Supercontinuum Generation at 1.6 μm Region Using a Polarization-maintaining Photonic Crystal Fiber *

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Abstract The generation of supercontinuum in the 1.6 μm region was reported in a polarization - maintaining photonic crystal fiber. The optical pulses produced by optical parameter amplifier (OPA) with the central wavelength of 1.5938 μm, the repetition rate of 250 kHz, the pulse duration of 250 fs were coupled into a 0.2m - long, polarization - maintaining photonic crystal fiber. The broadened spectrum with the bandwidth of 45.8 nm(1.5892 ~ 1.6350 μm) in the 1.6 μm region was obtained.

Keywords Photonic crystal fiber; Supercontinuum; Optical parameter amplifier

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0 Introduction

Photonic crystal fibers (PCFs)[1,2], a novel class of fibers in which a solid cladding, typical of standard optical fibers, is replaced by a silica - air or glass - air microstructure cladding, offer new and exciting possibilities in many application fields. PCFs are attracting considerable interest as transmission media and optical functional devices[3~5]. Since the first realization of a PCF[1], intense research has been conducted to determine the propagation mode characteristics[5] and dispersion characteristics as well as to reduce the propagation loss[4], and realize polarization maintaining characteristics and highly nonlinear characteristics. One of the promising applications of PCFs is supercontinuum generation[6~9]. Supercontinuum (SC)[10], produced by various nonlinear effects in optical fibers such as self-phase modulation (SPM), four-wave mixing (FWM), and cross-phase modulation (XPM), is an attractive technology for providing an economical method to generate ultrashort pulses over a wide spectral range[11]. Recently, SC has been successfully applied in high-speed wavelength-division multiplexing (WDM) and wavelength-division multiplexing over optical- time-division multiplexing (WDM/OTDM) systems [12,13].

For efficient supercontinuum generation in a PCF, polarization-maintainability is indispensable for stable operation[4,7]. To our knowledge, this paper is the first to experimentally verify 1.6 μm band supercontinuum generation in a polarization-maintaining (PM) PCF pumped by the optical parameter amplifier system (OPA). Supercontinuum with a spectral width of 45.8 nm (1.5892 ~ 1.6350 μm) is generated in a 0.2 m-long PM-PCF.

1 The experimental setup

Fig. 1 shows the schematic diagram of the experimental setup. The optical parameter amplifier (Coherent OPA 9800) was pumped by the ultrashort pulses (about 200 fs) at 800 nm with the repetition rate of 250 kHz which was produced by a regeneratively amplified Ti: sapphire laser (Coherent RegA 9000 and Mira 900F). The OPA system had frequency-tunability, which allowed us to research the spectral broadening in the PCF with different pumping wavelength. In our experiments, we applied the OPA output wavelength of 1.6 μm as the pumping light of the PM-PCF. The laser pulses with the average power of 10 mW, the repetition rate of 250 kHz and the pulse duration of about 250 fs[14], generated by OPA, were focused into a 0.2 m-long, polarization-maintaining photonic crystal fiber (PM-PCF). For the focusing, a 25 × microscope objective with a numerical aperture of N. A. = 0.4 was used in our experiments. The numerical aperture was smaller than that of the PM-PCF used in our experiments, so the pumping power can be coupled efficiently into the PM-PCF. The PM-PCF was mounted on a six-dimension translational stage, so that we can adjust it with high precision.

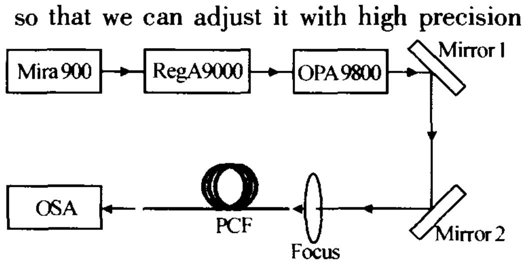

Fig. 1 The schematic diagram of the experimental setup

2 Results and discussion

Fig. 2 shows the micrograph of the crosssection (left) and the center (right) of the PM-PCF used in our experiments. The cladding diameter and the coating diameter were designed to be 127 μm and 235 μm,

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respectively. The parameters, such as the average core size of 1.8 μm, the air hole pitch (Λ) in the cladding layer of 1.6 μm and the average pitch to hole size ratio of 0.8, were designed to achieve low dispersion and high nonlinearity. Fig. 3 shows the far field distribution of the pumping light. The PM-PCF has a zero dispersion wavelength of 700 nm and has a high average numerical aperture (N. A.) of 0.47 due to the large index step between the air hole cladding and the fiber core. It led to the high power intensity and strong nonlinear effects in the PM-PCF. Using approximately the area of the center core as the effective core area (A_{eff}) of the PM-PCF[15~17], the nonlinear parameter γ ($\gamma = \frac{n_2 \omega}{c A_{eff}}$) of the PM-PCF at the wavelength of 1.6 μm was calculated to be about 40 $W^{-1}km^{-1}$, which is much larger than the value of 19 $W^{-1}km^{-1}$ reported in Ref. 4. Here the nonlinear refractive index of the PM-PCF $n_2 = 2.6 \times 10^{-20}$ m^2/W, the center angular frequency ω and the velocity of light in vacuum c were applied.

