Liquid crystal phase shifter integrated in a silicon photonics platform

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ABSTRACT

We demonstrate a compact phase shifter using liquid crystal actuation, integrated in an established silicon photonics platform. The devices are fabricated using IMEC's iSiPP50G platform with a simple post-processing, making this technology compatible with current fabrication possibilities. In this first device demonstration we measure 0.75π phase shift for 10 V actuation over a 60 μm length.

Keywords: compact phase shifter, liquid crystal, integrated silicon photonics, low loss.

1 INTRODUCTION

IMEC's iSiPP50G silicon photonics platforn has become mature over the past few years, and it enables different possibilities to implement thermo-optic phase shifter and electro-optic modulators. [1] The key functional difference between a phase shifter and a modulator is the operation speed, and the trade-off with the strength of the effect. Carrier-based modulation is fairly weak and usually accompanied with a significant insertion loss, while thermal tuners have a stronger effect on the effective index, but are limited in speed and come with a high, constant power consumption. A compact phase shifter with short optical path length requires a strong effect, and are very useful when switching times are not critical to tune devices on a chip.

In this paper we explore the integration of liquid crystal(LC) phase shifters into the existing iSiPP50G platform as a mechanism for slow responding but strong phase shifts. One of the major drawbacks in earlier demonstrations of LC-based tuning was the necessity of a very high voltage to get the required effect [2]. Another demonstration uses a slot waveguide filled with liquid crystal[3], but coupling light into the slot proves to be problematic in itself and the slot waveguide has high optical propagation losses. The phase shift reported by the slot waveguide system is very promising because of the high optical overlap with the liquid crystal and the high electric field between the two actuated halves of the slot waveguides. So in this work we try to achieve a similar actuation effect using the LC as a waveguide cladding, keeping the light confined in a single waveguide core, but using a similar lateral actuation between the waveguide and a narrow bar of silicon on the side of the waveguide core. In addition, we do this without sacrificing any of the functionality in IMEC's platform, so we can combine the LC phase shifters with modulators and Germanium Photodetectors, and use the built-in metallization to contact the LC electrodes.

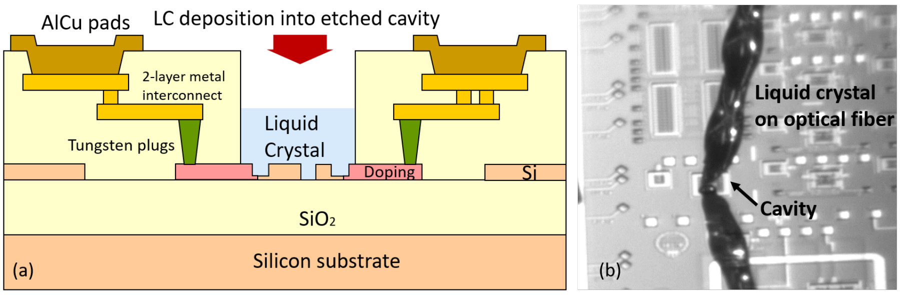

Figure 1. (a) Integration of liquid crystal in iSiPP50G platform (b) Experimental deposition of liquid crystal in etched cavity, using a motorized cleaved fiber as delivery mechanism

2 FABRICATION

The phase shifter has been implemented in the iSiPP50G plaform from IMEC, consisting of silicon with various doping levels and two levels of metal interconnects, as shown in Fig. 1a. One of the features of the iSiPP50G is a local back-end opening step that exposes the top surface of the waveguide. We use these cavities for the liquid crystal. In a short post-processing buffered HF etch, the oxide next to the silicon waveguides is removed, so we can introduce the LC to the side of the waveguide. This post-processing is part of a process flow developed in the MORPHIC project to add MEMS functionality to the iSiPP50G. [4].

In this work, we present the results of a first exploratory attempt to fill such a cavity with liquid crystal. A tweezer is dipped in LC and stroked against an optical fiber. The LC covered fiber was positioned in such an etched cavity, making careful contact with the bottom at low speed to force a capillary flow of the LC into the cavity. To release the droplet from the feeding (depositing) fiber it is pulled up at higher speed, releasing a droplet of LC into the cavity, as shown in Fig. 1b.

