Dual-concentric-core Photonic Crystal Fiber with -5400ps/nm/km Dispersion Coefficient

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Abstract: We present the design and measured results of the highest dispersion value from photonic crystal fibers reported so far. The dual core photonic crystal fiber exhibits chromatic dispersion value of about -5400ps/nm/km around 1.56 µm.

OCIS codes: 060.2280

1. Introduction

In the last decade, there has been an increasing use of lasers operating at 1.55 µm in the optical communication systems. However, at 1.55 µm, the fibers exhibit a chromatic dispersion of about 17 ps/nm/km. Fibers designed for dispersion compensation in optical communication have shown that very high values of dispersion (D >－100ps/nm/km) can be achieved. The dispersion compensation fibers (DCFs) should have a very high negative dispersion coefficient while maintaining minimum losses and low cost. Since the first working model was demonstrated in the year 1996, photonic crystal fibers (PCFs) [1] with an array of periodic air-holes running down the length of the fiber, have gained an increasing popularity due to their unique properties such as endlessly single-mode operation [2], high non-linearity [3], ultralow loss [4], and so on. PCF structures can be designed to have higher negative dispersion values compared to conventional DCFs [5, 6]. This paper presents a design of a dual concentric core PCF to achieve a very high negative dispersion coefficient of about -5400 ps/nm/km. The dispersion value was experimentally confirmed.

2. Theory and design of a dual concentric-core PCF

The mechanism of a dual concentric-core PCF is very similar to that of a directional coupler [7]. The central core and the outer core behave like two parallel waveguides and the high dispersion is from the coupling between the two waveguides. The detailed theory was presented in a previous paper [8].

Fig.1 shows the designed microstructure of highly dispersive photonic crystal fiber. The structure period is 2.51µm, the central core is a positively doped silica region with diameter d1 of 0.85*Period, the first air hole ring diameter d2 is 0.73*Period, the outer core is a negatively doped silica region with diameter d3 of 0.8*Period, and all other outer air holes diameter d4 is 0.4*Period. The central core is positively doped (d1 region) and has a doping concentration that raises its refractive index by 1.35% compared to background silica. The outer core (d3 region) is negatively doped and has a doping concentration that lowers its refractive index by -0.7% compared to background silica.

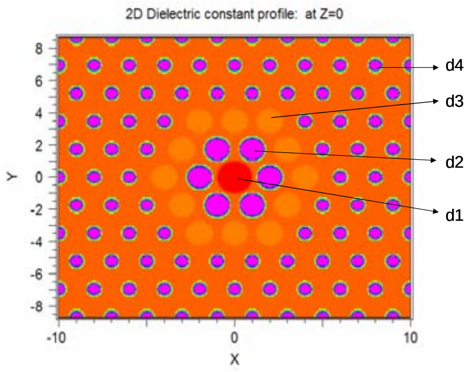

Fig. 1 Microstructure of highly dispersive PCF .

Due to their intrinsic constitution with two concentric cores, these fibers theoretically propagate two supermodes, with the first one leading to a negative dispersion, and the second one to a very positive coefficient [1]. For wavelengths less than the phase matched wavelength, the fundamental mode is guided primarily in the inner core, and for wavelengths greater than the phase matched wavelength, the mode is guided in the outer core. For wavelengths around the phase matched wavelength, a part of the mode energy is confined to the inner core and a part is guided in the outer core. Due to this redistribution of mode energy around the phase matched wavelength, there is a sudden change in the refractive index, leading to a very high dispersion value. A necessary selective injection is needed to ensure that the dispersion will be negative or positive. However, in real application, the injection condition is random and cannot guarantee to generate negative or positive. Since we always connect the highly dispersive fiber to single mode fiber, we followed Frederic Gerome to use the phase delay method to simulate the dispersion value because this method is very accurate to describe the chromatic dispersion behavior and widely used in chromatic dispersion measurement systems [9]. The simulated dispersion curve is shown in Fig.4. The maximum negative dispersion is -5400ps/nm/km at 1547nm. The maximum positive dispersion is +5400ps/nm/km at 1560nm. At phase match wavelength 1553.8nm, the dispersion is zero.

