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Electro-Optically Tunable Modified Racetrack Resonator in Hybrid Si_3N_4-$LiNbO_3$

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Abstract: We experimentally demonstrate the first Si_3N_4-$LiNbO_3$ hybrid electro-optic tunable racetrack resonator with the modified electrode to enhance the modulation efficiency. The measured tunability and the intrinsic Q are 2.8 pm/V and 8×10^6 respectively.

OCIS codes: 040.6040, 130.3730, 250.6715, 250.5300, 230.5750.

The microresonator is a key building block of future photonic integrated circuits (PICs), with applications spanning on-chip data centers, microwave photonics, quantum computing, high sensitivity sensors etc. [1,2]. It offers various functionalities such as optical switching, filtering, high-speed modulation, wavelength division multiplexing (WDM) and frequency comb generation on a chip scale [3]. Silicon-based micro-rings are widely investigated. But due to the intrinsic properties of silicon, the application is limited by its nonlinear response, temperature sensitivity and high insertion loss [4–6]. The Si_3N_4-$LiNbO_3$ hybrid platform has recently been investigated with great potential due to its superior optical properties and the versatile functionality [7–10]. This hybrid material system combines the strong linear electro-optic (EO) effect in $LiNbO_3$ with ultra-low propagation loss, low nonlinearity, small thermo-optic coefficient, and wide optical transparency window of Si_3N_4 to achieve low optical insertion loss, low nonlinearity due to plasma dispersion, ultra-fast modulation and low voltage operation compared to existing tuning methods. Furthermore, a strip-loaded Si_3N_4 waveguide on thin-film $LiNbO_3$ allows $LiNbO_3$ etch free fabrication. The highly confined optical mode together with closely placed RF electrodes significantly reduces the driving voltage required for electro-optical tuning. Generally, the electrodes are placed along its optical micro-ring resonators'. [8]. In $LiNbO_3$, the EO effect in r_{33} crystal orientation dominates. As a result, such a ring structure would fail to take full advantage of r_{33} due to the change in crystal direction along the optical waveguide in the resonators. To attain optimal modulation, the resonator structure needs to be modified to maximize the use of r_{33} and provide a strong modal overlap between the RF signal and the fundamental transverse electric (TE) optical mode.

In this paper, we report a modified Si_3N_4-$LiNbO_3$ hybrid racetrack resonator where the modulating electrodes are placed on both sides of the long arm of the racetrack so that only the r_{33} Pockels coefficient is utilized for wavelength tuning/modulation. The modified structure improves the tunability by a factor of 1.6 over that of the micro-ring resonator [8]. A high intrinsic Q-factor of 8×10^6 is experimentally measured for the proposed resonator structure.

The proposed hybrid racetrack resonator is shown in Fig. 1 (a). The hybrid waveguide core is formed by depositing a 200 nm plasma-enhanced chemical vapor deposition (PECVD) Si_3N_4 strip on top of the 300 nm *X*-cut thin-film $LiNbO_3$ with a 2 µm SiO_2 bottom cladding layer. The thickness and width of the Si_3N_4 strip are 200 nm

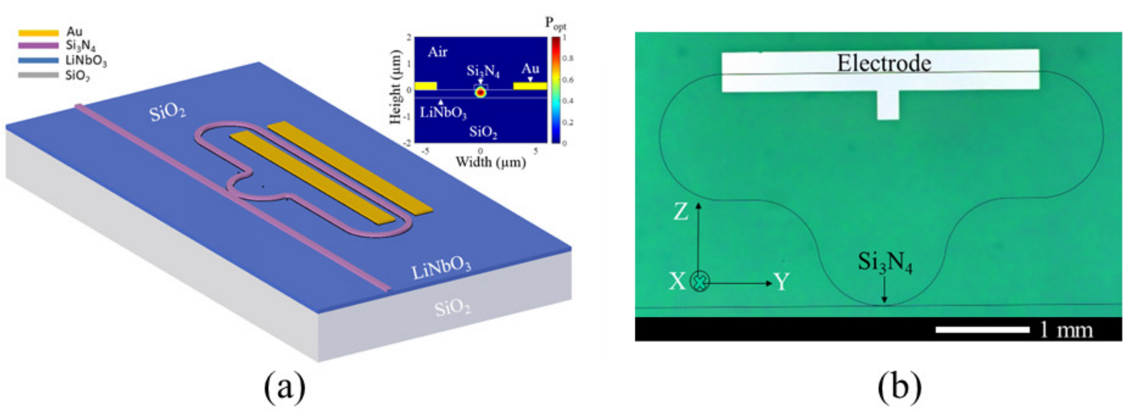

Fig.1. (a) Schematic of the tunable hybrid Si_3N_4-$LiNbO_3$ racetrack resonator with integrated electrodes (not drawn to scale). Simulated TE mode-field profile of a hybrid Si_3N_4-$LiNbO_3$ waveguide formed by a 200 nm × 1.2 µm Si_3N_4 loading strip at 1550 nm (inset). (b) Microscope image of the hybrid Si_3N_4-$LiNbO_3$ racetrack resonator with integrated electrodes.

