Membrane Microlasers for the Integration of Photonic and Electronic ICs.

Joris Van Campenhout, Dries Van Thourhout, Peter Bienstman,
C. Seassal*, P. Rojo-Romeo*, L. Di Cioccio** and J.M. Fedeli**

Promoter(s): Roel Baets

Abstract— **For future generation electronic circuits, a severe bottleneck is expected on the global interconnect level. With decreasing device dimensions, it is increasingly difficult to keep propagation delays and power consumption acceptable. Therefore there is a need for radically different interconnect approaches and one of the most promising solutions is the use of an optical interconnect layer. A possible approach for a compact optical link is the use of a Silicon-on-Insulator (SOI) passive waveguide layer in combination with III-V semiconductor microlasers and microdetectors, which are defined in a III-V membrane bonded on top of the SOI-stack. This work focuses on the design, fabrication and characterization of such membrane microlasers. Current state-of-the-art membrane microlasers involve microdisk lasers and photonic-crystal lasers. However, electrical injection remains a major difficulty. In this paper, we present modeling results, the fabrication procedure, and first measurement results on two types of electrically injected membrane microlasers.**

Keywords— **microlasers, electrical injection, optical interconnect, heterogenous integration**

I. Introduction

THE increase in integration density in the field of microelectronics will cause a bottleneck on the global interconnect level. The use of traditional electrical interconnects will be problematic in terms of speed, power consumption and signal integrity. An optical link that includes a laser source, an optical waveguide and a photodetector can offer a promising alternative. To offer an advantage over traditional metallic interconnects, optical interconnects should have a low power consumption and a small footprint. Closely packed passive optical waveguides can be implemented in the Silicon-on-Insulator (SOI) material system [1]. A promising solution concerning the laser sources is to use low-threshold InP microlasers defined in a InP membrane bonded on top of the SOI-waveguide (see figure 1). The emission wavelength is in the 1.3–1.6 μm range, for which Si is transparent. Optically pumped laser emission has already been demonstrated in InP membrane microlasers bonded on top of a Si wafer [2]. However, electrical injection remains a major challenge. This work focuses on the design and fabrication of electrically injected InP membrane microlasers, coupled to a passive SOI-waveguide. Two types of microlasers are considered: microdisk lasers and DBR-microlasers. A microdisk can support high-quality *whispering gallery* laser resonances. In this case, the light is guided at the edges of the disk, by total internal reflection. For the DBR-microlases, light is guided in a rib waveguide by total internal reflection and is reflected by *Bragg reflection* at the DBR-mirrors at the ends of the rib waveguide (DBR = Distributed Bragg Reflector). Both devices can emit light into an underlying SOI-waveguide by evanescent coupling.

J. Van Campenhout, D. Van Thourhout, P. Bienstman and R. Baets are with the Department of Information Technology, Ghent University (UGent), Gent, Belgium. E-mail: Joris.VanCampenhout@Intec.UGent.be.
*Laboratoire d'Electronique, Microelectronique et Micro-systmes, Ecole Centrale de Lyon, 36 Avenue Guy de Collongue, 69134 Ecully cedex-France
**CEA-DRT/LETI, 17 rue des martyrs, 38054 Grenoble cedex 9-France.

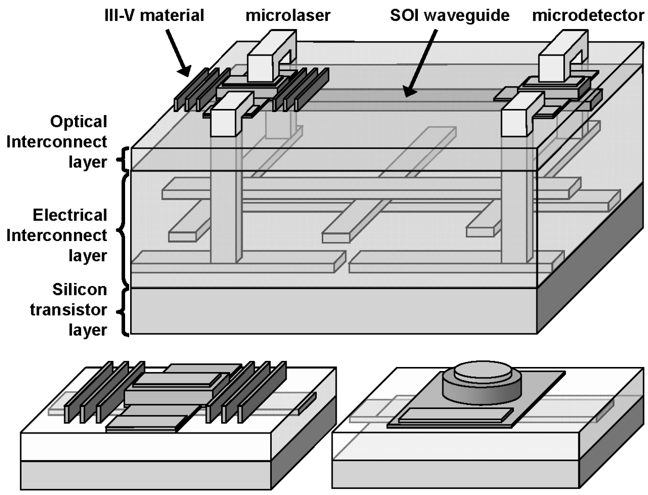

Fig. 1. Top: general layout of an SOI-based optical interconnect on CMOS. Bottom: two possible candidates for the membrane microlaser. Left: DBR-microlaser. Right: microdisk laser.

II. Design issues

If one wants to adapt existing optically pumped membrane microlasers for electrical injection, one needs to add doped semiconductor layers to form a pn-junction around the active layers of the laser. Also, two metal contacts need to be added to inject the electrical current. All these elements typically cause (huge) absorption losses, thereby reducing the quality of the laser resonator. It is clear that we need a good design strategy in order to control these losses. Basically, we used two approaches: for microdisk lasers, the metal contact was only placed in the center of the disk where the light intensity is low. For DBR microlasers, the InP membrane thickness is adjusted and a low-loss metal contact is used. A rigorous modeling of a microdisk laser coupled to an SOI-waveguide is a very challenging task due to its inherent 3D aspect. Therefore, we focused modeling efforts on the DBR-microlaser, which can be modeled to good approximation in a 2D cross section. In summary, these modeling results indicate that perfectly fabricated and optimized DBR-microlasers with a length of about 20 μm and a width of about 4 μm should have a threshold current of about 2 mA with a slope efficiency in the range 0.1 mW/mA.

