CLOSED LOOP OPTICAL RESONATORS FOR NANO-BIOSENSING

Prabodh Panindre[1*], Sunil Kumar[1,2]

[1]New York University, 6 Metrotech Center, Brooklyn, NY 11201, USA
[2]New York University Abu Dhabi, PO Box 129188, Saadiyat Island, Abu Dhabi, UAE

Optical dielectric closed loop microresonators have been studied in the literature because of their potential applications as interconnects in optical telecommunications circuits, and, more recently, as optical sensing elements for biological and environmental sensing. Whereas most studies have explored the design and performance of primarily circular ring shapes, few have considered optimization of shape and the effects of thermal environment and fluctuations.

The present study examines (i) the effect of geometrical design parameters of a microloop resonator on its optical characteristics with the goal to optimize its performance for label-free detection of nano-size biomarkers, and (ii) the effect of temperature fluctuations on the performance and detection characteristics for such resonators. The sharp resonance peak in the wavelength spectrum serves as the high resolution measurement value, and the highly sensitive dependence of the resonance wavelength on the microloop's environmental conditions is the high resolution signal that detects minute changes due to the presence of biomarkers when all other conditions remain constant.

Geometrical parameters such as the total loop length, the gap for evanescent coupling between the source waveguide and the resonant closed loop, and the waveguide / loop widths are analyzed and quantified for an operational range of wavelengths between 1309-1311 nm for round-cornered square-shaped and circular resonators on a silicon chip. An electromagnetic frequency domain analysis utilizing finite element numerical technique is used. A theoretical coupling model for the resonator-waveguide assembly is also developed. The quality factor of resonance, measuring the sharpness of the resonance peak, is quantified and the optimized. The ability to optically detect a nanoparticle representing a cell vesicle is demonstrated. The enhanced quality factor through optimization allows highly sensitive and rapid detection of biomarkers and measurement of their size.

Although sensitive to temperature variations, the effect on temperature on microresonator performance is often overlooked. The sensitivity of resonance to temperature arises from thermal expansion or contraction based change in physical path length of the loop, and from minute changes in dielectric material refractive index. The multiphysics finite element approach used combines the heat transfer with solid mechanics to understand the micro-level deformation of optical resonator due to thermal heating. This is coupled with electromagnetic frequency domain analysis of Maxwell's equations with temperature dependent refractive indices to quantify the change in resonant frequency. It is found that the temperature induced change in refractive index of the resonator material is the primary driver of change in resonance wavelength, and that thermal fluctuations could exhibit same results as presence of biomarkers. Thus it is imperative that thermal fluctuations be suppressed in order to separate biomarker detection from thermal variations.

[*] Corresponding Author: prabodh@nyu.edu