Tuning Silicon-On-Insulator Ring Resonators in In-Plane Switching Liquid Crystal Cells

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Abstract—**We show tuning of the resonance wavelength of Silicon-On-Insulator ring resonators with a liquid crystal cladding layer. In-plane switching of the liquid crystal director causes a shift towards longer wavelengths. The magnitude of the shift is 0.7 nm. We confirm our experiments with simulations using a fully anisotropic mode solver and explain the tuning mechanism.**

Keywords-Liquid crystals, silicon-on-insulator, tunable filters

I. INTRODUCTION

Ring resonators are very small and efficient optical filters. They are already used as components for (de-) multiplexers in optical networks. Reconfigurable optical networks require tunable ring resonators to control the filtering of wavelengths. The most common ways to achieve this are heating or carrier injection. In literature, tuning with a liquid crystal (LC) cladding layer has been shown [1,2]. This way, the effective index of the waveguide mode can be influenced and the resonance wavelength of the ring resonators tuned by an externally applied electric field. This is an interesting option as the optical anisotropy of LCs can be large, a birefringence Δn of 0.2 is common in nematic LCs. This allows for wide tuning ranges. It has been demonstrated that with a top-bottom electrode configuration, a shift to shorter wavelengths can be achieved [2]. In this paper we discuss Silicon-On-Insulator (SOI) ring resonators tuned by in-plane switching (IPS) of the LC cladding. In the next section we discuss the cell consisting of the chip, the LC and the electrodes, in the third section we show our experimental results and in the final section we explain our simulations and clarify the tuning mechanism.

II. CELL OVERVIEW

The SOI chip consists of a Si substrate, a 2 μm thick insulating layer of SiO_2 to prevent leakage of light to the substrate and a 220 nm thick Si layer in which the photonic structures are defined. We use ring resonators with radii between 4 and 6 μm. The waveguides are 450nm wide and 220 nm high. The structures are designed to work for TE polarized light, which allows for very small components due to the strong confinement of the mode in the waveguides. The structures are fabricated using deep UV lithography [3]. This mass production technique renders the chips very cheap. Using UV curable glue and spacers with a radius of 1.6 μm we attach a glass plate on the chip. On this glass plate we spincoated a nylon alignment layer. This forces the LC director on the glass-LC interface parallel to the input waveguides of the ring resonators. From experience we know that on the chip surface the director follows the local waveguide structures. On the glass we made Indium Tin Oxide (ITO) finger pattern electrodes of which the fingers are parallel to the waveguides (see Figure 1) and spaced 12 μm apart. When a voltage is applied, there will be an electric field between two neighbouring fingers, orthogonal to the waveguides. We fill the cell with 5CB, a common nematic LC, often used in display technology. Capillary forces draw the LC into the heated cell which is then cooled down gradually to avoid the formation of domains.

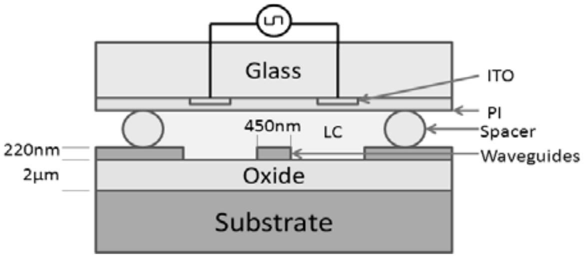

Figure 1. Schematic overview of an IPS cell

III. OPTICAL CHARACTERIZATION

The waveguides on the chip are equipped with grating couplers. These periodic structures are used to couple light (coming in vertically from an optical fiber) in and out of the chip [4]. The couplers have an efficiency of 30%. We use a tunable laser as light source and measure the output with a power meter. We apply a square wave of 1 kHz frequency between the fingers of the electrodes and measure the output spectrum of the ring resonators. For increasing voltages we clearly see a gradual increase of the resonance wavelength. For low voltage levels we see no change as the electric field is too weak to overcome the elastic forces holding the LC. For a certain voltage we can see a clear threshold where the electric fields compensate exactly for the elastic forces. After this Freedericksz transition the resonance wavelength increases until it reaches a saturation level. All the molecules are now

