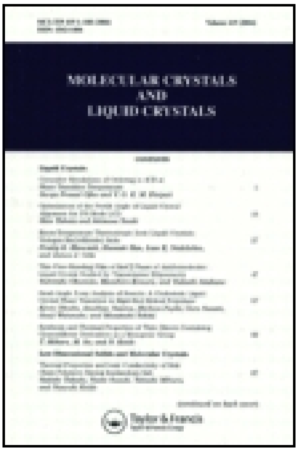

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BPM Analysis of an Integrated Optical Switch using Polymeric Optical Waveguides and SSFLC at 1.55 μm

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BPM Analysis of an Integrated Optical Switch using Polymeric Optical Waveguides and SSFLC at 1.55 μm

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An optical switch using polymeric waveguides and ferroelectric liquid crystals (FLC) has been modelled by using a 3D vectorial beam propagation method (BPM) at the wavelength of 1.55 μm used in optical communications. The switch structure is a vertical directional coupler consisting of a surface stabilised FLC (SSFLC) embedded between two polymeric optical waveguides and ITO layers as electrodes. A polymeric buffer layer has been introduced to reduce losses due to ITO absorption. Polymeric waveguides and buffers used in our analysis can be obtained by different compositions of P(PFS-GMA) (poly(pentafluorostyrene-co-glycidyl methacrylate)). Several devices have been modelled with different values of the refractive indexes of the individual layers. Simulations show the benefits in terms of loss reduction due to the presence of the buffer. An optimised device presents an extinction ratio of more than 50 dB and losses lower than 1 dB with a coupling length of only 174 μm.

Keywords: optical switches; polymers; liquid crystals; integrated optics.

INTRODUCTION

There is an intense scientific activity in the telecommunications area to understand which will be the winning technology to build optical switches, key components for the realisation of optical networks. Great expectations come from liquid crystals and polymers, to make devices with low losses, fast switching (microsecond range), low switching power, bistability, low crosstalk and low cost [1].

A bistable coupled-waveguide switch based on voltage controlled reorientation of a SSFLC has been designed [2] and realised [3] at the wavelength of 632.8 nm. In this paper we present a device based on the same working principle but operating at the wavelength of 1550 nm. Polymers are used for waveguides and buffers, and the active layer is an FLC commercial mixture. Device performances versus several fabrication parameters such as refractive indexes and thicknesses of the structure layers have been analysed. Simulations have been carried out in order to obtain an optimised device in terms of high extinction ratio and low losses. The optimised device shows an extinction ratio of 50.09 dB with a coupling length of 174 μm and losses of 0.95 dB.

DEVICE STRUCTURE AND WORKING PRINCIPLE

The proposed device consists of a multilayer structure (Fig. 1) made of an FLC, FELIX-M4851-025 from Clariant, with a Nylon alignment layer embedded between two polymeric waveguides. Two ITO (Indium Tin Oxide) electrodes to apply voltage for switching the LC are deposited on the substrates. Polymeric buffers are used to reduce losses due to ITO absorption. The polymeric films we used in our design can be obtained by different compositions of the P(PFS-GMA) (poly(pentafluorostyrene-co-glycidyl methacrylate)) [4]. The substrate of the cell is quartz (n_q=1.44462 @ 1550 nm).

In such a device, the transfer of optical power from one waveguide to the other (cross-state) is obtained when TE polarised beam "sees" a LC refractive index higher than that one of the waveguides. Instead when the LC refractive index is lower, the optical power remains in the same waveguide (bar-state).

