Wide Range Tunable Wavelength Conversion Using Parametric Effects and Raman Amplification in a Double-Pass System

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Abstract: *We achieve an efficient wavelength converter using parametric-Raman interactions in a double-pass system. Conversion efficiency greater than 0 dB over 50nm is obtained and the converted idler wavelength can be adjusted more than 10nm continuously.*

Introduction

All-optical wavelength conversion is a key technology for improving the flexibility and increasing the capacity of optical fiber networks [1]. The use of parametric four-wave mixing (FWM) for wavelength conversion attracted considerable attention because of its potential applications in wavelength division multiplexing (WDM) lightwave systems. Wavelength converters based on the dual-pump parametric amplification have been proposed to realize broadband features [2]. In order to employ the wide range amplification property of stimulated Raman scattering (SRS), a Raman-assisted parametric frequency conversion scheme has been reported [3]. In this paper, we propose and implement a simple scheme of a highly efficient wavelength converter utilizing the interaction between the parametric-FWM and the SRS in highly nonlinear fibers (HNLFs). A double-pass Raman amplifier is used to form a fiber Raman oscillator in which a tunable optical filter (TOF) and a wideband mirror are used to generate a lasing light in the normal dispersion region of HNLF. We achieve the wavelength conversion with an efficiency larger than 0 dB over 50-nm signal bandwidth. Arbitrary new wavelength in the tunable range of filter can be obtained for a given signal.

Technical concepts

Let us recall the theoretical results of the influence of FWM on SRS for a better understanding of our experiments. SRS is characterized by a down-conversion of a pump photon into a low-frequency Stokes photon through excitation of a vibrational mode of the transmission medium [4]. An up-conversion process that generates an upshifted anti-Stokes wave is also possible through the parametric FWM. The anti-Stokes is located symmetrically to the Stokes wave around the pump wavelength. This FWM-influenced Raman scattering is highly dependent on the dispersion of the pump wavelength. On one hand, significant gain improvements can be obtained for the Stokes and anti-Stokes if the pump is in the anomalous dispersion region. The phase matching due to the cancellation of linear phase-mismatch and nonlinear self-phase modulation can be achieved under appropriate conditions [4, 5]. On the other hand, if the pump is located at the normal dispersion region, the parametric suppression of the seeded Stokes exponential amplification takes place and the anti-Stokes idler generation and amplification occur although phase matching is unsatisfied. Similarly, the seeded anti-Stokes light of the pump can transfer the energy downshifted to the Stokes idler due to the Raman effects [3].

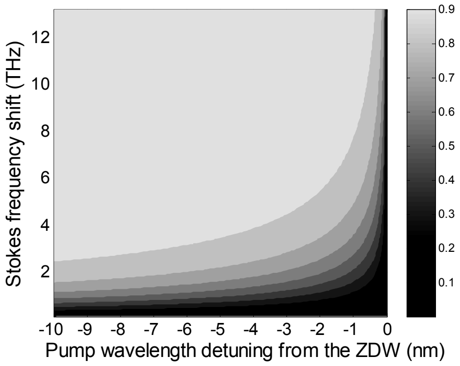

Fig. 1. Contour map of Raman gain suppression effects when pump is 0.1 W.

Experiments and results

The HNLF is used for optical signal processing due to its quite large Raman gain coefficient ($g_R = 5.9\ W^{-1}km^{-1}$) and nonlinear coefficient ($\gamma = 10\ W^{-1}km^{-1}$). The zero dispersion wavelength (ZDW) of the HNLF is at 1559 nm with a dispersion slope 0.02 $ps/nm^2/km$ and a cut-off wavelength below 1200 nm. The typical loss is less than 0.75 dB/km from 1550-1650 nm. In order to obtain the frequency conversion between Stokes and anti-Stokes, the pumping wavelength should be selected carefully to provide partial suppression of Raman gain and maintain a small phase mismatch. We calculated and plotted the Raman gain suppression as a function of pumping wavelength and Stokes shifts in Fig. 1 with pump power of 100 mW. The suppression factor is defined as the ratio between the parametric-Raman gain coefficient and the normal Raman gain at the same Stokes shift. The smaller the suppression factor, the stronger the suppression effect. It is clear that significant Raman gain suppressions can be obtained when the Stokes shifts is less than 3 THz (25 nm) which leads to about 50 nm useful bandwidth for the efficient conversion between Stokes and anti-Stokes waves. Thus we implement the wavelength conversion in a double-pass Raman amplifier as depicted in Fig. 2. The TOF with 3-dB suppression width of 0.65 nm can be tuned in the C-band (1530-1565 nm). The HNLF is pumped by a 1455 nm Raman fiber laser (RFL). The wideband fiber mirror is used with the TOF to form a laser acting as a second-order pump. The signal from the tunable laser source (TLS) is injected through the optical circulator to be a control light. The converted idler wave is monitored at the output of the circulator. Note that a Faraday rotator mirror optimized for 1556 nm is used here to eliminate the polarization dependent gain (PDG). The lasing light in the HNLF is measured to be 21 dBm when the RFL's power is 450 mW. The converted idler waves located inside the Raman gain spectrum of the RFL are amplified to obtain a further efficiency enhancement.

