Single mode ZnO/Al_2O_3 Strip loaded waveguide at 633 nm visible wavelength

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Abstract

In this work, we proposed a technique in which two-dimensional (2-D) confinement of light is achieved in one-dimensional (1-D) planar waveguide by loading it with a low refractive index material. A waveguide design is based on ZnO/Al_2O_3 dielectric materials for integrated photonics. These waveguides are capable of propagating TE and TM polarization at 0.633 μm visible light. Based on these waveguide structures, many optical elements such as S-bend, Y-splitter can be realized which will provide a compact platform for integrated optics.

Keywords: Strip-loaded waveguide; Beam propagation method; visible light; ZnO; Al_2O_3; Y-splitter

1. Introduction

Optical communications through fibre optics have long been the technology of choice for high-speed long distance data links [1]. Gradually, as the capacity requirements have increased, the optical links have developed into shorter distance applications, such as fiber-to-the-home, local area network, and even into fibre optic interconnects between boards and cabinets. Ultimately, optics would be used to interconnect integrated circuits on a board or even to be used in intra-chip interconnects [2, 3]. That is, electrical interconnects, which have dominated since the infancy of electronics, are likely to be substituted with optical interconnects in some cases [4]. The basic component of any optical circuit is the optical waveguide, which is able to connect different optical devices. In order to replace the microelectronic circuits, there is a need to develop integrated optical circuits that contain optical waveguides. These waveguides should be capable of confining the light in a size of the order of the wavelength. Optical waveguides can be categorized conferring to their geometry, the number of modes, refractive index distribution and material. They are designed as energy flow only along the propagation direction of the light but not perpendicular to it, therefore radiation losses can be avoided. Generally, optical integrated waveguides depend on the principle of total internal reflection, using materials with low absorption loss [5-12]. The waveguide cross section should be small to permit a high-density integration, functionally linking devices or systems or implementation of complex functionalities, such as splitters/combiners, couplers, AWGs, and modulators. A wide variety of materials can be used with their corresponding benefits and shortcomings. The improvement of optical interconnects devices including waveguides will continue through a harmonious collaboration among materials and processing technologies, design and fabrication of integrated optoelectronics, and optoelectronic packaging technology [4].

In this paper, we proposed a technique in which two-dimensional (2-D) confinement of light is achieved in one-dimensional (1-D) planar waveguide by loading it with a low refractive index material [13-15]. These waveguides are established on the effective index modification caused by a planar waveguide loaded with a material having a different refractive index, which causes a lateral confinement of light. Eventually, a lateral variation of the effective index is induced, which depends on the dimensions and the refractive index of the top structured region (cladding). As a consequence, a 2D effective index distribution is attained, which is capable of lateral confinement of light. Fig. 1, shows the schematic of the strip loaded waveguide.

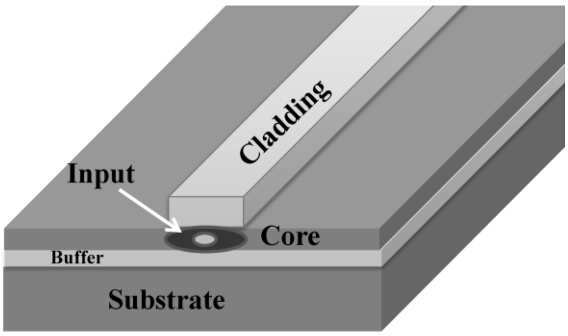

Fig.1. Schematic of strip loaded waveguide, where light propagating in the planar waveguide is confined in 2-D by loading the waveguide with low refractive index material.

2. Modeling of the waveguide

Nowadays, an increasing number of optical modulators, filter and other functions relevant to telecommunication networks have been proposed as integrated or embedded in waveguides [16, 17]. Many of them share the widespread feature of being based on the propagation of the light beam inside a waveguide which has been designed to sustain only its fundamental mode of propagation to allow lower insertion losses when coupled to optical fibres. For the modeling of such waveguides, we propose ZnO (n=1.989 @633 nm) [18] and Al_2O_3 (n=1.766 @633nm) [19] with refractive index contrast (Δn) of 0.223. The materials in which the guided light propagates must avoid scattering and absorption losses in the wavelength range of interest [13]. Three layers are deposited on top of the quartz substrate with Low-High-Low refractive indices. At first thin layer of Al_2O_3 is deposited which acts as a buffer while ZnO functions as a core for the propagation of light. As a final point, a cladding layer of Al_2O_3 is deposited on the top of the core layer. The structuration of the cladding layer can be achieved by means of the method of [11, 20]. This structured cladding layer provides the lateral confinement of the light by a local escalation in the effective refractive index of the planar waveguide. The propagating mode is confined in the region far from the lateral walls of the ridge, which can help to avoid the losses that could arise from the roughness of the etched walls [21].