The Scanning electron microscope (SEM) picture of the fabricated PCF using stack-and-draw technique is shown in Fig. 2.

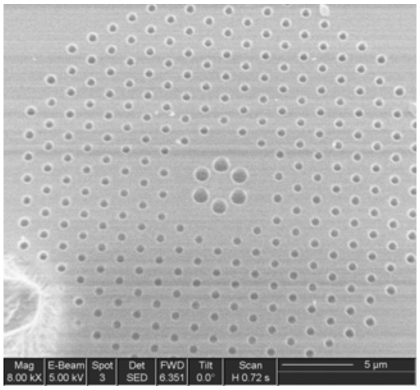

Fig. 2 Scanning electron microscope (SEM) picture of the fabricated highly dispersive PCF.

3. Experimental results

The chromatic dispersion of the fabricated fiber is measured using a phase-shift method [10]. From our initial tests on the PCF, we found out that the signal output from the PCF is sensitive to bending. Therefore, in all subsequent measurements, we consider the use of straight segments of PCF. The experimental setup is illustrated in Fig.3. The RF signal from the 8510C HP vector network analyzer is modulated onto a tunable optical carrier using a $LiNbO_3$ electro-optic (EO) modulator. After the signal propagates through a 1.0m long straight segment of PCF, different phase shifts will be generated for different optical wavelengths. The signal is then detected by a photodetector and fed into the network analyzer to measure the RF phase. The time delay (t) generated when the wavelength is tuned from λ_1 to λ_2 is given by

$$t = L \cdot \int_{\lambda 1}^{\lambda 2} D(\lambda) d\lambda \qquad (1)$$

where $D(\lambda)$ is the dispersion coefficient, λ is the optical wavelength, and L is the length of the PCF.

The phase difference measured by the network analyzer is expressed as:

$$\Delta\theta = 2\pi \cdot t \cdot f \qquad (2)$$

where f is the RF frequency.

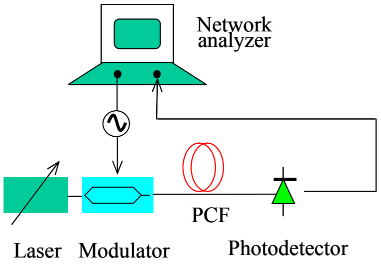

Fig. 3 System setup to measure dispersion value of PCF using phase-shift method.

Making use of the values of *t* derived from eqn (2) into eqn (1), the dispersion coefficient of the fiber was derived. The dispersion curve of the PCF thus derived is shown in Fig. 4. The simulation result is also drawn in Fig. 4 for comparison. From our measurement, we find that before the phase match wavelength 1553.8nm, the curve shows a negative peak around -5400ps/nm/km at 1549nm. The dispersion becomes null almost halfway between the two peaks near 1555nm. There is a sudden change in the sign of the dispersion coefficient, and the value becomes highly positive +3900 ps/nm/km near 1560nm. The experimental data are in reasonably good agreement with simulation results. The fluctuations are attributed to the variation of the optogeometrical parameters of the fiber during drawing.

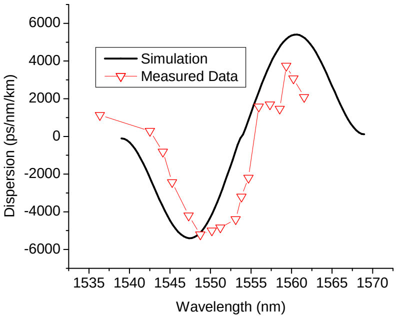

Fig. 4 The simulated and measured dispersion curve of the under test PCF.

4. Conclusion

A photonic crystal fiber with dispersion of -5400ps/nm/km was designed, fabricated and measured. The measured dispersion values agree well with simulation results. This highly dispersive fiber may find application in signal processing, dispersion compensation, pulse compression, beamsteering and etc.

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