Long-wavelength Generic Components in COBRA Platform

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The importance of Photonic Integrated Circuits (PICs) operating at wavelengths around 2 µm is rapidly increasing. Applications are in the bio/chemo sensing domain, e.g. gas detection in breath analysis. The COBRA research group at the University of Eindhoven is developing a generic integration platform functioning at wavelengths up to 2.1 µm. The research in this platform covers integration of a number of active and passive building blocks. Integration of active and passive waveguides is achieved with excellent butt-joint quality, leading to the first COBRA laser emitting at 2 µm. Research on a library for passive components is underway.

Introduction

Generic photonic integration technology is an approach which offers monolithic fabrication of miniaturized photonic devices with diverse functionalities at a reduced price. This goal is achievable through development of a library of fully-characterized basic building blocks including passive components, detectors, modulators, lasers and optical amplifiers (SOAs). In this context, integrated circuits on Indium-phosphide (InP) substrate are of particular interest since both active and passive components are supported [1]. Since the launch of InP-based generic integration concept in 2007 by the European Network of Excellence (ePIXnet), the COBRA research group together with some other leading partners have successfully demonstrated a number of milestones for devices operating at 1.55 µm. A next step is to extend the platform operation to wavelengths around 2 µm. The wavelength range around 2 µm is of great interest since strong absorption lines of various gas species (carbon dioxide (2.05 µm), nitrous oxide (2.13 µm) and carbon monoxide (2.33 µm)) are located in this region and the absorption of water is very low. This provides excellent opportunities for trace-gas monitoring applications in environmental and medical diagnostics.

Since the existing platform for PICs at 1.55 µm has become mature the targeted long-wavelength platform will be based on the same principles but with some minor adaptions. This comprises changes in the active and passive building blocks. The latter is easily achievable since the fabrication technology is already in place for PICs at 1.55 µm. Some redesigning is required to adjust the dimensions of the existing building blocks at 1.55 µm for operation at 2 µm wavelength. In this paper, the focus of our study is on the long wavelength active material and its integration with the passive waveguides which resulted in the first COBRA laser emission at ~ 2 µm. Moreover, some simulations results on an important, but still missing building block in the COBRA platform, i.e. a Spot-Size Convertors (SSCs) for adapting the small size of an InP-based waveguide mode to that of a (lensed) fibre, will be discussed.

Long-wavelength active material

The long wavelength active material is a multi-quantum well (MQW) structure consisting of 4 periods of compressively-strained (2.12%), 5.5-nm-thick InGaAs(Sb) wells, placed between the 22.5-nm-thick InGaAs barriers, lattice matched to InP. This layer stack is sandwiched between InGaAsP separate confinement heterostructure (SCH) layers (band gap=1.25 µm), thus forming a ~ 500-nm-thick active core waveguide. The peak photoluminescence (PL) of this material was measured to be at 2.06 µm. The antimony (Sb) plays the role of a surfactant in the active material growth. It enables suppressing the very high compressive lattice strain originating from high concentrations of Indium (In), which is required to achieve long-wavelength emission [2]. The gain of this material was determined by the variable-stipe-length (VSL) method. Through this technique, a modal peak gain of 7 cm^{-1} was measured at a current density of 3.5 kA/cm^2 [3].

Active-passive integration

Having the active material characterized, the next step is to integrate it with the passive core material (InGaAsP, band gap of 1.25 µm). The procedure includes definition of the active regions via a lithography step followed by etching of the surrounding (unmasked) material and do a passive regrowth followed by the top cladding layer growth. In the last step, the contact layer will be grown on the top. Figure 1 shows a SEM image of the realized active/passive butt-joint. Following this process, a very smooth transition between the active and passive core was achieved.

