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A novel polarisation independent phase conjugator/ wavelength converter utilising inline fibre distributed feedback lasers

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Abstract

We propose and demonstrate a novel technique for optical wavelength conversion and phase conjugation by fibre four-wave mixing (FWM) using inline fibre distributed-feedback (DFB) lasers.

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Optical phase conjugation has been attracting considerable attention, for the compensation of chromatic dispersion and nonlinearities in optical fibre communication systems using the midspan spectral inversion (MSSI) technique[1][2], and also for its potential application in wavelength conversion in future wavelength-division multiplexed (WDM) optical networks. It has been conventionally accomplished by four-wave mixing (FWM) in a dispersion-shifted fibre (DSF) or a semiconductor optical amplifier (SOA), in which the optical signal is combined with externally injected pump light through a fibre coupler, and fed into a DSF or an SOA to generate a wavelength converted conjugate output. The signal and pump polarisation states must be aligned to get maximum conversion efficiency, which is not practical since any cable fluctuation will cause the signal light polarisation to fluctuate and will affect the power of the conjugated light. Two solutions have been proposed to achieve polarisation independence in the device: (i) a polarisation-diversity arrangement[3][4], and (ii) injection of two orthogonally polarised pump beams[5][6]. However, they add more complexity in the phase conjugator/ wavelength converter. FWM in a distributed-feedback (DFB) semiconductor laser[7] is attractive because it does not require external injection of the pump light, but its polarisation independent implementation requires a phase-diversity arrangement[8]. In this paper, we propose and demonstrate a novel phase conjugation/ wavelength conversion technique by FWM using two orthogonally polarised pump lights from inline fibre DFB lasers. This technique features polarisation independent operation, and simple configuration without the need for external injection of the pump.

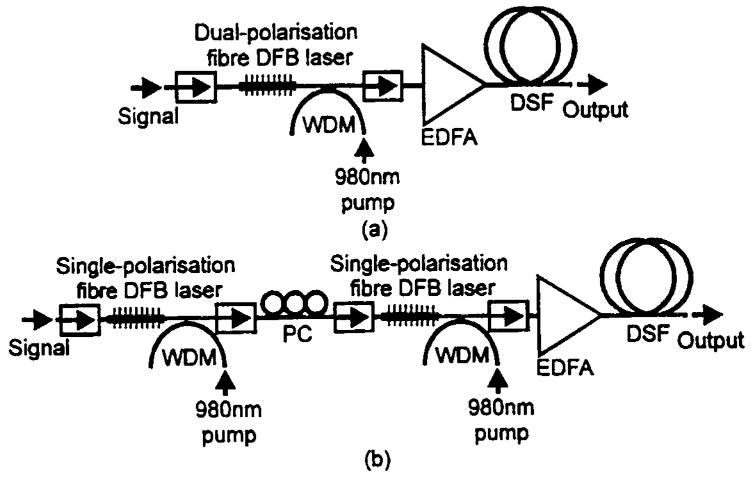

Fig.1 Configuration of the proposed phase conjugator/ wavelength converter.
(a) Using a dual-polarisation fibre DFB laser.
(b) Using two single-polarisation fibre DFB lasers.

Figure 1 shows the configuration of the proposed phase conjugator/ wavelength converter. The FWM pump sources are Er^{3+}:Yb^{3+} fibre DFB lasers[9] pumped with 980nm 100mW laser diodes (LD's). To achieve polarisation independence, the FWM pump sources must be orthogonally polarised and equal powers[5][6], so we use either (a) a dual-polarisation fibre DFB laser (Fig.1(a)), or (b) two single-polarisation fibre DFB lasers cascaded through a polarisation controller (PC) (Fig.1(b)). Since the fibre DFB lasers are transparent at the signal wavelength, the signal and the DFB generated FWM pump beams are combined through direct injection of the signal light into one end of the fibre DFB laser. This eliminates the need of a polarisation combiner and a signal/ pump coupler as required in a conventional polarisation independent device. After amplification by an Er^{3+}-doped fibre amplifier (EDFA), the signal and pump waves are launched into a DSF, generating a conjugate output which is insensitive to the signal polarisation owing to the two orthogonally polarised pumps.

