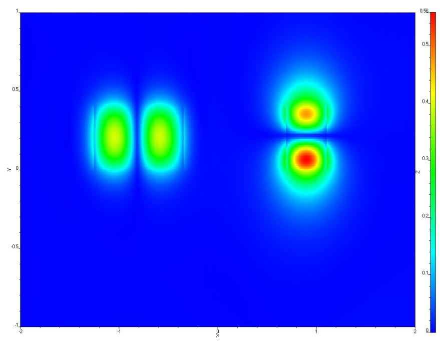

Figure 3. Excitation of vertical and the horizontal first order modes at the end of the section "B".

Once the two first order modes are generated at the end of "B" zone, they are recombined in another directional coupler ("C" zone). At the end of the simulation layout one can notice the generation of the optical vortex. The radiation propagation through the circuit is represented in Fig. 4, and the field configuration at the end of the computational domain showing an optical vortex is represented in Fig. 5.

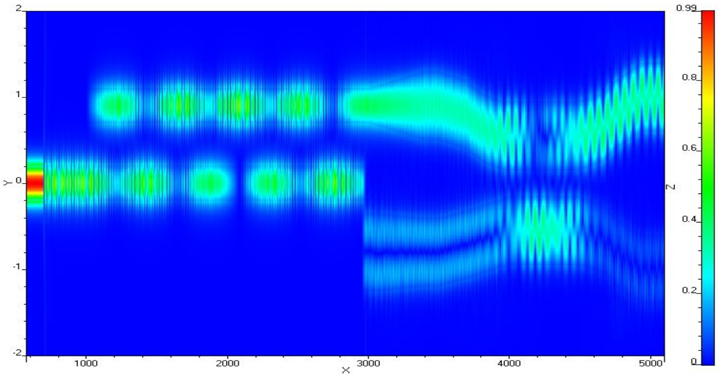

Figure 4 Simulation of the radiation propagation in the layout shown in fig 1..

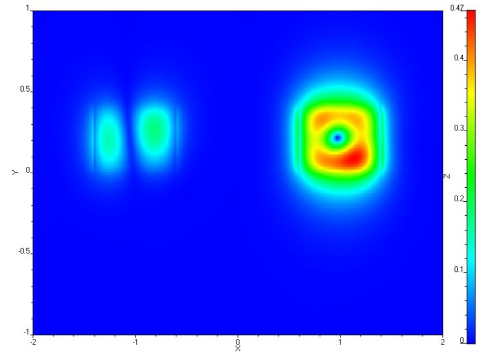

Figure 5 The radiation field at the end of computational domain with an optical vortex propagating in one of the exit waveguides

3. CONCLUSIONS

We have theoretically demonstrated an integrated optical circuit based on silicon nitride waveguides for generation of optical vortex with OAM=±1. The proposed layout does not require vertically integrated waveguides as it was proposed in [4]. The much simpler approach will ease significantly the fabrication process.

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REFERENCES

[1] Nenad Bozinovic et al. in Fibers Terabit-Scale Orbital Angular Momentum Mode Division Multiplexing Science **340,** 1545 (2013);

[2] Cai X, Wang J, Strain M J, Johnson-Morris B, Zhu J, Sorel M, O'Brien J L, Thompson M G and Yu S Integrated compact optical vortex beam emitters Science **338** 363–6 (2012)

[3] Zhang D, Feng X, Cui K, Liu F and Huang Y Generating in-plane optical orbital angular momentum beams with silicon waveguides IEEE Photonics J. **5** 2201206 (2013)

[4] Rebeca Tudor, Mihai Kusko, Cristian Kusko Generation of optical vortices in an integrated optical circuit, Journal of Optics, 19, 095801 (2017)

[5] www.optiwave.com