Highly efficient coupling to photonic crystal waveguides from optical fiber tapers

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Abstract: Nearly-complete mode-selective coupling from an optical fiber taper to a photonic crystal defect waveguide is demonstrated experimentally. We observe 95% power transfer with a 20 nm bandwidth and a coupling length less then 65 μm.

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While the theoretical design of novel optical devices employing photonic crystals (PCs) continues to advance rapidly, the experimental demonstration of many of these structures is hindered significantly by the difficulty of efficiently coupling light into and out of them. The large index contrast of PCs results in optical modes with a small length scale and complex mode shape, making direct end-fire coupling techniques from optical fiber or diffraction limited free-space beams extremely inefficient. Recent work studying adiabatic mode converters to increase efficiency of coupling between PCs and semiconductor ridge waveguides as well as optical fibers promises improved efficiency. Another technique, using evanescent coupling from a PC membrane waveguide (PCWG) to a parallel optical fiber taper, elegantly circumvents these problems by burying the adiabatic transition in the fiber taper while exploiting matching momentum rather then spatial overlap to achieve nearly-complete mode-selective power transfer. Here we present the first demonstration of this technique, using a fiber taper as an optical probe to achieve 95% power transfer over a coupling length of less then 65 μm to a linear defect PC waveguide mode.

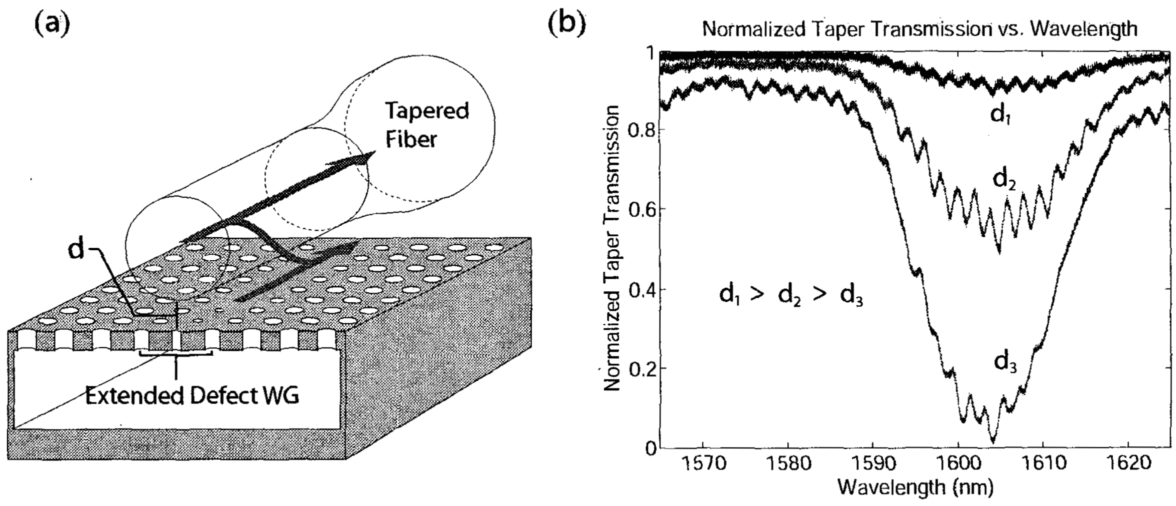

Fig. 1. (a) Schematic of the coupling scheme. (b) Normalized fiber taper transmission as a function of wavelength for varying taper-PCWG gap: $d_1 = 2.25$ μm, $d_2 = 1.55$ μm, $d_3 = 1.10$ μm.

Figure 1(a) shows a schematic of the evanescent coupling scheme. The small diameter of the fiber taper allows its evanescent tail to interact with the PCWG, and the undercut membrane structure of the PCWG prevents the fiber taper from radiating into the substrate. If there exists a pair of modes (one in each waveguide) which are phase matched and which have appropriate transverse spatial overlap, complete mode-selective power transfer is possible over short ($\approx$ 50 lattice constant) length scales [1].

We fabricated a PCWG from a silicon-on-insulator (SOI) wafer, and the defect waveguide was formed by introducing a lateral grading in the hole radius similar to the PC defect cavities studied in Ref. [2]. An approximately 1.2 μm diameter fiber taper was fabricated by simultaneously heating and stretching a segment of standard single mode telecommunication fiber. The fiber taper was positioned above and parallel to the PCWG using a stage with 50 nm resolution along the vertical axis. A 1565nm – 1625nm swept wavelength semiconductor laser source was transmitted through the fiber taper and measured at its output as a function of wavelength.

Figure 1(b) shows the fiber taper transmission as a function of wavelength for varying height of the taper above the PCWG. For a taper-PCWG gap of 1.10 μm the transmission is less then 1%. This indicates nearly complete power transfer to the PCWG, roughly 95% when taking into account a 5% off resonance insertion loss. When the gap is decreased further the transmission recovers, indicating that the coupling is codirectional. As shown in Figure 2(a), when the fiber is kept at constant height and displaced laterally from the center of the PCWG the transmission recovers, indicating that the taper coupling is to a PCWG mode localized to the defect region.

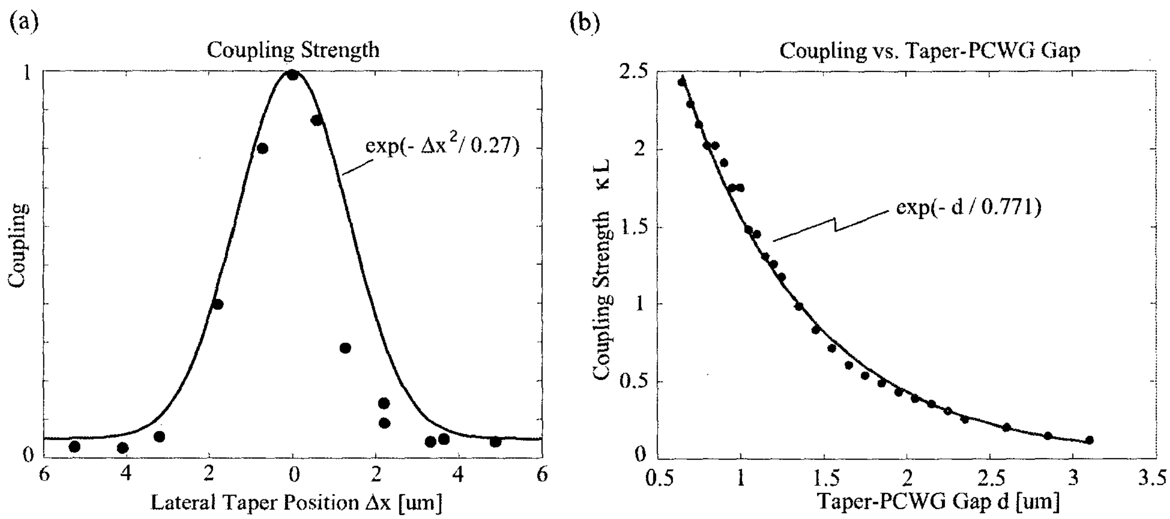

Fig. 2. (a) Coupling (1 - fiber taper transmission) to the PCWG when the taper is displaced laterally from the PCWG center. (b) Coupling strength as a function of taper-PCWG gap, derived from the transmission minimum using a simple couple-mode theory.

References

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