New concept for a co-directional polarization insensitive SOA-based wavelength converter

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VPI-simulation of a new all-optical wavelength converter is presented. It is based on interferometric effects in two Mach-Zehnder interferometers (MZI), parallel connected by polarization components (PCs). The PCs provide filtering between probe and signal wavelengths, and polarization-insensitive operation. Different efficiency values for PCs are supposed. Simulation shows wide operational range (10 dB) for the input power. Results obtained are also suitable for cascading these devices in optical networks (extinction ratio >10 dB, isolation >20 dB).

Introduction

For wavelength routed optical networks, a compact and monolithically integration of components which can provide all-optical wavelength conversion is highly needed. It increases the flexibility of networks by offering a dynamic exchange of signals between different wavelengths. Interferometric wavelength converters based on cross phase modulation (XPM) by using Semiconductor Optical Amplifiers (SOA) as nonlinear element seems to be the most promising. They are compact, stable, they give low chirp and high extinction ratio. In these configurations, SOAs are placed in the two arms of standard Mach Zehnder interferometer (MZI).

The swapping of the wavelength is produced by launching the new wavelength (the probe) coming from a CW laser equally in the two arms of the MZI. Simultaneously the old wavelength (the control signal) is introduced in one of the arms in such a way that a phase difference between two arms can be obtained at the output of the MZI. Co-directional coupling (the two signals propagate in the same direction) has a better performance (higher extinction ratio (ER), larger input dynamic range) at high speed than counter-directional because the interaction time between the two signals in the SOA is longer. Also co-propagation gives higher optical signal to noise ratio compared to counter-propagation [1]. However tunable filters are needed in that case at the output of the wavelength converter to separate the control and the data signals. These filters introduce losses and modify the pulse form of the short signals. They are difficult to integrate and are expensive [2] and conversion to the same wavelength is impossible. This latter option is desirable to keep full flexibility, to provide the implicit regeneration at the wavelength converter and to strip the frequency and phase noise from the signal. To circumvent external wavelength filters and have the possibility to convert to the same wavelength, a counter-propagation configuration may be used despite the limitations mentioned above.
As the signal in the network has an unknown state of polarization, polarization insensitive wavelength converters are needed. This can be achieved by using polarization insensitive SOAs. This will limit the design options for these devices.

In this paper we present a new co-directional polarization insensitive SOA-based wavelength converter. This converter provides implicitly filtering of the data signal, thus allowing conversion to the same wavelength. Its components may be monolithically integrated.

Concept of the wavelength converter

The new concept is shown in figure 1. It consists of two Mach-Zehnder interferometers (MZIs) parallel connected by polarization components. The aim of using the polarization components is to have a polarization insensitive co-propagation wavelength-converter even when using polarization sensitive SOAs, and high isolation between the two signals.
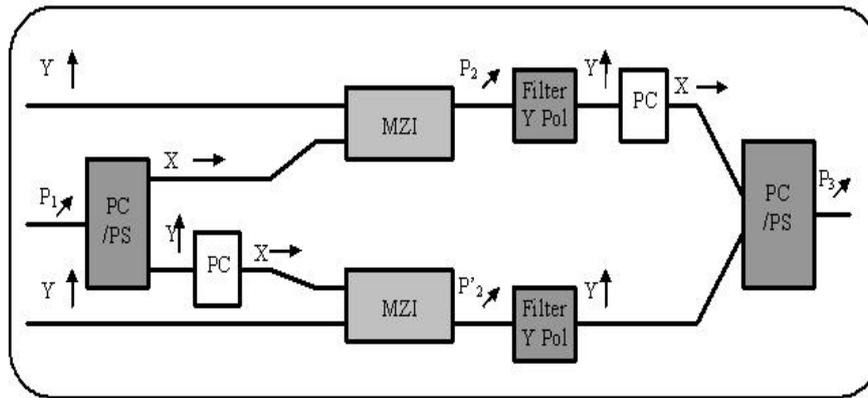

Fig. 1: Polarization independent co-directional SOA-based wavelength converter which uses polarization components for separation of the control and the probe signals.

In this configuration the local light coming from the CW laser is launched in two MZIs with polarization Y (e.g. TM), however the incoming signal from the network is with the other polarization X (e.g. TE). In this way, both signals can be separated by using polarization filters after the interaction in the MZIs. As the signal coming from the network has an arbitrary polarization a polarization splitter is used to split the signal to X and Y polarizations. Then a polarization converter rotates Y polarization to X polarization. After interaction in the MZIs and filtering Y polarizations, the two Y polarizations are combined using a polarization combiner. This needs two inputs with different polarizations, therefore the Y polarization in the appropriate branch is rotated to X polarization.

Simulation results

In a simulation study, some key parameters of the basic components are changed to find out the tolerance allowed in their fabrication. Parameters of the SOA used in the simulation are shown in table 1. The polarization components are assumed to have an efficiencies of 95 % or 99 %.

In figure 2 the Bite Error Rate (BER) versus input power for different incoming polarization is presented. It is clear from the curves that this configuration shows a wide operation range despite the change in polarization and the power of the input signal. When the line width enhancement factor and the polarization efficiency are increased, shift of the curves to the lower powers is found.

