Design of a twin guide quantum well laser for the Indium Phosphide membrane on Silicon platform

Vadim Pogoretskiy, Yuqing Jiao, Jos J.G.M van der Tol, Meint K. Smit

COBRA Research Institute, Technische Universiteit Eindhoven,
De Zaale, 5600 MB Eindhoven, The Netherlands

This work presents the design of an integrated twin guide quantum well membrane laser based on the IMOS (Indium Phosphide Membrane On Silicon) platform. The laser is predicted to have a threshold current of 1 mA and small footprint of 100 μm^2. The layerstack is designed to allow integration with passive devices as well as with quantum well based electro-absorption modulators and photodetectors.

Introduction

Photonic integration on membranes can be used to heterogeneously combine electronic and optical functionality in a single chip. An InP membrane on Si (IMOS) [1] is an advantageous solution, since it can include lasers, detectors and waveguide devices (Fig. 1a). It is crucial to have a room temperature CW small footprint integrated laser in the IMOS platform (See Fig. 1b). The first attempt to fabricate such a laser is addressed in [2]. In this work we will discuss the possibilities to improve the laser in terms of optical and electrical aspects, as well as discuss the integration of the laser with quantum well based electro-absorption modulators and photodetectors.

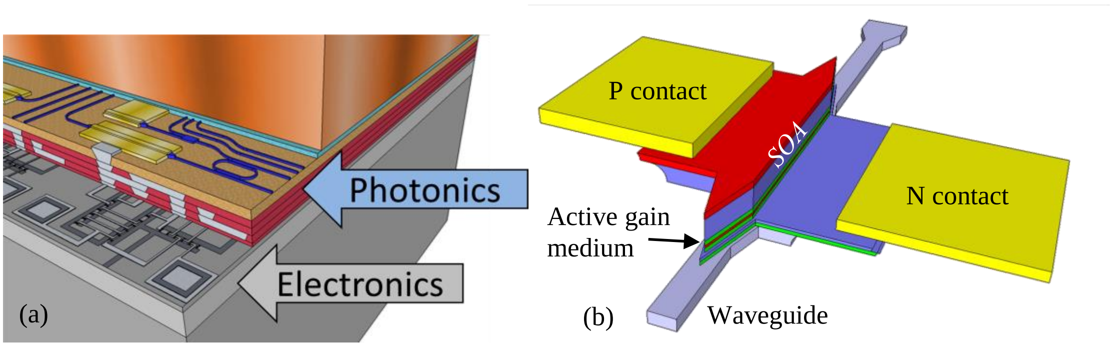

Fig. 1. (a) Schematic of the IMOS chip; (b) Schematic of the integrated IMOS twin guide laser.

Laser Integration

We propose to use the same active layerstack for a laser, photodetector and quantum confined Stark effect (QCSE) modulator.

It will be discussed later in the paper that the laser is predicted to have the best performance with 4 QWs as a gain medium, however we propose to increase the number of quantum wells up to 8 in order to compromise laser, photodetector and modulator performance. We are currently performing two fabrication runs with 4 and 8 QWs structures respectively. The integration scheme is presented in Fig. 2a. The laser is designed as a twin-guide structure which guides the light in the different layers depending on the active or passive function. Transition between active and passive parts of the chip is performed with tapers where light is pushed down to a passive waveguide when traveling from active region, or vice versa (Fig. 2b.).

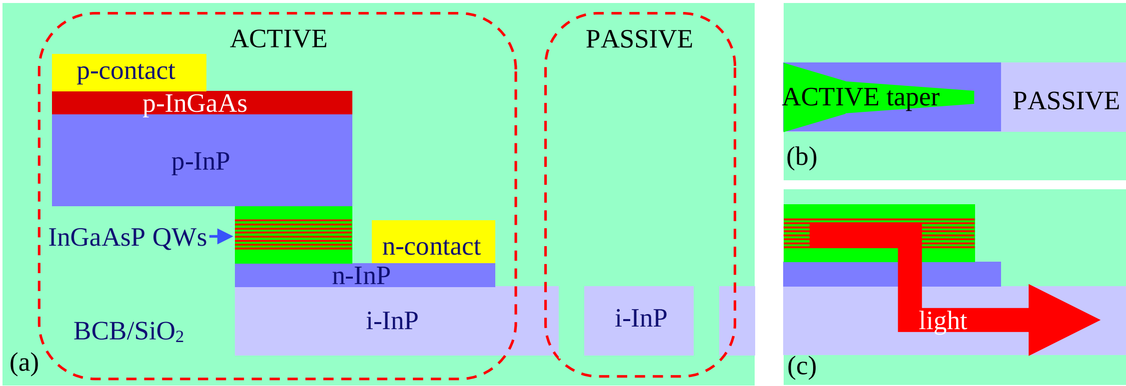

Fig. 2. (a) The IMOS integration scheme for a 8QWs active layerstack; Schematic: (b) Top view of the twin guide transition; (c) 90 degree side view.

The fabrication of such a platform requires 8 lithography steps, 3 dry etching steps and a wafer bonding step. More specifically, fabrication involves 5 optical lithography steps for deep markers, wet etching of waveguide cladding layers, two contacts lift-off and contact accessing from the back side. Mesa and gratings are defined with electron beam lithography and etched with a dry process.

Laser Design

To design a laser we have to consider the following: 1) Integrability with other devices; 2) Optical performance; 3) Electrical performance.