and 1.2 μm, respectively. The dimensions are chosen to support a fundamental TE mode that offers a bending loss less than 0.01dB/90° bend. The mode confinement factor in the $LiNbO_3$ is ~ 65% for this configuration. The inset in Fig. 1(a) shows the TE field distribution in the straight waveguide section. The modulated racetrack arm is 2 mm long and is connected to the straight bus waveguide by three half circles and two S-shaped bends; all of which have a 300 μm bending radius. The tuning electrodes are patterned on top of the *X*-cut $LiNbO_3$ film with a 6 μm gap centered on the racetrack straight arm. The racetrack is designed such that the device conserves the optical quality factor (bus to racetrack coupling coefficient, absorption loss) and has access to the maximum r_{33} electro-optic coefficient. This design yields strong overlap between the optical and applied electric fields. An optical microscopy image of the fabricated device is shown in Fig. 1 (b).

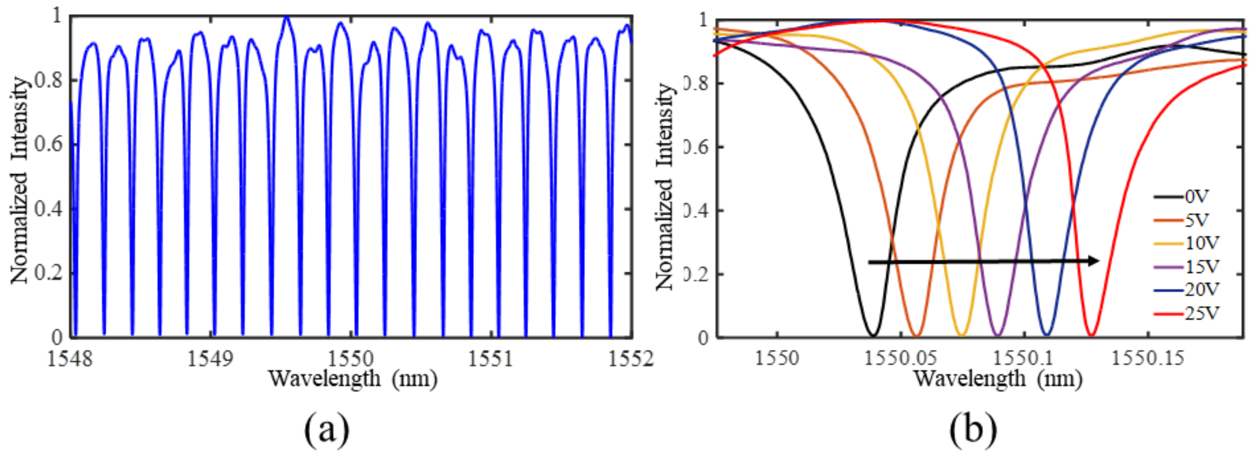

Fig. 2. (a) The measured transmission spectrum of the passive racetrack resonator at the through port for the TE mode using a tunable laser near 1550 nm. The free spectral range is 0.2 nm. (b) The spectrum resonance shift for different DC voltages from the 1550.03 nm resonant wavelength.

The measured transmission spectrum of the modified hybrid racetrack resonator around 1550 nm is shown in Fig. 2 (a). The spectrum exhibits predioc dips and uniform spacing between the adjacent dips. The measured linewidth and free spectral range are $\delta\lambda_{FWHM}$ = 0.016 nm and $\Delta\lambda_{FSR}$ = 0.2 nm, respectively. The intrinsic quality factor of 8×10^6 is extracted at 1550.03 nm by fitting the central transmission dip with a Lorentzian. The tunability of the modified racetrack device is measured by applying a different DC voltage to the device electrodes. The resonance wavelength shifts by 71 pm from the centered wavelength 1550.03 nm for a voltage sweeping from 0 V to 25 V, demonstrating a wavelength tunability of 2.84 pm/V as shown in Fig. 2 (b). The demonstrated tunability is 1.6 times higher than that of our previous micro-ring based resonator [8]. One factor of consideration for this modified structure is the large footprint of the racetrack compared to the micro-ring resonator.

In summary, we demonstrate a tunable modified racetrack resonator using a Si_3N_4-$LiNbO_3$ hybrid platform that exhibits a high intrinsic Q factor along with high tunability of 2.8 pm/V. The modified racetrack design in both optical and electrical domains offers the maximum application of electro-optic coefficient of $LiNbO_3$ to the resonant structure, thereby achieving enhanced modulation efficiency compared to a micro-ring resonator.

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