Tab.1: parameters of SOA used for simulation

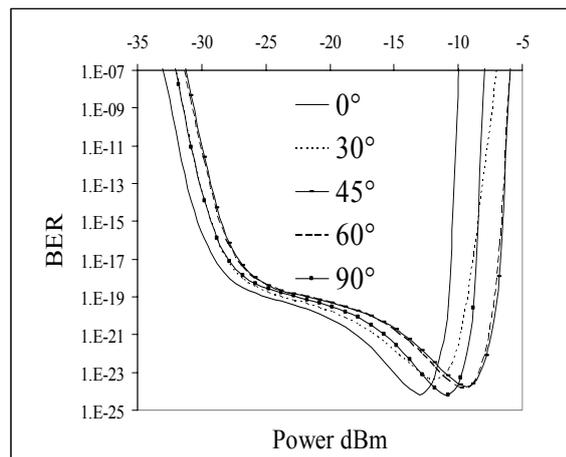| Injection current	250 mA
Length	500 μm
Width	2 μm
Height	80e-9 m
Confinement factor	0.25
Internal losses	40e2 m^{-1}
Differential Gain	2.78e-20 m^2
Carrier density at transparency	1.4e24 m^{-3}
Linewidth enhancement factor	**5 or 8**
Recombination constant A	1.43e8 s^{-1}
Recombination constant B	1e-16 m^3/s
Recombination constant C	3e-41 m^6/s
Initial carrier density	3e24 m^{-3}

Fig. 2: BER for different polarization of the incoming light

The isolation between the probe and the control signal is also studied, since the polarization components are introduced mainly to separate the two signals from each other. Figure 3 shows the isolation versus the input power for a polarization of π/4 (worst case). As it is observed, the isolation increases when better SOAs and polarization components are used. The reason is that for high line width enhancement factors the control signal modulates the probe signal stronger. Furthermore, increase in the efficiency of the polarization components improves the filtering of the signals, as well as corrects the polarization for best interaction in the MZI.
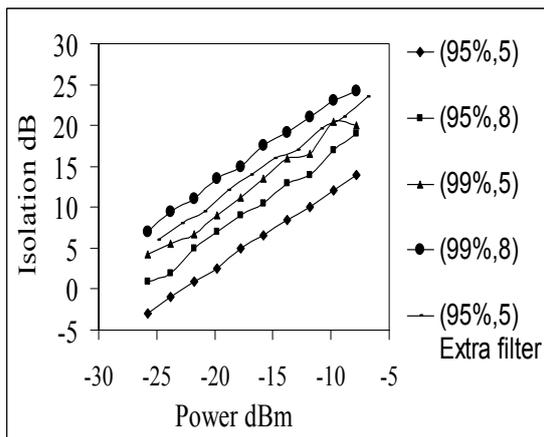

Fig. 3: Isolation between the probe and the control signal for polarization of the control signal of π/4 (worst case). The data are shown for different values of the PC efficiency and the line width enhancement factor.
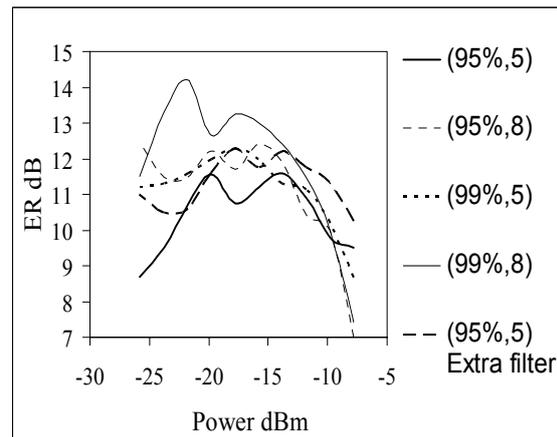
Fig. 4 Extinction ratio versus input power for polarization of the control signal of π/4 (worst case). The data are shown for different values of the PC efficiency and the line width enhancement factor .

In the case that 99 % efficiency of the polarization components can not be reached, we studied the possibility to add an X polarization filter to remove the residual Y polarization in the control signal before reaching the MZI. In this case more than 20 dB of isolation can be reached for the highest input power. Values more then 20 dB offer

the possibility to cascade wavelength converters in the network. Another crucial parameter for cascading these devices is the extinction ratio (ER). In figure 4, we show the behavior of this parameter as a function of input power, line width enhancement factor and polarization components efficiency. The input ER was 7 dB. 2R regeneration can be obtained for input power less than -9 dBm. The ER improves also when the line width enhancement factor and the filtering increase. This is presumably because of the same reasons as mentioned before for the isolation between the wavelengths.

We also looked at the change in the output power versus the input power for different polarizations of the incoming light (data not shown). The output power was independent from the polarization of the incoming light, which is very important to avoid the problem of the dynamic range of the functionality of these devices.

Conclusions and discussion

As a conclusion, we studied a new configuration for a wavelength converter based on XPM in a SOA-MZI, which uses polarization components to isolate the probe and the control signals.

The configuration seems promising since it works in co-propagation and allows conversion to the same wavelength. Despite the wide range where the BER is lower than 10^{-12}, only a narrow input power range (of around 3 dB) can be found where high ER (more than 10 dB), high isolation (more than 20 dB) and low BER can be obtained at the same time. This range is found around -11 dBm in this simulation study.

The polarization components needed for an integration of this configuration on indium phosphide based materials are already fabricated in our laboratory [3], [4]. The structure will be developed and realized within the framework of the European project IST-STOLAS.

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