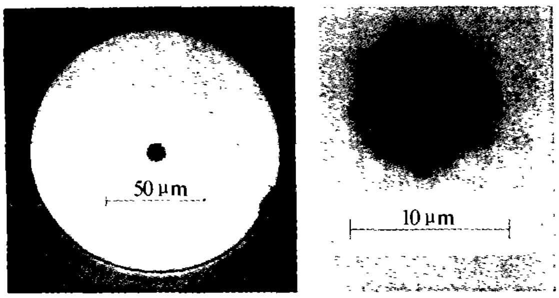

Fig. 2 The micrograph of the crosssection (left) and the center (right) of the PM-PCF

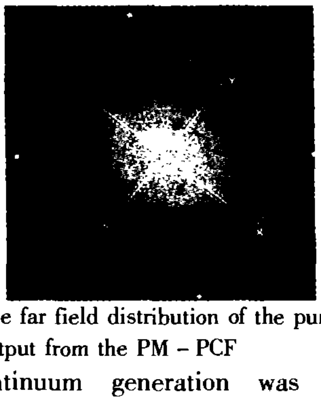

Fig. 3 The far field distribution of the pumping light output from the PM-PCF

Supercontinuum generation was achieved by injecting 250 fs ultrashort optical pulses produced by OPA into the PM-PCF. This is the first demonstration of the supercontinuum generation in the PM-PCF in the 1.6 μm region. Fig. 4 shows the OPA output spectrum measured by the optical spectrum analyzer (OSA) (AV6361). Before injecting the PM-PCF, the center wavelength and the full width of half maximum (FWHM) of the spectrum were measured to be 1.5938 μm and 35.2 nm, respectively. The pumping wavelength lied in the anomalous dispersion region of the PM-PCF. Fig. 5 shows the whole profile of the generated supercontinuum spectrum at the output of the PM-PCF with the average pumping power of 10 mW and the corresponding peak power of 160 kW and the energy of 40 nano-joules per pulse. From Fig. 5, we can see that the optical spectrum was broadened to be 45.8 nm (1.5892 ~ 1.6350 μm), which was over 10 nm wider than that of the OPA output spectrum. The center wavelength of 1.6121 μm was red-shifted by 18 nm compared with that of the OPA output spectrum.

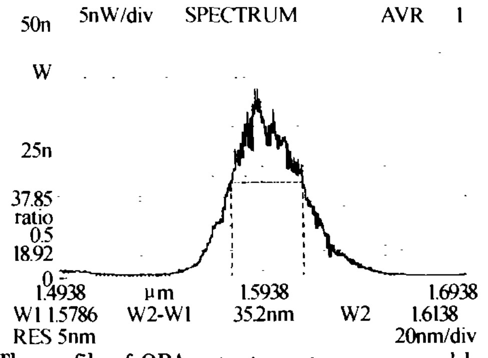

Fig. 4 The profile of OPA output spectrum measured by OSA before injecting into the PM-PCF

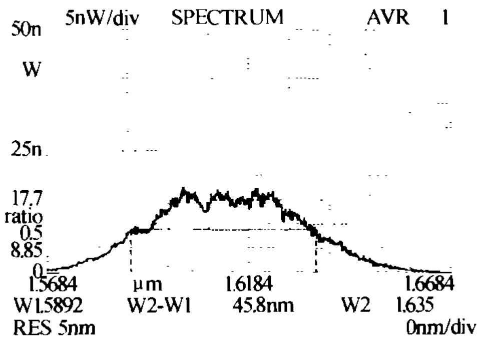

Fig. 5 The whole profile of the generated supercontinuum spectrum at the output of the PM-PCF with the average pumping power of 10 mW and the corresponding peak power of 160 kW

It was interpreted that the spectral broadening was due to the nonlinear effect of self-phase modulation (SPM). The dispersion length of $L_D = \frac{T_0^2}{|\beta_2|}$ and the nonlinear length of $L_{NL} = \frac{1}{\gamma P_0}$ were calculated to be about 6 m and 2×10^{-4} m, respectively, where T_0 was the half-width at the 1/e intensity point, β_2 was the dispersion coefficient, γ was the nonlinear parameter and P_0 was the peak pulse power. The length of the PM-PCF $L = 0.2$ m met the expression

$$L \ll L_D, L > L_{NL} \quad (1)$$

so the nonlinear effect was dominated the propagate process, the dispersion term can be negligible.

The spectral profile of the generated supercontinuum exhibited quite flat characteristics, which was very important in the application of the multi-channel optical source. Although the peak level decreased as the spectrum broadened, no increase in the noise level was observed. Supercontinuum generation in the PM-PCF with a low pumping power indicated the strong nonlinear effects of the PM-PCF in our experiments. This PM-PCF is applicable to a multi channel optical source with ultrashort pulsewidth for WDM communication and photonic network systems.

3 Conclusions

In summary, efficient supercontinuum generation at 1.6 μm region was achieved for the first time, to our knowledge, using a polarization maintaining PCF. Broadened optical spectrum with spectral width of 45.8 nm was obtained from a 0.2 m-long PM-PCF pumped by 10 mW, 250 kHz, 250 fs optical pulses with center wavelength of 1.5938 μm produced by optical parameter amplifier (OPA).

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采用保偏光子晶体光纤在 1.6 μm 区域产生超连续谱

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摘 要 报道了利用保偏光子晶体光纤在 1.6 μm 区域产生超连续谱. 通过将光参量放大器产生的中心波长为 1.5938 μm、重复频率为 250 kHz、脉冲宽度为 250 fs 的光脉冲耦合进纤芯直径为 2.0 μm、长度为 0.2 m 的保偏光子晶体光纤,获得了 1.6 μm 区域的光谱展宽,展宽的光谱带宽为 45.8 nm (1.5892 ~ 1.6350 μm).

关键词 光子晶体光纤;超连续谱;光参量放大器

Yu Yongqin was born in Jan. 1976 and received her Ph. D. degree in State Key Laboratory of Crystal Materials, Shandong University in July 2003. At present, she is working as a postdoctor in Shenzhen University. Her research interests include nonlinear optics in photonic crystal fibers and femtosecond laser micromachining.