Modeling of Slow-light Structure for Sensing of Watery Solutions

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Abstract

Theoretical investigations on the enhancement of integrated optical sensor performance by utilizing the slow-light phenomenon are presented. For this study, we take a sensor consisting of a Mach-Zehnder Interferometer (MZI) layout, which employs ring-resonator-based coupled-resonator optical waveguides (CROWs) slow-light structures in both the sensing and reference arms. The waveguides are assumed to be made of Si$_3$N$_4$ material, grown on a thermally oxidized silicon wafer, and covered by a PECVD grown SiO$_2$ cladding. Through a window etched on top of the CROW section at the sensing arm, the evanescent tail of light traveling in the resonators interrogates the solution to be sensed either directly or through a selective chemo-optical transduction layer. The phase shift between the two arms readout by the interference in the MZI is a measure of the refractive index or the concentration of specific chemical substance of the solution. Using the transfer matrix method and the complex transmission coefficient approach, we modeled the CROW and derived parameters related to the sensing performance and their relation to the slow-light phenomenon. We show quantitatively, how much advantage can be expected by exploiting the slow-light phenomenon in the CROW in terms of sensitivity, resolution, and figure of merit (if compared with a sensor made of ordinary waveguides in terms of chip area and sensing solution volume reduction for the same sensitivity, or sensitivity gain for the same chip area occupation). By taking realistic structure parameters, we obtained that a resolution in refractive index changes down to $2\times10^{-9}$ corresponding to a sensing layer thickness resolution of $10^{-6}$ nm can be obtained with light as slow as $v_g/c=0.01$, using a 3-resonator CROW with ring-resonators with an attenuation constant of 1 dB/cm. For this result, we assume that an insertion loss of 20 dB is tolerable by the detection system and a wavelength in the neighborhood of 0.6328$\mu$m is used. We also show that resonator loss is the parameter, which limits the achievable light slowness and sensor resolution.

Keywords: slow-light, refractive index sensing, coupled-resonator

References