Tunable optical mode converter based on SOI asymmetric channel waveguides

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***Abstract*—An optical mode converter based on asymmetric dual channel waveguides is reported and analyzed. The first channel is infiltrated with nematic liquid crystal (NLC) material while the second one has BK7 glass core. The first higher order mode of the NLC core is coupled to the fundamental mode of the neighboring core with high coupling efficiency. The full vectorial finite difference method is utilized to study the modal characteristics of the reported design. The geometrical and material properties of the proposed mode converter are studied to achieve mode conversion with high wavelength selectivity and compact device length. In addition, the effect of temperature variation is also studied. Compact device length of 515.2 µm is achieved at λ = 1.55 µm. Therefore, the proposed design can be used efficiently in integrated photonic circuits.**

***Index Terms*— Channel waveguides, Liquid crystals, Mode Converter, Coupled mode theory.**

Recently, the mode conversion technology attracted the attention of many researchers to improve the transmission capacity of the optical networks[1,2]. Silicon (Si) is the most used semiconductor material due to its advantages such as high-quality native oxide, high stability with the temperature, easy to form a single crystal with high purity, available in abundance, and superior electrical and thermal characteristics. Silicon on insulator (SOI) technology depends on the fabrication of silicon devices through layered silicon–insulator–silicon substrate, to scale down the parasitic capacitance within the device with enhanced performance[3]. The SOI platform is used to design/fabricate optical waveguides and other optical devices such as electro-optical (EO) modulators and optical sensors[4]. Further, dual-core couplers based on SOI platform are employed in wide applications such as beam splitters[5], multiplexers-demultiplexers[6], and mode converters[7]. In SOI structures, the core region can be easily infiltrated with the NLC material showing great benefits due to the tunability of the LCs against both temperatures and applied electric fields[8,9,10,11]. Furthermore, the NLC infiltration inside the photonic structures including SOI based devices gives a promising usage in mode converter applications[12].

In this work, the proposed design is based on two asymmetric channels where one channel is infiltrated with the NLC material while the other channel has BK7 glass[13]. The basic idea of the proposed mode converter is the coupling between the first higher order mode of the NLC core and the fundamental mode of the BK7 core at a single phase matching wavelength (λ_{PMW}) due to the asymmetry of the two cores[12]. Here, λ_{PMW} can be tuned through controlling the NLC parameters via temperature and/or applied electric field. Due to the anisotropy of the NLC material, only one polarization is coupled from the input (NLC) core to the other one while the other polarization is kept propagating in the launching core with no coupling.

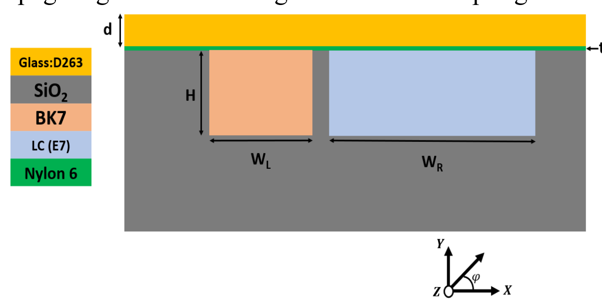

Fig. 1. Cross-section of the proposed ADC-WG.

Figure 1 depicts the proposed structure of the asymmetric dual channel waveguides based on SOI platform. The right core of width W_R is a large rectangular core infiltrated with NLC material of type E7. However, the left core of width W_L is a BK7 solid core. Both asymmetric cores in the Silica (SiO_2) cladding are in the same horizontal level and have the same height (H). Then, a very thin layer of Nylon6 with thickness *t* is mechanically rubbed with a velvet cloth to promote planar, homogeneous alignment of LC, along the longitudinal direction. Additionally, there is an upper cladding glass layer made of glass: D263 with a thickness *d*. The dielectric permittivity tensor of the NLC material is reported in[11] where it has two refractive indices; ordinary refractive index n_o, and extraordinary refractive index n_e. The angle between the director of the rod-like molecules and the x-axis is called rotation angle (ϕ) as shown in Fig. 1. The proposed in-plane alignment of the NLC material can be exhibited through appropriate homeotropic anchoring conditions[14].

According to the coupled mode theory[15], every single core in the dual-core waveguide structures is firstly considered as an independent waveguide. For the proposed asymmetric dual channel waveguides, the power transition will occur at the phase matching wavelength (λ_{PMW}). The coupling strength is decreased by shifting away from λ_{PMW} due to the disappearance of phase matching condition. First, the two cores are studied independently to adjust the phase matching point exactly at the telecommunication wavelength: λ=1.55 µm. Thus, the dispersion characteristics of the studied TE modes in both BK7 core and NLC core at different temperatures are investigated as depicted in Fig. 2. At T=25° C, the phase matching between the two modes supported by the two cores is obtained at λ=1.55 µm at which the two effective indices of the two studied modes are equal (the intersection point) as may be seen in Fig 2. Changing the temperature of the NLC material would affect the n_o and n_e which shifts λ_{PMW} as may be noticed from the different intersection points between the n_{eff} curves of the two modes supported by the two cores: Fig. 2.

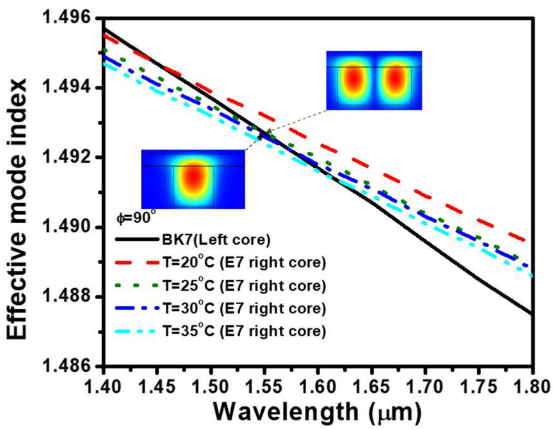

Fig. 2 Dispersion curves of the fundamental TE mode supported by the left BK7 core and those of the first order modes of the NLC right core at different temperatures where φ = 90°.

It is evident from Fig. 2 that there is a strong coupling between the first order TE mode in the right (NLC) core and the fundamental mode in the left (BK7) core. Additionally, the coupling occurs at a wavelength λ=1.55 µm at T=25°C and ϕ=90°. However, at ϕ = 0° (via applying an external electric field), the coupling occurs for the TM modes at the same wavelength i.e., λ=1.55 µm.

Figure 3 depicts the normalized powers of the fundamental TE mode supported in the left core as a function of the propagation distance at different temperatures and ϕ=90°. The power of propagation is obtained using the Lumerical Software Package[16] depending on the coupled mode theory. It may be seen that nearly 98.5% of the optical power is coupled from the left core to the right core at λ=1.55 µm and T=25°C after a propagation distance of 515.2 µm. Therefore, the reported converter has advantages of high tunability, high convergence efficiency with compact device length.

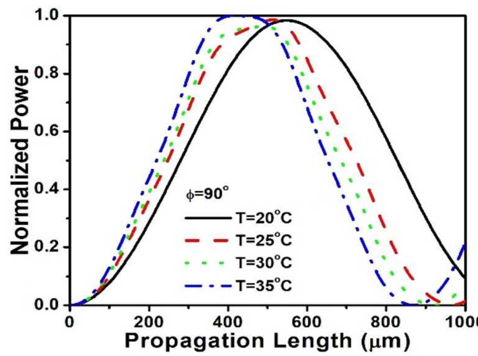

Fig. 3 Normalized powers for TE modes in the left core at different temperatures in the case of ϕ=90°.

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