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Wavelength conversion technique based on self phase modulation in highly nonlinear microstructure fiber*

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A wavelength converter based on the self phase modulation (SPM) effect in highly nonlinear microstructure fibers (MFs) is proposed. The core diameter and the pitch of the fiber are 2.05 μm and 5.0 μm, respectively, and the diameter of the air-holes in the fiber cladding is 4.50 μm. The calculating nonlinear coefficient is 112.2 $W^{-1}km^{-1}$ and it is 11 times higher than that of a conventional dispersion-shift fiber and 56 times higher than that of a conventional single-mode fiber. The length of the fiber is 100 m. The core area of the microstructure fiber is 3.3 μm^2. The self phase modulation effect is enhanced in the highly nonlinear microstructure fiber due to the very small fiber core area, and then the efficiency of the wavelength conversion is also improved. The wavelength conversion over ±4 nm is obtained with a good efficiency.

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In recent years, a study focus of optical communications is the all-optical-network (AON). The key techniques of AON include all optical switching/routing, optical cross connection, all optical buffering, all optical wavelength conversion, and so on, where the wavelength conversion has been demonstrated using many types of techniques[1]. A key goal in any future wavelength division multiplexing (WDM) network is to make the conversion enable data transparency, as well as the broadband, high speed, low chirp, low additive noise, high efficiency and high data extinction radio[2].

Microstructure fibers (MFs)[3-5] with a high nonlinearity are the most commonly used types of photonic crystal fibers (PCFs). They can be used within a wide field ranging from spectroscopy and sensor applications to the direct telecom oriented cases. The high nonlinear coefficient and designable dispersion properties make these fibers used for many nonlinear applications, such as supercontinuum generation, parametric amplifiers, pulse compression and all-optical switching etc[6-9]. The high nonlinear coefficient of the MF may be a good solution for effective optical wavelength conversion techniques. In this paper, the wavelength conversion based on the highly nonlinear MF is demonstrated. This fiber is manufactured by FiberHome Technologies Inc. of China. The numerical simulating software is Optisystem 6.0 from Optiwave Inc..

The cross structure of the MF used in the wavelength conversion is shown in Fig.1(a). It is made of pure silica and has a very small core in the center of the cross section. The core diameter and the pitch of the fiber are 2.05 μm and 5.0 μm, respectively, and the diameter of the air-holes in the fiber cladding is 4.50 μm. Large air holes are used so that the cladding can have very high air-filling fraction. This fiber can confine the mode field very tightly in the small core region. The calculating nonlinear coefficient is 112.2 $W^{-1}km^{-1}$, which is about 11 times higher than that of a conventional dispersion-shift fiber. The length of the used fiber is 100 m. The loss of this MF is 45 dB/km. To splice a standard single-mode fiber with the microstructure fiber as a pigtail, a highly nonlinear fiber with an appropriate core size is used between the standard single-mode fiber and the MF as a mode converter, as shown in Fig.1(b). The length and core diameter of the highly nonlinear fiber are 15 cm and 3.5 μm, respectively. The total splicing loss of one pigtail is 3.2 dB.

Our demonstrated wavelength converter is based on the SPM[10,11]. The SPM effect in optical fibers originates from the nonlinear refraction, which refers to the intensity depen-

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dence on the fiber core refractive index. In the simplest form, the fiber core refractive index can be written as

$$n(\omega,|E|^2)=n(\omega)+n_2|E|^2\ , \tag{1}$$

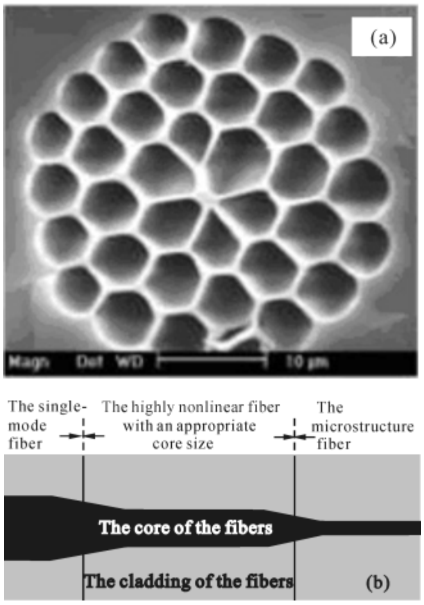

Fig.1 Cross structure of (a) the MF and (b) the mode converter

where $n(\omega)$ is the linear part of refractive index, which can be well approximated by the Sellmeier equation[6], ω is angular frequency of the light, n_2 is the nonlinear index coefficient, and $|E|^2$ denotes the optical intensity inside the fiber core. This refractive index intensity dependence can lead to a large number of interesting nonlinear phenomena, which mainly include the SPM and cross phase modulation (XPM) in optical fiber communications. The SPM refers to the self-induced phase shift through an optical field during its propagation in optical fibers. The phase change of an optical field can be obtained by

