Broadband continuum generation in an irregularly multicore microstructured optical fiber

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A broadband continuum generation is reported in a novel multicore microstructured optical fiber (MOF) where irregular air holes are randomly distributed in cladding. By launching ultrashort light pulses from a Ti:sapphire laser into a 190-mm-long fiber of this type, we have observed a group of continua generated from different cores, each with distinct color. 20-dB bandwidth of the broadest continuum is 1260 nm with an average power of 143 mW. The result confirms that the multicore MOF can be fabricated, with different dispersion profiles tailored for specific supercontinuum (SC) generation towards practical applications.

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Microstructured optical fibers (MOFs) or holey fibers[1−4] have proved to be one of the most promising media to supercontinuum (SC) generation, largely because of their high degree of light confinement[5,6] and the phase matching of nonlinear optical processes via tailoring the dispersion profiles[7]. Up to now, the fission of higher order optical solitons[8−11] combined with four wave mixing (FWM)[12−15] is regarded as the underlying mechanism for SC generation. The broadest continuum is measured from 350 to 2200 nm in 40-dB bandwidth for a soft glass photonic crystal fiber[16]. Recently, researchers have demonstrated that MOFs with randomly distributed air holes in cladding can also generate SC as long as pump light is tightly confined in a small core region[17−19]. When several glass cores with different sizes are put together in the manufacturing process, a single strand of multicore MOF can be produced. The continuum generation in such multicore MOFs is reported by using 15-fs pump pulse, but with only one core pumped[19]; moreover, the generated continuum in this paper is discontinuous and not flat, which has a 1350-nm bandwidth with a 50 dB vertical scale.

In this paper, a newly designed irregular multicore MOF is employed for SC generation. We have demonstrated that such a multicore MOF function like several different MOFs bound together, and for different cores very different spectra with distinct colors can be produced. The broadest spectrum has a 20-dB bandwidth extending from 490 to 1750 nm, with long wavelength end limited beyond the spectral response of the optical spectral analyzer. The experimental results confirm that the multicore MOF with different dispersion profiles tailored for specific SC generation is feasible in practical applications.

The irregular multicore MOF (Infrared Optical Fibers and Sensors Institute, Yanshan University) is fabricated by pure quartz glass for reducing unwanted absorption loss. The outer diameter of the fiber is approximately 400 μm. Figure 1(a) shows the cross-section structure of its central part. This fiber is a combined structure of different units and every unit is a designed MOF, Fig. 1(b) is one of the units in which several cores with different sizes are put together. As can be seen in this figure, the white dots are cores, and the black dots are air holes. The fiber has randomly distributed cores ranging from 0.6 to 1.5 μm, which can provide abundant nonlinear effect when pumped by unamplified ultrashort laser pulses. While the air holes ranging from 0.4 to 3.4 μm have irregular shape and are distributed randomly in microstructure region due to some unexpected factor in the process of drawing. In the experiment only 190-mm-long fiber of this type is enough to generate broadband continuum.

The dispersion of the fiber is of utmost importance as it governs the phasematching of nonlinear processes. We employ a similar method to approach the dispersion profiles of the MOF[20]. The net dispersion is a total of the waveguide dispersion and the material dispersion in our calculation. Figure 2 shows the different dispersion

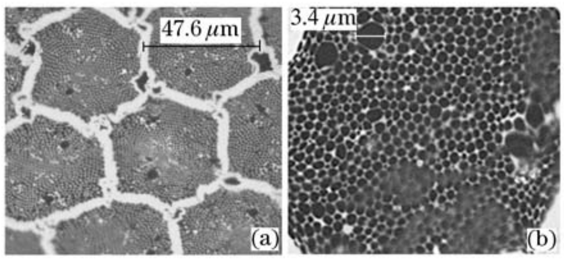

Fig. 1. The center micrograph of the multicore MOF (a) and the micrograph of one unit in the multicore MOF (b).

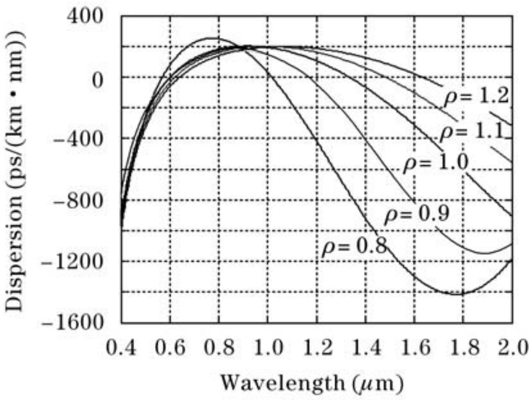

Fig. 2. The dispersion profiles with different core sizes (ρ refers to the core diameter).

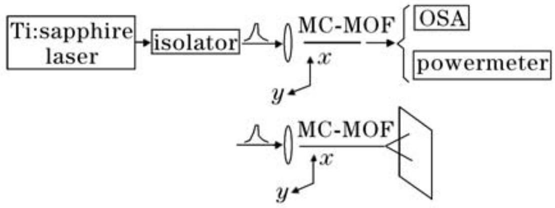

Fig. 3. The schematic of the experimental setup.

profiles of cores when their diameters vary from 0.8 to 1.2 μm, which indicates that the dispersion properties are greatly infected by the core diameter in the multicore MOF. Moreover, as shown by earlier theoretical work[21,22], we also proved that there usually exist two zero dispersion wavelengths (ZDWs) when the diameter of core is less than 1.3 μm. It is the distinctly different from the MOF in Ref. [19]. We also point out that smaller cores have smaller interval between the two ZDWs.

