Arbitrary Wavelength Conversion in Entire CL-band Based on Pump-Wavelength-Tunable FWM in a HNLF

Masanori Takahashi, Shigehiro Takasaka, Ryuichi Sugizaki and Takeshi Yagi
Fitel Photonics laboratory, Furukawa Electric co., Ltd., 6, Yawata-kaigandori, Ichihara, Chiba, 290-8555, Japan
Takahashi.masanori@furukawa.co.jp

Abstract: Pump-wavelength-tunable FWM was demonstrated using a zero dispersion and dispersion slope HNLF. Signal in CL-band was converted to any wavelength in entire CL-band and measured power penalties were less than 1dB for 10Gbit/s NRZ signals.

OCIS codes: (060.2310) Fiber optics; (190.4370) Nonlinear optics, fibers

1. Introduction

All optical wavelength conversion is one of key techniques for increasing flexibility of optical networks. As been well documented, optical wavelength conversion of a data channel is effective to avoid contention and increase network throughput drastically. In recent years, ultrafast and high capacity optical network technologies, such as a reconfigurable optical add/drop multiplexer (ROADM), have become of considerable interest worldwide. In these applications, demands for wavelength conversion devices are on the rise.
Arbitrary all optical wavelength conversion based on various types of wavelength conversion techniques have been reported [1-3]. Tuning range was limited to less than 30nm due to some limitations for arbitrary wavelength conversion such as strict phase matching condition in the reported arbitrary wavelength converters. High power penalties up to 14 dB were also reported in them. So, wider tuning range and a lower power penalty are desired to use arbitrary wavelength converters in various optical networks.
Entire CL-band arbitrary optical wavelength conversion based on four-wave mixing (FWM) in a highly nonlinear fiber (HNLF) [4] has been reported [5]. This technique is one of the most attractive candidates for arbitrary wavelength converter due to its wide tuning range. To use this in the practical applications, it is necessary to investigate characteristics for data transmission. In this paper, we have experimentally confirmed the characteristics for data transmission of entire CL-band arbitrary wavelength converter, and have demonstrated an error free conversion in entire CL-band with power penalties less than 1 dB.

2. Arbitrary FWM wavelength conversion scheme

We employed a simple wavelength conversion scheme based on FWM with a single pump light. Figure 1 shows the principle of the arbitrary wavelength conversion. As λ_P is fixed to zero dispersion wavelength (λ_0) of the fiber, signal wavelength (λ_S) is converted to one specific idler wavelength (λ_I) in the case of a conventional technique. In the proposed scheme, λ_S is converted to arbitrary λ_I by tuning λ_P. Tuning range of λ_P is strictry limited because to satisfy a phase matching condition which depemds on the dispersion characteristics of optical fibers is required for FWM operation [6]. From the experimental result using a conventional low dispersion slope HNLF, conversion bandwidth was reduced to less than 1/2 by shifting λ_P only 2nm from λ_0 [4]. Therefore λ_P needs to be set to λ_0 of optical fibers strictly. To realize arbitrary wavelength conversion proposed in figure 1, we designed and fabricated a HNLF with zero dispersion and zero dispersion slope in the CL-band to satisfy phase matching condition while changing λ_P.
Figure 2 shows the dispersion characteristics of fabricated zero dispersion and zero dispersion slope HNLF (ZD-DS HNLF) and a conventional dispersion shifted fiber (DSF). This HNLF has two λ_0 at 1556 nm and 1600 nm. Dispersion slope at each λ_0 was 0.004 ps/nm^2/km and -0.005 ps/nm^2/km, respectively. Zero dispersion slope was measured at 1579 nm. Nonlinear coeffecient γ of this HNLF was 23 W^{-1}km^{-1} measured by XPM technique (14 w^{-1}km^{-1} for SPM technique).
Wavelength conversion experiments were performed while changing λ_P from 1530 nm to 1610 nm by using 100 m of fabricated ZD-DS HNLF. Figure 3 shows the relationships between λ_S and normalized conversion efficiency for each λ_P. The maximum conversion bandwidth of 70 nm was measured at λ_P of 1570 nm. Though the conversion bandwidth was decreased by changing λ_P from 1570 nm, the conversion bandwidth was maintained over harf of the

maximum bandwidth for more than 30 nm of λ_P variation. The significant advantage of the ZD-DS HNLF was shown.

Figure 4 shows the contour map of the normalized conversion efficiency measured from λ_P arbitrary wavelength conversion experiments. The effective arbitrary conversion region, whose normalized conversion efficiency is within -3dB, covers almost whole wavelength range of 1530–1610 nm. This means that λ_S in the whole C-L band can be converted to an arbitrary wavelength in almost whole C-L band.