3 OPERATION PRINCIPLE

Liquid Crystal (LC) is an an-isotropic material due to the high molecular aspect ratio. The permittivity (and consequently the refractive index) felt by electric field along the ”long direction” of the molecules is higher compared the two other axes. Using this mechanism one can tune the cladding of a waveguide. The modified cladding index leads to a change in the effective index of guided modes in the waveguide core, and this induces a phase delay/shift. LC molecules will align along electric field lines. This is shown in Fig. 2b, where a square wave of 500 Hz is applied, causing a quasi homogeneous electric field in the gap between the silicon structures. The square wave modulation is used to avoid the formation of an ionic charge layer at the edges, which means the average voltage should be zero [3], but the nematic LC molecules we use here still orient themselves along the field direction.

The iSiPP50G platform can connect the silicon device layer with metal contact pads via the 2-layer metal interconnect, tungsten plugs and doped silicon. This enables us to apply an electric field over the gap between two silicon ridges. In [3] this was used to create a strong field in a slot waveguide without resorting to a high voltage. But as slot waveguides have a considerable loss, we create a strong field on the side of the waveguide. The guided modes stays largely confined in the single mode waveguide (450 nm wide), improving the loss dramatically, while still having the possibility of reorienting the molecules without resorting to very high voltages. The smaller silicon electrode (220 nm wide) supports no guided modes at 1550 nm wavelength.

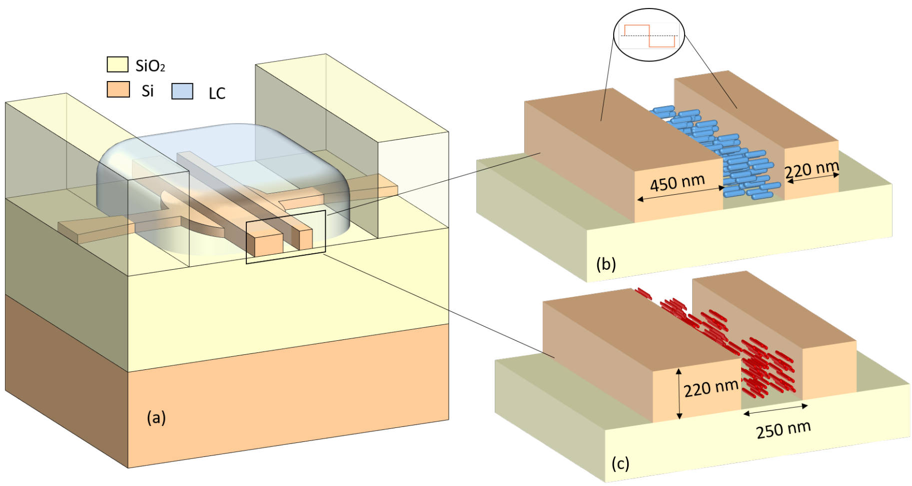

Figure 2. Operation principle of the phase shifter. (a) a shifter with an etched opening with a droplet of liquid crystal, accessed by silicon which is electrically connected to the oxide-clad back-end. (b) LC molecules oriented when a voltage is applied. (c) LC molecules relaxed along the waveguide when no voltage is applied.

Figure 2c shows the orientation of the molecules without an applied electric potential. Mechanical relaxation processes dominate in the liquid crystal, forcing it to align itself in the gap along the longitudinal direction of the waveguide. Note the gap of 250 nm between waveguide and electrode structures, making electric fields for reorientation possible at reasonable voltages.

4 MEASUREMENT AND RESULTS

The phase shifter is designed in an on-chip Mach-Zehnder interferometer (MZI) where one arm has no etched cavity, and the other has the LC phase shifter. In Fig. 3a it is shown a filled cavity can be identified using a visible light camera (the used LC has scattering and absorption loss in the visible wavelength range). The filled cavity blacks out of the camera image, making it distinguishable from the unfilled cavities. Once a liquid crystal drop is deposited in the cavity as discussed in the fabrication process, probes are placed in contact with the metal contact pads and the optical fibres are aligned to sweep the transmission in wavelength, as shown in Fig. 3b. From the measured MZI responses, a phase shift could be determined as function of the applied voltage. These results are shown in Fig. 4. It can be noticed that the LC is not yet in saturation (fully reoriented), but due to the equipment limitations 10 V was the maximum in this experiment. In future measurements will go beyond this voltage to determine an actual $V_\pi \cdot L_\pi$ number.