$$\phi=n(\omega,|E|^2)k_0L=(n(\omega)+n_2|E|^2)k_0L=\phi_{\mathrm{L}}+\phi_{\mathrm{NL}}\ , \tag{2}$$

where $k_0=2\pi/\lambda$, L is the fiber length, $\phi_{\mathrm{L}}=n(\omega)k_0L$ is the intensity independence, and the intensity-dependent nonlinear phase shift $\phi_{\mathrm{NL}}=n_2|E|^2k_0L$ is due to the SPM. The SPM is responsible for spectrum broadening of ultra-short pulses which propagate inside optical fibers. In this paper, a wavelength converter is demonstrated based on the spectrum broadening effect due to SPM in highly nonlinear MF.

The wavelength conversion system based on highly nonlinear MF is illustrated in Fig.2. The pulse width is 20 ps with 1550 nm central wavelength. The average output power is 0 dBm. After an EDFA, the amplified laser pulses are sent into the highly nonlinear MF through the mode converter with 3.2 dB loss. The EDFA with 30 dBm saturation output power can enhance the power of the light, which is sent into the MF. The peak power of the optical pulses, which are sent into the highly nonlinear MF, is about 10 W. Then the output light from the MF is split into two beams. One is sent into an optical spectrum analyzer, which is used to obtain the broaden spectrum of the laser pulses. The other is also sent into the optical spectrum analyzer or an optical oscilloscope after a tunable optical filter. The bandwidth of the optical filter is 50 GHz (0.4 nm). By the tunable optical filter, we can realize wavelength conversion from the central wavelength of the pulse laser to that of the optical filter.

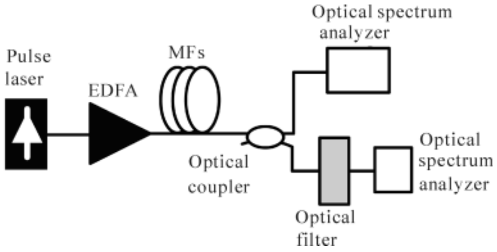

Fig.2 Wavelength conversion system based on highly nonlinear MF

Fig.3 shows the spectra of output light pulses from highly nonlinear MF with different EDFA average output power values. We can see that the spectrum is broadened when the EDFA output power is increased.

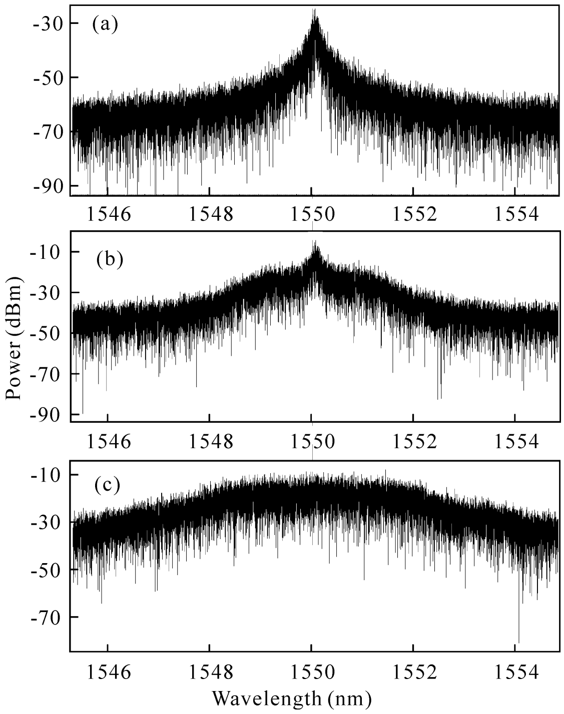

Fig.3 Spectrum broadening effect due to SPM in highly nonlinear MF with EDFA average output power of (a) 0 dBm, (b) 20 dBm and (c) 25 dBm, respectively

Fig.4 shows the optical spectrum after the filter with central wavelength of 1554 nm. The average output power of the EDFA is 29 dBm. The power peak is located at 1554 nm.

