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Optics & Laser Technology 35 (2003) 261–265
Optics & Laser Technology
www.elsevier.com/locate/optlastec

Performance analysis of an all-optical wavelength converter based on XPM in semiconductor optical amplifiers

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Received 1 March 2002; received in revised form 1 November 2002; accepted 13 December 2002

Abstract

Performance analysis is carried out for an all-optical wavelength converter based on cross-phase modulation in two semiconductor optical amplifiers (SOAs) arranged in a Mach–Zehnder interferometer configuration to evaluate the efficiency of conversion and the signal-to-crosstalk ratio (SCR) at the output of the converter. The results evaluated analytically for input non-return to zero signal at a bit rate of 10 Gb/s show that conversion is possible over a wavelength separation of 2 nm between the pump and the input wavelengths. It is further noticed that SCR of the order of 50 dB or more can be achieved at a bit rate of 10 Gb/s, optical amplifier bandwidth of 10 times bit rate and driving current of 600 mA when the input pump is 60% of saturation intensity. The range of wavelength conversion can further be increased by increasing the driving current.

Keywords: Semiconductor optical amplifier; Cross-phase modulation; Mach–Zehnder Interferometer

1. Introduction

All-optical wavelength converters are the key components for multi-wavelength optical transport networks and are expected to provide wavelength conversion in optical domain without significant distortion of the input signal [1]. Wavelength converters offer the advantages of increased flexibility in wavelength routing and avoidance of wavelength blocking in a wavelength division multiplexing (WDM) network node. As a consequence, the capacity of an optical multi-wavelength network can be considerably increased with the use of wavelength converters at different nodes [2]. Wavelength converters based on SOAs and semiconductor lasers have been the focus of considerable research interests during the last few years [3,4]. A variety of all-optical wavelength converters have been reported such as; semiconductor optical amplifier converters based on cross-phase modulation (XPM) [5,6], cross-gain modulation (XGM) [7,8], and four-wave mixing (FWM) [9–12], bistable lasers using saturable absorbers, injection locked Y-lasers and distributed-feedback (DFB) lasers relying on optical frequency or intensity modulation. Previous studies have been carried out experimentally [13–15] and by simulation to evaluate the efficiency of wavelength conversion and the noise characteristics of wavelength converters with some experimental results on the bit error rate performance of an optical link using wavelength converters.

In this paper, performance analysis is carried out for an all-optical wavelength converter based on XPM in two semiconductor optical amplifiers arranged in the two arms of a Mach–Zehnder interferometer (MZI) [16]. The analysis is carried out to determine the efficiency of wavelength conversion and the amount of crosstalk introduced during wavelength conversion with optical filtering taking into account the effect of optical amplifiers' spontaneous emission (ASE) and the signal to crosstalk ratio (SCR) at the output of the converter is derived.

2. System model

The block diagram of the wavelength conversion scheme is shown in Fig. 1. The input random non-return to zero (NRZ) data stream is used to modulate the intensity of the transmitting laser source and the output optical signal of the

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0030-3992/03/$ - see front matter
doi:10.1016/S0030-3992(03)00003-3

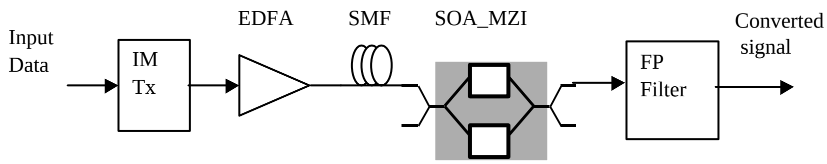

Fig. 1. Block diagram of the wavelength conversion scheme using two SOAs in an MZI configuration.

transmitter is amplified by an erbium-doped fiber amplifier (EDFA) and launched into the single mode fiber (SMF). The signal at the output of the fiber is passed through an SOA-based converter in an MZI configuration.