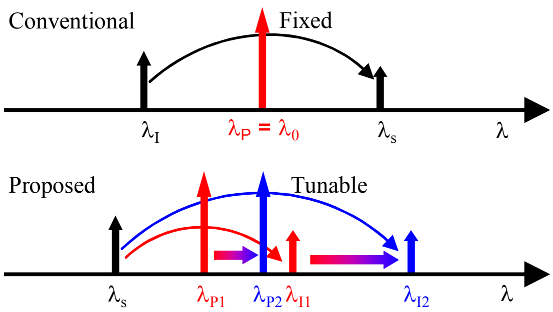

Fig. 1 Notion of arbitrary FWM wavelength conversion

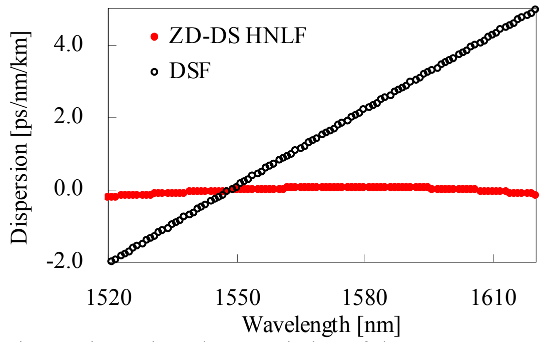

Fig. 2 Dispersion characteristics of the ZD-DS HNLF

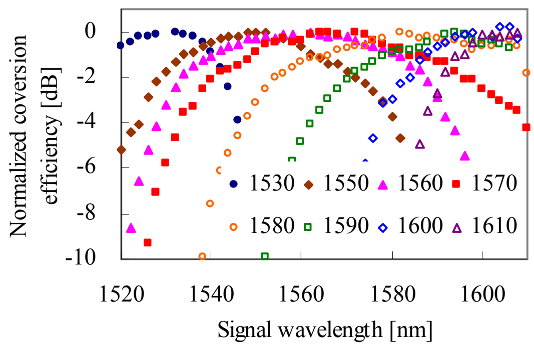

Fig. 3 Results of wavelength conversion for various λ_P

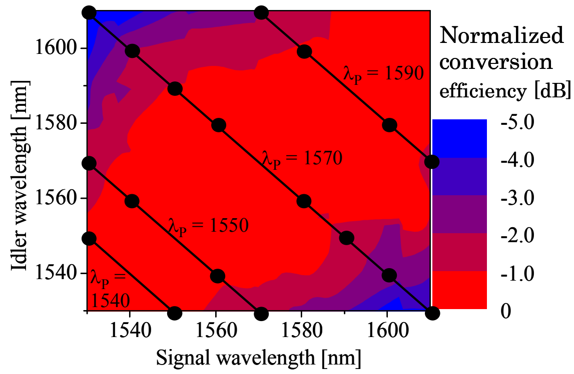

Fig. 4 Contour map of the conversion efficiency

3. Power penalty measurements for arbitrary wavelength conversion

We have performed the transmission experiments by using the arbitrary wavelength conversion scheme. Figure 5 shows the experimental setup. Tunable laser sources (TLSs) were used for a pump and a signal light. The signal was modulated by $LiNbO_3$ modulator (LN), and 10 Gbit/s, NRZ signal with pseudorandom binary sequence length of 2^{31}-1 was generated. The pump and the signal were amplified by EDFAs and band-pass filter (BPF) was used to suppress ASE noise. The pump and the signal were coupled in a coupler after polarization controllers (PCs). The coupled lights were launched into the HNLF. The output spectrum measured by an optical spectrum analyzer (OSA). The converted signal was filtered by a BPF and its power was adjusted by variable optical attenuator (VOA). An intensity of the converted signal was measured by an optical power meter (PM) as an received power for bit error rate (BER) measurements. Then converted signal was amplified by an EDFA and BPF was used suppress ASE noise. BER was measured by an error detector (ED). In this experiment, we used two types of commercial EDFAs for C-band (1530 nm – 1560 nm) and L-band (1570 nm – 1610 nm) amplification.

λ_P was set to 1540, 1550, 1570, and 1590 nm in these experiments, and BER was measured for various λ_S shown as closed circles in figure 4. A fiber length of the ZD-DS HNLF was set to 100 m. Pump power (P_P) was set to 18.5 dBm, and signal power (P_S) was set to -2.0 dBm at the input end of the HNLF. A difference between input P_S and output idler power (P_I) was measured as a conversion efficiency, and the maximum conversion effeciency was -21 dB. Almost the same conversion efficiency and conversion bandwidth were confirmed comparing to the experimental results in ref. 5 that used coutinuous wave (CW) as a signal.

Figures 6-9 show the mesured BER. In figure 7 and figure 8, about 2 dB of received power difference was measured between the C-band (1530-1560 nm) receiver and L-band (1570-1610 nm) receiver due to the noise figure of the EDFAs. So, we compared BER of converted signals with BER of back-to-back signals at the λ_I. Error free operation (BER of 10^{-9}) was comfirmed for all measurement even for the wavelength with lower conversion efficiency (ex. 1530 nm to 1610 nm conversion). And almost power penalty free (less than 1 dB) operation was also confirmed. These results shows that the signal from entire CL-band is converted to the arbitrary wavelength in entire CL-band with error free and power penalty less than 1dB by the pump-wavelength-tunable FWM in the ZD-DS HNLF.

