Optimization of an integrated-optical ring-resonator slow-light-based sensor

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A 3-D, vectorial, and multimodal model that incorporates realistic losses was developed to study the performance of Si₃N₄ based integrated-optical ring-resonator slow-light-based refractometric sensor. Efficient optimization of the coupler gap and tolerance analysis were also performed using the model.

Summary

Integrated-optical ring-resonators have since long been considered as good candidates for enhancing optical sensor performance [1]. Slow-light plays an important role for such enhancement [2]. The light slowness is a result of interplay between the waveguide losses and the coupling constant [2]. Furthermore, the optimal light slowness is a result of trade-off between sensitivity and insertion loss tolerable by the detection electronics. Obviously, optimization is an important part in designing a ring-resonator based sensor.

In this work, we develop a 3-D, vectorial, and multimodal model of ring resonator sensing circuit. The model combines the use of vectorial mode solvers, realistic loss model supported by measurement of prefabricated test structures, 3-D vectorial coupled-mode theory [3] and multimodal transfer matrix method and complex transmission coefficient approach. The model also takes into account the fact that waveguides outside and inside the sensing window are different, and uses realistic waveguide length coming out of mask layout design.

The model was applied to a Si₃N₄-based structure. The straight and ring waveguide cross-sectional structure and dimensions have been chosen as a compromise between single-modeness, available fabrication technology limitations, and losses for operation at visible wavelength. For such realistic structure, the model was applied to find the optimal coupler gap. By taking 20dB as insertion loss budget, operating the circuit at resonant wavelength nearest to 632.8nm, and taking realistic phase detection limit, a theoretical refractive index detection limit of 1.5E-9 RIU was obtained at the optimal gap size with acceptable fabrication technology accuracy tolerance.

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References