Integration of an Electrically Driven InGaAsP Based Microdisk Laser with a Silicon based Passive Photonic Circuit

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Abstract: Electrically driven InGaAsP based microdisk lasers are bonded on a 200 mm SOI Wafer with submicron Silicon waveguides. Experimental results at room temperature of electrically pumped lasers coupled to a Si waveguide are exposed.

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1. Introduction
In order to develop new optical links for future optical interconnects, a key issue is to fabricate an efficient optical microlaser connected with an optical waveguide that can be integrated on top of a silicon integrated circuit. Circuit-scale predictive simulation showed that such optical links should exhibit high efficiency, low power consumption and low footprint [1] An approach based on hybridization of AlGaInAs on Silicon, and evanescent coupling was recently proposed, and promising results were obtained [2]. However, this approach does not enable drastic reduction of the laser source dimension and threshold. A few years ago, we proposed an original approach that consists in heterogeneous integration of high optical confinement InP-based photonic structures onto silicon [3] Coupling such ultracompact optical source with high index contrast passive waveguide could enable the implementation of efficient optical links on top of a silicon circuit.

In order to implement such optical links, we selected photonic devices that use relatively mature concepts and that in the same time enable a high compactness: InP-based microdisk lasers, and optical waveguides with sub-micron dimensions, patterned in an Silicon-on-Insulator (SOI) wafer. Microdisk lasers have been extensively studied in the past decade, both under optical and electrical pumping. In case of electrical injection, most of the structures are pedestal disks realized in a thick membrane [4]. In this communication, we focus on the design, fabrication and preliminary test of an heterogeneous system composed of an electrically pumped laser that uses a thin InP heterostructure and passive photonic circuit based on a nanostructured 200 mm SOI wafer.

2. Fabrication
In a first step, optical monomode waveguides are defined on a 200 mm SOI wafer, using DUV lithography and dry etching. The waveguides have a width of 500 nm and are 220 nm thick. The buried oxide layer is 1 μm thick. Prior to the III-V dies molecular adhesion, a 700 nm thick TEOS SiO2 is deposited. After a planarization step by Chemical-Mechanical polishing (CMP), 200 nm of silica are left on top of the Si waveguides. This 200 nm SiO2 layer is used as a coupling distance between the microlaser and the waveguide. This thickness is a critical step, since it influences directly the efficiency of the optical coupling between the microlaser and the Si waveguide. The III-V structure is as follow : the active structure is grown by Solid Source Molecular Beam Epitaxy (SSMBE) and consists of three 6 nm thick InAsP quantum wells (QWs) separated by 20 nm InGaAsP InP barrier layers. The n+ type contact is a 5x10^18 cm^-3 Si doped layer. The usual p+ type contact is replaced by a p+p++ tunnel junction [5]. The laser structure is depicted in the Fig. 1a. The 2 inch III-V wafer is then covered with a 10 nm thick Electron Cyclotron resonance (ECR) silica layer. The wafer is then separated into dies, which are bonded on top of the patterned SOI wafer (see Fig. 1b).

Since the III-V dies are unpatterned at this step, no accurate alignment is needed and a fast pick and place bonder can be used for the die bonding process. After a grinding step to reduce the III-V structure thickness, the remaining InP substrate and the AlGaInAs sacrificial layer are removed in HCl and FeCl3 solutions, respectively.

Lasers devices, which include Microdisks with diameter from 5 to 10 μm have been fabricated. The bottom layer formed by a 80 nm thick n+ doped membrane obtained by controlled partial Reactive Ion Etching (RIE). The structures are then covered with a low index dielectric layer (Benzocyclobutene BCB) [4] prior to the contact metal deposition.
3. Results
3D Finite Differences Time Domain (FDTD) simulations show that the bottom contact slab has a negligible influence in terms of optical losses [5]. The simulation of a coupling waveguide located below the disk has been done, for a 8 μm diameter and a silica coupling distance of 200 nm. The main effect of the presence of the guide is a lowering of the quality factor Q of the microdisk, due to the coupling. By comparing the Q values of coupled and uncoupled microdisks, we estimated that at least 80% of the power can be coupled into the guide.

Emission spectra were measured on the fabricated devices under optical pumping, for both coupled and uncoupled microcavities. The coupling efficiency ηc can be estimated from the values of the quality factors obtained for the coupled (Qc) and uncoupled (Q0) microdisks [6]. For an uncoupled disk Q0 is approximately 20000, whereas for a coupled microdisk Qc is lowered down to approximately 8400, leading to a coupling efficiency of 60%. Finally, a complete microdisk laser has been characterized under pulsed electrical injection, at room temperature. Fig. 2 displays a section of a microcavity showing the waveguide (left), and the electroluminescence spectrum of a 7.5 μm diameter microdisk, collected at the output of the coupling SOI waveguide (right). Lasing was observed on microdisks with diameters 7.5 and 10 μm, with threshold currents of 3 and 5 mA, corresponding to a current density of approximately 6.5 kA/cm².

4. Conclusion
We have fabricated electrically injected microdisk lasers on a thin InP based membrane bonded on top of a nanopatterned SOI wafer. First results of lasing in pulsed regime at room temperature, of a electrically pumped microcavity coupled to a Si waveguide are shown. The influence of the misalignment between the disk and the waveguide will be explored. The quality of the contact injection and its possible improvements to reduce the laser threshold will be discussed.

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