Figure 3 shows the schematic of the experimental setup. The pump source is a mode-locked Ti:sapphire laser (Spectra-Physics, Tsunami), which generates 82-MHz, 35-fs pulses centered at 803 nm with an average power of 0.4 W. These pulses are coupled into the multicore MOF by using a 40× microscope objective with a numerical aperture of 0.65. The SC and the responsible output power at the fiber end are recorded using a fiber-coupled optical spectrum analyzer (ANDO AQ-6315E) and an optical power meter (Spectra-Physics, 407 A). The intensity profiles are projected on a black screen and recorded using a digital camera.

By adjusting the transverse position of the MOF, we are able to couple the pump pulses into different cores and obtain the results of continuum generation. In Fig. 4 we present the spectral continua generated in four different cores. Their corresponding intensity profiles of the exiting light beam are placed on the top right corners of the spectra. The 20-dB bandwidth, the output power, and the main characteristic colors are listed respectively in the figures. By comparing these spectra, we can see that firstly the spectral components in the visible range differ greatly from each other, which is responsible for the distinct colors of the different cores. In particular, the spectral peaks in the visible are centered at 660, 410, 470, and 552 nm, respectively, and their corresponding main colors are red, purple, blue, and green. We interpret these characteristics to be an indication of the different dispersions of these cores, which give a different phase matching conditions in the nonlinear conversion process.

In all of the measured spectra, the broadest continuum spaning from 490 nm at least to 1750 nm is shown in Fig. 4(d). Noted that a spectral peak near 1750 nm, we can consider there still exists continuum in the longer wavelength, but it is beyond the spectral response range.

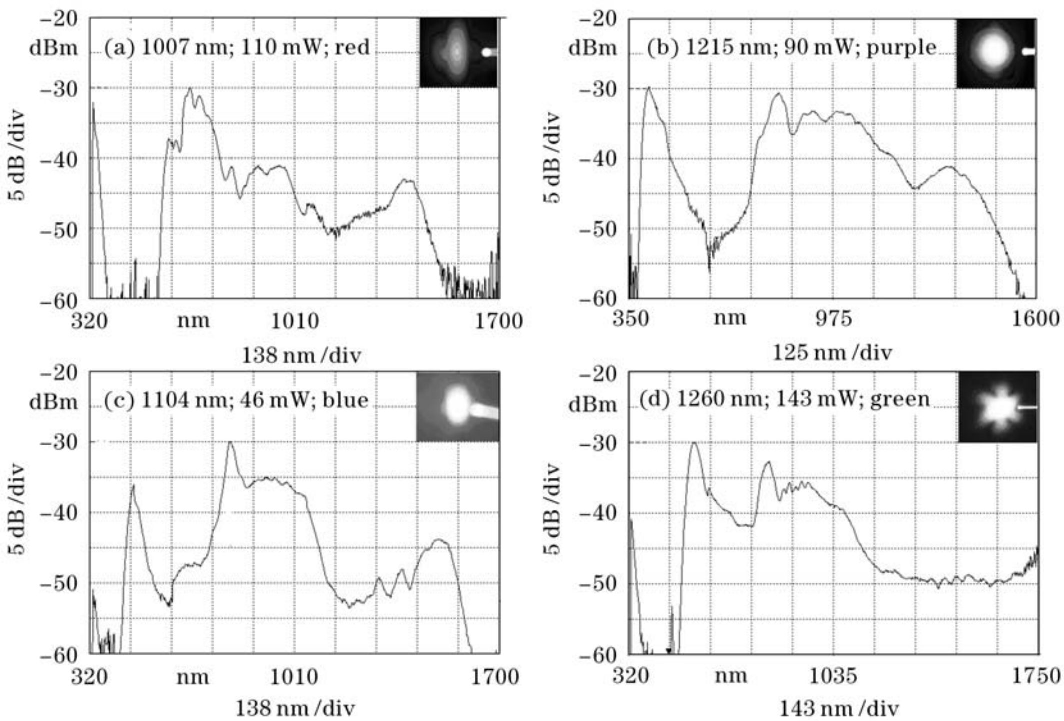

Fig. 4. SC generated in four different cores.

The measured average output power at the fiber end is 143 mW. Compared with the reported continuumin in Ref. [19] in the irregular MOF, the flatness of broadband continuum and the output power have been improved. We consider that the generated broadband continuum might have a close relation with the dispersion characteristic of two distant lying ZDWs. Since the pump wavelength lies in the abnormal dispersion region, the soliton waves would generate and red-shift. After the soliton waves shift close to the ZDW at the longer wavelength end, they each would play as a pump wave to amplify the dispersion wave in the normal dispersion region beyond the ZDW at the longer wavelength end, which has has been proven in Ref. [21]. However if the fiber has two close lying ZDWs, the region of soliton self frequency shift would be reduced, which is disadvantage for the broadband continuum generation[22]. So it can be approximately estimated that the core diameter in Fig. 4(d) is beyond 1.0 μm since the interval of the two ZDWs is large in these cores, while the dispersion profile is flat as shown in Fig. 2, which is in favor of the broadband continuum generation too.

In conclusion, we have demonstrated visible SC with distinct colors produced in different cores of a 190-mm-long newly designed multicore MOF. We attribute the different colors produced by each core to the variation of their dispersion profiles. These characteristics of the multicore MOF maybe provide a feasible method in laser color display and optical data memory. A 20-dB bandwidth of the maximum broadband continuum extends at least from 490 to 1750 nm with an average power of 143 mW. This work confirms the feasibility to fabricate a multicore microstructured fiber with different dispersion profiles tailored for specific SC generation towards practical applications. However, when it comes to fibers with prescribed dispersion, further work is still needed to control the fabrication process.

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