

# Fano-Resonant Coupled Sagnac Loop Resonator for Enhanced Integrated Refractive Index Sensing

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## INTRODUCTION & AIM

Silicon photonics provides an attractive platform for on-chip refractive index sensing due to its CMOS compatibility, high index contrast, and strong light–matter interaction. Integrated sensors based on microring resonators, Sagnac interferometers, and cascaded resonator networks offer high spectral resolution for label-free detection, but their performance can be limited by fabrication-induced phase errors, limited tunability, and sensitivity constraints. Coupled-resonator optical waveguides (CROWs) have emerged as promising alternatives because multi-cavity interference enables sharp resonances and flexible spectral responses within a compact footprint. Incorporating Sagnac loop reflectors (SLRs) further introduces Fano-type resonances with steep spectral slopes, improving sensing accuracy. Here, we propose a compact refractive-index sensor composed of two inversely coupled Sagnac loop reflectors connected by a feedback waveguide on the SOI platform. Finite element simulations in COMSOL show that introducing a subwavelength grating feedback section significantly enhances refractive-index sensitivity while maintaining a compact and fabrication-tolerant design.

## METHOD

The proposed sensor is implemented on the silicon-on-insulator (SOI) platform and consists of two inversely coupled Sagnac loop reflectors connected through a self-coupled feedback waveguide (Fig. 1). Each Sagnac loop reflector contains a directional coupler and a waveguide loop that supports counter-propagating optical waves. When these waves recombine, wavelength-dependent interference occurs, forming sharp resonances in the transmission spectrum. Coupling two such reflectors allows strong interaction between the optical fields, producing asymmetric Fano-type resonances with steep spectral slopes[1].

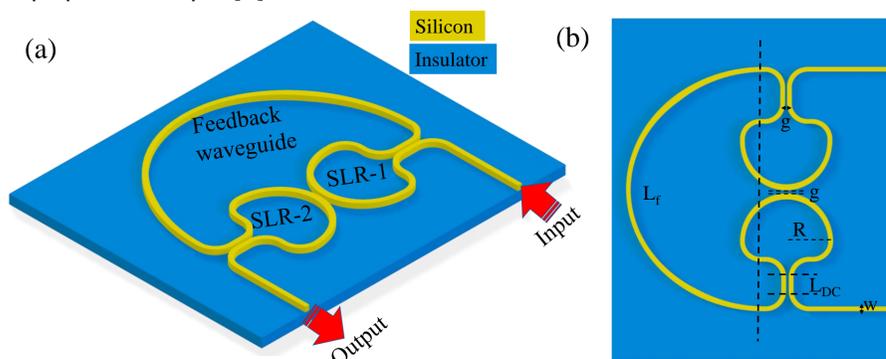


Fig. 1. (a) 3D representation, (b) 2D representation, of CROW-based sensor employing SLRs [1].

For sensing, the loops and feedback waveguide interact with the surrounding analyte through the evanescent optical field. Changes in the refractive index of the external medium modify the effective propagation index of the guided mode, which results in a measurable shift in the resonance wavelength. The device behavior was analyzed using COMSOL Multiphysics based on the finite element method. A two-dimensional effective-index model of the SOI waveguide was used to simulate the transmission spectra across the C-band, enabling evaluation of the spectral response and sensing performance of the proposed structure.

## RESULTS & DISCUSSION

The device was optimized by systematically varying key structural parameters of the coupled-SLR CROW architecture while monitoring the transmission spectrum. First, the SLR loop radius was varied from 2  $\mu\text{m}$  to 5  $\mu\text{m}$  while keeping the coupling gap and directional coupler length fixed, allowing evaluation of its effect on the round-trip optical path and free spectral range. Next, the directional coupler length was adjusted to control the strength of interference between the resonant and broadband transmission pathways, enabling tuning of the Fano-type resonance asymmetry and slope. The coupling gap was then varied to regulate the evanescent coupling strength between waveguides, which strongly influences resonance depth and the formation of distinct Fano features.

Finally, the feedback waveguide length was modified to adjust the overall round-trip phase and spectral spacing of the resonances without changing the cavity geometry. Through this parameter sweep, an optimized configuration was obtained that preserves strong Fano-type resonances with steep spectral slopes suitable for high-resolution refractive-index sensing [1].

