Ultra-sharp optical decision characteristic from a laser diode integrated with a semiconductor optical amplifier

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Abstract: An ultra-sharp optical decision characteristic is obtained from a semiconductor optical amplifier and a laser diode in a feedback scheme. The operation of the component is based on a flipping of the spatial hole burning.

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1. Introduction

Optical regeneration has been identified as a key functionality that will be required in future optical networks. Many of the optical regenerators presented so far are based on interferometers and still have a few drawbacks. E.g. it is not so easy to make them polarisation independent since both the refractive index change and the gain have to be equal for both TE and TM polarisation in this case. These regenerators also either don't exhibit a very steep decision characteristic [1-3] or are not capable of very high speed operation [4].

Here we present a regenerator that gives a steep decision characteristic without making use of interferometric structures. The regenerator is based on an SOA in a feedback scheme with a DFB-laser. The design can more easily be made polarisation independent and with the proper SOA and laser design it should be capable of high speed operation as well.

In this paper we present simulations of the static performance of the new proposed scheme. These simulations show a very sharp optical decision characteristic that can easily be tuned. Since there is no interference involved in obtaining the optical decision characteristic the regenerator can be used over a wide wavelength region.

2. Principle

The photonic circuit (which can be implemented as an integrated circuit) with very sharp decision characteristic is shown schematically in Figure 1. It consists of a travelling wave semiconductor optical amplifier (TW-SOA) of which a part 1-x of the output is connected to a laser diode.

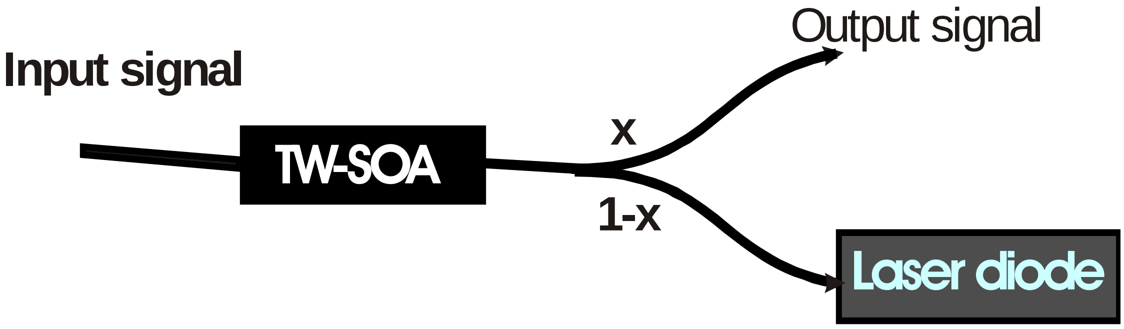

Fig. 1: Schematic of a semiconductor laser integrated with an SOA

For the laser diode we assume an AR-coated DFB-laser (e.g. quarter-wave shifted) with a Bragg wavelength that is significantly different from the signal wavelength, such that the fraction 1-x of the output signal from the SOA is injected into the laser diode, but not reflected. An equal fraction of the laser light from the DFB laser is injected into the r.h.s. facet of the SOA.

The operation of the circuit is based on the spatial hole burning inside the SOA. At low signal input power, the signal injection into the laser diode is weak, the laser diode emits a high power and hence a high power is injected at the r.h.s. facet of the SOA. The spatial hole burning in the SOA is then such that the carrier depletion is especially strong on the l.h.s. of the SOA. However, when the input signal power increases, the injection into the laser diode increases, the laser power decreases and so does the injection of laser power into the SOA. The injection of power into the SOA thus becomes more evenly distributed over both facets and the spatial hole burning decreases and is characterised by a more symmetric carrier density distribution. This lower spatial hole burning results in a higher gain for the input signal, which in turn results in a larger injection into the laser diode, a decreased laser power and a decreased injection at the r.h.s. facet of the SOA. This last effect results in a further decrease of the spatial hole burning and hence a further increase of the gain for the signal and eventually a further reduction of the laser power. At a certain input power, this multiplicative effect is so strong that the spatial hole burning flips from being predominantly determined by the laser power to being predominantly determined by the signal power. It is exactly this flipping of the spatial hole burning which results in a very sharp decision characteristic.

At low input powers the high power injected from the laser into the SOA results in a suppression of the signal ouput power. When a high signal power is injected in the SOA, and as a result the laser power drops significantly, the output signal power rises very quickly resulting in a very sharp optical decision characteristic.

Furthermore, since the SOA is always in saturation in this configuration, a high speed can be obtained if we can avoid the laser switching off at high input powers. This is done by setting the currents of the SOA and laser together with the coupling factor (1-x) such that the output saturation power of the SOA multiplied with that coupling factor (1-x) forces the laser to operate just above threshold. In this way, we avoid the turn-on delay of the laser at switch-on. Obviously, also a fast laser with a large 3-dB modulation bandwidth must be chosen to get high speed operation.