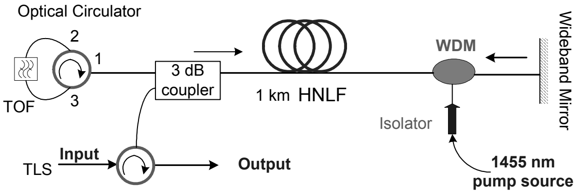

Fig. 2. Experimental setup.

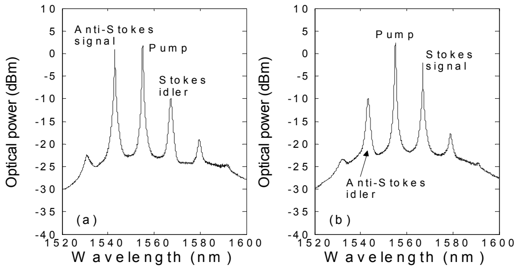

Fig. 3. Example of converted waves at the output with a control signal at 1543 nm (a) or 1567nm (b). Resolution is 0.2 nm.

Fig. 3 shows an example of the spectrum at the output of our system when the input signal is –8 dBm at1543 nm (Fig. 3. (a)) and 1567 nm (Fig. 3. (b)) with a pump wavelength at 1555 nm. The wavelength conversion efficiency over a wide bandwidth is measured (idler power at the output of the HNLF/signal power at the input of HNLF) by monitoring the output with an optical spectrum analyzer and plotted in Fig. 4 at different input signal power levels. As can be seen from Fig. 4, we obtain a conversion efficiency greater than 0 dB for over 50 nm signal bandwidth (1530 – 1580 nm) with an input signal power of –8 dBm. When the signal shifts toward the pump from the 1580 nm, the linear phase mismatch reduces such that a strong FWM-Raman gain of idler wave occurs. However, with further shift, the FWM is nearly phase-matched because of the flat dispersion slope. Cascaded FWM happens through the beat between pump and idler so the conversion efficiency at the idler wave deceases. A maximum efficiency can be observed in Fig. 4.

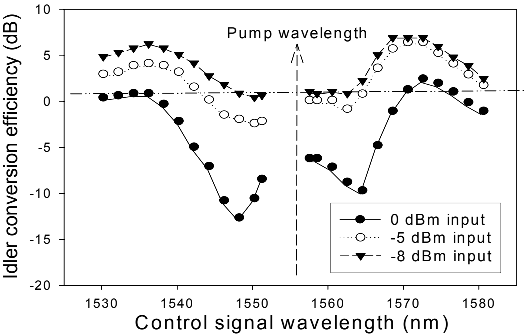

Fig. 4. Idler conversion efficiency measured while different signal power levels are used. Pump wavelength is 1555 nm.

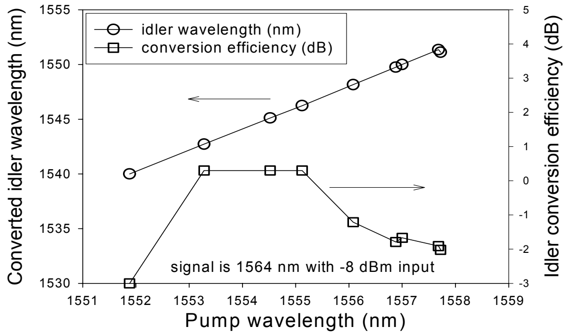

Fig. 5. Tunable idler wavelength (left axis) and conversion efficiency (right axis) as a function of pump wavelength.

Besides wide wavelength operation ranges, our wavelength converter can also provide an arbitrary new wavelength when the phase-mismatch is not serious. When the input control signal is –8 dBm at 1564 nm, by tuning the TOF to keep the pump wavelength inside the normal dispersion region, we obtained the idler wavelength and conversion efficiency versus the pump wavelength as plotted in Fig. 5. When the pump wavelength shifts from 1558 nm to 1552 nm, an idler from 1540 nm to 1552 nm can be adjusted continuously with a conversion efficiency larger than –3 dB.

Conclusions

We propose and demonstrate a simple scheme to achieve a highly efficient wavelength converter through the dynamics of FWM-Raman interaction in HNLFs. Wavelength conversion with an efficiency larger than 0 dB over 50 nm signal bandwidth is realized. A new wavelength idler with a conversion efficiency greater than –3 dB can be adjusted arbitrarily in a wavelength range of over 10 nm.

Reference

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