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Double Cladding Seven-core Photonic Crystal Fiber

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ABSTRACT

A double cladding seven-core PCF was presented for high power supercontinuum generation. The calculated zero dispersion wavelength is located at 912 nm, which has a good agreement with the measurement. The attenuation is measured 6 dB/km at 1590 nm and lower than 14.5 dB/km at 1060 nm, the water-loss peak at 1380 nm is about 134 dB/km; Supercontinuum spanning over more than 1500 nm was generated when the designed seven-core PCF was pumped by a gain-switching Yetterbium-doped fiber laser. These results will be helpful in the future design of multicore photonic crystal fibers (MCPCF) with proper guidance properties for high power supercontinuum generation.

Keywords: Photonic Crystal Fibers; Supercontinuum Generation

1. Introduction

There has been a drastic increase in the output power of Supercontinuum generation with photonic crystal fiber in recent years [1-2]. Previously, SCG power more than hundreds watts in single core high nonlinear photonic crystal fiber (HNPCF) is reported [3], nevertheless, but it is particularly challenging to further improve the SC power which is restricted by the splicing issue. Multicore PCFs was proposed as a valuable solution for further scaling of the maximum generated SC power because of their large effective mode area and their better thermal dissipation properties. Meanwhile, the multicore PCFs can achieve the high beam quality output based on the beam coherent combination effect by careful design of structure parameters [4-5]. In 2012, X. H. Fang firstly reported the 5.4 W coherent SC output range from 500 nm to 1700 nm with a high spatial and spectral quality based on the 20-m-long seven-core PCF [6]. However, the experiment utilized space coupling method that was complicated and very unstable. Recently, H. F. Wei reported 42.3 W all-fiber SC source range from 720 nm to 1700 nm using a piece of seven-core photonic crystal fiber [7]. But the zero dispersion wavelength (ZDW) of the seven-core fiber they used is unsuitable which located at 1115 nm.

In this letter, we present a new kind of double cladding seven-core photonic crystal fiber.

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2. Fiber Design and Characteristic

With the help of a scan electron microscope (SEM), **Figure 1** shows the cross section of our designed seven-core PCF. In the inner cladding in which laser light propagates six rings of air holes with small diameter D_1= 1.54 μm are arranged in a hexagonal pattern in a simple cladding of pure silica glass. In order to form a seven- core PCF, six alternative air holes in the second ring are removed and each core has diameter of R = 3.2 μm. The distance between the adjacent air holes centers is pitch Λ = 2.50 μm and the air filling radio F_1 = 0.61 (defined as D_1/Λ). It has been postulated that an outer cladding with high air-filling fraction would provide a low effective index [8-9]. As to the outer cladding, the air filling F_2 was increased to 0.75 as the air hole diameter D_2 = 3.26 μm.

In our seven-core PCF each separated core is designed to sustain a single mode only, however, optical fields

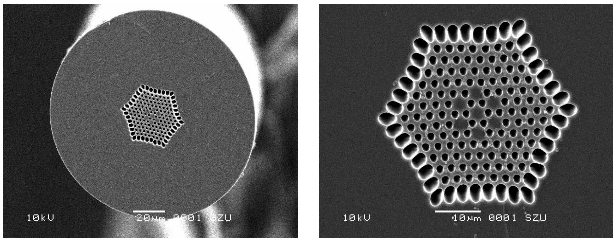

Figure 1. SEM pictures of seven-core PCF: (a) the end face (b) the core region.

propagating in multicore fibers are coupled evanescently which results in what are called supermode. Only the in-phase mode (IPM) provides the best beam quality with a near Gaussian far field, which requires each mode propagating in different core has both the same polarization state and the same phase state.

Under the designed parameter, and the free space wavelength λ = 1060 nm, the mode fields of all the supermodes are calculated by the finite element method with an optimized hexagon perfectly matched layer boundary condition. **Figrue 2(a)** & **(b)** shows the intensity profiles of supermodes.

Considering that fiber structures determined the ZDW range of fiber, we calculate the dispersion profile of our designed seven-core PCF under the condition that material dispersion of silica is included. The calculated dispersion curve as well as the measured dispersion data is shown in **Figure 3**. As can be seen, the measurements (red points), which are achieved via Chromatic dispersion system (CD400) are in good agreement with the theoretical predictions (solid blued line). The inset clearly shows the ZDW is at 912 nm.

The attenuation spectrum from 700 nm to 1700 nm of the fabricated seven-core PCF based on a cut-back technique shown in **Figure 4**. The lowest attenuation of 6 dB/km is at the 1590 nm. The attenuation at 1060 nm wavelength and the water-peak (1380 nm) is 14.5 dB/km and 134 dB/km, respectively.

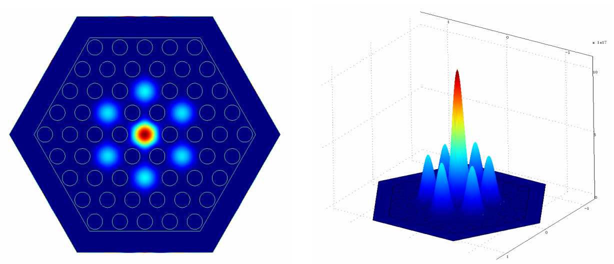

Figure 2. Calculated mode profiles of supermodes in seven-core PCF.