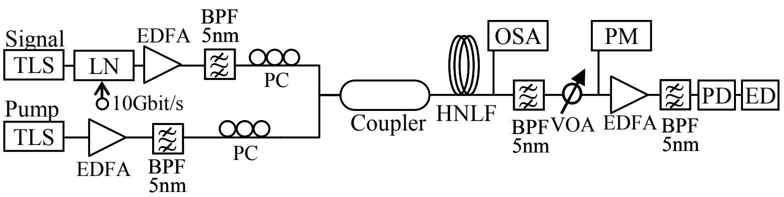

Fig. 5 Setup for BER measurements for arbitrary wavelength conversion

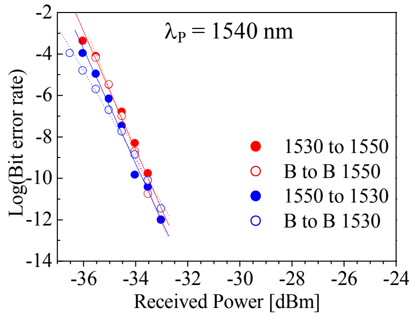

Fig. 6 BER at λ_P of 1540 nm

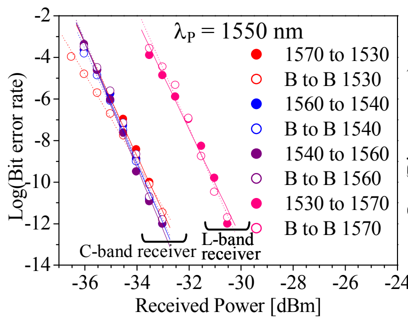

Fig. 7 BER at λ_P of 1550 nm

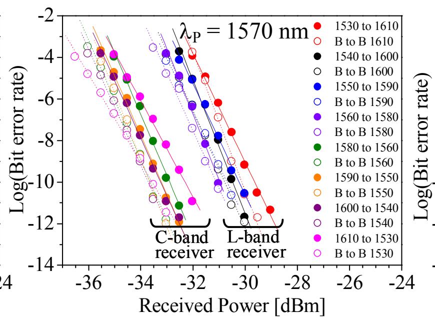

Fig. 8 BER at λ_P of 1570 nm

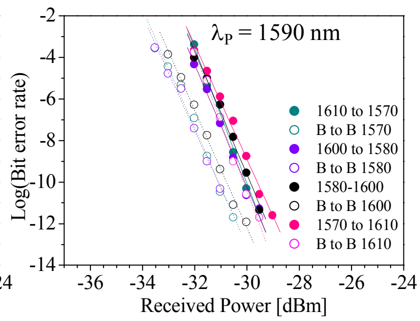

Fig. 9 BER at λ_P of 1590 nm

4. Conclusions

We have demonstrated all optical arbitrary wavelength conversion using pump-wavelength-tunable FWM in the ZD-ZS HNLF. Tuning range of λ_P was all CL-band (1530-1610 nm), and the signal from entire CL-band was converted to the arbitrary wavelength in entire CL-band by this effect. The Bit error free operation of the converted signal with power penalties less than 1 dB has been confirmed for 10 Gbit/s NRZ signals. These results indicate that proposed technique would be feasible to employ for an arbitrary wavelength converter in optical network nodes.

5. References

[1] H. Sotobayashi et al., “Wideband tunable wavelength conversion of 10-Gbit/s return-to-zero signals by optical time gating of a highly chirped rectangular supercontinuum light source”, Optics Lett., Vol. 26, pp.1314-1316, September, 2001.

[2] V. G. Ta’eed et al., “Error free all optical wavelength conversion in highly nonlinear As-Se chalcogenide glass fiber”, Optics Express, Vol.14, pp. 10371-10376, October, 2006.

[3] W. Astar et al., “Polarization-Insensitive Wavelength Conversion by FWM in a Highly Nonlinear PCF of Polarization-Scrambled 10-Gb/s RZ-OOK and RZ-DPSK Signals”, Photon. Technol. Lett., Vol. 19, pp. 1676-1678, October, 2007.

[4] M. Takahashi et al., “Low-Loss and Low-Dispersion-Slope Highly Nonlinear Fibers”, Journal of Lightwave Technology, Vol. 23, No. 11, pp.3615-3624, November, 2005.

[5] M. Takahashi et al., “Full C-L Band Tunable Wavelength Conversion by Zero Dispersion and Zero Dispersion Slope HNLF”, ECOC2009, P1.08, 2009.

[6] N. Shibata et al., “Phase-mismatch dependence of efficiency of wave generation through four-wave mixing in a single-mode optical fiber”, Journal of quantum Electron., Vol. 23, pp. 1205-1210, July, 1987.