Wavelength-selective coupling of dual-core photonic crystal fiber and its application

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We investigate the coupling characteristics of photonic crystal fiber composed of two cores with different index profiles. The index curves of the fundamental modes of the two cores can cross at a desired wavelength by choosing appropriate index profiles of the cores. As a result, wavelength-selective coupling is achieved. The designed coupler can be applied as an optical fiber bandstop filter with 26-nm bandwidth.

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Wavelength-selective fiber devices such as fiber filters are basic components in wavelength-division multiplexing (WDM) optical fiber communications and optical fiber measurements. There are a number of methods to fabricate fiber filters, including polished dissimilar fiber coupler[1], concatenated fused-taper coupler[2], and dissimilar fiber Mach-Zehnder interferometers (MZIs)[3]. The operation of fiber filters typically involves energy transfer over a coupling length between two distinct fiber cores coupled by proximity interaction. A fiber coupler based on asymmetrical twin-core optical fiber exhibits narrowband filtering characteristics and allows accurate control of the filtering wavelength[4,5]. Recently, photonic crystal fibers (PCFs) have attracted a lot of attention[6−11]. Dual-core PCFs have also been investigated[12−19]. Applications of dual-core PCFs as polarization splitters[14,15] and WDM components[12,17−19] have been proposed. However, in these reports, the dual-core PCFs are index-matched at all wavelengths, thus making it difficult to achieve band-pass or bandstop filtering characteristics.

Recently, a novel wavelength-selective hybrid light-guiding PCF coupler has been obtained by selectively filling the holes of a normal index-guiding solid core PCF with high refractive index material[18]. In this letter, we report the design and investigation on a novel index-guiding dual-core PCF. The effective indices of the two cores are index matched at the desired wavelength. Wavelength-selective coupling of the dual-core PCF is demonstrated numerically. The application of the fiber as optical fiber filter is proposed and discussed.

The cross-section of the proposed dual-core PCF is illustrated in Fig. 1. The air-holes are arranged in a triangular lattice in the background of pure silica. The center-to-center distance of the two nearest air-holes is set as Λ. In addition, the normalized air-hole diameter of the cladding is set as d/Λ=0.3. The background silica index is assumed to be 1.45, and the material dispersion of silica is neglected for simplicity. The fiber is composed of a large central core and a small side one. The central core is realized by the omission of seven air-holes in the center of the fiber, and a down-doped silica rod is inserted. The diameter of the rod is 2.2Λ and the index difference between the down-doped silica and pure silica is −0.001. The small core is realized by the replacement of an air-hole with an up-doped silica rod. The index difference of the doped rods with the pure silica is set as Δ=0.001, and the diameter of the small core rod is set as $d_s = \Lambda$. The default operating wavelength is set as 1.55 μm.

In coupled-mode theory, each core in the fiber can be treated as an independent waveguide that is perturbed by the presence of fields propagating in the other core. We investigate firstly two kinds of single-core PCFs, one with only the side core and the other with only the center core. When the dispersive mode of the side core PCF interacts with the mode of the center core PCF, propagation constants of the two supermodes are matched. Then, the maximum power transferring can be achieved at the wavelength point. At other wavelengths, the lower power transferring is desired. Therefore, the center core and the side core PCFs should have large difference between the index curves. The aim of introducing a large central core is to increase its index difference with the small cores.

By applying the CUDOS MOF Utilities[20], the effective indices of the small and large core PCFs are

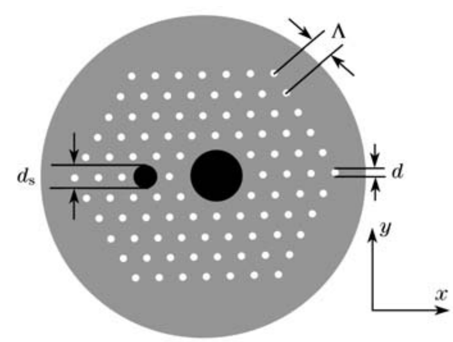

Fig. 1. Cross-section of the proposed PCF. The gray area denotes pure silica, the white areas represent air holes, and the dark areas denote doped silica.

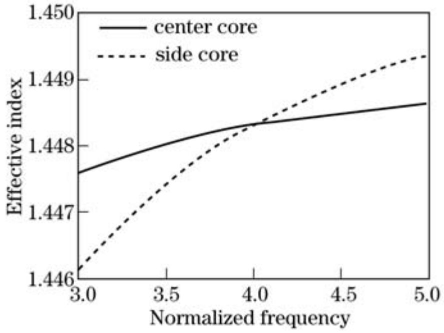

Fig. 2. Effective indices of the single-core PCFs.

calculated. Figure 2 shows the effective indices of the large core and small core PCFs as functions of normalized frequency. It is seen that the mode indices of the large core and the small core meet at the frequency point of Λ/λ=4.945. The fundamental mode loss of the large core is found to be lower than 0.1 dB/m for the wavelength range of interest. Since we wish the light at the wavelength of 1.55 μm be coupled to the small core, we should set λ to be 1.55 μm. Therefore, the value of Λ should be 7.66 μm.