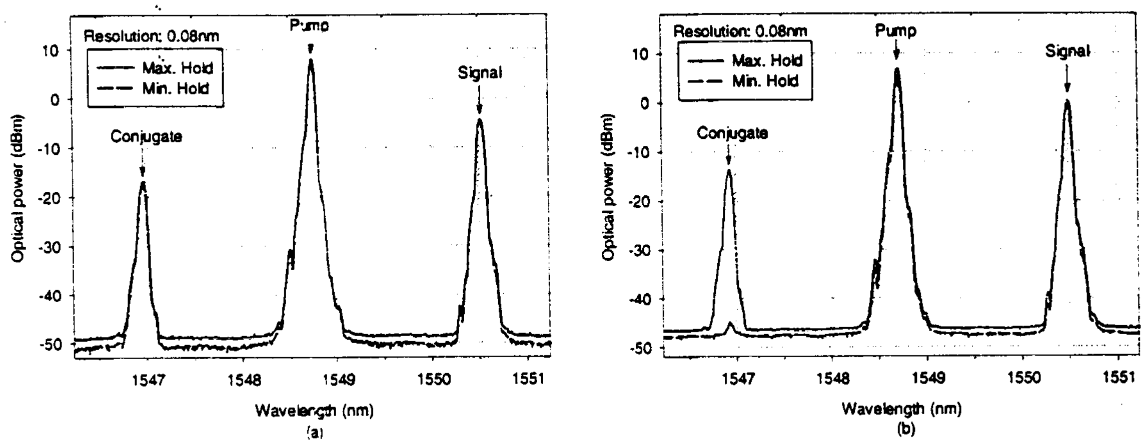

Fig.2 Output optical spectra of the phase conjugator/ wavelength converter using (a) a dual-polarisation fibre DFB laser, and (b) a single-polarisation fibre DFB laser.

Figure 2 shows the output optical spectra of the phase conjugator/ wavelength converter using a dual-polarisation fibre DFB laser in Fig.1(a). The fibre DFB laser is 5cm in length, operating at 1548.7nm in two orthogonal polarisations separated by about 0.8GHz, due to the birefringence in the fibre DFB resonator. The optical powers of the two polarisations are slightly different at the "free-running state", but they can be changed by applying a stress at the mid-point of the fibre DFB laser as a result of the anisotropic phase shift induced in the two birefringent axes. By proper adjustment of the strength, the orientation and the position of the stress, we could force it to operate either in two polarisations with equal powers, or in a single polarisation. The half-width of the unpumped DFB resonator stopband is measured to be about 0.2nm. The passband insertion loss of the DFB laser module including two isolators is about 2.7dB. This can be reduced to be less than 1dB with better components and splices. A tunable single frequency laser operating at 1550.5nm is used as a signal source, and a 11km-DSF with zero-dispersion wavelength at 1548nm is used as a nonlinear FWM media. The output spectrum is measured using multiple scans of an optical spectrum analyser (OSA) (with 0.08nm resolution) employing the maximum (solid) and minimum (dashed) hold trace functions. The signal polarisation state is varied arbitrarily over all states using a PC throughout the measurement. Figure 2(a) shows the output spectrum when the fibre DFB laser operates on both polarisations. As expected, nearly polarisation independent phase conjugation was realised. Remaining polarisation dependency is about 0.5dB. When the fibre

DFB laser operates at a single polarisation (Fig.2(b)), the conjugate light suffered large fading over 30dB.

It must be noted that this dual-polarisation fibre DFB laser can not be used with signal bit-rate of higher than 400Mbit/s, because the signal bit-rate must be less than half of the frequency separation of the orthogonal pumps[6]. However, the frequency separation can be expanded to more than 40GHz using a highly birefringent Er^{3+}:Yb^{3+} fibre[10].

