

# Multi-wavelength heterogeneously integrated lithium niobate on silicon nitride tunable filters and switches.

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## ABSTRACT

Heterogeneous integration of lithium niobate (LN) onto silicon nitride (SiN) enables compact electro-optic tuning by combining LN its strong Pockels effect with CMOS-compatible low-loss SiN photonics. Building on earlier demonstrations of LN-on-SiN all-pass modulators, we demonstrate micro-transfer printed racetrack-shaped LN slabs of 250 nm and 200 nm thickness onto add-drop SiN racetrack resonators to achieve tunable filtering and switching at 1550 nm and 1310 nm. By varying the bus-resonator gap from 510 nm to 710 nm, critical coupling is obtained, with passive measurements showing 26 dB extinction, a 940 pm FSR, and a 24 pm FWHM at C-band.

**Keywords:** micro-transfer printing, lithium niobate, add-drop racetrack resonators

## 1. INTRODUCTION

Integrated photonics is rapidly advancing toward highly scalable, low-power, and reconfigurable optical systems for applications in communications, sensing, and quantum technologies<sup>1</sup>. Among the key building blocks enabling this progress are on-chip tunable switches and filters, allowing dynamic control over light propagation, routing and spectral selection within photonic circuits<sup>2</sup>. Silicon nitride (SiN) has emerged as a leading platform for low-loss photonic circuits due to its wide transparency window, low propagation losses and CMOS-compatibility<sup>3</sup>. However, SiN is intrinsically passive and does not exhibit a significant Pockels effect, limiting EO modulation and switching within SiN circuitry. Lithium niobate on the other hand is a well-established electro-optical material with a strong Pockels coefficient, enabling on-chip tuning<sup>4</sup>. Through heterogeneous integration of LN thin films onto a SiN platform, the best of both of these materials is combined, allowing for CMOS-compatible tunable filters and switches at different wavelength ranges<sup>5</sup>. In this paper, heterogeneous integration of thin-film LN racetrack resonators on SiN add-drop circuitry is presented. Micro-transfer printing ( $\mu$ TP) allows for the fabrication of several TFLN racetracks with different thicknesses, which can be printed on multiple SiN circuits. This enables the fabrication of compact on-chip tunable filters and switches at O-band, C-band and 980 nm.

## 2. FABRICATION

The fabrication of the tunable filters and switches corresponds to these papers<sup>5,6</sup>. The devices are made of LN racetrack resonator source slabs with size 250  $\mu$ m X 500  $\mu$ m, with varying thicknesses of 300 nm, 250 nm, 200 nm and 150 nm. These slabs are encapsulated with resist for additional support, and are suspended before being picked up. Using a PDMS stamp, the racetracks are micro-transfer printed onto low-loss SiN add-drop circuits<sup>7</sup>. Figure 1(a) shows the schematic representation of the  $\mu$ TP process. The platform is made of 300-nm-thick SiN, with a waveguide width of 1.25  $\mu$ m. The coupling gap between the bus waveguides and the SiN racetrack resonator are varied between 510 nm and 710 nm with an

increasing step of 50 nm. The devices after printing are shown in Figure 1(d), where the different colors of the LN racetracks correspond to different slab thicknesses of 250 nm (purple) and 200 nm (yellow), due to thin-film interference. After printing, the devices are finalized with one metallization step. The final device is shown in Figure 1(c), as well as the cross section of the hybrid device, see Figure 1(b).

