Saturation properties of four-wave mixing between short optical pulses in semiconductor optical amplifiers

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Published in:
Proceedings of CLEO'99

Link to article, DOI:
10.1109/CLEO.1999.834103

Publication date:
1999

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):

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directional MSSI swapping at 10 and 20 Gbit/s are shown in Fig. 3. The coupled CW pump power in the experiment was 6 to 7 dBm. The coupled signal power was around -6 to -7 dBm. The difference in CW pump power for equal FWM output power for up- and down-conversion was 2-3 dB. These values are in good agreement with the model predictions.

In conclusion, large signal simulations of a novel scheme of bi-directional FWM are shown to be in good agreement with experiments and identify critical aspects of the system performance.

2. A. Buxens et al., ECOC'98 3, 95 (1998).

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Demonstration of four wave mixing in an integrated pump laser and semiconductor optical amplifier for mid-span spectral inversion dispersion compensation
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Non-degenerate four wave mixing (NDFWM) has been studied extensively in recent years as both a method for compensating against the dispersion of standard single mode optical fibre via mid-span spectral inversion (MSSI) and as a transparent wavelength conversion mechanism. NDFWM has been reported in many devices, including semiconductor optical amplifiers (SOAs), distributed feedback (DFB) lasers, nonlinear waveguides and optical fibre itself. SOAs are promising devices for NDFWM due to their small size, large gain bandwidth and high speed (>100 Gb/s). However, an external pump laser and EDFA are required which adds both cost and complexity to the system. Recently, an integrated DFB laser and SOA has been reported for wavelength conversion under static conditions. Here, for the first time we believe, the use of a similar device for dynamic MSSI dispersion compensation is demonstrated. The experimental arrangement is depicted in Fig. 1.

A 10 GHz train of 18 ps pulses is generated by gain-switching a 1555.2 nm DFB laser. These pulses are amplified by an EDFA and injected into a 25 km span of standard fibre. The output of the span is passed via an optical circulator into another EDFA and filter before injection into the DFB laser section of the phase conjugator. A polarisation controller is used to match the polarisation of the incoming signal to that of the DFB pump beam. The DFB pump wavelength is at 1553.6 nm and has a linewidth of ~2 MHz when both it and the SOA are biased at 250 mA. The newly generated phase conjugate signal at 1552 nm is filtered to remove the pump and original signal before being amplified, filtered again and transmitted back over the span. The received signal is analysed after traversing an additional 1 km of standard fibre, which compensates for the dispersion induced by the wavelength difference on the two spans. The pulses are examined using a 32 GHz photodiode and 50 GHz sampling oscilloscope.

The optical spectra produced from the output of the phase conjugator are shown in Fig. 2 before and after filtering. The average injected signal power to the phase conjugator is +3.5 dBm. After filtering it can be seen that the residual peak pump level is over 30 dB lower than the phase conjugate.

In conclusion, for the first time, an integrated DFB/SOA laser has been shown to operate as an MSSI dispersion compensator via NDFWM with a 10 GHz pulse train and 2.5 Gbit/s data. Although the former does show some degradation, it is believed that further optimisation of the device (such as reduced DFB linewidth) will lead to far superior performance. A full beat rate analysis and results at 10 Gbit/s will be presented at the conference.

due to carrier heating and spectral holeburning) that all contribute to gain saturation and therefore counteract the FWM process. The characteristics depend strongly on the operation conditions, i.e., SOA gain, input power, bitrate and pulseswidth.

Figure 1 shows the experimental set-up. Pump and probe pulses are generated using two synchronized external cavity semiconductor modelocked lasers, which can be tuned in pulseswidth and repetition rate. The pulses are injected, co-polarized and temporally overlapping into a 1500 nm bulk InGaAsP amplifier. The efficiency (conjugate power at output divided by probe input) and the signal-to-background ratio (SBR) are measured using an optical spectrum analyzer (1 nm resolution) as a function of the saturated SOA gain. Measurements of a constant average input powers were 3 dBm for the pump and -7 dBm for the probe. The saturated gain is the fiber-to-fiber gain, including an estimated total coupling loss of -7 dB. Due to the saturation of the gain coefficients themselves, which is not included in the model.

In conclusion, we report the first comparison between theory and experiment on the FWM between trains of short pulses in SOAs. The theory is able to explain all qualitative features seen in the experiment. Figure 2(a) shows the measured data. The existence of a certain gain, or injection current, that optimizes the SBR is special to the parameters of the investigated pulseswidths. We notice that the inclusion of saturation effects due to ultrafast carrier dynamics is absolutely necessary in order to obtain the qualitative dependencies seen in the experiment. For increasing gain the ASE therefore grows faster than the conjugate energy and a maximum is obtained. Both the calculated and measured data show that the maximum moves to larger gain for the higher repetition rate, but changes only in amplitude for the investigated pulseswidths. We notice that the peak power of L1 is either -11, or -7, or -2.2 dBm. This simulates a 9, 21, or 61 (-20 dBm/channel) channel WDM system where 8, 20, or 60 channels are added/dropped, respectively, in a purely homogeneous gain medium. Figure 2(b) shows the power excursions to be 0.27, 0.6, and 1.5 dB, respectively, for the 3 cases. By comparison, Figure 2(b) shows the power excursions when a single-stage experiment is shown in Fig. 1. Light from a 1545 nm laser, L1, is sent through an acousto-optic switch to simulate the addition/dropping of channels. A 1550 nm probe laser, L2, serves as the surviving channel, and is combined with L1 via a 50/50 coupler, followed by the overpumped EDFA, consisting of input and output isolators, 13 m of Lucent's HP-980 erbium-doped fiber, and two WDMs. The pump laser is a fiber-coupled SDL MOPA, providing 450 mW of co-propagating 984 nm power. The output of the EDFA is then passed through a 1-nm bandwidth filter and the 1550 nm signal is displayed on an oscilloscope.

The single-stage experiment is shown in Fig. 1 Light from a 1545 nm laser, L1, is sent through an acousto-optic switch to simulate the addition/dropping of channels. A 1550 nm probe laser, L2, serves as the surviving channel, and is combined with L1 via a 50/50 coupler, followed by the overpumped EDFA, consisting of input and output isolators, 13 m of Lucent's HP-980 erbium-doped fiber, and two WDMs. The pump laser is a fiber-coupled SDL MOPA, providing 450 mW of co-propagating 984 nm power. The output of the EDFA is then passed through a 1-nm bandwidth filter and the 1550 nm signal is displayed on an oscilloscope. The small-signal gain and noise-figure are measured to be 20 dB and 3.8 dB, respectively, with ~40 mW of absorbed pump power.

The power of L2 into the EDFA is -20 dBm and the peak power of L1 is either -11, -7, or -2.2 dBm. This simulates a 9, 21, or 61 (-20 dBm/channel) channel WDM system where 8, 20, or 60 channels are added/dropped, respectively, in a purely homogeneous gain medium. Figure 2(a) shows the power excursions to be 0.27, 0.6, and 1.5 dB, respectively, for the 3 cases. By comparison, Figure 2(b) shows the power excursions when a single-stage experiment is shown in Fig. 1. Light from a 1545 nm laser, L1, is sent through an acousto-optic switch to simulate the addition/dropping of channels. A 1550 nm probe laser, L2, serves as the surviving channel, and is combined with L1 via a 50/50 coupler, followed by the overpumped EDFA, consisting of input and output isolators, 13 m of Lucent's HP-980 erbium-doped fiber, and two WDMs. The pump laser is a fiber-coupled SDL MOPA, providing 450 mW of co-propagating 984 nm power.

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