In this work we use the InGaAs/InGaAsP quantum well (QW) gain medium to obtain a minimum threshold current. This QW system is sandwiched between doped InP layers to form the double heterostructure (DHS), providing our laser with electrical and optical confinement (Fig 3b. top right). In Fig 3a the threshold current dependence on cavity length for different cavity reflectivities and modal loss of 30/cm for bulk and 4 QWs case is presented. We can see that we can obtain the minimum threshold current below 10 mA for 4QWs system with lengths around 30-500 μm. In Fig. 3b the measured net modal gain with 4QWs is presented. Taking into account that for these geometries a threshold gain is below 60/cm which consist of the modal loss and cavity loss of less than 30/cm for at least 30 μm cavity length and reflectivities of 90%, we can obtain the threshold current density of 1.5 kA/cm^2.

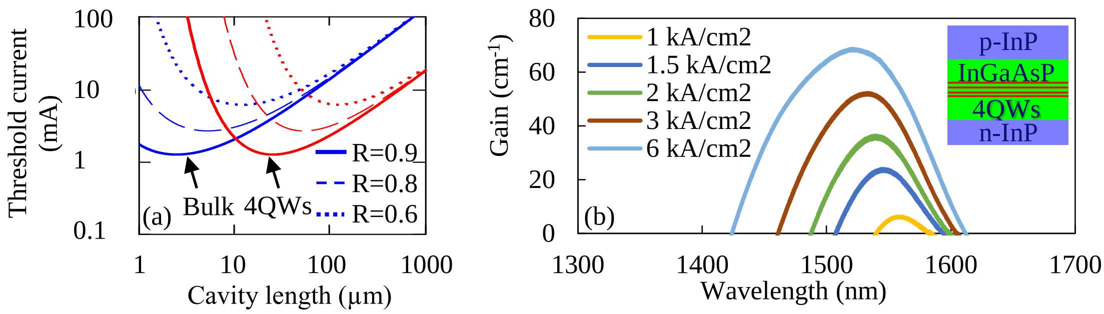

Fig. 3. (a) threshold current dependence on cavity length for different cavity reflectivities and modal loss of 30/cm for bulk (blue) and 4 QWs (red) case; (b) Net modal gain of the 4QW system.

By optimizing the structure we achieve a loss of semiconductor optical amplifier (SOA) of around 3/cm without current injection effect. The mode profile is presented in Fig. 4a. Confinement factors for 4 and 8 QWs are 4.2 % and 8.2 % respectively.
To simulate the electrical performance we solve the self-consistent Poisson equation in the two dimensional DHS structure. The series resistance of the device is calculated to be around 90 Ohms for ultra-small (30 μm^2) devices. In Fig. 4b the current distribution at 0.9 volts is presented. One can see that the active region at 0.9 V forward bias is pumped completely with a current density of at least 3 kA/cm^2, which is twice higher than we need to achieve the threshold.

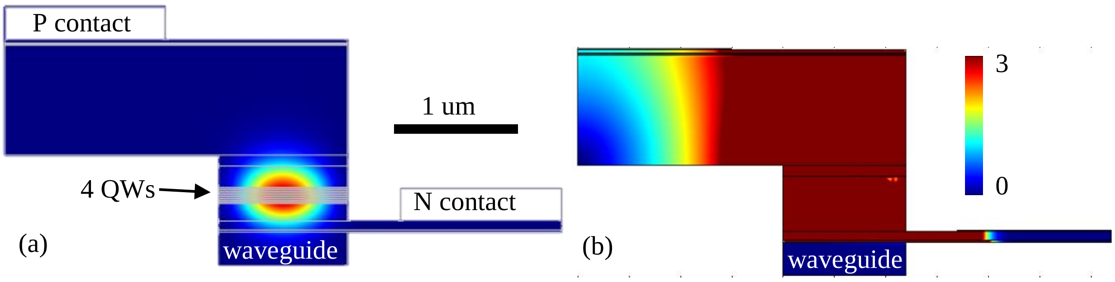

Fig. 4. (a) Mode profile |E^2|; (b) Current density (kA/cm2) in the device crossection at 0.9 V.

To simulate the tapers of the active devices we use 3D finite difference time domain (FDTD) calculations. A 30 μm long taper consists of two parts, where in the first part, with a length of 10 μm, it converges from the SOA width to a width of 0.7 μm. In the second part, with a length of 20 μm, it converges further to a tip of 0.2 μm. The calculations show 98% light transmission from the active layerstack to the passive part of the chip. The field distribution within the taper is presented in Fig 5.

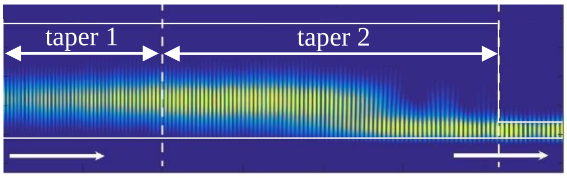

Fig. 5. Field distribution within the taper (side view).

Furthermore, we simulated the performance of the passive distributed Bragg reflectors (DBR) [3] which we will use to form the laser cavity. The DBR gives us 90 % of reflectivity which will reduce the threshold current and therefore the Joule heating of the device. Alternatively, we can use photonic crystal mirrors which give 99% of reflections according to FDTD simulations [4].

Conclusion

In this work we have presented the concept of an improved twin-guide integrated laser for the IMOS platform. The device is expected to have a small footprint between 30 to 500 μm^2 and a threshold current density around 1.5 kA/cm^2 with a 4 QWs gain medium. The laser can be integrated with other active and passive devices using the same layerstack with 8 QWs for photodetectors and modulators.

Acknowledgements

We would like to thank the all members of Photonic Integration group for useful discussions and nanolab @ TU/e for provided fabrication facilities. The research is performed under the grant "Zwaartekracht".

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