2.1. Dependence of the propagation power on the thickness of planar waveguide layer

Strip loaded waveguide structures were simulated by using Rsoft Beam Prop software [22] which is based on the beam propagation method (BPM) in order to obtain the optimized geometrical parameters for the propagation of a fundamental guided optical mode at 0.633 µm. The confinement of light under the cladding structure highly depends on the thickness of the planar waveguide. We used different thicknesses of the core layer to monitor the power propagation in the area under the cladding structure. The parameters used in this analysis are shown in table 1.

Table 1. Optimization of core height of strip loaded waveguide at 0.633 µm.

Design no.	ZnO	Al_2O_3	
	Core height, µm	Cladding height, µm	Cladding width, µm
1	0.5	1	3
2	0.7	1	3
3	0.9	1	3

In order to simulate the propagation of light along the z-axis, Implicit Crank-Nicolson scheme was used with a grid size of 0.04 µm in X, Y and Z and by applying the Simple Transparent Boundary Condition (TBC). The power versus propagation distance plot for table 1 is shown in fig. 2, where CW and CH are the width and height of the cladding layer, respectively. The propagation length of the straight strip loaded waveguide is 3 mm.

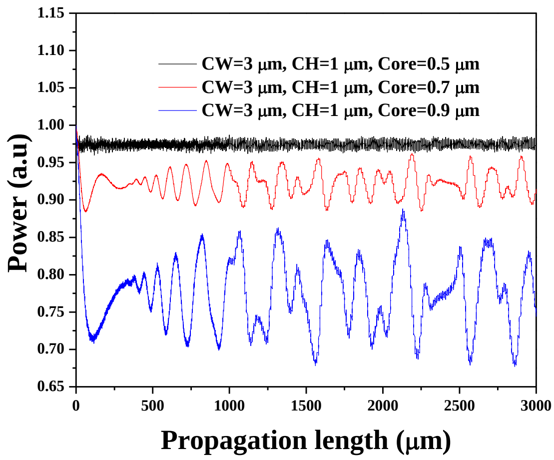

Fig. 2. Power versus propagation distance plot for the designs of straight strip loaded waveguide.

It is well noting that the planar waveguide with a small thickness is able to confine the light better than the layer with a greater thickness, having constant dimensions of cladding layer on top of it. After optimizing the core thickness, next thing is to verify the dependence of cladding width and height on the output.

2.2. Dependence of the propagation power on the width and height of the cladding layer

Cladding dimensions play an important role to confine the light in the planar waveguide by introducing an effective index distribution. In this section, we verify the effect of the cladding width and height on the propagation power in the core. A power monitor equals to the width of the cladding layer is placed in the planar waveguide just under the cladding region. The parameters used in this analysis are shown in table 2, where cladding width is varied by keeping the core height and cladding height constant.

Table 2. Optimization of the cladding width of strip loaded waveguide at 0.633 µm.

Design no.	ZnO	Al_2O_3	
	Core height, µm	Cladding height, µm	Cladding width, µm
1	0.5	1	1
2	0.5	1	3
3	0.5	1	5

The power versus propagation distance plot for the designs (table 2) is shown in fig. 3, where CW and CH are the width and height of the cladding layer, respectively. The propagation length of the straight strip loaded waveguide is 3 mm. From fig. 3, it can be seen that, at 1 µm of cladding width, the light spreads in the full area of the planar waveguide and cladding is unable to provide the confinement under it. That is why a drop of power is observed by the power monitor, whereas, at 3 µm, maximum confinement of light is obtained. However, multimode appears when cladding width goes beyond 5 µm. The width of the launch field was fixing at the width of the cladding layer (in each design) and height of the launch field was equal to the core. From the simulation, it was observed that the height of the cladding layer (thickness= 0.2, 0.5, 1, 2 µm) has no such influence on the confinement of the light in the planar waveguide.

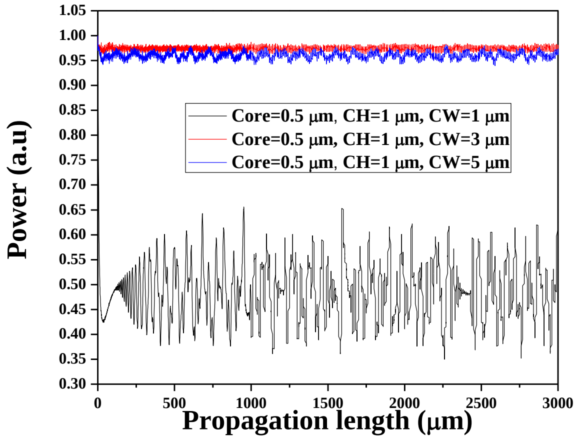

Fig. 3. Power versus propagation distance plot for the designs of straight strip loaded waveguide.