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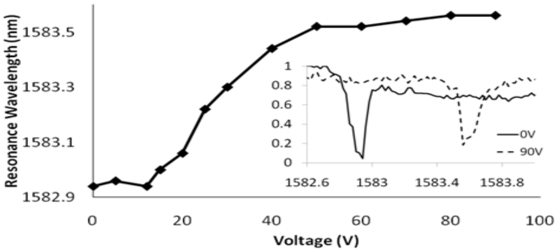

Figure 2. Experimental observation of the change in resonance wavelength for increasing voltage. Spectra for 0V and 90V are shown in inset.

fully reoriented to their maximum twist angle (i.e. perpendicular to the waveguide). We are able to tune the resonance wavelength of the ring resonators towards longer wavelengths over 0.7nm (see Figure 2), which is the largest reported shift for TE based rings.

IV. VERIFICATION OF THE EXPERIMENTS

A. *Simulations*

It is not trivial to calculate the modes of a waveguide with an LC cladding in the presence of an electric field. A first problem is the calculation of the liquid crystal orientation (Figure 3). In this work a variable order calculation [5] is used based on the minimization of the Landau-deGennes free energy functional [6]. This was developed in collaboration with University College London. A second problem is the calculation of the optical waveguide modes. Commercial simulation tools often do not allow full anisotropy. We have developed in collaboration with UCL a mode solver that incorporates the full anisotropy of the dielectric tensor. The output of the liquid crystal orientation calculation is used to calculate the modes. This calculation is based on the solution of the variational form of the curl-curl equation of the electric field, implemented with higher-order edge elements [7]. These two tools allow us to calculate the effective index of the waveguide mode for different voltages. From this the resonance wavelengths can be obtained. The simulation space is 3 µm high and 5 µm wide. At the bottom there is a 1 µm thick layer of SiO_2 with a waveguide on top (220 nm high, 450 nm wide). The electrodes are in the top right and left corner and are spaced 3 µm apart. We calculate the resonance shift in ring resonators based on these waveguides for different voltages. We find a curve very similar to the experimentally found curve (Figure 4). The tuning range is smaller in the experiments. This is because the fingerpatterns only influence a part of the circular ring structure. For an optimized electrode configuration, the simulations predict a range of 6 nm.

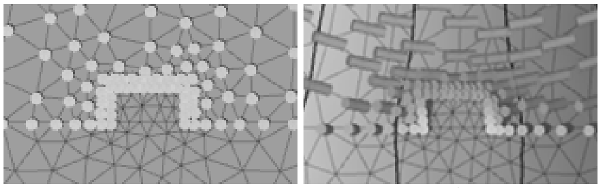

Figure 3. Simulated LC orientation without voltage (left) and with 15V applied (right). Images are close-ups around the waveguide.

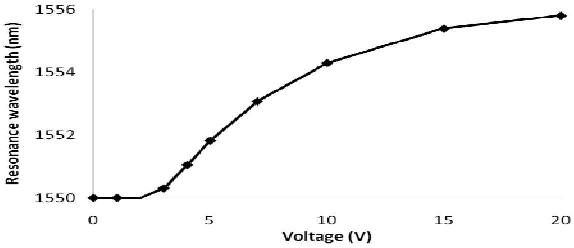

Figure 4. Simulated resonance shift

B. *Tuning mechanism explained*

The evanescent tails of the waveguide mode around the waveguide are for the largest part TE-polarized. Without voltage applied, the LC is oriented parallel to the waveguide and the transversal component of the electric field of the light ‘sees’ the short axis of the molecules and thus a low refractive index results. As the molecules turn under influence of the external field, they present their long axis. This effect causes an increase of the effective index of the mode.

V. CONCLUSION

We have shown tuning of SOI optical ring resonators with an LC cladding in an in-plane switching configuration. With this method we are able to tune the resonance wavelength over 0.7nm towards longer wavelengths.

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