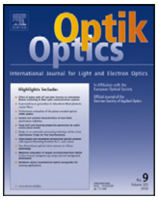
Optik 123 (2012) 502–506

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo



Wavelength conversion based on high nonlinear microstructured fiber

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ARTICLE INFO

Article history:
Received 19 November 2010
Accepted 30 April 2011

PACS:
42.79.Sz
42.65.Wi

Keywords:
Wavelength conversion
Four wave mixing
Microstructured fiber

ABSTRACT

A wavelength conversion based on high nonlinear microstructured fiber is demonstrated. Core diameter and pitch of the microstructured fiber used in this wavelength conversion method are 2.05 μm and 5.0 μm, respectively. Diameter of the air-holes in the fiber cladding is 4.50 μm, the nonlinear coefficient of the microstructured fiber is 112.2 $\mathrm{W}^{-1}\,\mathrm{km}^{-1}$ and it is 60 times higher than that of a conventional dispersion-shift fiber, the length of the fiber is 100 m. Four-wave-mixing effect is improved in the high nonlinear microstructure fiber and then the efficiency of the wavelength conversion is improved also. 10 Gbps Not-Return-to-Zero (NRZ) modulation format and 10 Gbps Return-to-Zero (RZ) modulation format are converted effectively by our method. This study can provide a new alternative solution for high effective all-light wavelength conversion in high speed optical communication systems with multi-wavelengths and all-light optical networks.

1. Introduction

In recent years, a focus on the study of optical communication is All-Optical-Networks (AONs), and it is the necessarily developing result for network due to avoiding "electrical bottleneck" effect. The key techniques of AONs include all optical switching/routing, optical cross connection, all optical buffering and all optical wavelength conversion, and so on, where wavelength conversion can help reduce the blocking probability in all-optical wavelength division multiplexing (WDM) networks and can effectively resolve connection and dramatically increase network throughput. This is traditionally accomplished by converting the signal to the electrical domain and retransmitting it at another wavelength. Optical wavelength conversion has been demonstrated using many types of wavelength conversion techniques [1]. A key goal in any future WDM network is for the conversion approach to enable data transparency, as well as to be broadband, high-speed, low chirp, low additive noise, high efficiency and high data extinction radio [2].

Microstructured fibers [3–5], also called photonic crystal fibers, with periodic transverse microstructure, can allow remarkable control of key optical properties such as dispersion, birefringence, nonlinearity and the position and width of the photonic band gaps (PBGs) in the periodic photonic crystal cladding. Microstructure fibers, with high nonlinearity, are today the most commonly used types of photonic crystal fibers. Their uses are within a wide filed of applications ranging from spectroscopy and sensor applications to the directly telecom oriented. The high nonlinear coefficient and designable dispersion properties makes these fibers for many nonlinear applications, such as supercontinuum generation, 2R regeneration, parametric amplifiers, pulse compression, all-optical switching, etc. [6,7]. The high nonlinear coefficient of the microstructured fiber may be a good solution for effective optical wavelength conversion techniques. In this paper, we demonstrate wavelength conversion method based on high nonlinear microstructured fiber. This fiber manufactured by FiberHome Technologies, Inc., of China. The numerical simulating software is Optisystem 6.0 from Optiwave, Inc.

2. Four-wave-mixing effect in the microstructured fiber

Our demonstrated wavelength conversion method is based on four-wave mixing (FWM) effect [8]. So firstly, the four-wave mixing effect is discussed in brief. The origin of FWM effect lies in the nonlinear response of bound electrons of materials to an electromagnetic field. FWM effect is third-order parametric process with nonlinear interaction among four optical waves. Considering the fiber nonlinearity and multi-waves transmission, the total polarization $\vec{P}$ can be written as:

$$\vec{P} = \varepsilon_0(\chi^{(1)} \cdot \vec{E} + \chi^{(2)} : \vec{E}\vec{E} + \chi^{(3)} \vdots \vec{E}\vec{E}\vec{E} + \ldots), \tag{1}$$

where ε_0 is the vacuum permittivity and is j th order susceptibility and is $j+1$ rank tensor, $\vec{E}$ is the electric field. The main features of

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doi:10.1016/j.ijleo.2011.05.015

FWM effect in microstructured fiber can be understood from the third order polarization term in Eq. (1):

$$\vec{P}_{NL} = \varepsilon_0 \chi^{(3)} \vdots \vec{E}\vec{E}\vec{E}, \tag{2}$$

where $\vec{P}_{NL}$ is the induced nonlinear polarization.

