2022 IEEE Photonics Society Summer Topicals Meeting Series (SUM) | 978-1-6654-3489-8/22/$31.00 ©2022 IEEE | DOI: 10.1109/SUM53465.2022.9858217

Low power phase shifter using liquid crystal on an integrated silicon photonics platform

Lukas Van Iseghem,[1,2] Umar Khan,[1,2], Ewout Picavet,[1,2,3,4] Alain Yuji Takabayashi,[5]
Peter Verheyen,[6] Niels Quack,[5] Klaartje De Buysser,[3]
Jeroen Beeckman [4,2] and Wim Bogaerts [1,2,*]
[1] Photonics Research Group, Ghent University - IMEC, Dept. of Information Technology, Belgium
[2] Center for Nano- and Biophotonics (NB photonics). Ghent University , Belgium
[3] Sol-gel Centre for Research on Inorganic Powders and Thin films Synthesis, Ghent University, Dept. of Chemistry, Belgiu
[4] Liquid Crystals and Photonics Group, Ghent University, Dept. of Electronics and Information Systems, Belgium
[5] École Polytechnique Fédérale de Lausanne, Switzerland
[6] IMEC vzw, 3DSIP department, Leuven, Belgium

***Abstract*—We report a low-voltage optical phase shifter using liquid crystal actuation integrated in IMEC's iSIPP50G platform fabricated using inkjet printing as a deposition mechanism. A π phase shift is obtained at 3Vrms, almost 3π is obtained at 9Vrms. (Abstract)**

***Index Terms*—low power phase shifter, liquid crystal, silicon photonics, integrated photonics**

I. Introduction

A compact low-power, low-loss phase shifter is an essential element for large scale and programmable photonic integrated circuits (PIC). To create compact phase shifters a strong electro-optic (EO) effect is essential, usually this is done using heaters or micro-electromechanical systems (MEMS). Another interesting candidate for compact phase-shifting is presented by liquid crystals (LC), as these materials exhibit a strong anisotropy in optical properties causing birefringence. LC molecules tend to align along an externally applied electric field making them good candidates for low-power compact phase shifters. Previously, LC-based phase shifters have already been demonstrated using high voltages, which are required because of the electrodes are positioned far away from the waveguide to avoid absorption [1]. Low-voltage liquid crystal phase shifts have also been demonstrated using slot waveguides but this technique suffers from high insertion losses due to the transitions and propagation in a narrow slot [2]. In this work, we demonstrate a low-voltage/power phase shifter with lower insertion losses.

II. Operational principle

Our phase shifter consists of a single mode silicon waveguide accompanied by a narrow silicon rail which is optically in cut-off at the operation wavelength (1550 nm). The silicon rail acts as an electrode placed close to the waveguide which makes it possible to attain high electric field strengths for low

This work was supported by the European Research Council (ERC) under grant agreement no. 725555 (PhotonicSWARM) and by the European Union through grant agreement no. 780283 (MORPHIC)

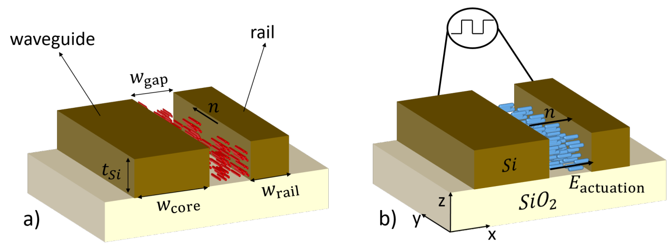

Fig. 1. operational principle a) director aligned in gap without applied voltage b) director reorientation with electric field

or modest voltages. This architecture also allows low insertion loss operation because the light is always confined within the waveguide core without any mode conversion. Without an applied voltage the LC director $\vec{n}$(the average direction of the molecules) is aligned along the direction of propagation (Fig. 1a)). When a quasi-static electric field $\vec{E}_{\text{actuation}}$ is applied (of which the polarity needs to be alternated to avoid ion drift), the LC director rotates, changing the refractive index in the gap (Fig. 1b)). This changes the effective index of the propagating optical mode in the waveguide core, leading to a phase shift. Because the rail is a high refractive index material it also serves as an index perturbation enhancing the index change achieved when actuating.

III. Fabrication

The device was fabricated using IMEC's established iSIPP50G silicon photonics platform. [3] Because this platform has integrated modulators, photodetectors and two layers of Cu interconnects, the back-end-of-line dielectric stack needs to be locally etched to expose the waveguide. This process step is available in the platform, usually to create sensors, creating a local recess of 5-6 μm around the targeted device. After this opening, only the top surface of the waveguides is exposed, so we applied a short timed buffered hydrofluoric acid (HF) etch to clear the sidewalls of the waveguides and

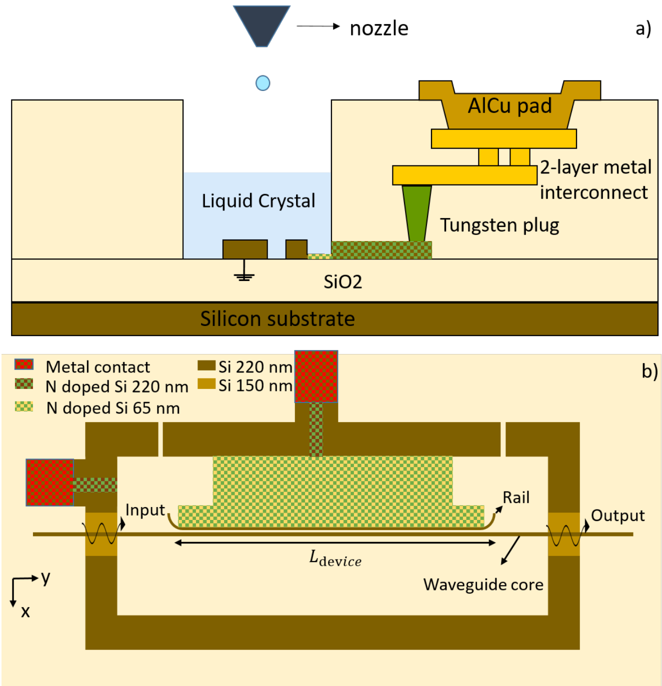

Fig. 2. a) top view of recess with silicon rim b) cross-section of device with inkjet deposition

