Design of a POLIS multi-wavelength laser

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POLIS (POLarization based Integration Scheme) is a new idea for combining passive and active components on a chip. It requires only one type of material, and obtains different functions (passive or active) by using polarization depended absorption in strained quantum wells. The simulation of a first integrated POLIS-circuiton InP is presented: a multi-wavelength laser. This circuit contains gain blocks, polarization converters and a phased array demultiplexer. The simulations demonstrate a multi-wavelength laser with 2 compressively strained quantum wells. The simulated threshold current is 90 mA. Predicted output power is above 40 mW, for each of four wavelength channels, at 200 mA current.

Introduction

Integration of components with different material requirements is the ultimate bottleneck for photonic integrated circuits. This holds especially for the combination of active components, like lasers and detectors, and passive ones, like waveguides and filters. Overgrowth is one of the techniques being developed to overcome this. In POLIS (POLarization based Integration Scheme) overgrowth is avoided by using the polarization dependent properties of strained quantum well materials [1]. In this way polarization can be used as a parameter to change material properties, making one and the same material suitable for both active and passive devices. With such a technique it should be possible to achieve a simpler and cheaper integration of optical functions.

In this paper we describe the first study on an integrated circuit for the POLIS-technique, in the InP/InGaAsP material system. It is a WDM transmitter, implemented as a multi-wavelength laser. This circuit comprises both active components (gain blocks) and passive ones (waveguides, polarization converters and a phased array demultiplexer or phasar).

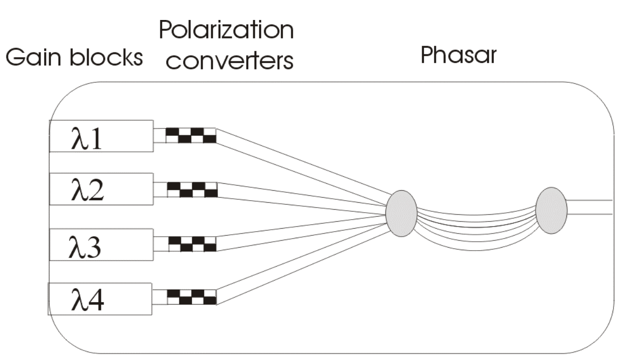

Fig. 1: Integrated POLIS multi-wavelength laser

Concept of the device

An integrated multi-wavelength laser is one of the devices that can bring the cost of WDM-systems down, so that these become feasible for use in local networks. Price and production volume, more than performance, are then the prime issues. The multi-wavelength laser therefore doesn't have to achieve the number of wavelength channels and the bit rates required from WDM-sources in the higher network layers.

The integrated multi-wavelength laser (see figure 1) consists of one optical chip, on which the generation of light, the optical filtering and the modulation is performed. Within the POLIS-concept this implies the following: Light is generated, and modulated, by current injection in the gain blocks in the TE polarization. The gain blocks are coupled to the passive waveguide circuit through polarization converters (see fig. 2, [2], [5]). These transform the light into the TM-polarization. The material, as explained in the next section, is chosen such that it is transparent for TM. The passive circuit contains a wavelength selective device: a phased array demultiplexer, also known as phasar (see fig. 3, [3]). It has four input ports, which are connected with the four gain blocks through the polarization converters, and one output port connected with the edge of the chip. This edge constitutes one mirror for the laser cavity, supplying the necessary feedback. The transmission between each phasar input port and its output port is wavelength selective, so that (within the gain profile of the gain blocks) only one wavelength is fed back into the gain block. Therefore the laser cavity for this gain block will oscillate at that wavelength. Since for each gain block a different wavelength is selected, the light signal emerging from the output will contain these four wavelengths.

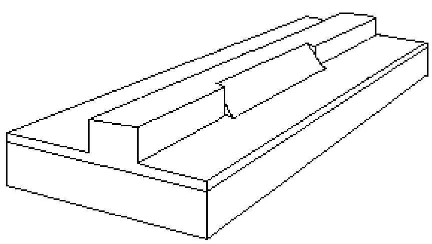

Fig. 2: A passive polarization converter, consisting of one block with an angled sidewall [5]. The length is about 200 micron

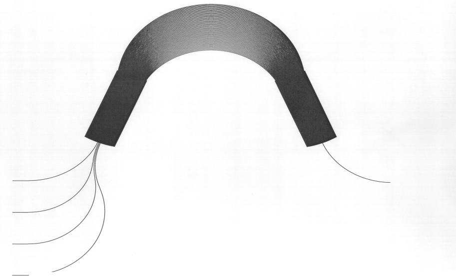

Fig. 3: A Phasar (Phased Array demultiplexer), providing optical filtering between 4 ports (left) and one port (right)[3]

Material requirements

The main issue for the POLIS integration is the choice of material. It must contain strained quantum wells, in order to achieve the required polarization dependent absorption. Since lasers operate more efficiently in TE-polarization, we choose compressively strained quantum wells, which have transparency for TM in the 1550 nm wavelength window. The strain should be as high as possible, to have the polarization dependence as large as possible. In practice a value of 1 % of strain can be reach in epitaxial growth without causing crystal defects. The calculated absorption spectrum of the quantum well selected for POLIS is given in fig.4.

The position of the quantum wells in the waveguide layer appears to be important. The non-dominant field components of the TM-polarized mode are sensitive to the high absorption in the quantum well for electric fields in the plane of the well (the "TE-absorption), leading to a high loss for this polarization. Fortunately these non-dominant field components are zero in the center of a symmetric waveguide layer, so that is where the quantum wells need to be placed in order to have transparency for the TM-polarization.

