Modeling of Multimodal Effects in Two-port Ring-Resonator Circuits for Sensing Applications

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Multimodal effects in two-port ring-resonator circuits for sensing applications were modeled using a transfer matrix method and previously published rigorous 3-D modeling tools. Device parameters which are relevant for evaluating sensing performance are numerically deduced from the model. Some examples will be given.

Summary

A two-port ring resonator (TPRR) circuit is an interesting integrated optical structure for sensing applications. One of the widely used criteria for designing such a structure is its monomodality, which leads to a simple and well-understood model. However, achieving such a monomodal condition is not always trivial and may conflict with other design criteria and fabrication technology limitations. For structures based on high-contrast materials, especially in the short wavelength regime (e.g. in the visible wavelengths where absorption of watery solution is low), such a monomodal condition generally requires small waveguide dimensions which might be beyond the capability of the available fabrication technology. In some circumstances, the application of the monomodality requires sacrificing the optimal value of other device parameters. A monomodal waveguide normally has a relatively weakly confined modal profile. Consequently, for such a situation, scattering loss, substrate leakage loss, and bend loss, are generally higher than for a well confined mode. Since modal loss plays an important role as a limiting factor for the resolution of ring resonator sensing platform, enforcing monomodality might end-up with a low resolution.

Considering the implications discussed in the previous paragraph, in some circumstances, relaxing the monomodality design criteria might be an alternative choice. In such design, multimodal effects take place as intermodal coupling is unavoidable, e.g. in the coupler region. We should note that different modes have different values for the modal loss (which implies different values for the required coupling constant to interrogate the sensing analyte effectively) due to different modal field confinement, in addition to different modal effective indices (which implies different values of resonant wavelength). Such differences help to separate the contribution of each individual mode to the response curve of the device. Hence, a multimodal TPRR, if carefully designed, could still work as a good sensing platform. For designing such a multimodal TPRR, a corresponding model is important. In this work, we present a model for evaluating the multimodal effects in the TPRR, using a transfer matrix method and previously published 3-D rigorous vectorial modeling tools (i.e. coupled mode theory [1] and mode solvers [2], [3]), taking also the effect of substrate leakage loss, scattering loss, and bend loss of each individual mode as well as waveguide dispersion and coupling between such modes into account. Using the model, we numerically deduce device parameters which are relevant for evaluating sensing performance, i.e. power transmittance, amplitude transmission coefficients, Q-factor, group index, and sensitivity of transmittance and phase shift to an infinitesimal change in the measurand refractive index. Some examples will be given.

References

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