Synthesis of High-Q Linear Photonic Crystal Microcavities Based on a Real-k Band Structure Solver

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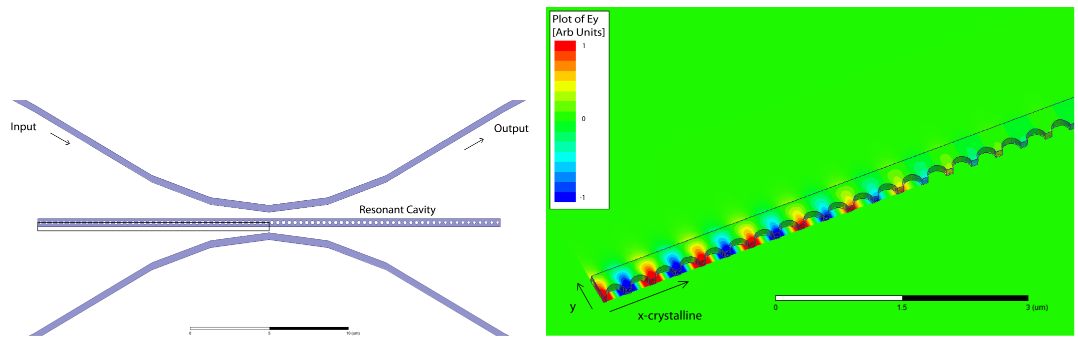
We present a rigorous and fast method for the design of linear photonic crystal (PhC) microcavities with high radiation quality factor (Q) and small modal volume (V) based on 3D, real-k band structure solver simulations. We further build on previous literature by studying critical design parameters including resonant wavelength walkoff, and resonant mode field distribution and its real and k-space engineering. Our approach treats equally efficiently various geometries of periodic structure including holes, slots, or other deformations in the linear waveguide. We compare a number of periodic structure designs, including the inclusion of reflectors such as circular holes and full width slots in a dielectric waveguide to form the cavities.



(a) (b)

Figure 1: (a) Full PhC with coupling waveguides. Boxed portion is shown in Fig. 1b (b) Portion of a 1D PhC with plot of the Electric Field (Ey)

The design method includes defining a unit cell of the crystal and tapering a single degree of freedom. Any parameters of the cavity (hole radius, slot width, guide width, etc.) can depend on this degree of freedom. The conduction (air) and valence (dielectric) bands of the unit cell are calculated at the Brillouin zone edge ($k = \pi/a$), where a is the periodicity of the unit cell and k is the crystal lattice vector, for a range of values of the degree of freedom. This yields the mirror strength as a function of the tapered degree of freedom for a target cavity resonance frequency. By fitting the mirror strength data to a polynomial function, a high-Q cavity can be designed by synthesizing a mirror strength distribution corresponding to a field distribution (e.g. Gaussian) with low radiation loss. Quality factors up to $Q = 10^{10}$ are seen with a mode volume of $V = 1.1(\lambda/n)^3$. The effects on both Q and mode volume are analyzed for different linear tapers. The difference of the target resonance frequency and the actual cavity resonance frequency is also assessed. A number of unit cell geometries are examined and the relationship between the magnitude of the band-gap between the conduction (air) and valence (dielectric) band and Q is examined. This design approach has been used to design PhC resonators for fabrication in standard silicon photonics as well as advanced CMOS electronics-photonics integration.