Furthermore, a number of trade-offs have to be taken into account for the POLIS multi-wavelength laser. First of all, there are opposing requirements with regard to the number of quantum wells. For efficient and robust laser operation a high number seems desirable, but this is limited by the residual loss that the TM-polarization experiences in the quantum wells. In our final design two quantum wells turned out to be an optimal compromise. A second issue relates to the choice of the doping profile. For low threshold currents and high quantum efficiencies high doping levels close to the active region are required. This is however unacceptable for the passive waveguide circuits, Because of high optical absorption losses. Based on both laser and waveguide simulations a compromise was found.

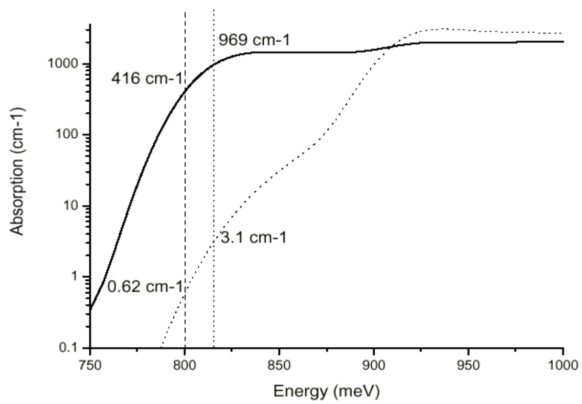

Fig. 4**:** 3 nm thick compressive strain QW of $In_{0.64}Ga_{0.36}As$ on InP. The dotted line is the absorption for TM polarization, the straight line for the TE polarization [1,4].

Design and simulation

Bringing together the separate designs of the gain block, the polarization converter and the phasar one can build up the circuit for the multi-wavelength laser. The gain block was designed as an FP-laser, including also thermal effects and operation with extra cavity losses. The most critical part of the circuit is the polarization converter. The conversion should be achieved in a very short length, since the TE-polarization experiences a very high absorption. Therefore a one-block device was chosen (fig. 2), for which a fabrication technology has been developed in [5]. For this device a tolerance analysis is made, looking at deviations in the width of the device, which is the most critical parameter. The converter with a width deviation of ± 0.1 micron shows that at least 60% of the inputted TE-polarized power is exiting in the TM polarized mode. In this simulation both the (high) loss of the TE-mode, the residual loss of the TM-mode and the coupling losses between waveguide sections were taken into account.

For simulation of the complete circuit it is necessary to include to the laser simulation two additional items. These are the wavelength selection by the phasar. and the extra loss of the passive circuitry, which includes propagation losses (1 dB/cm) and component losses (2 dB for the polarization converter, taking the tolerances of ±0.1 micron into account, and 1 dB for the phasar).

The results of the simulation are given in fig.5. Shown is laser action for a wavelength of 1.54 μm, below the wavelength range of interest, in order to investigate a worst-case situation. A threshold current of 90 mA is found and the differential quantum efficiency is 0.90, leading to 40 mW output at 200 mA current. The total size of the multi-wavelength laser is approximately 0.3x.9 mm^2. The cleaved facets of the chip are uncoated, giving reflections of 32% at both ends of the cavity. The back facet is placed next to the gain blocks. Also a thermal simulation has been done of the laser operation. There it was found that the temperature increase at 200 mA is about 6 degrees, while it was verified that the laser still functions at increases of more than 50 degrees.

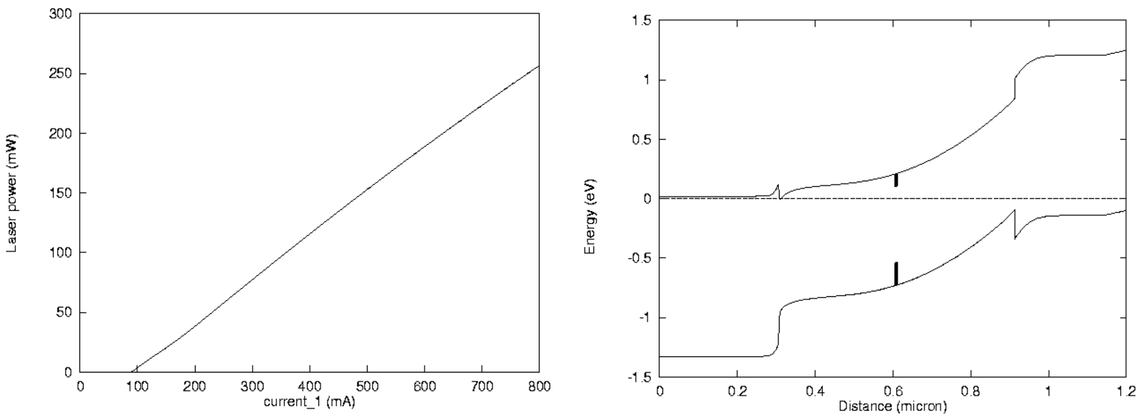

Fig.5: Simulation results on the POLIS multi-wavelength laser. Left: L-I curve. Right: Band diagram under forward bias, as a function of depth.

Conclusions

The possibility of a multi-wavelength laser within the POLIS-technique has been studied with a design and simulation study. Such a device indeed appears to be possible, taking the constraints within this technique into account. The design showed an acceptable simulated performance with respect to threshold current, output power and thermal stability.

This shows that based on polarization dependent absorption in strained quantum wells it seems possible to realize active and passive components without regrowth processes, and with acceptable performance for devices in the local network.

References

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