3. Simulation results

Simulations were performed using commercially available software (*VPI Transmission Maker*, *VPI inc.*). The structure from Figure 1 with the following parameters was simulated: the laser was a bulk $\lambda/4$-shifted DFB laser with L_d = 500 µm, $\kappa L_d = 3$, the length of the SOA was L_a = 500 µm. Both laser and SOA had an inversion factor $n_{sp} = 2$. The Bragg wavelength of the laser is 1552 nm. The coupling factor (1-x) was chosen as 0.75, providing a strong coupling between the laser and the SOA.

The simulation results shown in Figure 2 show a very steep optical decision characteristic that is nearly digital. The signal wavelength is 1542nm. The output power shifts from the low to the high level over an input power range of less than 0.5mW. We also show the possibility to control the decision point by adjusting the currents of SOA and/or laser. One can see that noise suppression at the zero-level could be difficult due to the rising slope. This slope follows directly from the working principle as the rising input powers get less suppressed bij the (decreasing) laser power. For input powers above the decision point we see a flat one-level of which the height is determined by the output saturation power of the SOA.

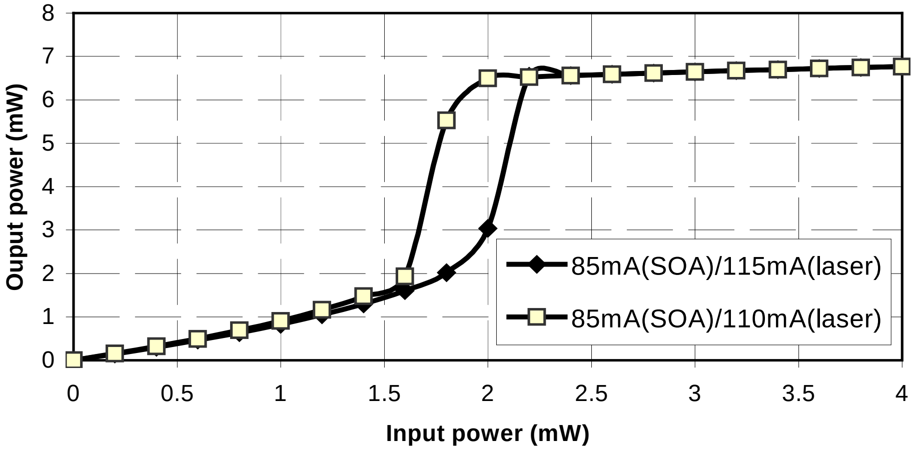

Fig. 2: Optical decision characteristics of a semiconductor laser integrated with an SOA

An important feature of optical regenerators is the ability to regenerate signals over a wide wavelength range. In Figure 3 the decision characteristics for different wavelengths are shown. The currents for the SOA and laser are 80 mA and 110 mA respectively while the coupling factor remains at 0.75. One can clearly see that there is little or no wavelength dependence over a wavelength region of 15 nm. The behaviour of the regenerator remains the same as long as the signal wavelength is far enough from the Bragg wavelength of the laser diode.

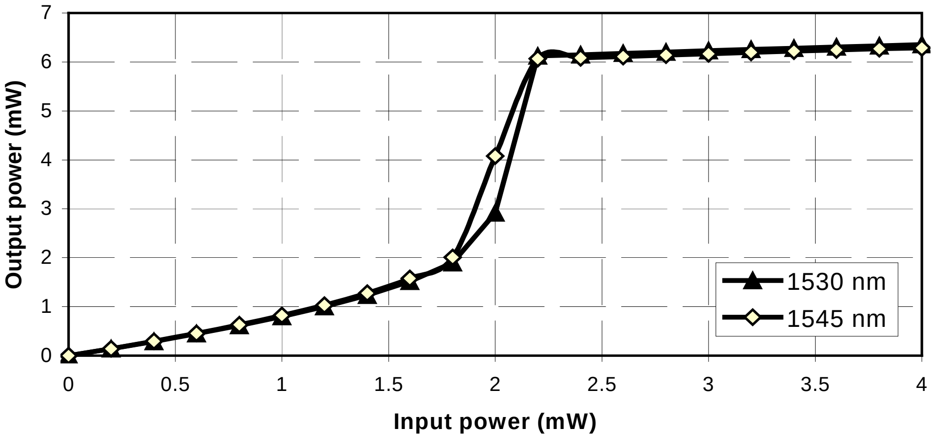

Fig. 3: Optical decision characteristics for different wavelengths and identical device settings

4. Conclusion

We have proposed a new photonic integrated circuit for optical signal regeneration or other optical logic functions. Simulations show that such a circuit gives an ultra-sharp optical decision characteristic based on the flipping of the spatial hole burning in an SOA. In principle the maximum speed of the circuit can be very large since the SOA always operates under high input power conditions and the laser diode doesn’t need to be driven below threshold and can be a fast laser diode. The propagation time between SOA and laser diode could be made of the order of a few ps if the passive splitter is made short.

The circuit has a very simple structure and requires very little control. Moreover, since there is no interference involved the decision characteristic can be obtained over a wide wavelength range.

As a next step further simulations will be performed to check the dynamic behaviour of the regenerator. This will be accompanied by both static and dynamic experiments on a regenerator consisting of discrete elements.

5. References

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