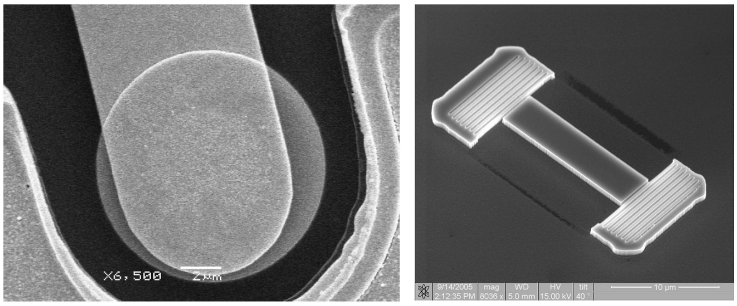

Fig. 2. SEM pictures of a fully processed microdisk laser (top) and an unfinished membrane DBR-microlaser (bottom).

III. Fabrication aspects

The fabrication of membrane microlasers is a non-trivial task which involves the collaboration of other research groups. We have developed a fabrication process for microdisk and DBR-microlasers. It consist of the following steps:

- epitaxial growth of the InP-based heterostructure
- definition of waveguide structures on the SOI-wafer
- waferbonding of the InP-wafer on top of the SOI-wafer
- microlaser processing in the InP membrane
  - sub-micron e-beam lithography (DBR-microlasers)
  - InP etch steps
  - isolation layer deposition
  - metal contact deposition

Most fabrication steps were already available but needed to be optimized for microlaser processing.

IV. Characterization

The microlasers can be tested during various stages of their fabrication. Before the application of the metal contacts, this is done by means of micro-photoluminescence (μPL) measurements. For these measurements, a beam of laser light with a photon energy larger than the band gap of the active material of the microlaser is used as an optical pump. When the excited carriers fall back, they can cause optical gain. For well-processed samples, lasing emission at about 1.5 μm can be observed. When the complete fabrication process is completed, the microlasers can be tested by doing electroluminescence (EL) measurements. Here, an electrical current is sent through the device and the emitted light is collected and analyzed by a spectrum analyzer. For the moment, only microdisk devices have successfully completed the whole processing scheme (without SOI-waveguide). On one sample, electrically injected lasing emission was measured, with a laser threshold of about 1.5 mA. However, the voltage required for lasing was about 5 V, and lasing was only possible for a pulsed injection regime. To our knowledge, this is the first demonstration of an electrically injected membrane laser bonded on Si.

V. Conclusions

We have performed an extensive modeling of membrane DBR-microlasers, coupled to an SOI-waveguide. This analysis yields threshold currents in the mA-range with slope efficiencies up to 0.1 mW/mA, for laser dimensions of $20\times4\,\mu\mathrm{m}^2$. A

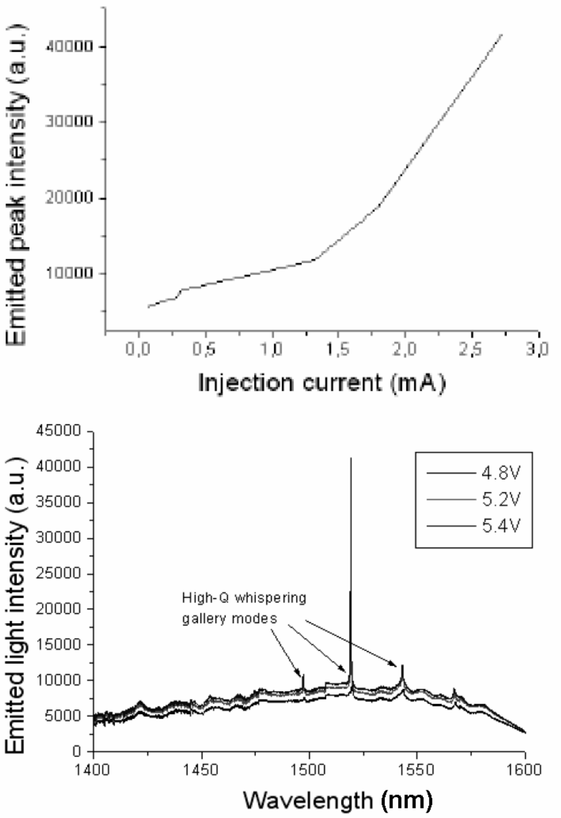

Fig. 3. Measurement results of an electrically injected membrane microdisk laser.

fabrication process was developed for both microdisk lasers and DBR-microlasers. First membrane microdisk lasers were fabricated and electrically injected laser emission was demonstrated in pulsed regime. Future work includes coupling to an SOI-waveguide and fabrication of DBR-microlasers. We conclude that these microlasers have a good potential as laser sources that can be integrated with CMOS on a waferscale.

Acknowledgments

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