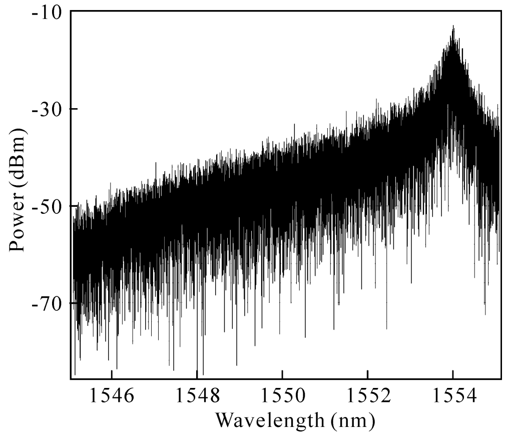

Fig.4 Optical spectrum after the filter with central wavelength of 1554 nm

The initial optical pulse waveform from the laser with wavelength of 1550 nm and the converted one with wavelength of 1554 nm are shown in Fig.5. It can be concluded that the wavelength conversion from 1550 nm to1554 nm is achieved with a good efficiency.

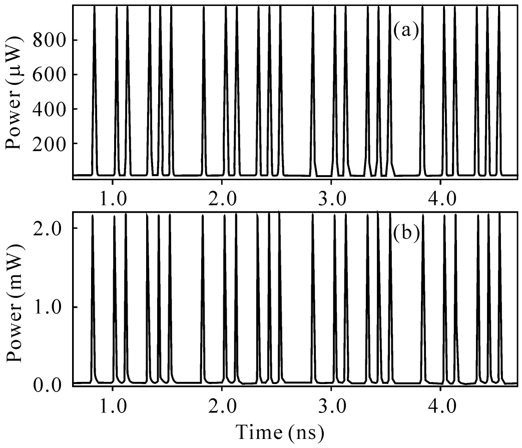

Fig.5(a) Initial optical pulse from the laser with central wavelength of 1550 nm; (b) Converted optical pulse after the optical filter with central wavelength of 1554 nm

Fig.6 shows the output power after the optical filter with 1554 nm central wavelength versus the EDFA average output power. With the EDFA average output power increasing, the output power after the optical filter is increased. When the EDFA average output power increases, the slope of the curve is increased due to the threshold effect of SPM. That is to say that SPM can be achieved when the input optical power is high enough, as shown in Fig.6. We can achieve ±4 nm tunable wavelength conversion by the tunable optical filter due to the symmetry of the spectrum broadening effect of SPM.

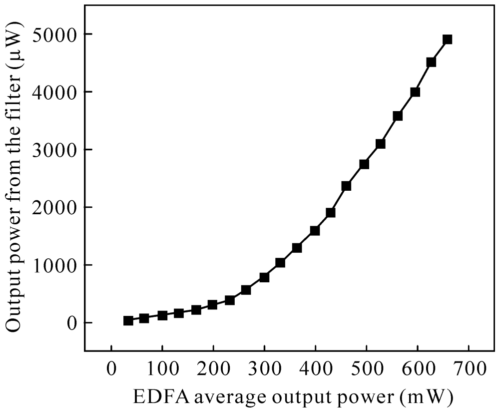

Fig.6 Output power after the optical filter with 1554 nm central wavelength versus the EDFA average output power

A wavelength converter based on highly nonlinear microstructure fiber is demonstrated. The core diameter and the pitch of the fiber are 2.05 μm and 5.0 μm, respectively, and the diameter of the air-holes in the fiber cladding is 4.50 μm. The calculating nonlinear coefficient is 112.2 $W^{-1}km^{-1}$, which is about 11 times higher than that of a conventional dispersion-shift fiber. The fiber length is 100 m. The core area of the microstructure fiber is 3.3 μm^2. Using the symmetrical spectrum broadening of SPM in highly nonlinear MF and a tunable optical filter, ±4 nm tunable wavelength conversion is achieved with a good efficiency. Based on SPM of highly nonlinear microstructure fiber, our wavelength converter can obtain transparent wavelength conversion for single wavelength or multi-wavelength. This study may be a new alternative solution for high effective all-optical wavelength conversion in high-speed optical communication systems and all-optical networks.

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