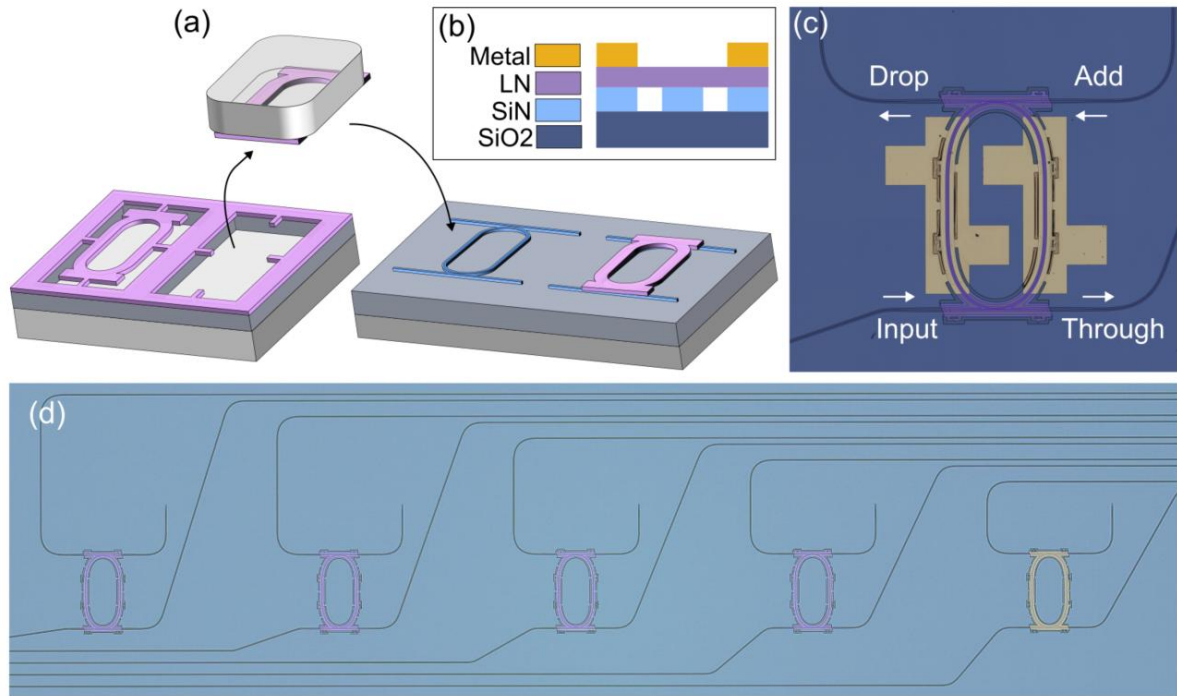


Figure 1. (a) Schematic representation of micro-transfer printing of lithium niobate racetrack slabs onto silicon nitride add-drop resonators. (b) Cross-section of the device. (c) Microscopic picture of the final device. (d) Microscopic picture of transfer printed devices with thickness 250 nm (purple) and 200 nm (orange), before metallization.

By fabricating LN racetrack of different thicknesses, as well as varying the coupling gap of the SiN, more degrees of freedom are available for the manufacturing of these devices. Figure 1(b) shows the cross-section of the device in which the hybrid mode propagates. The thickness of the LN slab influences the tuning efficiency of the device, but also the coupling loss going from SiN circuitry to the hybrid device. Furthermore, these different parameters allow to fabricate on-chip tunable switches and filters at several wavelengths. Through transfer printing onto different SiN add-drop circuits with different waveguide thicknesses and coupling gaps, tunable filters can be fabricated at 1550 nm, 1310 nm and 980 nm using the same source LN racetrack slabs.

### 3. RESULTS

The fabricated devices have been characterized in terms of transmission spectrum of both through and drop port, as well as their tuning efficiencies. Figure 2(b) shows the transmission spectra of both ports of a device with coupling gap 510 nm and LN slab thickness of 250 nm. These spectra indicate a free spectral range (FSR) of 940 pm, an extinction ratio (ER) of 30 dB and exhibit a 24 pm full width half maximum (FWHM) at C-band. Furthermore, the tuning efficiency of both drop and through port has been measured, see Figures 2(c,d). The slope of these graphs indicates a tuning efficiency of 1.7 pm/V. Figure 2(a) presents the transmission spectra of both drop and through port after tuning, as a function of the applied voltage.

Initial measurements at 1310 nm have also been performed at the same device with coupling gap of 510 nm, and LN slab thickness of 250 nm. These result in an FSR of 1560 pm, an ER of 25 dB and a FWHM of 26 pm. However, these measurements indicate that the current devices are under-coupled at the O-band. To address this, new SiN chips are being

fabricated with reduced coupling gaps between the bus waveguides and racetrack resonators, without making any adjustment to the LN source slab. In this way, both improved O-band performance and on-chip tuning at 980 nm is targeted. This allows for potential integration with other functionalities, such as transfer-printed on-chip GaAs single photon sources<sup>8</sup>, where the LN racetracks function as tunable filters. This is currently ongoing and initial co-integration is being investigated.