## SENSITIVITY ENHANCEMENT

In the conventional configuration with a ridge feedback waveguide, the sensor detects refractive-index variations through shifts in the resonance wavelength. As the surrounding refractive index increases within the range typical for aqueous sensing environments, the transmission spectrum exhibits a systematic red shift of the resonance dips. This behavior confirms strong evanescent-field interaction between the guided optical mode and the external analyte. The resonance wavelength varies linearly with refractive index across multiple resonant dips, yielding sensitivities of approximately 106–120 nm/RIU. The preservation of the asymmetric Fano-type resonance indicates stable interference between the resonant cavity mode and the broadband transmission pathway, enabling reliable refractive-index sensing.

Fig. 2 highlights the sensitivity enhancement achieved by replacing the ridge feedback waveguide with a subwavelength grating (SWG) feedback section. The SWG structure increases the evanescent field interaction in the feedback path by reducing the effective refractive index and allowing greater field penetration into the surrounding medium. As a result, the resonance dips exhibit larger wavelength shifts for the same refractive-index change, while the characteristic Fano lineshape remains intact. The resonance wavelength versus refractive index plots in Fig. 2(b) show sensitivities in the range of 185–212 nm/RIU,  $\sim 2\times$  the sensitivity compared to the conventional ridge-feedback configuration. This improvement arises from the stronger modal overlap with the analyte and enhanced phase modulation within the coupled cavity, demonstrating that integrating the SWG feedback waveguide significantly improves the refractive-index sensing performance of the device.

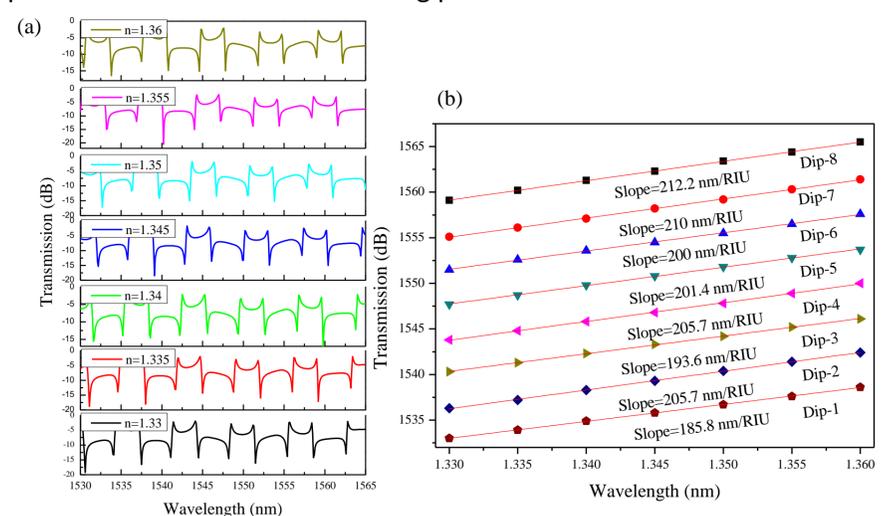


Fig. 2. (a) Simulated transmission spectra of the coupled SLR sensor incorporating an SWG feedback waveguide for refractive indices ranging from 1.33 to 1.36, (b) Corresponding resonance wavelength shift as a function of refractive index for Dip-1 to Dip-8. Device parameters:  $R = 3 \mu\text{m}$ ,  $L_{DC} = 2 \mu\text{m}$ ,  $g = 150 \text{ nm}$ , and  $L_r = 52.62 \mu\text{m}$  [1].

## CONCLUSION

A compact refractive index sensor based on a coupled-SLR CROW architecture on the SOI platform has been numerically demonstrated. The structure supports Fano-type resonances with steep spectral slopes, enabling precise detection of refractive index variations. The conventional design achieves sensitivities above 100 nm/RIU, while integrating a SWG feedback waveguide enhances the sensitivity to  $\sim 212$  nm/RIU. The proposed architecture offers a compact, fabrication-compatible, and highly sensitive platform for integrated refractive-index sensing.

Reference: [1] Muhammad A. Butt, Bartosz Janaszek, A coupled resonator optical waveguide-based refractive index sensor employing sagnac loop reflectors, Sensors 2026, 26(5), 1448.