Trimming Silicon-On-Insulator Ring Resonators with a Polymerizable Liquid Crystal Cladding

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Abstract—The trimming of Silicon-On-Insulator ring resonators with a polymerizable liquid crystal cladding is demonstrated. A blue shift of 0.56 nm is obtained. The characteristics of the polymerizable liquid crystal are given, the tuning mechanism is explained and the experimental trimming results are given.

Keywords—trimming of optical filters, polymerizable liquid crystals, silicon-on-insulator

I. INTRODUCTION

There is a growing interest in silicon-on-insulator (SOI) as a platform for integrated optical components [1]. The high refractive index contrast between the silicon core and the oxide cladding (or in this case, LC cladding) enables small bend radii and dense integration. Fabrication of SOI components is relatively cheap because mature fabrication techniques from the CMOS industry are available. When CMOS technology is used for fabrication however, there are small non-uniformities in the critical dimensions of the optical filters. These cause a deviation of the resonances from the desired wavelengths. The most common solution to this issue is placing a resistive heater in the vicinity of the optical filter to shift the resonances by thermal tuning. This is however a power consuming technique since it requires a constant current supply.

In this paper we propose a new solution for the trimming of optical filters using polymerizable liquid crystals (PLCs). In literature, tuning with a liquid crystal (LC) cladding has been shown [2], [3]. By applying an electric field over the cladding the effective index of the waveguide mode can be influenced, causing a shift in the resonances of the optical filter. In this paper a top-bottom electrode configuration is used to influence the longitudinal field component. This causes a blue shift of the resonances that is fixed by polymerizing the cladding, after which the voltage supply is no longer needed.

In the next section the characteristics of the PLC are given. In the third section the cell consisting of the chip, the PLC and the electrodes is discussed and in the fourth section the tuning mechanism is explained. In the final section the experimental results are given.

II. POLYMERIZABLE LIQUID CRYSTAL

A. Composition of the mixture

The PLC used as a cladding on the ring resonators contains three types of reactive mesogens (RM23, RM82 and RM257 from Merck), a small amount of non-reactive LC (<10% 5CB), initiator (Irgacure 815 from Ciba) and inhibitor (t-butylhydroquinone). The initiator enables polymerization by UV illumination. The inhibitor prevents spontaneous chemical reactions with the environment. A combination of different liquid crystals is used to increase the nematic temperature range of the material. In the nematic phase the mesogens can move freely but have orientational order, which leads to anisotropy on a macroscopic scale. The average direction of the main axis of the mesogens is described by a vector called the director.

B. Material properties

To enable characterization of the material by spectrometry it is placed in a cell consisting of two glass plates held at a fixed distance by spacers (radius 3.4 µm). The glass plates are coated with a conducting ITO (Indium Tin Oxide) layer and with a PI (polyimide) layer that is rubbed to align the LC molecules uniformly.

The transmission spectrum of the material between two parallel polarizers was analyzed. The cell behaves as a Fabry-Perot etalon, therefore the distance between two adjacent peaks in the spectrum depends on the refractive index experienced by the light passing through. When the polarizers are perpendicular to the director, the ordinary refractive index $n_o$ of the LC can be determined. We found values that increase from 1.55 to 1.65 for increasing voltage. The filled markers are values before polymerization; the empty markers are values after polymerization.

Fig. 1. Average birefringence of the polymerizable liquid crystal in a cell for increasing voltage. The filled markers are values before polymerization; the empty markers are values after polymerization.
\[
I = M \left( \sin^2 \left( \frac{\pi d \Delta n(\lambda)}{\lambda} \right) \right) + O
\]

where \( \Delta n(\lambda) = (A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}) \). The PLC has a birefringence between 0.24 and 0.28 for \( \lambda = 400-750 \) nm. The calculated values of \( \Delta n \) at \( \lambda = 750 \) nm for five samples are given in figure 1. When a voltage is applied between the ITO electrodes, the molecules in the bulk of the material reorient themselves along the electric field, causing a decrease in the average birefringence. A low-frequency AC voltage is applied to prevent molecular drifts in the LC [4]. The material in each cell is polymerized under a different voltage by UV illumination. Polymerization causes a small decrease in \( \Delta n \) \((< 5\%)\), but the orientation of the mesogens is preserved for the most part. When the voltage is removed after polymerization, the birefringence does not change anymore. The molecules are ‘frozen’ into their reoriented state.

III. CELL OVERVIEW

The SOI chip consists of a Si substrate, a 2 \( \mu \)m thick SiO\(_2\) layer and a 220 nm thick Si layer in which the waveguides (500 nm wide) and ring resonators (radius 6 \( \mu \)m) are defined. The structures are fabricated using deep UV lithography. The SOI chip is covered with a glass plate which is held at a fixed distance by spacers (radius 3.4 \( \mu \)m). There is a conducting ITO layer and a PI alignment layer on the glass plate (Fig. 2). The PI layer is rubbed so that the LC director is forced parallel to the input waveguides of the ring resonators. From previous research it is known that the director follows the waveguide structures on the SOI surface [3]. The PLC is placed near the edge of the heated cell and is drawn in by capillary forces. The cell is then cooled down to room temperature, at which the PLC is in the nematic phase. When a voltage is applied between the ITO layer and the Si substrate, a vertical electric field arises.

IV. TUNING MECHANISM

The longitudinal electric field component of the guided mode is influenced by the reorientation of the mesogens as shown in figure 3. When no voltage is applied, the z-component ‘sees’ the long axis of the molecules and experiences a refractive index \( n_{rz} \). As the molecules align themselves along the electric field, the refractive index experienced by the z-component decreases towards \( n_{rz} \). This causes a decrease of the effective index of the mode and a blue shift in the resonances of the ring resonator.

V. EXPERIMENTAL RESULTS

Light from a tunable laser is coupled into and out of the waveguide on the chip using grating couplers. The output is measured with a power meter. The applied voltage is a square wave of 1 kHz. Below a certain threshold value, the electric field is too weak to overcome the elastic forces between the LC molecules. Above threshold, the resonance wavelength gradually shifts towards lower values. When the molecules are reoriented to their maximum angle, the shift saturates. The maximum shift before polymerization is 0.91 nm. The sample was polymerized under an applied voltage of 50 V, corresponding to a blue shift before polymerization of 0.87 nm. After polymerization the blue shift is 0.56 nm. Further research is needed to determine what the cause of the red shift during polymerization is and whether the magnitude of this shift can be predicted. The blue shift is preserved when the voltage source is disconnected, so we have succeeded in trimming the microring resonator. The trimming range can presumably be increased by applying a higher voltage during polymerization.

VI. CONCLUSION

A polymerizable liquid crystal cladding was proposed for the trimming of optical filters. The results show a maximum trimming range of 0.56 nm.

REFERENCES