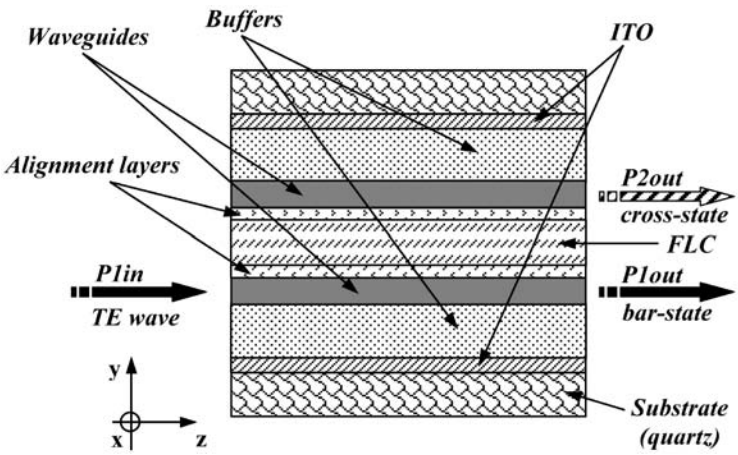

FIGURE 1. Multilayer device structure and working principle.

The liquid crystal molecules of the SSFLC cell are obliged in one of the two stable positions on the smectic cone with angle 2θ. To improve the device performances it is possible to choose the refractive indexes of the liquid crystal by changing the angle α of the normal to the smectic layers respect to the propagation direction z (Fig. 2) [2]. During the switch operation all the molecules move from one position to the other one. The two possible positions refers to bar-state and cross-state of the device.

The refractive index of the liquid crystal depends on the angles α and θ, and from the ordinary and extraordinary refractive indexes values:

$$n_{FLC}^{cross} = \frac{n_e n_o}{\sqrt{n_o^2 \sin^2(\alpha + \theta) + n_e^2 \cos^2(\alpha + \theta)}}$$

$$n_{FLC}^{bar} = \frac{n_e n_o}{\sqrt{n_o^2 \sin^2(\alpha - \theta) + n_e^2 \cos^2(\alpha - \theta)}}$$

The smectic cone angle θ at 25 °C is 26° for the considered FLC mixture.

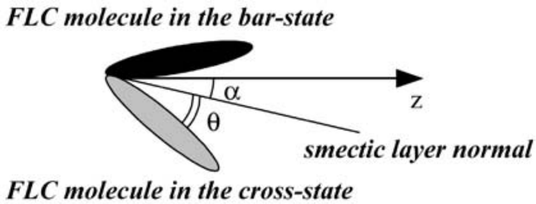

FIGURE 2. FLC molecules orientation in bar-state and cross-state.

DESIGN AND OPTIMISATION

A study of the device performances has been accomplished at the wavelength of 1550 nm by using a commercial BPM (*BeamPROP^{TM}* by Rsoft, Inc.). In the BPM simulations alignment layers and electrodes have been taken into account for the optimisation. A value of the ITO refractive index equal to 1.9 + i 0.075 have been extrapolated from experimental data of a commercial ITO [2]. A layer of Nylon 6 with a standard thickness of 40 nm and refractive index of 1.5 has been considered in the calculations. The extraordinary and ordinary FLC refractive indexes have been estimated by using a Cauchy dispersion formula [5]. The thickness of the buffer has been chosen of 6 μm to prevent optical field tails in the waveguides to reach the ITO electrodes.

The device design has been optimised by varying the angle α in a suitable range (Fig. 3), the refractive index of the waveguide n_{WG} (Fig. 4), and the refractive index of the buffer n_{BUF} (Fig. 5).

Each point on these plots represents a single simulated device and each graph is carried out fixing all the parameters and changing only ones at a time. The extinction ratio ER is defined as the power in the second waveguide at a given distance z over the power in the launch waveguide 10Log(P2out(z)/P1out(z)). For each device the maximum ER along the propagation direction is calculated and the relatives losses are evaluated for this length. The losses are defined as 10Log(P1in(0)/P2out(z_{MAX})) where z_{MAX} is the propagation length with the maximum ER.