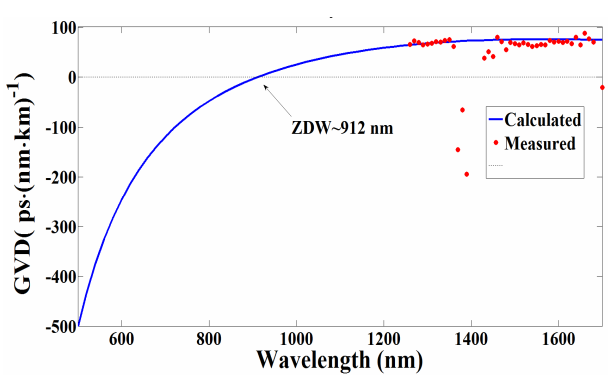

Figure 3. Calculated dispersion profiles of seven-core fiber as well as the measurements.

3. SCG in Double Cladding Seven-core PCF

The experiment setup was shown in **Figure 5**. We used a picoseconds Yetterbium-doped fiber laser, made by Wuhan YSL Photonics Co. Ltd, which delivers pulses with constant length of 150 ps and an average output optical powers of up to 4.5 W via an short piece of pigtail polarization maintaining PANDA fiber (20/125). Taking account of the oscillator of 1MHz the maximum peak power is 28 KW while the corresponding maximum energy in the pulse reaches 4.5 nJ. An piece of 35 m-long seven-core PCF was spliced with the pigtail PANDA fiber through a Fujikura FSM-45PM fiber splicer. With a careful adjustment on the splice parameter, a coupling efficiency of around 30% was measured considering the transmission loss of the fiber length.

The output radiation from the tested PCF was inserted into Yokogawa optical spectral spectrometer through a fiber adaptor to record spectra. Limited by our instrument, we just record the spectrum range from 400-1800 nm.

Figure 6 shows the spectral evolution of seven-core PCF for different output power. Considering the ZDW at 912 nm and the input pulse at 1064 nm, the SCG is under the soliton regime. With the increasing of pump power, SCG broad to long wavelength direction mainly because there is little dispersion wavelength derived from low-order soliton fission. When the output power comes to 137.5 mW, dispersion wave increases resulting in the short wavelength broadening and intrapulse Ramam Scattering (IRS) begins to show up at 1055 nm. Further increasing pump power, IRS contributes to the spectral component spectral at the long wavelength.

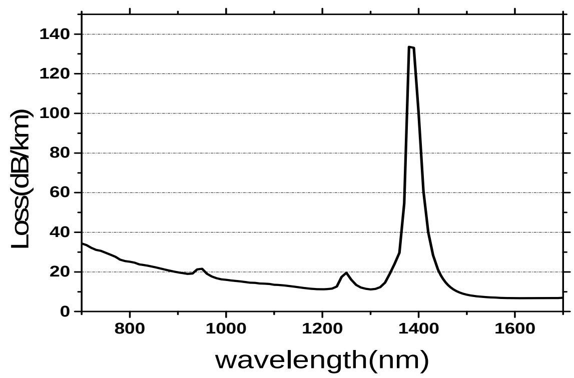

Figure 4. The attenuation spectrum of seven-core PCF.

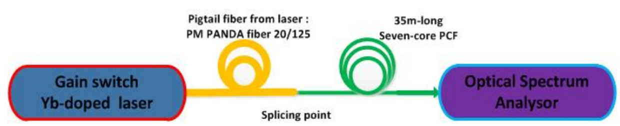

Figure 5. A scheme of measurement set-up. A piece of 35m-long seven-core PCF is pumped with 160ps pulses from an Yetterbium-doped fiber laser. The output signal is registered with spectrometers.

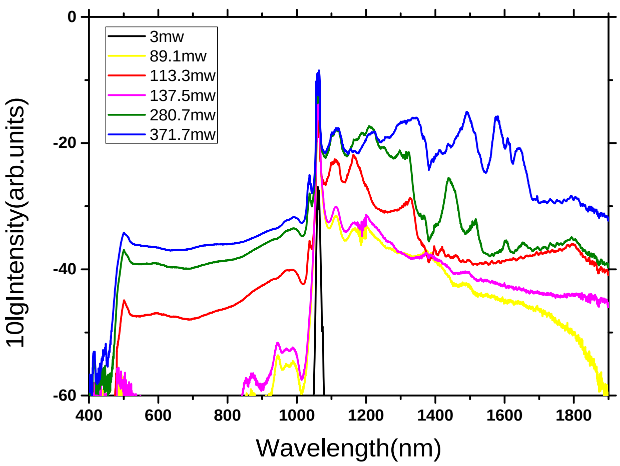

Figure 6. Spectral evolution of seven-core PCF for different output power.

Figure 7. Beam profile of SCG after the seven-core fiber.

The beam profile was also recorded by a camera (Cannon) as shown in **Figure 7**.

4. Conclusions

We presented a double cladding seven-core PCF for SCG. The PCFs are well designed for obtaining a in-phase mode. The calculated ZDW is located at 912 nm, which has a good agreement with the measurement. The attenuation is measured 6 dB/km at 1590 nm and lower than 14.5 dB/km at 1060 nm, the water-loss peak at 1380 nm is about 134 dB/km; Supercontinuum spanning over more than 1500 nm was generated when the designed seven-core PCF was pumped by a gain-switching Yetterbium- doped fiber laser. These results will be helpful in the future design of multicore photonic crystal fibers (MCPCF) with proper guidance properties for high power supercontinuum generation.

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