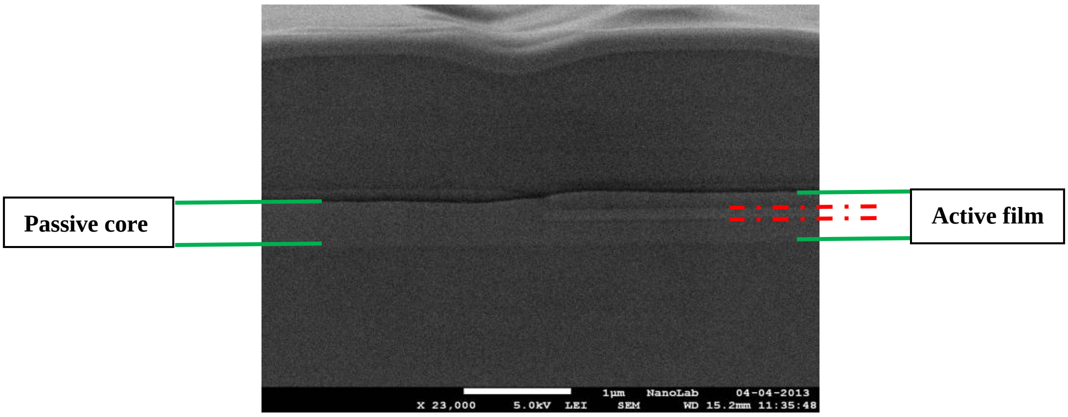

Figure 1 - SEM image of the realized active/passive butt-joint. The dash/dot lines show the active region sandwiched between the top and bottom InGaAsP layers (solid line). The perturbation in the middle is the point where the passive core starts.

In order to have a qualitative evaluation of the butt-joint, shallowly-etched straight waveguides were fabricated through the active regions. The chip was cleaved through the passive waveguides at both ends to form Fabry-Pérot laser architecture. The active region was pumped under continuous wave (CW) regime and the device temperature was actively controlled using a thermo-electric cooler. The single-side edge emission was collected by a lensed fibre and sent to an optical spectrum analyzer (YOKOGAWA AQ6375). The results of the measurements for a typical device with active region length of 750 µm over a total device length of 4.6 mm are shown in the following graphs (figure 2).

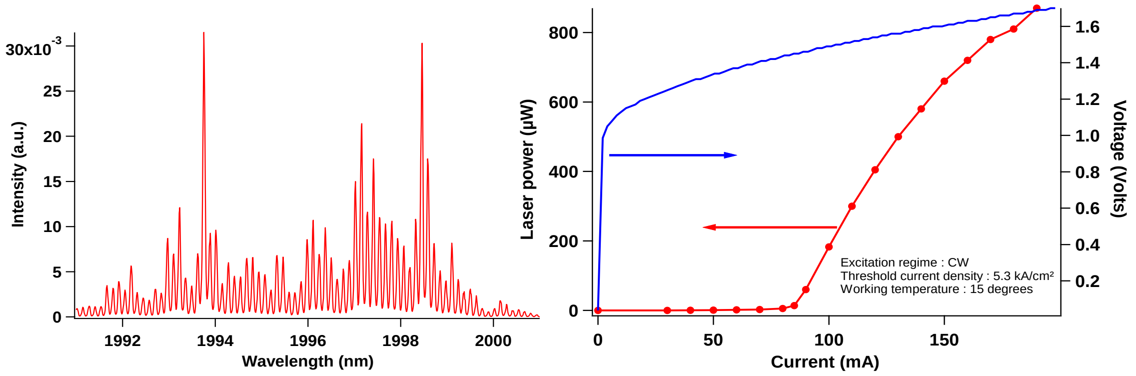

Figure 2 - (left) typical lasing emission spectrum above threshold. (right) L-I-V curve of the device under test. The filled circles are the power values measured by the optical spectrum analyzer.

