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Tunable wavelength division multiplexer based on thermal liquid-filled photonic crystal fiber

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ABSTRACT

By filling high refractive thermal liquid (toluene) into the total internal reflection dual-core photonic crystal fiber (DC-PCF), the coupling behaviors of the DC-PCF for different temperature is analyzed by using finite element method, and then a tunable wavelength division multiplexer realized for 980/1550 nm and 1310/1550 nm is obtained at a fixed DC-PCF length of 2475 μm.

1. Introduction

Wavelength division multiplexer (WDM), a device that can separate different wavelength light, is an important passive device in the optical communication systems. In recent decades, because of its high design flexibility, photonic crystal fibers [1,2] (PCFs) are already used in designing WDM. Saitoh et al. [3] designed a wavelength multiplexer-demultiplexer based on PCF for the first time, and the numerical results demonstrate that it is possible to realize short device length. Eom et al. [4] proposed a WDM coupler which has been made with PCFs by using the fused biconical tapered (FBT) method, and it can be tuned by adjusting the pulling length during the FBT process. Besides, with the developments of filling method for PCFs, it provides a promising platform for photonic devices. Different materials and different filling methods are reported in many research articles [5–7], and obtained excellent theoretical and experimental results.

For traditional WDM based on PCFs, once the fiber length and structure parameters are determined, the WDM device can only be used for specific wavelength group. In this paper, by selectively filling high refractive thermal liquid into the dual core photonic crystal fiber, a tunable wavelength division multiplexer is presented, that is, more wavelength groups could be multiplexed by using a fixed fiber length. It solved the problem that a fixed-length fiber can only achieve two specific wavelength multiplexing. Numerical results demonstrate that this kind of WDM is realized for 1310/1550 nm (temperature 31 °C) and 980/1550 nm (temperature 5 °C) at a fixed fiber length of 2475 μm.

2. Structure and analysis

The triangular-lattice total internal reflection photonic crystal fiber structure is shown in Fig. 1. The hole pitch and the big air hole diameters are Λ and d, respectively. The diameters of the two small air holes in core A and core B are d_0. The background material is pure silica.

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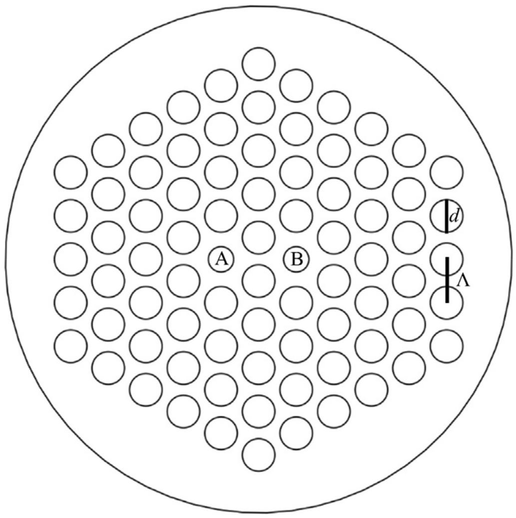

Fig. 1. Cross section of fiber structure.

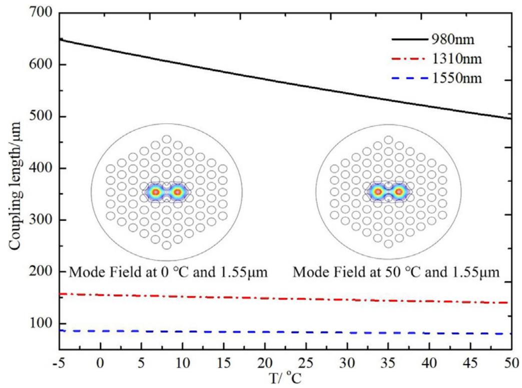

Fig. 2. Coupling length at different temperatures.

High refractive thermal liquid (toluene) is selected to fill the two small air holes. There are two reasons: the thermo-optic coefficient α of toluene is 5.273×10^{-4}/K, which is two orders of magnitude higher than that of pure silica ($\alpha = 8.6 \times 10^{-6}$/K), so the effects of thermal expansion of background material for the transmission performance can be ignored; the refractive index of toluene is higher than that of the pure silica [8], so the light wave is guided in this PCF by total internal reflection. Because of the convenience for modeling, calculating and higher accuracy, the full-vector finite-element method is applied to calculate the proposed PCFs. The refractive index of the background material can be obtained from the Sellmeier formula [9], and the refractive index of toluene which is a function of the temperature and the incident wavelength is given by $n(\lambda, T) = 1.474775 + 0.0699031/\lambda^2 + 2.1776 \times 10^{-4}/\lambda^4 - \alpha \times (T - T_0)$, where λ is the wavelength of the incident light and $T_0 = 20\,^{\circ}$C.

For the WDM device that based on dual core PCF, its essence is the energy coupling effect between the two cores. The coupling lengths which mean the length of a complete power transfer from core A to core B are different with the wavelength and temperature, so different wavelength lights can be separated by setting proper fiber length. According to the coupling theory, the coupling length (L) is defined as $L = \pi/(\beta_{even} - \beta_{odd}) = \lambda/(2n_{even} - 2n_{odd})$, where β and n denote the propagation constant and the effective refractive index which can be obtained by full-vector finite-element method. Assuming that the input port is core A and the input power is P, the output power in core A is given by $P_{out} = P\cos^2[\pi z/(2L)]$, and the normalized power (NP) is $NP = P_{out}/P = \cos^2[\pi z/(2L)]$, where L is the coupling length and z is the fiber length [10].

The wavelength of 980 nm is used as pump light in erbium-doped fiber amplifiers, and 1310 nm and 1550 nm are used as the communication windows for long-distance transmission in optical communication systems. The transmission characteristics of these kinds of light are calculated in the following section, and the proposed WDM is used to multiplex the wavelength groups of 980/1550 nm and 1310/1550 nm. In order to strengthen the coupling effect and shorten the length of WMD to some extent, the geometrical parameters are $\Lambda = 1.2\,\mu$m, $d = 0.8\,\mu$m and $d_0 = 0.6\,\mu$m. Theoretically, it can also be used for multiplexing more wavelength groups by setting appropriate geometrical parameters.

The coupling behaviors of the proposed PCF for different temperature are depicted in Fig. 2, and the embed figures are the mode fields at different temperature. It is obvious that the coupling lengths decrease as the temperature increases and