Feasibility study of an InP membrane on silicon laser

S.P. Bhat, J.J.G.M. van der Tol, and M.K. Smit
PhI group, COBRA Research Institute
Eindhoven University of Technology
Eindhoven, the Netherlands

G. Roelkens
Photonics Research Group
Ghent University/imec
Ghent, Belgium

Abstract — **Realizing an electrically pumped membrane laser with acceptable performance has been a major challenge so far. In this paper the possibility for such a device is investigated by simulating its optical and thermal properties.**

Keywords-InP; membrane; photonic integration; laser; electrically pumped; simulation; optical; thermal;

I. INTRODUCTION

Recently, high index contrast photonic integrated circuits have become important due to their promise to reduce the footprint and hence their cost. As explained in [1], one of the approaches taken uses an InP-membrane that contains both passive and active regions. To exploit the potential of the compact passive devices already fabricated it is essential to have an on-chip laser.

The idea here is to make the laser by selectively removing the gain material from regions where it is not required and retaining it in regions only where it will be made use of. The controlled partial oxidization of an InAlAs layer, based on [2], will act as a current blocking layer preventing leakage paths and allowing the current only to flow through the core of the active region. This will enhance the efficiency of the laser.

To check for the feasibility, capability and limitations of such a device in an InP membrane adhesively bonded to silicon, optical simulations are performed for confining and guiding light at 1550nm with minimal losses. Along with this, thermal simulations are also carried out to check the power dissipating capability of such a membrane structure

II. OPTICAL SIMULATIONS

The first step towards making any device based on III-V membranes is to make a choice of the layer-stack. This involves selecting the order of the materials in the stack, the thickness, doping type and doping level for each layer. The layers are grown on an n-type InP substrate in the following order: n-InP, n-InAlAs, an active layer consisting of three InGaAs quantum wells separated by Q1.25, p-InP and p-InGaAs. Other parameters for the layer stack are based on simulations [3]. A further choice that has to be made is the geometry of the laser. To avoid complications a simple Fabry-Perot type geometry is chosen.

A. Mode Confinement

The gain layer and the n-InP layer, in which we intend to fabricate the passive waveguides, are vertically separated. So, the mode has to be present in both the layers to a significant extent. This is determined by the thickness of individual layers. Width determination is based on gain considerations and the position of the metal contacts. These contacts have to be far from the active region to avoid high losses and yet have a sufficiently large contact area with the InGaAs layer to minimize electrical resistance. These requirements resulted in the configuration shown in Fig.1.

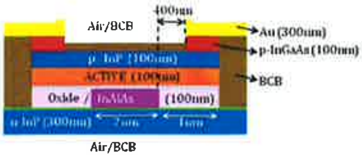

Fig. 1: Laser geometry showing the layer stack and the considered dimensions

B. Doping Effects

A high doping in the different layers decreases the electrical resistance for the current flow. On the other hand, an increase in doping level also increases the optical loss. So, a compromise between the two effects has to be reached. Various doping levels for p- and n-type in the relevant layers are simulated [3]. The optical absorption coefficients are calculated based on [4]. As can be seen from Fig.2, an increase in p-doping has a more significant effect on the loss than the n-doping. Doping levels of $1\text{x}10^{18}$ cm^{-3} for both p- and n- type are chosen as the points of compromise as the resistance value for this doping was acceptable (~ 35Ω). This point will become more apparent later.

C. Metal Absorption Loss

Apart from the losses due to doping and a high loss in the InGaAs layer, metal contacts are also an important source of optical loss. To gauge their contribution and to reduce them,

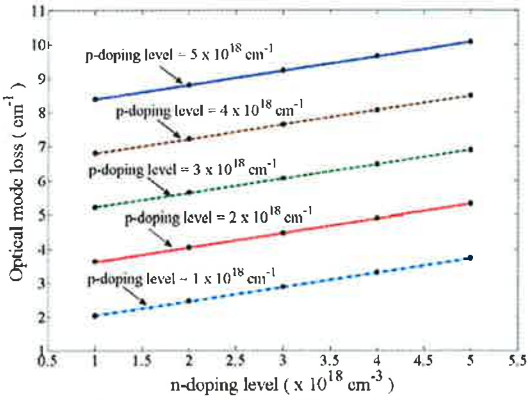

Fig. 2: Optical loss as a function of p-type and n-type doping

---

The authors thank STW-IMOS project for financial support

more simulations are done [3]. As is apparent from Fig.3, larger distances from the active region reduce the optical loss but increase the electrical resistance. A distance of 400 nm from the interface between InAlAs and its oxide was found to be optimal (see Fig.1).

