Evanescent coupling from optical fiber tapers to photonic crystal waveguides and resonators

Paul E. Barclay, Kartik Srinivasan, Oskar Painter

Department of Applied Physics, California Institute of Technology, Pasadena California 91125
phone: (626) 395-6269, fax: (626) 795-7258, email: pbarclay@caltech.edu

Abstract: Using a coupled mode theory and finite-difference time-domain calculations nearly complete evanescent power transfer between a fiber taper and a photonic crystal defect waveguide which is ideal for probing high-Q cavities is predicted.

OCIS codes: (130.2790) Guided waves, (230.7370) Waveguides

Evanescent coupling from fiber tapers to air bridge photonic crystal (PC) waveguides provides a wafer-scale probe of PC devices for applications ranging from optoelectronics to quantum optics. By relying on matching momentum rather than spatial overlap, evanescent coupling circumvents the problems caused by the intrinsic spatial mismatch between PCs and traditional optics. We discuss the general k-space design of a PC waveguide for efficient evanescent coupling to the fiber taper, and show how this same waveguide can couple efficiently to a high-Q (10^5) defect cavity.

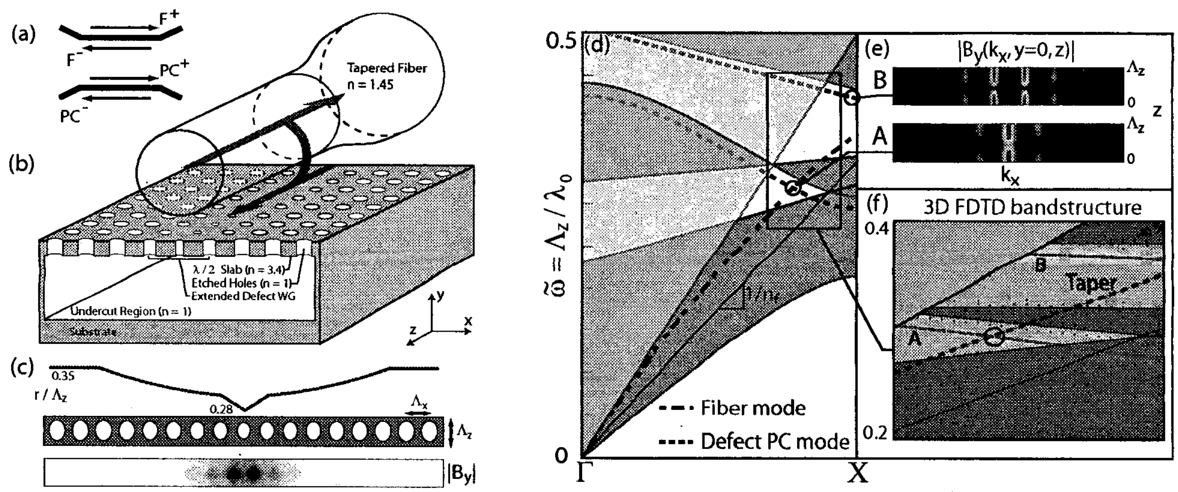

Fig. 1. (a) Schematic of coupling scheme. (b) Coupling geometry. (c) Waveguide unit cell. (d) Effective index bandstructure and fiber taper dispersion. (e) Transverse momentum distribution of defect modes A and B. (f) 3D FDTD PC bandstructure and dispersion for a fiber taper of radius $7\Lambda_z/6$.

Two dimensional PC membrane waveguides are ideally suited to evanescent coupling as their zone-folded dispersion enables optical coupling to waveguides with a dissimilar refractive index, and their undercut structure prevents radiation into the substrate. Evanescent coupling between two parallel waveguides (Fig. 1b) requires that there exist a pair of modes (one in each waveguide) which (i) are phase matched in the propagation direction for maximum power transfer, and (ii) share similar symmetry and transverse Fourier components, resulting in a significant total transverse overlap of their evanescent tails and an acceptable coupling length. Since the fundamental fiber mode varies slowly in the transverse direction compared to the PC, to maximize the PC-fiber coupling the transverse Fourier spectrum of the PC mode must have a large zero frequency component. This corresponds to waveguide modes formed from bulk PC modes whose dominant Fourier components lie parallel to the defect waveguide (the $\Gamma - X$ band in this case). Refering to Fig. 1 which describes coupling to a waveguide formed in a square lattice, mode A satisfies this criteria, while mode B does not. By using a compressed-lattice graded-defect waveguide (Fig. 1c) we obtain a defect mode which couples efficiently to a fiber taper and is ideal for tunneling light into and out of the high-Q cavities designed in

[1]. The graded defect results in a mode profile similar to [1]'s high-Q cavity mode ($|\langle B_y^{\mathrm{WG}}|B_y^{\mathrm{Cav}}\rangle_{xy}| \approx 0.988$), and the compressed lattice matches the frequencies of the waveguide mode and the uncompressed defect cavity mode without requiring any lattice stitching (choosing $\Lambda_x^{\mathrm{PC}} = \Lambda_x^{\mathrm{Cav}}$ requires $\Lambda_z^{\mathrm{PC}}/\Lambda_z^{\mathrm{Cav}} = \tilde{\omega}^{\mathrm{Cav}}/\tilde{\omega}^{\mathrm{PC}}$).

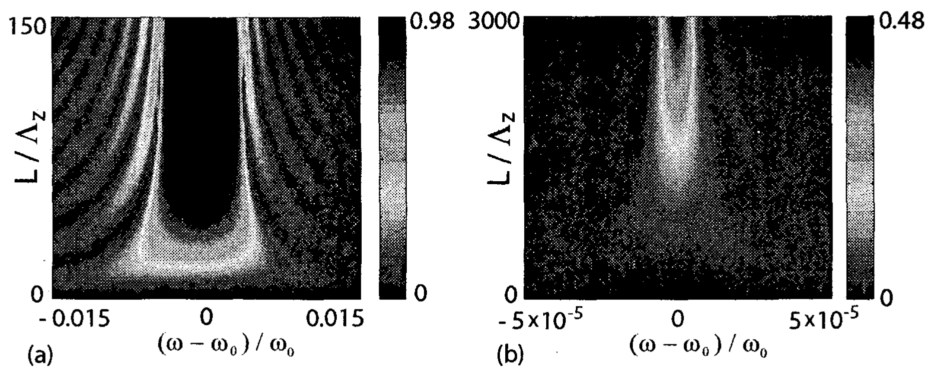

Fig. 2. (a) Coupled power to mode A. The fiber has radius $r = 7\Lambda_z/6$, and is placed $d = \Lambda_z$ above the PC. (b) Coupled power to mode B. $r = 10\Lambda_z/6$ and $d = \Lambda_z$.

Using the coupled mode theory discussed in [2], the power transfered to the PC waveguide (mode A) as a function of coupler length and detuning from phase matching was calculated (Fig. 2a). For $\omega = \omega_0$ and $L = 50\Lambda_z$ the coupled power is greater than 90%, and reaches 98% for $L = 80\Lambda_z$. Additionally, phase matched coupling to mode B was calculated (Fig. 2b) and found to be very weak, consistent with the k-space analysis discussed above. These results suggest that light can be efficiently evanescently coupled into a well designed PC waveguide which can be subsequently used to passively probe the resonant properties of high-Q defect cavities.

References

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