An all-active 2R regenerator using POLIS

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We hereby present a new concept for the use of polarization dependent gain in highly strained quantum well waveguides (the POLIS concept) to create a 2R regenerator. Advantage is taken of the different material properties for the two polarization states to overcome the obstacles caused by the conflicting requirements that active and passive components would impose on the materials used. The regenerator consists of a series of polarization converters and SOAs. Non-linear interactions in the SOA will influence the interference between the two polarization states. This results in a S-shaped transfer function, a property that could be used to achieve mode-locking.

Introduction

Integration of active and passive optical devices on a single chip, imposes conflicting requirements on the materials used in the chip. Several solutions have been proposed in the recent past to overcome the problems caused by the material restraints. Many of them, however, are expensive or require complex processing schemes. Devices developed within the POLIS [1] concept, avoid these problems by taking advantage of the different material properties for the different polarizations of light.

This difference is caused by applying high compressive strain (0.92 %) to the quantum well waveguide layer. The compressive strain causes the light-hole band to be pushed out of the quantum well, thereby excluding it from the radiative recombination process. In the recombination process, the recombination of electrons with heavy-holes results in purely TE polarized light, while recombination of electrons with light-holes can result in light of both polarizations. Since we have excluded the light-hole band from the recombination process, the gain of the material only contributes to the TE polarized fraction of the light [2]. For light of the TM polarization the material is almost transparent. This is shown in figure 1. Figure 1 was obtained with HS Design for a wafer incorporating a single quantum well and a minority carrier concentration of $20 \cdot 10^{17} cm^{-3}$ under pumping conditions.

Polarization converters, recently developed within the POLIS concept [3], enable the interesting possibility to create an interferometric structure, capable of 2R regeneration, in the POLIS material scheme. The main difference with common interferometric devices is that the interferometry occurs between the light in the two different polarizations in the same waveguide, instead of between the light in two different branches. The S-shaped transfer function of the device, necessary for 2R regeneration, is obtained by the non-linear effect of Self Phase Modulation (SPM) in the POLIS amplifier. The origin of the S-shaped transfer function can be derived by means of a static analysis.

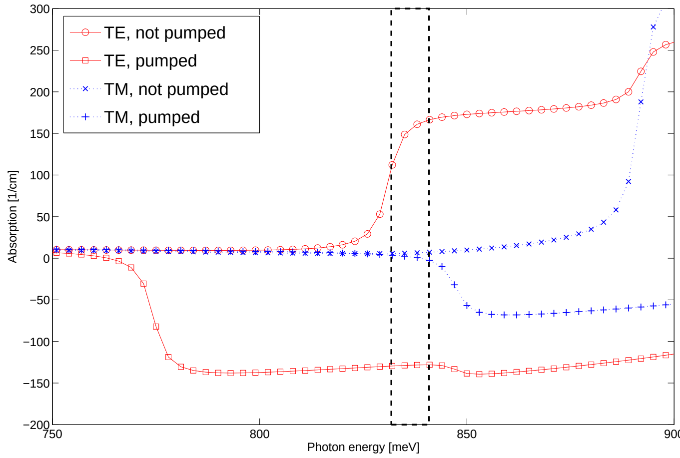

Figure 1: The absorption spectrum of a POLIS wafer. The vertical, dashed lines mark the region with all the desired properties

Principle of operation

The device consists of a series of (partial) polarization converters and SOAs, as is shown in figure 2. In the static analysis two different operating regimes have to be considered. The first is the low input power regime, where only linear effects occur in the SOA. The second regime is the non-linear regime, which occurs at higher input powers. If light of

Figure 2: The 2R regenerator

the TM polarization is applied to the input of the device, the first polarization converter transfers 25% of the input power to the TE polarization. The light, now circularly polarized, travels through the SOA, in which only the TE polarized fraction is amplified. The TM polarized part remains unaffected, but both polarizations obtain a different phase shift. After passing through the first SOA, power and phase of both polarizations are now interchanged by a full polarization converter. The light then passes through a second SOA, in which the part that remained unaffected by the first SOA, is now amplified. Again both polarizations acquire a different phase shift.

At this point the light has passed through two SOAs, in which both fractions of the light were amplified and both have experienced a TM and a TE phase shift. In principle both polarizations are now equal in phase. However, this is not entirely true, since both polarization conversions introduce a 90 degrees phase jump as well. Therefore the TE and TM polarization are 180 degrees out of phase. The light now passes through the third and last partial polarization converter, which recombines both fractions of the light in the TE polarization, a conversion reciprocal to that of the first polarization converter.

The final result of these manipulations of the light is not interesting in the linear regime. Both partial polarization converters cancel eachothers effect out, as do the two SOAs with the interchanged polarization modes. The only real conversion is done by the full polarization converter, which causes the light at the output to be TE polarized. However, when the power is increased to the non-linear regime, the behavior of the device changes drastically. The SOAs are now able to reach saturation. Since both SOAs operate on a different part of the input power, they reach different levels of saturation, resulting in a different TE gain and phase shift for the two SOAs. Because of this, the phase difference after the second polarization converter is not equal to 180 degrees anymore and the recombination by the last polarization converter into the TE polarization is not complete. A fraction of TM polarized light will now appear at the output.

In the POLIS concept, only TM polarized light can propagate through waveguides without suffering from major losses. Only if the power of the light at the input is sufficiently high, a fraction of this light will appear at the output in the TM polarization. So the POLIS regenerator, in combination with the waveguides, shows the same behavior as a saturable absorber for TM polarized light.