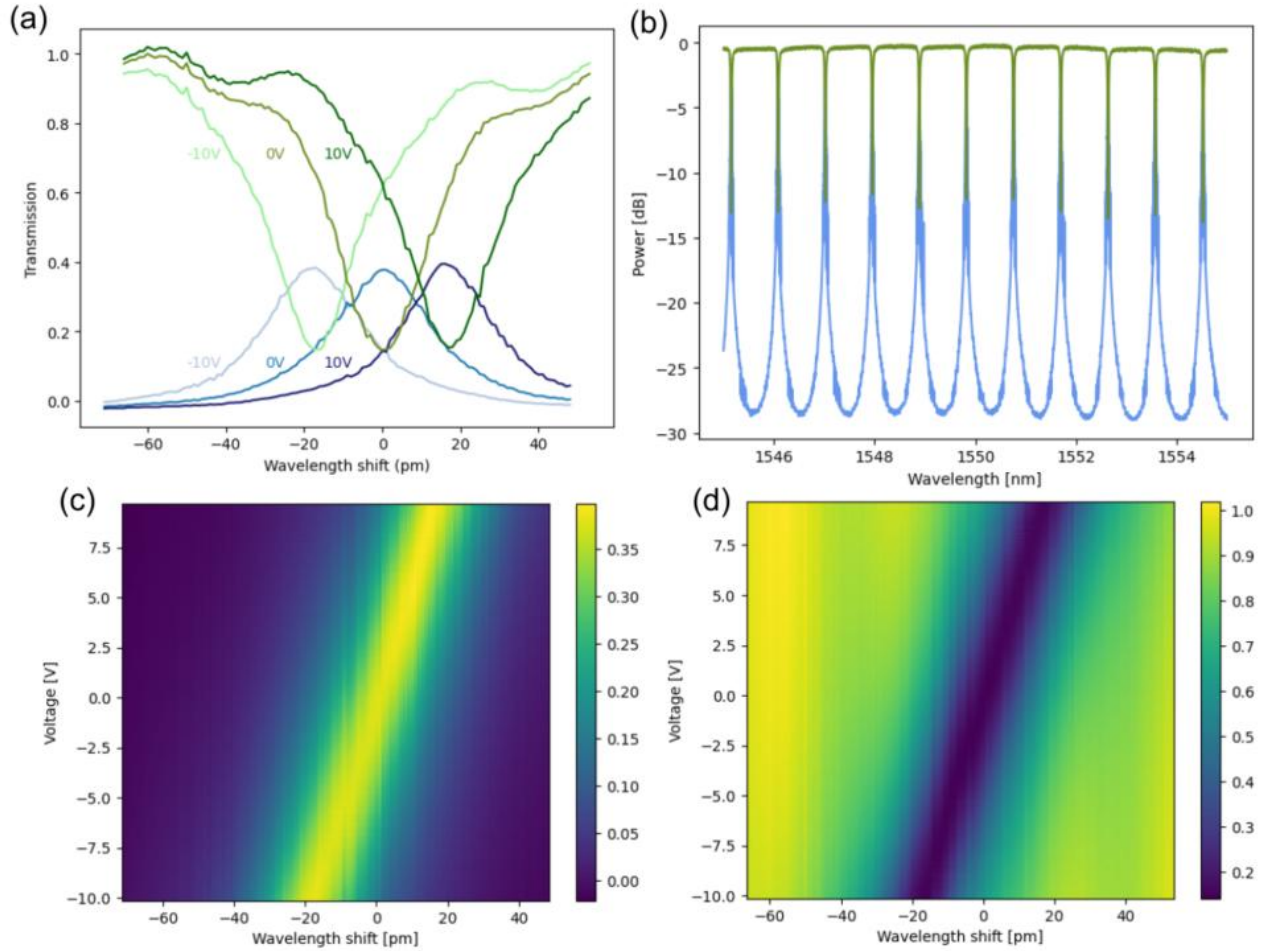


Figure 2. (a) Transmission spectra of the through (green) and drop (blue) port after modulation. (b) The transmission spectrum of the device of through (green) and drop (blue) port. (c) Resonance wavelength shift as a function of the applied voltage of the through port. (d) Resonance wavelength shift as a function of the applied voltage of the drop port.

In conclusion, in this work we demonstrate tunable on-chip filters and switches at 1550 nm and 1310 nm. Thanks to the availability of several source LN racetracks with different thicknesses, as well as the freedom to adjust the coupling gap between the SiN bus waveguide and resonator, these devices can be fabricated at multiple wavelengths. Initial measurements at 1310 nm have been performed, revealing that the current devices operate in an under-coupled regime. Furthermore, this work opens up the possibility of the heterogeneous integration of multiple components onto the same platform, such as on-chip filtering of transfer printed single-photon sources<sup>8</sup>.

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