Design and Simulation of a Photonic Crystal Cavity in InP-based Membranes On Silicon

R. Zhang[1], J.J.G.M. van der Tol[1] and M.K. Smit[1]
[1]COBRA Research Institute, Technische Universiteit Eindhoven. Address: P.O. Box 513,5600 MB Eindhoven, The Netherlands

***Abstract*— We aim to make an electrically pumped photonic crystal laser in InP-based membrane on Si. A "W1 like" photonic crystal cavity is designed and simulations show good performance in terms of quality factor and manufacturing tolerance.**

Keywords-photonic crystal laser;electrical pumping; InP_based menbrane bonded on Si; manufacturing tolerance

I. Introduction

The complexity of photonic integrated circuits (PICs) has been raised significantly these last few years, following Moore's law in Photonics[1]. To satisfy the need for even more complexity, devices and waveguides have to be made smaller and less power consuming. This is especially so for using PICs in combination with Silicon and CMOS chips. InP-based Membrane On Si (IMOS) technology, which has a high vertical index contrast with an ultra-thin (200nm) adhesively bonded membrane layer (see Fig.1), allows the realization of very small devices. A wide range of passive components such as MMIs and ring resonators, have already been realized in this platform with good performances[2]. In COBRA, we are now moving towards making the active devices, such as lasers and amplifiers, in IMOS. Photonic Crystal (PhC) lasers, with its ultra-high Q-factor and low mode volume, has been a hot research topic for more than 30 years. Yet making a directly electrical pumped PhC laser is still quite a challenge, although it has been shown in a few papers[3]. However, the performances of these devices clearly needs improvement. In COBRA, we aim at making a electrical pumped PhC laser in the IMOS platform. Together with the techniques of submicron active-passive integration[4] and AlInAs oxidation[5] developed previously, we expect to make electrically injected PhC lasers with high pumping efficiency and small threshold current as well as low power consumptions.

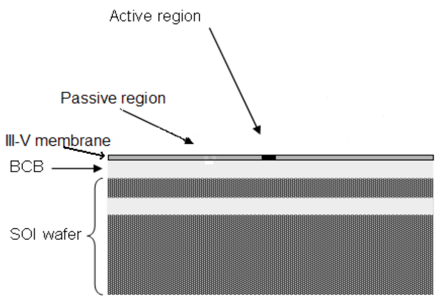

Figure 1. The layer stack of the IMOS platform

In this paper, we describe the design, simulation and tolerance check of a photonic crystal cavity, which we believe could be a promising candidate for the electrical pumped photonic crystal.

II. Photonic Crystal Cavity Model

There is a variety of PhC cavity types. In our case, a "W1 like" cavity (see Fig.2) is chosen. Since this type of cavity has shown to have a high quality factor[6] and meanwhile keeps a good tolerance to manufacturing errors. As shown in Fig.2, light source is in the middle, dark region represents the active material, which are QWs with InGaAsP as the barrier layers. The key feature of this cavity is an extremely small(0.124 um^3) buried active region located in a straight line-defect waveguide in an InP photonic-crystal slab. Optical confinement is realized both by photonic crystal band gap and the refractive index difference between the active region and the passive part.

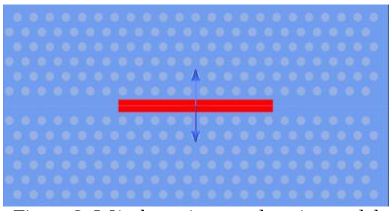

Figure 2. W1 photonic crystal cavity model

III. Simulation Results

A Finite-difference time-domain (FDTD) method is used to perform the 3-D numerical calculations.

A. Simplified and extended models

Firstly, numerical calculation is started with a simplified model. As shown in Fig.3, the main resonant mode shows a high Q factor of 17000 at the wavelength of 1576 nm. The field profile of the cavity mode is shown in Fig.4.