Static Analysis

To derive the transfer function of the 2R regenerator, the transfer matrix method was used. The transfer function is the result of the multiplication of all the transfer matrices of the subelements present in the regenerator. These matrices describe the relation between the amplitude and phase at the in- and output. The output power is then determined by taking the result of this multiplication and multiplying it with its complex conjugate. Equation 1 describes the linear gain of the 2R regenerator as a function of the input power. In this equation g_0 is the linear gain per centimeter, P_{sat} is the saturation energy in Watt and ϕ_{NL} is the non-linear phase difference between the to polarizaion modes given in radians.

$$\frac{P_{out}}{P_{in}} = \frac{3}{16}[e^{\frac{2g_0}{1+3P_{in}/4P_{sat}}} + e^{\frac{2g_0}{1+P_{in}/4P_{sat}}} - 2e^{\frac{g_0}{1+3P_{in}/4P_{sat}}}e^{\frac{g_0}{1+P_{in}/4P_{sat}}}\cos(\phi_{NL})] \quad (1)$$

Where the argument of the cosine function (ϕ_{NL}) is equal to equation 2. This yields the transfer function shown in figure 3.

$$\phi_{NL} = \frac{\alpha}{2}g_0[\frac{1}{1+\frac{P_{in}}{4P_{sat}}} - \frac{1}{1+\frac{3P_{in}}{4P_{sat}}}] \quad (2)$$

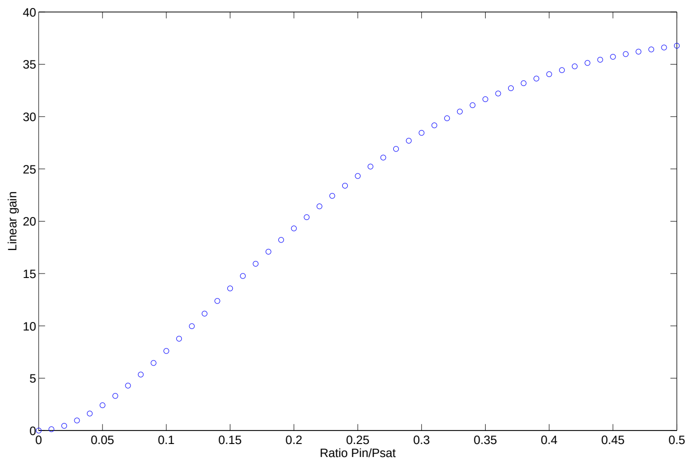

Figure 3: The TM-to-TE transfer function of the 2R regenerator

Mode-locked laser application

The S shape of the transfer function of the proposed structure is visible in figure 3, indicating that it is suitable for 2R regeneration. We are investigating whether this property can be used to achieve passive mode-locking. As we have pointed out earlier, the 2R regenerator behaves like a saturable absorber for TM polarized light. Since it also amplifies the incoming optical signals, the device may replace the amplifier and absorber in the ring structure of a mode-locked laser (figure 4).

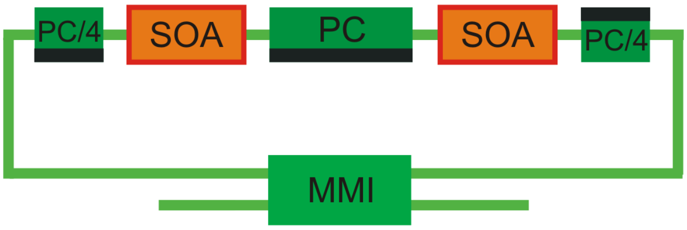

Figure 4: A mode-locked laser with the 2R regenerator

Within the mode-locked laser application, the 2R regenerator removes the low power flanks of the optical pulses traveling through the cavity, thereby reshaping the pulse and decreasing the pulse width. The pulse duration will be limited by other effects. These effects are the available bandwidth (see figure 1), the self-phase modulation, carrier heating and two-photon absorption. All these effects take place on small and different time scales, so a dynamical analysis is required to investigate the applicability of the regenerator in a mode-locked laser further. At the moment work to build a computer model, to simulate the dynamic behavior, is near completion.

Conclusion

The POLIS material scheme is suitable for implementing a device capable of 2R regeneration by means of interferometry. The interferometry utilizes a pathlength difference that originates from different propagation constants for the two polarization states. It has the advantage that no polarization filters are needed, since the waveguides act as polarizers themselves. There is also no need for active/passive regrowth techniques. We have shown that the proposed structure has a S-shaped transfer function, which indicates that it is suitable for 2R regeneration. We are investigating the usability of the device in a mode-locked laser by means of a dynamical analysis. The advantage of the 2R regenerator over the SOA/absorber in a mode-locked laser, is the instantaneous nature of the mechanism, which makes it faster.

References

[1] U. Khalique et al., ”Polarization based Integration Scheme (POLIS) for Active and Passive Components”, *ECIO Proc.*, Vol. 1, pp. 137-140, March 2003

[2] J. Piprek, ”Optical Gain”, in *Semiconductor Optoelectronic Devices*, Academic Press, San Diego, California: USA, 2003, pp. 131-135.

[3] U. Khalique et al., ”Ultrashort polarization converter on InP/InGaAsP fabricated by optical lithography”, *proc. IPRA 2005*, San Diego, California: USA, 2005, pp. 1-3, April 2005