For the device under test, a maximum output power close to 1 mW and a threshold current density of 5.3 kA/cm² were measured. The lasing threshold is a few times higher than the threshold current density of a similar structure at 1.55 µm, fabricated in COBRA runs. This may be due to lower available gain of the active material at longer wavelengths. Moreover, in the passive region, there are significant absorption losses at 2 µm wavelength caused by the p-dopants. Based on simulations, these losses increase by a factor of 3 from 3dB/cm at 1.55 µm to around 10db/cm at 2 µm wavelength [4]. This source of loss can be eliminated if the p-dopants can be restricted to the active regions. For this purpose, some tests will be done to examine local Zn (p-dopant) diffusion limited to the surface area above the active regions.

Passive building block investigation: Spot-Size convertor

A component which is still missing from the list of available passive building blocks in COBRA at 1.55 µm wavelength is the SSC. An investigation has been carried out on this module. In our approach, the design of SSCs is based on adiabatic lateral tapering. The FIMMPROP simulation tool from Photon Design was used to model the behaviour of the SSC. The simulated structure consists of a linear waveguide section with a length of 5 µm which is connected through a junction to a linearly tapered waveguide. The taper width varies linearly from 2 µm (optimized waveguide width for light propagation at 2 µm wavelength range) to 0.3 µm (the minimum width which we can be fabricated with optical contact lithography in combination with underetching) over the taper length. The taper length was varied from 0 to 2 mm. The fibre-matched waveguide width was set to be 5 µm with an etch depth of 6 µm (200 nm below the core layer). The simulation was carried out by using the FDM solver. The fundamental TE mode was launched at the input and the power of the first five excited TE modes at the output was monitored.

Based on the depicted graph in figure 3, it is predicted that for a taper length of 1000 µm, 94% of the input TE power is coupled into the fundamental TE mode at the output, and for a taper length of 1500 µm more than 99%. In practice, taking into account the propagation losses, we expect that more than 90 % of the power will be coupled to the fundamental TE mode at the output. A further reduction of the taper length to 800 µm can be achieved through etching of the top cladding down to 200 nm above the passive core.

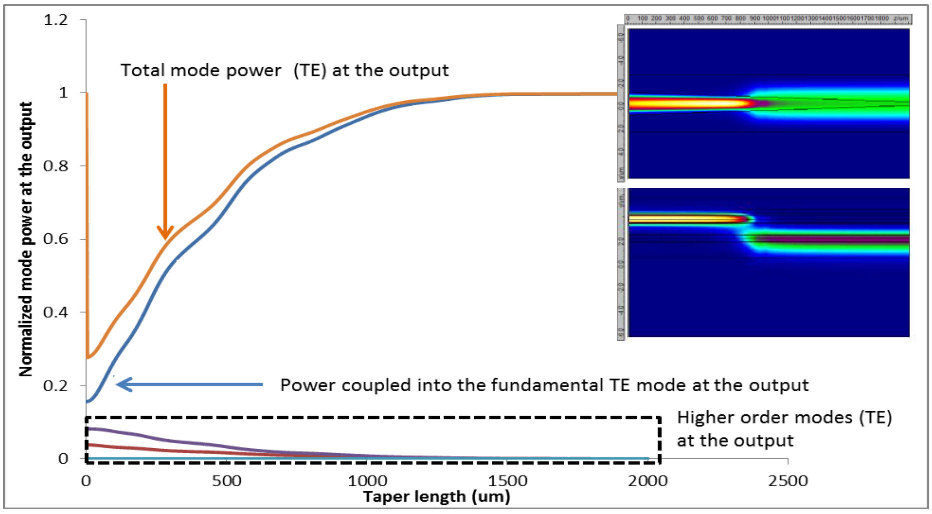

Figure 3 - Power evolution over the taper length for the first five TE modes. (inset) top and side view of the simulated structure showing the mode transition from the upper waveguide to lower fiber-matched waveguide.

Summary

We have successfully demonstrated Fabry-Pérot laser emission at 2 µm wavelength in an active-passive integrated structure. A maximum output power close to 1 mW and a threshold current density of 5.3 kA/cm² were measured. Design results for an integrated laterally-tapered SSC were presented. This has made the platform ready for a trial multi-project wafer run which is currently underway.

Acknowledgments

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