A novel 2R regenerator based on an asymmetric Mach-Zehnder interferometer incorporating an MMI-SOA

Jan De Merlier, Geert Morthier, Roel Baets

Department of Information Technology, Ghent University – IMEC,

St.-Pietersnieuwstraat 41, B-9000 Gent, Belgium, Europe, tel: +32 9 264 3316; fax: +32 9 264 3593; email: jan.demerlier@intec.rug.ac.be

Abstract

Simulations show an improved regenerative behaviour of a Mach-Zehnder Interferometer with an SOA in one arm and an MMI-SOA in the other arm, compared to the known layout with 2 identical SOAs. This proposed layout offers the possibility of a different non-linear behaviour in the arms, needed for regeneration, while the same single pass gain is obtained at low input powers. This means that, in contrast to the currently used layout with two identical SOAs it is possible to obtain total destructive interference at the low power side and thus to obtain a larger extinction ratio improvement.

Introduction

Data signals propagating through a network suffer from serious degradation, which is mainly caused by the accumulation of noise introduced by the amplifiers and by dispersion. Therefore regeneration of the signals at intermediate distances is needed. Because of the increasing data rates, all-optical techniques will be required to overcome the electronic bottleneck.

In recent years, several concepts for 2R regenerators have been proposed [1,2]. Among those, the components based on active interferometers such as the all-active Mach-Zehnder interferometer have been explored intensively and their optimisation has led to demonstrations of wavelength conversion with regeneration at bit rates as high as 40 Gb/s [3]. However, so far, regeneration has been performed with simultaneous wavelength conversion which implies the use af a CW laser and an optical filter at the output of the converter. In [4] and [5] regeneration has been suggested only making use of the data signal. The type proposed in [4], makes use of a Mach-Zehnder interferometer layout with a GC-SOA (Gain-Clamped SOA) in each arm, which means that an optical filter is still required to get rid of the laser light from the GC-SOAs. In the approach described in [5], 2 SOAs are incorporated in the arms of a Michelson interferometer. This type has been experimentally verified at 10 Gb/s[6], however the transfer function can still be improved significantly. We propose a novel type of 2R regenerator based on a Mach-Zehnder Interferometer with an SOA in one arm and an MMI-SOA in the other arm which shows an improved regeneration characteristic as compared to the layout with 2 identical SOAs.

Concept

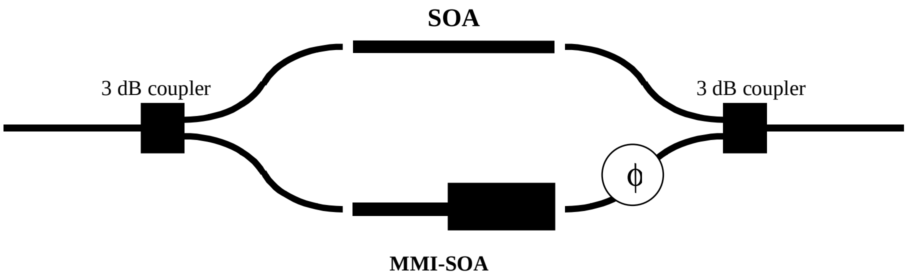

Fig.1: layout of MZI-based 2R regenerator incorporating an SOA and an MMISOA

The layout of the regenerator is shown in figure 1. In one arm, a single mode SOA is incorporated, in the other arm part of the SOA is replaced by a 1X1 MMI-SOA. The gain and the phase at the output of an SOA are determined by the electron density.
The relationship between the gain and the two most important parameters, the power P and the width 'b' of the SOA, is as follows:

$$g = \frac{g_0}{1 + \frac{P}{P_{sat}}} \qquad \text{with } g_0 = \Gamma a\left(\frac{J\tau}{qd} - N_0\right) \text{ and } P_{sat} = \frac{\hbar\omega bd}{\Gamma a\tau}$$

with Γ the confinement factor,a the differential gain, J the current density, τ the life time, q the elementary charge, d the thickness of the active layer, N_0 the transparency electron density, b the width of the active layer.

When a fixed current density is assumed in both the arms, the electron density (and as a consequence the gain) is equal in both the arms in the linear regime (see formula). So when the phaseshifter in one of the arms is adjusted such that both the beams interfere destructively in the output waveguide for low input powers, total destructive interference is obtained. When the input power is increased, saturation of the SOAs sets in.
Due to a larger active area in the MMI-SOA, the saturation power P_{sat} is higher. This implies that the saturation effects of the MMI-SOA will show up at higher powers. This means that high power signals will be amplified more in the MMI-SOA. Furthermore, the difference in saturation also causes a change in phase between the two arms. Thus at the high power side the beams will not interfere destructively at the output. This effect causes the regenerative behaviour of the component.

Numerical model

The SOA waveguide structure is assumed to be a ridge structure. The simulations have been performed, making use of a Beam Propagation Method which takes into account the lateral diffusion of the carriers in the active layer. The unimolecular, bimolecular and Auger recombination mechanisms have been considered. The gain g(N) is assumed to be linearly dependent on the electron density. In the simulations the lateral complex refractive index profile is recalculated after each propagation step of 5 µm.