The propagation of light in a waveguide with a design number 1(table 1) and the mode profile at the output of the waveguide is shown in fig. 4. Figure 4(a) shows the top view of the waveguide; it can be observed that the mode is travelling in the core layer confined under the structured cladding. Figure 4(b) shows the mode profile at the output of the 3 mm long waveguide.

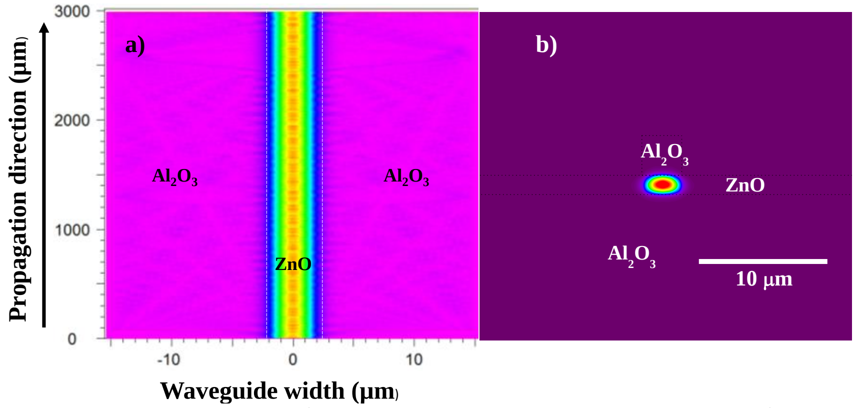

Fig. 4. Straight strip loaded waveguide (Design 1-table 1) with a fundamental mode at 0.633 microns (a) Propagation of light, (b) Mode profile at the output of the waveguide.

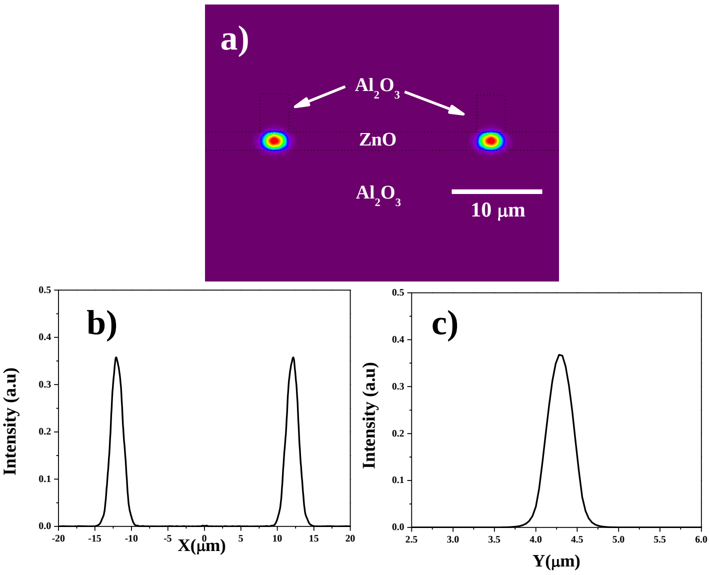

Fig. 5. Simulated results of a strip loaded Y-splitter at 0.633 µm, core height of 1 µm, cladding width and height of 3 and 1 µm, respectively: (a) Mode profile at the output of Y-splitter (b) Horizontal cross-section profile of the mode (c) Vertical cross-section of the mode.

3. Design of a power splitter structure

The behaviour of light in S-bend was investigated by designing a Y-splitter of 10 mm in length. The separation between two arms was kept at a safe distance of 24 μm to avoid any evanescence field coupling between two arms. Fig. 5, shows the simulation results for the Y-splitter structure at 0.633 μm by using Beam Prop software. The S-bend is made up of two matched bends and Y-branch is very long to avoid any field distortion and loss. As is evident from the figure, the optical field at the output of the matched S-bends and in the subsequent straight waveguide section is undistorted. The intensity of 0.36 a.u/arm was obtained in case of Y-splitter with 24 μm of separation between its arms. As a consequence, the fields at the Y-branch output are balanced. The high electromagnetic field confinement in strip loaded waveguide permits the realization of bends waveguides with a small radius of curvature.

4. Conclusion

We proposed a 2-D optical confinement of light in ZnO planar waveguide by loaded with a structured layer of Al_2O_3. Single mode waveguides are modeled by optimizing the core and cladding dimensions of the waveguide with the help of Beam Prop software. These waveguides are polarization independent and are able to guide light both in TE and TM polarization. Based on these waveguide structures, many optical elements such as S-bend and Y-splitter can be realized which can be used for diverse optical applications. A power splitter is also modeled for the visible wavelength of 0.633 μm by using the optimal parameters derived from the straight strip loaded waveguide. The estimation of total losses in power splitter is nearly 27 % in terms of intensity which makes these designs suitable for integrated optics.

Acknowledgements

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