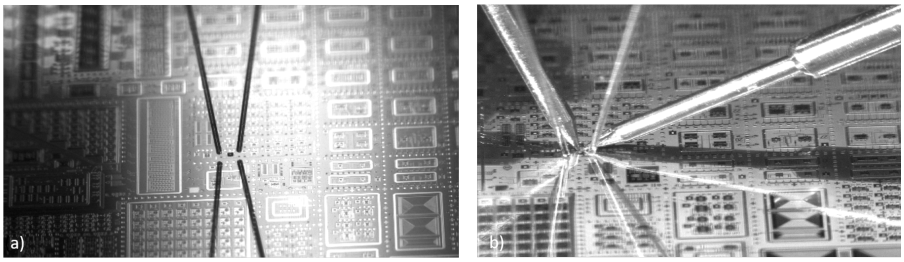

Figure 3. a) Camera picture of a cavity with deposited LC between two cleaved fibres.(b) Measurement setup, with electrical probes for the actuation and aligned optical fibers to vertical grating couplers to measure the MZI transmission spectrum.

For each measured spectra (Fig. 4a), a sine curve is fitted to determine the induced phase shift, which then gives us the response curve of the phase shifter, as shown in Fig. 4b. We see only the initial part of a sigmoid, and moving beyond 10 V we expect that the device will go in a more linear regime, as we have also observed in [3]. These early results are promising, giving almost 0.8π phase shift at 10 V.

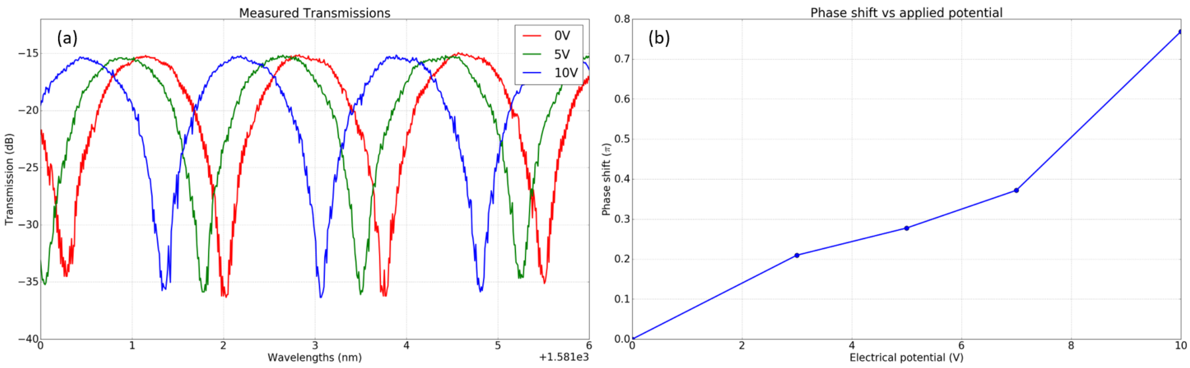

Figure 4. (a) Measured MZI responses for applied potentials of 0 V, 5 V and 10 V. (b) Phase shift for different applied voltages.

5 CONCLUSION

A first attempt to integrate a liquid crystal phase shifter in the iSiPP50G platform has been demonstrated and shows promising results. Future experiments will improve on this device by narrowing the gap, adding a second side electrode, and narrowing the core of the waveguide, which will push the mode more into the tunable liquid crystal cladding. Future measurements will move to voltages beyond 10 V and use a more controlled local deposition system for the liquid crystal. Optimal device parameters (such as gap, waveguide dimensions, electrode dimensions, etch depth, driving frequency, bias voltage, ...) can be determined in future measurements.

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