

Efficient phase shifter with inkjet-printed liquid crystal on an integrated photonics platform

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In large interferometric circuits on SOI-platforms a high number of phase tuners is required to control the flow of light. Furthermore, reconfigurable circuits rely on the control of the phase in each arm of a balanced Mach-Zehnder interferometer (MZI) to create a 2x2 coupler with full control on the coupling and phase difference between the output ports [1]. Consequently, such circuits require a large amount of phase shifters densely integrated on the chip surface. To enable this, each phase shifter should have a 2π tuning range at a low voltage to ease to co-integration with the driver electronics. Furthermore, as the mesh size increases the insertion loss (IL) should be limited to avoid signal degradation. Since these devices are densely integrated in such circuits, both the footprint and optical length should be as small as possible while avoiding cross-talk between neighbouring devices.

Since in this context the response time is less crucial than the footprint, phase tuners are usually implemented with slower electro-optical effects that have a large tuning range. A well-known established example are thermo-optic phase shifters, but these have issues with crosstalk and power consumption. Alternative techniques that are explored include micro electro-mechanical systems (MEMS), phase change materials (PCM) and liquid crystals (LC). MEMS have issues with yield as they are prone to collapse and usually require high drive voltages (i.e. $V > 10V$). PCM have limited controllability of the phase shift. Slot-waveguides infiltrated with LC can achieve very strong phase shifts at voltages below 5V. However, waveguide transitions to the slot increase IL.

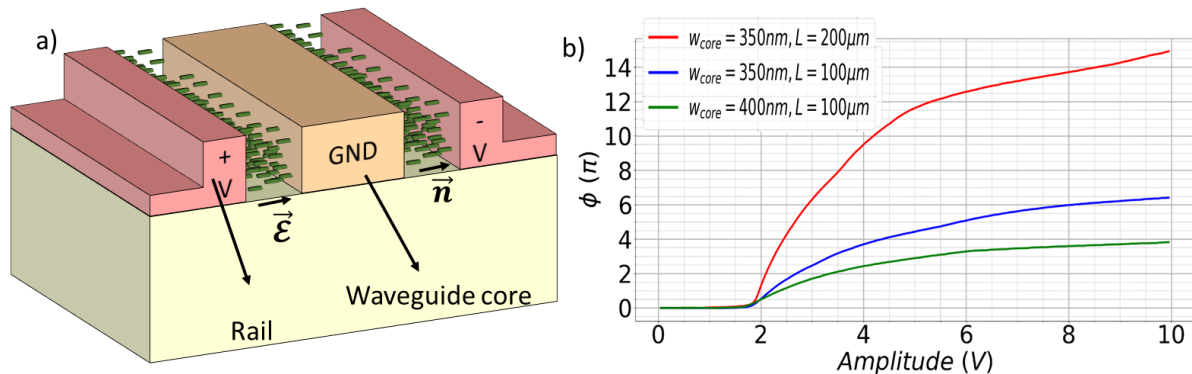


Fig. 1 a) Device architecture showing the single-mode waveguide core accompanied by two doped siderails with applied voltage. b) Measured electro-optic phase shift for different amplitudes of the applied square wave signal. Three devices are characterized.

We demonstrate a new device architecture consisting of a single-mode waveguide accompanied by two doped side-rails functioning as electrodes (which we name a *dual-rail waveguide*). Similar to slot waveguides, the narrow gaps between the waveguide core and side-rail provide an enhancement of the evanescent electrical field. These gaps are filled with liquid crystal which can be actuated at low voltages as the narrow gaps provide high electrical fields at low voltages. While the overlap of the optical mode and the LC actuation is smaller compared to a slot waveguide, the structure is easier to fabricate (as the gaps can be larger than a typical slot width). We have fabricated these devices on IMEC's ISiPP50G platform and perform limited post-processing after which LC is locally deposited with inkjet printing. Measurements show a world record V_π of 2.2V with a device length of 100 μm (see Fig.1b) and an IL below 1dB. We have extensive modelling of these devices explaining operation. These models suggest a power consumption <1nW. Furthermore, we demonstrate a new driving scheme where the time delay between two digital waveforms results in a phase shift.

Example References

[1] W. Bogaerts et al., «Programmable photonic circuits», Nature, vol. 586, n.o 7828, Art. n.o 7828, oct. 2020, doi: 10.1038/s41586-020-2764-0.

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