Biochemical sensing application of photonic crystal based devices in the far-infrared regime

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Peculiar properties of PC open up the potential applicability of them for bio-sensing purposes. We carried out electromagnetic simulations of two-dimensional photonic-crystal waveguide (PCW) and coupled-resonator optical waveguide (CROW) structures created by changing the radii of air holes in a given row to investigate the effects in the terahertz region of the electromagnetic spectrum of introducing small quantities of molecules, such as DNA, in the air holes. The terahertz interaction with the analyte is modeled as a Lorentz medium. The finite-difference time-domain method with recursive convolution is used for numerical analyses. Low group velocity around the photonic band edge and electric-field enhancements in the low-index medium enable significantly enhanced interaction of guided light with the molecular sample. The sensitivity dependence on the CROW structure parameters, such as intercavity distance and cavity type (donor/acceptor), is investigated for the effects in the terahertz region of the electromagnetic spectrum of introducing small quantities of molecules in the air holes. Introducing the absorptive material into the low-index medium greatly affects the shape of the propagating modes of the CROW and the transmitted electric field. The shift of the resonant frequency also depends linearly on the refractive index changes for off-resonant case (dispersive effect). The proposed device is predicted to exhibit sensitivity enhancement over bulk systems and requires a small analyte volume of picoliters.

The spectroscopic change in the transmission spectrum with the sample inserted into the air holes in the waveguide region is monitored to ascertain the effect of and the direct electromagnetic-matter interaction. The guided propagating signal interacts with the dispersion and absorption of the photonic crystal (PC) containing the biological material, which provides the sensing mechanism. The long effective path length over which the terahertz pulse interacts with the biological material was ensured without increasing the actual structure size by ensuring that the propagating mode in the band gap region has low group velocity. Moreover the field was confined largely within the holes where the biological material is placed.

Based on our detailed simulations (results will be presented in the conference), PCW's and CROW for bio-sensing applications are found to be promising. Low group velocity and localization of light in these structures result in enhanced terahertz absorption by DNA molecules (the specific example treated in this study) within the low refractive index medium. Compared with the freespace (bulk) approach, device size can be reduced dramatically, less sample material is needed, and an integrated system can be made with PC's; hence, different molecules could be analyzed simultaneously.