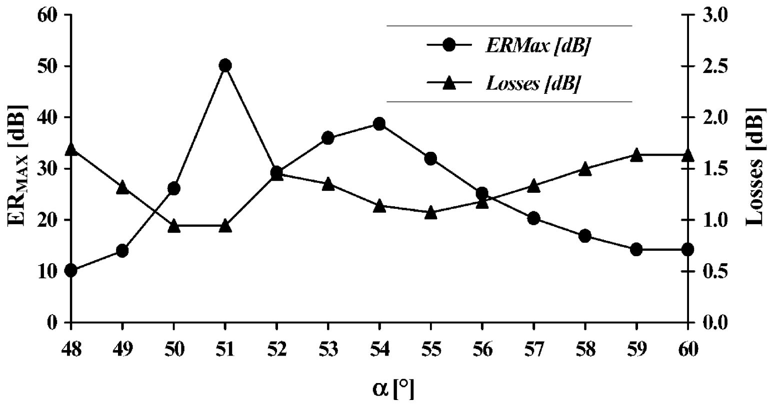

FIGURE 3. Maximum extinction ratio and losses versus α for n_{WG}=1.475, n_{BUF}=1.462.

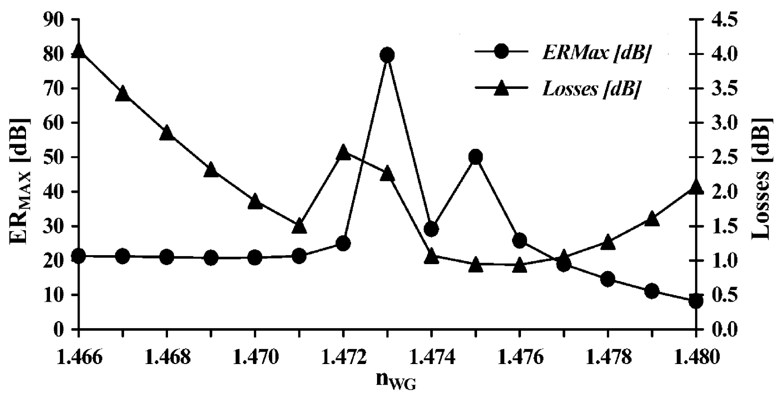

FIGURE 4. Maximum extinction ratio and losses versus n_{WG} for α=51°, n_{BUF}=1.462.

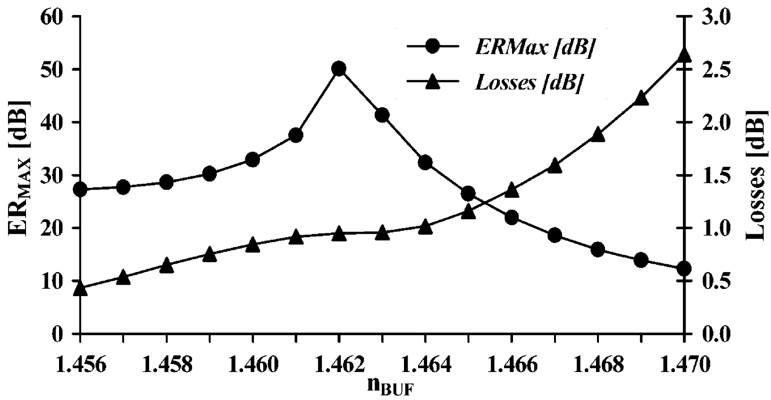

FIGURE 5. Maximum extinction ratio and losses versus n_{BUF} for α=51°, n_{WG}=1.475.

It is interesting to see from the plots of Figures 3, 4, 5 that most of the tested devices exhibit a maximum ER over 20 dB and losses below 2 dB over a wide range of design parameters. Therefore the device shows a good tolerance of fabrication parameters.

Plots of Figures 3, 4 and 5 allowed for an optimised device design, whose parameters are reported in Table 1, in terms of the best extinction ratio and low losses.

d_{FLC} = 5 μm	n_{FLC}^{cross} = 1.479 (α = 51°)
d_{ALL} = 40 nm	n_{ALL} = 1.5
d_{WG} = 3 μm	n_{WG} = 1.475
d_{BUF} = 6 μm	n_{BUF} = 1.462
d_{ITO} = 20 nm	n_{ITO} = 1.9 + i 0.075

TABLE 1. Designed parameters of an optimised device.