The SOA-MZI converter consists of two semiconductor optical amplifiers (SOAs) arranged in the two arms of an MZI as phase shifting elements. The MZI configuration is considered to provide better performance due to higher gain [7]. The two SOAs are biased asymmetrically to give different amount of phase shift. One of the two inputs is the input from the fiber which is the transmitted signal of wavelength λ_i and the other input is a continuous wave (CW) converter signal at an wavelength λ_c. The continuous wave light signal experiences a phase shift due to carrier density change induced by the intensity modulated signal. The amount of phase shift can be controlled by changing the bias currents of the two SOAs and/or their cavity lengths and the power input from the fiber. The increased amount of power injected from the fiber produces more stimulated emission and consequently the carrier density changes which in turn produces a change in refractive index of the active layer. This change in refractive index produces a change in group velocity and thereby the output phase of the CW signal by cross-phase modulation. The PM/IM conversion characteristic of the interferometer converts the phase modulated signal to an intensity modulated signal at the output of the converter due to destructive or constructive interference depending on the phase shift.

The signal output from the converter is filtered by a Fabry–Perot filter to filter out the spontaneous emission noise due to the SOAs and to reduce crosstalk.

3. Theoretical analysis

The output signal from optical amplitude shift keying (ASK) transmitter is given by

$$E_i(t) = \sqrt{2P_{in}} \sum_k a_k\, p(t-kT) \times \exp\left[j\left\{ \frac{2\pi}{\lambda_i} t + \phi_{ni}(t) \right\} \right], \qquad (1)$$

where P_{in} represents the input average power for the signal at an wavelength λ_i, $\{a_k\}$ represents the random NRZ bit pattern with elementary pulse shape $p(t)$, $\phi_{ni}(t)$ is the phase noise of the received signal due to non-zero linewidth of the transmitting laser.

The signal at the fiber output and input to the wavelength converter can be represented as

$$E_s(t) = E_i(t) \otimes h_f(t) = \sqrt{2P_s} \sum_k a_k\, p'(t-kT) \times \exp\left[j\left\{ \frac{2\pi}{\lambda_i} t + \phi_{no}(t) \right\} \right] + E_{spi}(t), \qquad (2)$$

where $P_s = P_{in} G_o L_f$ is the received optical pump signal power, G_o is the gain of the in-line optical amplifier, L_f represents the fiber loss, $p'(t) = p(t) \otimes h_f(t)$ is the effective output pulse shape, $h_f(t)$ is the fiber impulse response which includes the effect of dispersion, $\phi_{no}(t)$ represents the phase noise at the fiber output, $E_{spi}(t)$ is the spontaneous emission noise of the in-line optical amplifier and $\otimes$ denotes convolution. The gain of the optical amplifier is adjusted to minimize the fiber loss such that $G_o L_f = 1$.

The converter signal is a continuous wave signal at a wavelength λ_c and is given by

$$E_{c,in}(t) = \sqrt{2P_c} \exp\left[j\left\{ \frac{2\pi}{\lambda_c} t + \phi_{nc}(t) \right\} \right], \qquad (3)$$

where P_c is the average input power of the converter signal and ϕ_{nc} represents the phase noise of the converter laser.

When passing through the two SOAs in the wavelength converter, the modulated input signal produces a change in carrier density which in turn induces a change in refractive index of the active medium. The change in refractive index produces a change in phase of the converter signal.

The converter signals at the output of the two SOAs are given by

$$E_{ci}(t) = \sqrt{2P_{ci}\, G_i} \exp\left[\begin{array}{l} j\{\frac{2\pi}{\lambda_c} t + \phi_{nci}(t) \\ +\Delta\phi_i(t)\} \end{array} \right], \quad i = 1, 2, \qquad (4)$$

where $P_{ci} = \eta_i P_c$ is the converter power input to the ith SOA, η_i and G_i are the coupling coefficient and the gain of ith SOA respectively, $\phi_{nci}(t)$ is the phase noise of the converter signal and $\Delta\phi_i(t)$ represents the phase induced by the carrier density modulation in the ith SOA.

The change in converter signal phase in the two SOA's due to refractive index change induced by carrier density modulation is given by Durhuus et al. [7]

$$\Delta\phi_i = \frac{2\pi}{\lambda_c} L_i \left(\frac{\delta n_c}{\delta N} \right) \frac{\tau_s}{\sqrt{1 + (\Omega\tau_s)^2}} v_g g_i(N) \Delta N_i, \quad i, = 1, 2, \qquad (5)$$

where subscript i refers to the SOA-1 and SOA-2, L_i is the cavity length of the ith SOA, $\delta n_c/\delta N$ represents the refractive index change due to carrier density change induced by