A full vectorial beam propagation method (BPM) is used to investigate the coupling characteristics of the proposed fiber. An initial field is launched in the large core of the fiber and the normalized output power at the small core as a function of propagation distance is plotted in Fig. 3. When the effective indices are matched (Λ/λ_0=4.945), all of the energy will be transferred to the small core. The coupling length of the fiber is 29 mm. However, as mismatch is introduced, such as the case of Λ/λ_0=4.7, only a small amount of energy can be transferred to the small core. When increased mismatch is introduced, such as the case of Λ/λ_0=4.5, the energy transferred to the small core is always lower than −19 dB. In any case, the energy shows periodic transition in the two cores.

The field profiles of the proposed PCF with the fiber length L=29 mm at the wavelength of 1.55 μm are plotted in Fig. 4. As shown in the figure, the input field is launched into the large core, and then the power transfers from the large core to the small core very smoothly, and finally, at the propagation distance z=L, the field is transferred from the large core to the small core. The mode field diameter of the small core at the wavelength of 1.55 μm is 10.5 μm, which has a good compatibility with the standard single-mode optical fiber. In addition,

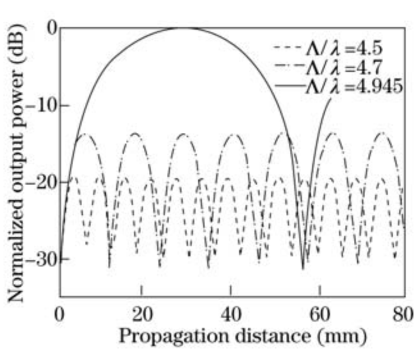

Fig. 3. Normalized power transfer curves for the small side core at 1.55 μm.

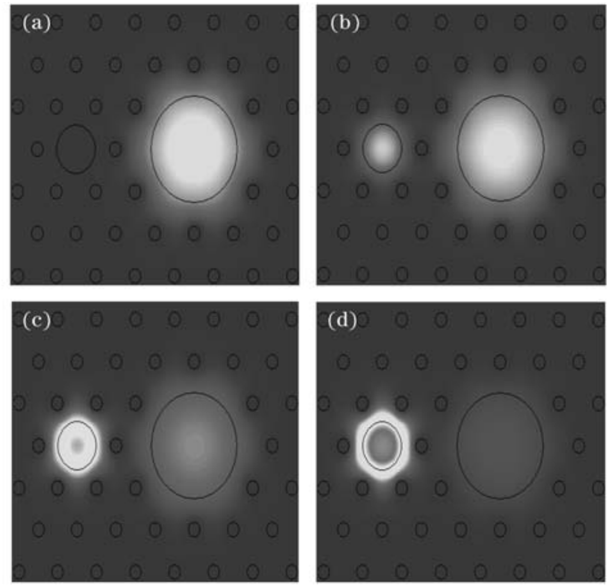

Fig. 4. Field profiles of the PCF at 1.55 μm for different propogation distances (a) z=0, (b) z=L/3, (c) z=2L/3, and (d) z=L.

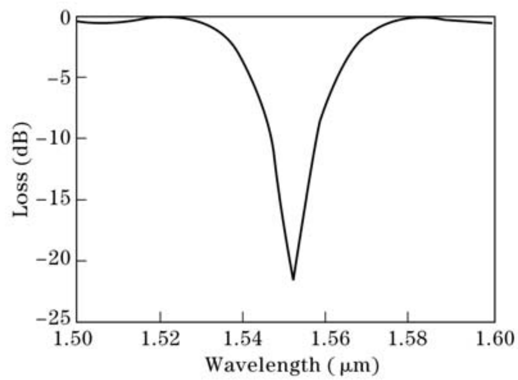

Fig. 5. Output power of the center-core of the proposed dual-core PCF coupler with L=29 mm.

the two cores are separated with the center-to-center distance as large as 43.61 μm, therefore, the light can be separated easily. The mode field diameter of the center-core PCF is 22 μm, which makes the splicing of light from the standard single-mode optical fiber easier.

Figure 5 shows the output power of the center-core of the proposed dual-core PCF. Only the x-polarized state is presented because similar result holds for the y-polarized state and it is omitted for simplicity. The bandstop happens only over a very narrow wavelength range. Although sidelobes are found, the induced losses are very small. In fact, the minimum value of the sidelobes is −0.54 dB. Therefore, they should have low influence on the properties of the transmitted signal. In contrast, the index difference between the fundamental modes of the two cores in a conventional mismatched dual-core optical fiber coupler is always small due to the low index contrast. The full-width at half-maximum (FWHM) bandwidth of the coupler is 26 nm. If the signal at the small core is exported, the fiber can be used as a bandpass filter, and the bandwidths can be reduced by cascading the proposed filters.

In conclusion, the coupling characteristics of a dual-core PCF with asymmetric cores are investigated. The selective coupling of the coupler is realized by introducing asymmetric cores in the PCF with index-matched coupling at the specified wavelength. The application of the fiber as bandstop filter is discussed and the bandwidth of the filter is found to be 26 nm with low sidelobes.

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