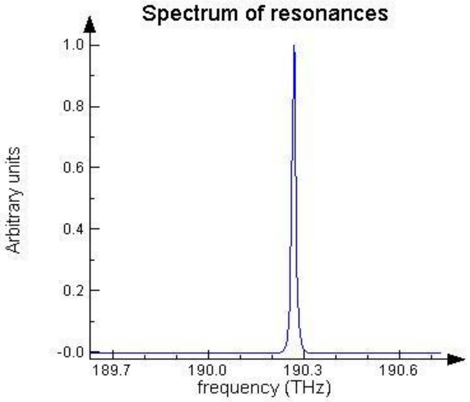

Figure 3. Main resonant mode of simplified model

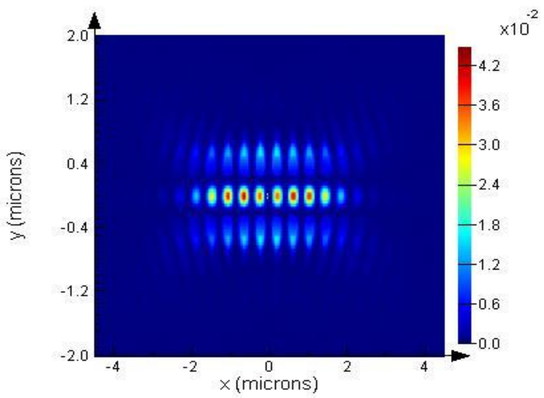

Figure 4. Mode field profile of the main resonant mode

Next, an extended and more complex model is simulated. This model includes more physical factors which could influence the performance of the cavity: doping , AlInAs oxidation and BCB bonding. A reduced quality factor (3507) at the wavelength of 1557 nm is obtained. This decreased value of quality factor is expected. First because doping, especially p-type doping, will increase the optical loss in the cavity and therefore reduce the quality factor. Secondly, oxidation of AlInAs is used to realize the current blocking function. The side-effect of this technique is that there is also a refractive index decrease with the oxidation of AlInAs, which subsequently influence the Q factor negatively. The blue shift of the wavelength is mainly due to the BCB bonding.

B. Tolerance check

Manufacturing imperfections are inevitable during the fabrication process. Therefore it is necessary to check whether this type of cavity is tolerant to the common manufacturing errors. In our simulations, two types of manufacturing errors are mainly considered. The first one is the misalignment of active region with respect to the photonic crystal and the second one is the variation of the hole radius in the PhC arrays.

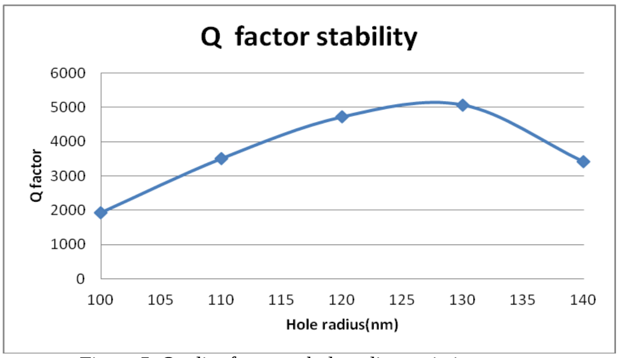

Figure 5. Quality factor vs hole radius variation

In the first case, the active region is “misaligned” by 100nm, which is the maximum alignment error for our Electron Beam Lithography machine. The Q- factor of the cavity decreases to 2623. Fig.5 shows how the Q factor changes with the variation of photonic crystal hole radius. Although there is a slight decrease in the quality factor, both tolerance checks show that this cavity is sufficiently tolerant to the typical manufacturing imperfections.

IV. CONCLUSION AND PERSPECTIVE

In this paper a “W1 like” photonic crystal cavity is designed and simulated. Results show that this cavity gives good performance in terms of quality factor and tolerance to manufacturing imperfections. Calculations also shows that doping and oxidation of AlInAs gives a negative effect on the Q factor, but the negative influence is acceptable and controllable. Together with the techniques of submicron active-passive integration and AlInAs oxidation developed previously, we expect to make electrically injected PhC lasers with high pumping efficiency and small threshold current as well as low power consumptions in the IMOS platform. In cooperation with PHILIPS, manufacturing of the device is currently pursued.

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