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# Mode-coupling in photonic crystal fibers with multiple cores

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## 09.15 CME3

### Fabrication of photonic crystal structure in fluorine-doped silicon dioxide film by dry and wet etching processes

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Photonic crystals have been studied extensively because of their strong possibility in light control. Several techniques to form such structures have been reported so far. In this paper, we propose novel method for fabrication of two-dimensional (sub-three-dimensional) periodic structures. We demonstrate the fabrication of a prototype structure, i.e. two-dimensional array of mushroom structures.

Figure 1 shows the fabrication process. Pure $SiO_2$ / F-doped $SiO_2$ two-layer thin film was formed on Si substrate by plasma enhanced chemical vapor deposition (p-CVD) using tetraethoxysilane (TEOS) and $CF_4$. The concentration of fluorine was estimated as about 10% in molar ratio. Then two-dimensional periodic structure was formed by photolithography and dry etching with $CF_4$. Finally, the mushroom structures were formed by the selective wet etching with 5%-HF solution. Figure 2 shows the fabricated structure. The period was 4.0μm, and the thickness of the two layers were about 1μm each. A mushroom structure was easily formed because the etching rate of the F-doped $SiO_2$ film was six times as high as that of undoped film. We are continuing experimental work to form the structure with shorter period and to examine the optical properties of such structures. The shape of each component was controlled precisely depending on the concentration of fluorine. The structure stacking with the mushroom shapes or other shapes will be demonstrated in the presentation.

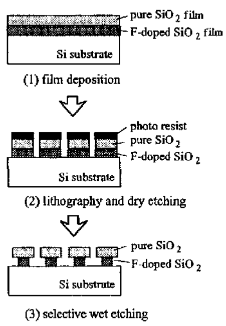

Fig. 1 Flow diagram of fabrication process

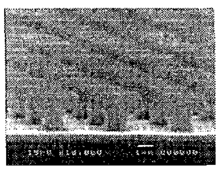
Fig. 2 SEM view of fabricated structure

## 09.30 CME4

### Mode-Coupling in Photonic Crystal Fibers with Multiple Cores

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We have fabricated photonic crystal fiber (PCF) [1] with multiple cores by drawing a fiber preform from stacked glass tubes [2]. Fig. 1 is a cross-section of the fiber showing the three cores. One core is near the center a second is to the right. The third is at the top right, well separated from the first two.

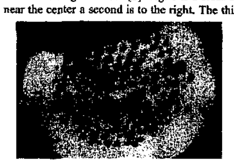
Fig 1: Cross section of PCF fiber with 3 cores Bend induced coupling is observed between the two cores close to the center at 632 8nm but not at 1550nm

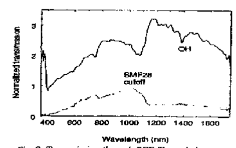

Fig 2: Transmission through PCF fiber relative to SMF28 (inserted as dashed line below in arbitrary units)

Transmission is high through each core despite many unintentional defects in the cladding indicating that the guidance is determined by the holes near to the core. The transmission spectrum through 1.5m of the central core is shown in Fig. 2. The cut-off wavelength is around 400nm indicating an unusually large bandwidth extending well beyond 1750nm. The broad dip at 1100nm is due to the cutoff in the SMF28 fiber used for butt coupling and for normalization of the signal. The SMF28 transmission is inserted as a dashed line. We find all PCF cores to support a single fundamental mode with a mode-field pattern similar to the core shape as shown in Fig. 3. We observe no change in the mode-field pattern when changing the in coupling or bending the fiber, confirming the single-mode behavior.

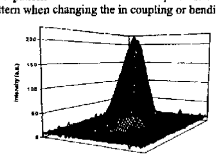
Fig 3: Central mode-field pattern at 632 8nm without bending

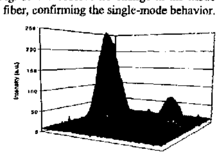
Fig 4: Bend-induced coupling to side core at 632 8nm

At 632.8nm bending induces coupling between the fundamental modes of the two central cores as shown in Fig 4. At 1550nm we observe no bend-induced coupling, indicating decreasing coupling efficiency as a function of wavelength in sharp contrast to standard optical fibers and waveguides This may be explained by a tunneling effect through the glass bridges connecting the core regions For long wavelengths the field is unable to penetrate through the narrow high-index bridges. When the wavelength gets comparable to the size of the bridge coupling occurs. This situation resembles that of a coaxial cable with a metal mesh cladding in the microwave region.

[1] J C Knight, T A Birks, P St J. Russell and D M Atkins, Opt Lett 21, 1547 (1996)
[2] J C Knight, J Broeng, T A Birks and P St J Russell, Science 282, 1476 (1998)