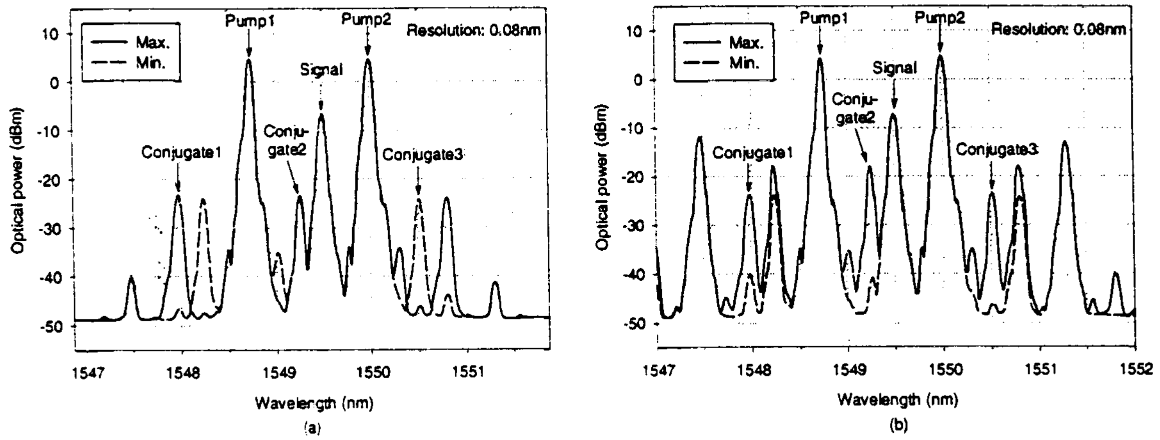

Fig.3 Output optical spectra of the phase conjugator/ wavelength converter using two single-polarisation fibre DFB lasers.

(a) Polarisation states of the two pumps are orthogonal.

(b) Polarisation states of the two pumps are aligned.

Figure 3 shows the output optical spectra of the phase conjugator/ wavelength converter using two single-polarisation fibre DFB lasers cascaded through a PC, as shown in Fig.1(b). The two fibre DFB lasers are operating at 1548.7nm (pump1) and 1550nm (pump2) each on a single polarisation. Incident FWM pump powers into the DSF are set to be equal by adjusting the respective 980nm pump powers of the fibre DFB lasers. Note that the isolators before and after the PC are not essential. Figure 3(a) is when the polarisation states of two pumps are set to be orthogonal by adjusting the PC between the two fibre DFB laser modules. The PC was actually set to minimise the mixing products between pump1 and pump2 appearing at 1547.4nm and 1551.3nm. The signal wavelength is set at 1549.5nm between pump1 and pump2. In this case, many mixing products are generated owing to the completely nondegenerate FWM process, and the phase conjugate components of the signal appear at 1547.9nm (conjugate1), 1549.3nm (conjugate2), and 1550.5nm (conjugate3). A solid trace is when conjugate1 reaches a maximum, and a broken trace is when it reaches a minimum. It is observed that conjugate2 is polarisation independent, whilst one of conjugate1 and conjugate3 each reach a maximum when the other reaches a minimum. Remaining polarisation dependency in conjugate2 is again about 0.5dB. Figure 3(b) is when the polarisation states of the two pumps are set to be aligned to maximise the mixing products between pump1 and pump2. Conjugate2 is found to have large polarisation dependency over 20dB, although the maximum conversion efficiency is improved by 5.3dB compared to that in Fig.3(a), which agrees well with the theoretical value of 6dB. The signal wavelength can be set far from the pump wavelengths, but the conversion efficiency becomes poor due to the nonideal zero-dispersion wavelength of the DSF.

In conclusion, we have proposed and demonstrated a novel technique for optical wavelength conversion and phase conjugation by fibre FWM using inline fibre DFB lasers as orthogonally polarized pump sources. It features polarisation independent operation and a simple configuration without the need for a polarisation combiner and a signal/ pump coupler as required in a conventional polarisation independent device. We have successfully demonstrated polarisation independent (0.5dB) operation of the phase conjugator/ wavelength converter. In addition, in the future it will also be possible to integrate the fibre DFB laser module into an EDFA. Furthermore, this technique is also applicable to FWM in an SOA.

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