Figure 6 shows the evolution of normalised power intensity in the launch waveguide (plain line) and in the other waveguide (grey line), and the evaluation of the ER (bold line) along the propagation direction.

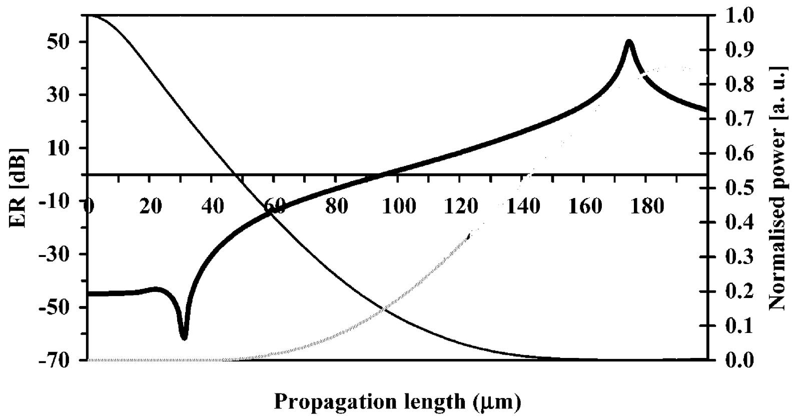

FIGURE 6. ER (bold line), normalised power in launch waveguide (plain line) and normalised power in second waveguide (grey line) for the optimised device with parameters of Table 1.

The maximum transferred normalised power from the first to the second waveguide is 0.847 at a propagation length of 188 μm. The peak of ER is at L_c = 174 μm, the best coupling length for this device, where there is also a good transfer of light from one waveguide to the other one corresponding to an optical power of 0.804.

A 3-D behaviour of the optical field of the optimised device is reported in Figure 7.

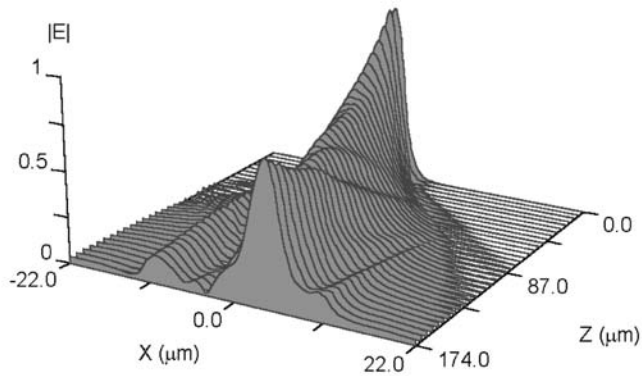

FIGURE 7. 3-D behaviour of the optical field for the optimised device of Table 1.

CONCLUSIONS

A novel optical switch is proposed, based on FLC and polymers at the telecommunication wavelength of 1550 nm. BPM simulations led to an optimised device with an extinction ratio of more than 50 dB and losses less then 1 dB with coupling length of only 174 μm, using 3 μm thick polymeric waveguides. The multilayer structure includes a 6 μm thick polymeric buffer as a separator between waveguides and ITO electrodes (20 nm thick), moreover 5 μm of ferroelectric liquid crystal and an alignment layer of 40 nm.

The benefits deriving from the buffer presence has been investigated, in terms of loss reduction and higher extinction ratios. In particular the same device without buffer gives an extinction ratio of 29.33 dB and higher losses of 1.36 dB.

The possibility to increase the ITO thickness has been also explored to have a more homogeneous and conductive layer. A device with 40 nm of ITO instead of 20 nm leads to higher losses of 5.55 dB without buffer that can be decreased to 1.35 dB by using buffer layers whose thickness is 6 μm. The device can be further improved by optimising the waveguide, FLC cell and buffer thicknesses.

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