open up the trench, creating the narrow gap. We then filled the created recess with an E7 liquid crystal mixture using an inkjet printing technique. [4] The inkjet printing has the advantage of localized and controlled deposition, avoiding spillage and interference with other optical components. The working principle is shown in Fig. 2 a).

We have used n-doped silicon as shown in Fig. 2 b) in order to reduce the electrical resistance within the circuit. The optical waveguide is at the ground potential while the voltage is applied to the rail placed next to the waveguide. That creates a cross-section as shown in Fig. 2 a). Results of the deposition are shown in Fig. 3.

IV. Measurement and Results

An unbalanced Mach-Zehnder interferometer (MZI) was designed with a LC phase shifter in one of the paths to characterize the phase shift. We report the results from a device with $w_{\text{core}} = 400nm, w_{\text{gap}} = 200nm, w_{\text{rail}} = 100nm$ and $L_{\text{device}} = 100\mu m$. A square wave of 20 kHz was applied for voltages up to 9 Vrms for these measurements. Results are shown in Fig. 4. A phase shift of almost 3π is obtained at 9 Vrms, while a π phase shift is obtained at 3Vrms. The device seems to suffer from phase flicker, which translates into noise on the wavelength scan. In future experiments we plan a more detailed analysis of this effect, where we expect it to reduce for higher modulation frequencies.

V. Conclusions

We report a low-voltage phase shifter using liquid crystal actuation integrated in IMEC's iSIPP50G platform fabricated

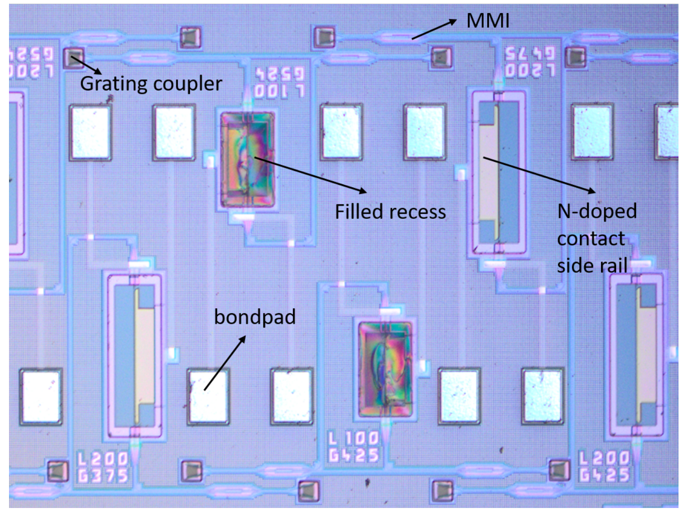

Fig. 3. Deposition results, filled and unfilled recesses can be seen

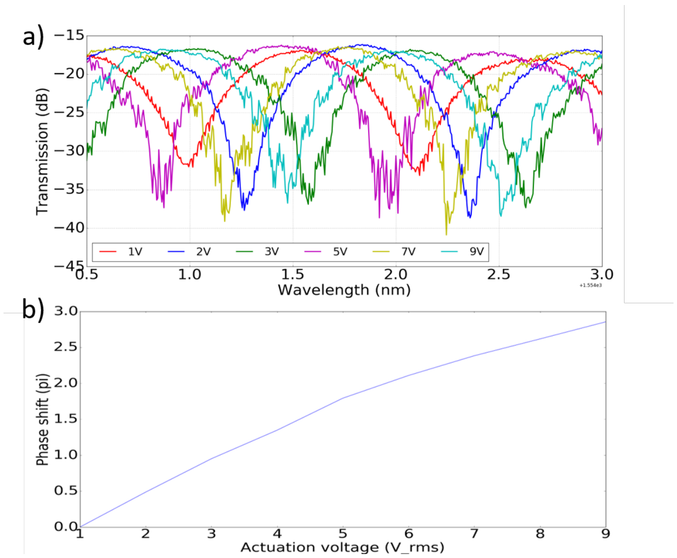

Fig. 4. a) measured spectra of the unbalanced MZI with different applied voltages b) extracted electro-optic response.

using inkjet printing as a deposition mechanism. Results are promising and more elaborate measurements will be performed to get a detailed understanding of the device behaviour and the effect of various design parameters.

References

[1] W. De Cort et al., "Wide tuning of silicon-on-insulator ring resonators with a liquid crystal cladding," Opt. Lett. 36, 3876 (2011)

[2] Y. X. et al., "Digitally Controlled Phase Shifter Using an SOI Slot Waveguide With Liquid Crystal Infiltration," Photon. Technol. Lett. 27, 1269–1272 (2015).

[3] P. Absil et al., "Silicon photonics integrated circuits: a manufacturing platform for high density, low power optical I/O's," Opt. Express 23, 9369–9378 (2015).

[4] M. Moirangthem et al., "A full color photonic polymer, rewritable with a liquid crystal ink," Chem. Commun. 54, 4425–4428 (2018).