III. THERMAL SIMULATIONS

The device fabricated in the InP membrane is to be adhesively bonded to a silicon substrate using BCB. The InP substrate is then etched away completely [5]. This leaves the device sandwiched between air on one side and BCB on the other – both being very good thermal insulators. Two main sources of heat in the laser are identified, the heat produced due to non-radiative recombination and ohmic heating in the resistive path. As there is no good conductive path for this generated heat to flow out, this has the effect of increasing the device temperature. This is confirmed by thermal simulations which show drastic increase in the temperature near the active region [6]. Since the stability of a laser oscillation critically depends on the temperature, a strategy had to be developed to overcome this problem.

A. *Power Dissipating Capability*

The best way to remove the generated heat is to transfer it to the silicon substrate. Moreover, a Peltier cooling element can be used to maintain the substrate at room temperature.

It is assumed that the laser will be operational upto 70°C. So, simulations are aimed at finding the maximum allowable power dissipation in the active region which raises the temperature of the device from room temperature (20°C) to 70°C [6].

Two strategies worked well in solving the problem. The first is increasing the areas of the metal pads and the second is decreasing the thickness of the BCB layer. Both had the effect of providing a better heat sinking path into the silicon substrate which is maintained at room temperature in all the simulations.

As can be seen from Fig.4, for a 100 μm device length, a power dissipation of 25 mW (through a 400 nm BCB adhesive layer) increased the temperature near the active region to 67°C (340 K). From the estimated voltage drop and resistance calculations, this power corresponds to a current of ~ 5 mA. From the data presented in [7], this is four times the threshold current required for such a laser to function. From a thermal point of view, it is thus feasible to implement such a structure.

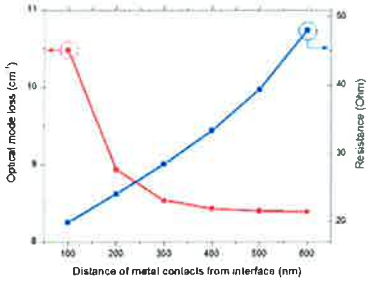

Fig. 3: Variation of the optical mode loss and electrical resistance with metal contact position

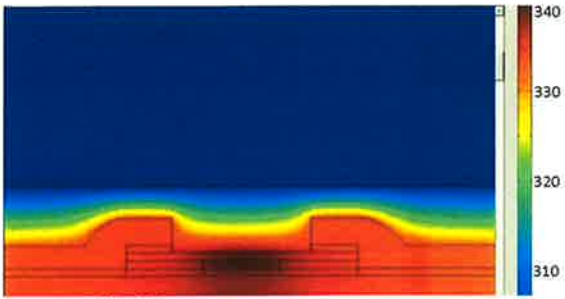

Fig. 4: Temperature contours due to self-heating

B. *Device Spacing*

Another important criterion which needs to be considered is how close two similar, power dissipating devices can be placed in order not to influence each other thermally. To simulate this, the side walls of the simulation window are modeled to be thermally insulating. This means that no heat enters or exits via these boundaries. The width of the window is expanded till the temperature at these points remains at room temperature; in other words, there is no heat flow into these regions. This results in a device spacing of 140 μm between the devices to thermally isolate them.

DISCUSSION AND CONCLUSIONS

Parameters for the layer stack and the dimensions of a membrane laser are determined using optical simulations. From a thermal point of view, it is feasible to work with such a structure. A device spacing of 140 μm determined from thermal simulations leads to a device density of 51 per mm^2 which is quite large. Together, these results indicate that an InP membrane laser is feasible.

ACKNOWLEDGMENT

S.P Bhat thanks J. Pello for his help with optical simulations, T. Spuesens and M. Tassaert for discussions on thermal simulations.