Simulation results

The width of the SOA has been assumed to be 2 μm and the width of the 1X1 MMI-SOA 8 μm and a length of 170 μm. So in one arm there is a single mode SOA of 470 μm and in the other arm an SOA consisting of a single mode part of 300 μm and the MMI.

Figure 2 shows the gain as a function of input power for the single mode SOA and the MMI-SOA. It becomes clear that at low input powers the gains are the same for the two SOAs while at the high powerside, the saturation behaviour is different. The currents, needed to obtain the same unsaturated gain, are slightly different due to the difference in confinement of the both structures.

In figure 3, the change in phase difference as a function of the input power is plotted. The phase difference moves from destructive interference to more constructive interference as a function of the input power.

Figure 4 gives the transfer characteristics for the layout with two identical SOAs and the alternative composition. This shows a significant improvement of the transfer function compared to the layout with the identical SOAs. The problem of the former layout is the fact that to obtain an asymmetry in the MZI the currents have to be different to obtain destructive interference at the low power side. The difference in current causes a difference in gain and implies interference of unequal beams at the output of the MZI.

The steep transfer function shows an extinction ratio improvement of 10dB at an input extinction ratio of 10 dB.

The decision point can be swept by changing the currents through the SOAs. This effect is shown in Figure 5.

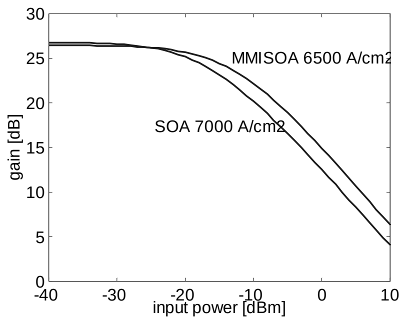

Fig.2: gain curves of SOA and MMI-SOA

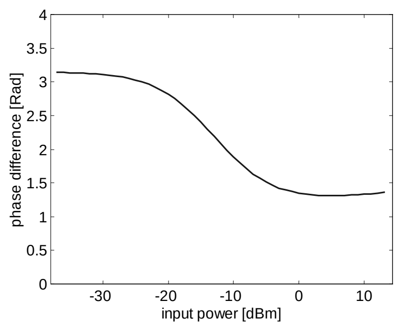

Fig.3: non-linear behaviour of phase difference

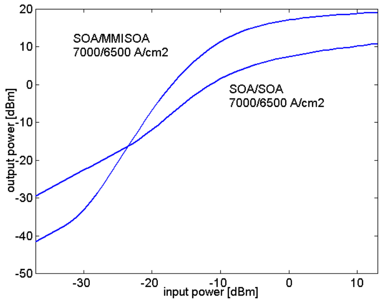

Fig.4: comparison regeneration characteristic MMI-SOA based layout and SOA based layout

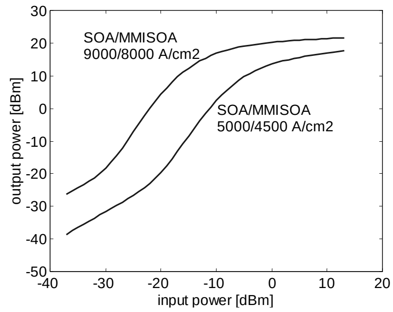

Fig.5: influence of current on the decision point

Conclusion

We have shown simulation results of a Mach-Zehnder interferometer incorporating an SOA and an MMI-SOA in the arms. The simulations show improved regeneration properties of this layout as compared to the layout with two identical SOAs. Extinction ratio improvements of 10 dB at input extinction ratios of 10 dB should be possible.

References

[1] M. F. C. Stephens, et al., "All-Optical Regeneration and Wavelength Conversion in an Integrated Semiconductor Optical Amplifier/Distributed-Feedback Laser", Phot. Techn. Lett., vol. 11, 979-981 1999

[2] B. Ma et. al., "Realisation of All-Optical Wavelength Converter Based on Directionally Coupled Semiconductor Optical Amplifiers", Phot. Techn. Lett., vol. 11, 188-190 1999

[3] D. Wolfson, et. al., "40-Gbit/s all-optical wavelength conversion,regeneration, and demultiplexing in an SOA-based all-active Mach-Zehnder interferometer", Phot. Techn. Lett., vol 12, 332-334, 2000

[4] G. Morthier, et. al.,:"A novel optical decision circuit based on a Mach-Zehnder interferomter and gain-clamped semiconductor optical amplifiers", Tech. Dig. OFC'98, San Jose,1998, paper WG2

[5] D. Wolfson, et. al., "All-optical 2R regeneration based on interferometric structure incorporating semiconductor optical amplifiers",Electron. Lett., vol. 35, pp 59-60, 1999

[6] D. Wolfson, et. al., "Experimental investigation at 10 Gb/s of the noise suppression capabilities in a pass-through configuration in SOA-based", Phot. Techn. Lett., vol. 12, 837-839 2000