Consider four continuous waves with frequencies $\omega_1, \omega_2, \omega_3$ and ω_4, respectively, and linearly polarized along the same axis x, the total electric field can be written as

$$\vec{E} = \frac{\hat{x}}{2}\sum_{j=1}^{4} E_j e^{[i(\beta_j z - \omega_i t)]} + c.c., \tag{3}$$

where the propagation constant $\beta_j = \tilde{n}_j \omega_j / c$, $\tilde{n}_j$ is the mode index, $\hat{x}$ is the unit vector along the axis x and then Eq. (2) can be expressed as

$$\vec{P}_{NL} = \frac{\hat{x}}{2}\sum_{j=1}^{4} P_j e^{[i(\beta_j z - \omega_i t)]} + c.c.. \tag{4}$$

New frequencies are produced by FWM effect in microstructured fiber, significant FWM effect occurs only if the phase mismatch nearly vanishes. This requires matching of the frequencies as well as of the wave vectors. The latter requirement is often referred to as phase matching. That is to say

$$\omega_4 = \omega_i + \omega_j - \omega_k, \tag{5}$$

$$\beta_4 = \beta_i + \beta_j - \beta_k. \tag{6}$$

When $\omega_i = \omega_j$, it is called degenerate FWM effect, and then we have

$$\Delta\beta = 2\beta_i - \beta_k - \beta_4. \tag{7}$$

When pump light with high power and signal light were coupled into high nonlinear microstructured fiber, the nonlinear refractive index of the fiber core materials will be changed due to the Kerr nonlinearity effect, the phase mismatching factor $\Delta\beta$ is also changed with the change of power of the pump light. The modified phase mismatching factor must be introduced:

$$k = \Delta\beta + \gamma(P_1 + P_2), \tag{8}$$

where P_1, P_2 are the power of the pump lights, $\gamma = n_{\text{ieff}} \cdot \omega_p / (c \cdot A_{\text{eff}})$, n_{ieff} is effective nonlinear index, ω_p is angular frequency of the pump light, c is the vacuum light speed, A_{eff} is the effective core area of the high nonlinear fiber. The phase-matching requirement is $k = 0$. For degenerate FWM effect, let $P_1 = P_2 = P/2$, then

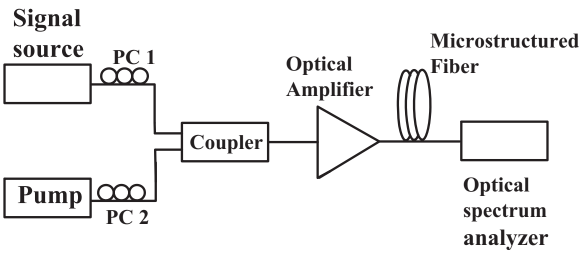

Fig. 1. Brief wavelength conversion system based on high nonlinear microstructured fiber.

$$k = \Delta\beta + \gamma P. \tag{9}$$

As we know, in the near of the zero-dispersion wavelength of the fiber, the phase matching condition can be obtained if we let $\omega_p = \omega_0$, where ω_0 is the angular frequency of the zero-dispersion wavelength. However, to adequately utilize the high nonlinearity of the fiber, we obtain the phase matching condition and realize the effective wavelength conversion by changing the power of pump light. This will be described in detail in the following parts of this paper.

3. Wavelength conversion system and results

A brief wavelength conversion system based on high nonlinear microstructured fiber is illustrated in Fig. 1, the signal source and pump light are coupled by an optical coupler after a respective polarization control (PC) device and the merged light be send into an optical amplifier, and then the amplified light transmits into a high nonlinear microstructured fiber. After the microstructured fiber, an optical spectrum analyzer is followed, as showed in Fig. 1.

The FWM effect is polarization-dependent and this polarization-dependent is illustrated in Fig. 2, the polarization states of the signal source light and pump light can be tuned by the two PC devices, as shown in Fig. 1. Fig. 2(A) denotes polarization direction of signal light is along that of the pump light (case A), (B) denotes polarization direction of signal light has 30° with that of the pump light (case B). The power of the idler light is higher about 12 dB in case A than that in case B. It can conclude that FWM effect is polarization-dependent, and we must make the polarization directions of the signal light and pump light in the same direction by careful mod-

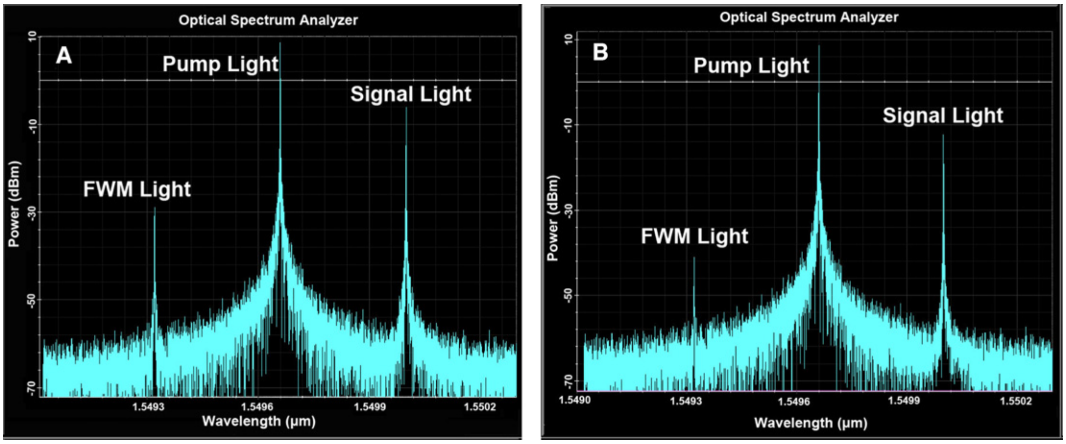

Fig. 2. Optical spectrum of the wavelength conversion system with different polarization of the signal light.