REFERENCES

[1] J.J.G.M. van der Tol, R. Zhang, J. Pello, F. Bordas, G. Roelkens, H. Ambrosius, P. Thijs, F. Karouta and M.K. Smit, "Photonic Integration in Indium-Phosphide Membranes on Silicon", IET optoelectronics, June, 2010.

[2] R. Zhang, J.J.G.M. van der Tol , H. Ambrosius, P. Thijs, B. Smalbrugge, T. de Vries, G. Roelkens, F. Bordas, and M.K. Smit, "Oxidation of AlInAs for Current Blocking in a Photonic Crystal Laser", Proc. COMMAD 2010, Canberra (Australia), paper105.

[3] Photon Design, Fimmwave v.5.1.1, http://www.photond.com.

[4] U. Khalique "Polarization based integration scheme" Phd. Thesis ISBN 978-90-386-1424-3, 2008, p. 16.

[5] Roelkens, G., Brouckaert, J., Van Thourhout, D., Baets, R., No¨ tzel, R., Smit, M.: 'Adhesive bonding of InP/InGaAsP dies to processed siliconon-insulator wafers using DVS-bis-benzocyclobutene', J. Electrochem. Soc., 2006, 153, pp. G1015–G1019.

[6] Comsol Multiphysics 3.0a, Heat transfer module, http://www.comsol.com.

[7] P.J.A. Thijs, L.F. Tiemeijer, P.I. Kuindersma, J.J.M. Binsma and T. van Dongen, "High-Performance 1.5 μm Wavelength InGaAs-InGaAsP Strained Quantum Well Lasers and Amplifiers", IEEE J. Quantum Elect., vol. 21, no. 6. June 1991, p. 1429.

Thursday, 19 April 2012 / Hall-Auditorium. Poster 2. 15:30h – 17:00h

- *Traveling wave model of an AWG-based multiwavelength laser (ID 166)*

This work presents a traveling wave model description of an arrayed waveguide grating (AWG) based multiwavelength laser. The purpose is to design a device with frequency spacing of 70 GHz between channels at 1550 nm central wavelength, aiming to dimension the required channel bandwidth to achieve a target side mode suppression ratio (SMSR) among longitudinal modes.

R.C.Guzman Martínez; L.J.Orbe Nava; G.Carpintero Del Barrio; A.Corradi; E.Bente

- *Nd3+-doped ion-exchanged aluminum germanate glass waveguide for O-band amplification (ID 61)*

K+—Na+ ion-exchanged channel waveguide has been fabricated in Nd3+-doped aluminum germanate (NMAG) glasses. The fabricated waveguide exhibits a loss of ~0.36dB/cm, is single mode at 1.3μm, and the maximum theoretical gain at 1.337μm is 16dB/cm. The ion-exchanged Nd3+-doped NMAG glass waveguide show promises in the development of O-band waveguide amplifier, infrared UV-writing grating waveguide laser, and compact integrated optical device.

B.Chen; S.T Chu; H.Lin

- *Feasibility of an InP membrane on silicon laser (ID 183)*

Realizing an electrically pumped membrane laser with acceptable performance has been a major challenge so far. In this paper the possibility for such a device is investigated by simulating its optical and thermal properties

S.Bhat; J.van der Tol; G.Roelkens; M.Smit

- *The role of index contrast in the efficiency of absorption and emission of a luminescent particle near a slab waveguide. (ID 185)*

The effect of waveguide index contrast on the absorption of the guided field by a luminescent particle near the core of a slab waveguide is analyzed, together with the Purcellenhancement of the spontaneous luminescence and it's coupling back into the guided mode. The overall conversion efficiency is strongest for excitation by a TM-pump and coupling of fluorescent light to the TM mode and depends approximately quadratically on the index contrast.

A.Dhakal; A.Subramainan; N.Thomas; R.Baets

- *Technology-transparent AWG design in photonic Ics (ID 194)*

Photonic IC manufacturing moves towards a generic-foundry model in technologies such as InP, SOI and Silicon. This paper discusses an AWG module as part of a Photonics Design Automation workflow, which provides AWG design across technology platforms.

R.Broeke