Heterogeneously integrated InP/SOI laser using double tapered single-mode waveguides through adhesive die to wafer bonding

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ABSTRACT

An InP/Silicon hybrid laser based on double taper adiabatic mode transfer and BCB bonding is demonstrated, exhibiting nearly 1 mW output power at room temperature in pulsed operation regime. Such a laser enables potentially a low threshold current and a high power conversion efficiency.

INTRODUCTION

The silicon photonics platform is drawing an increasing attention due to the promise of fabricating low-cost, compact circuits that integrate photonic and microelectronic elements [1]. Today, practical Si-based light sources are still missing, despite recent demonstration of optically pumped germanium lasers [2]. This situation has driven research to the heterogeneous integration of III-V on silicon. One of the heterogeneous integration approaches is the use of wafer bonding techniques [3-6]. In such an approach, InP dies are bonded on a SOI wafer, and then processed to fabricate lasers lithographically aligned to the silicon waveguides.

One of the critical issues of hybrid InP/SOI lasers is to design a laser structure, able to generate light in the III-V layer and then to couple it efficiently from the III-V layer to a silicon waveguide. The main solution proposed up to now is based on evanescent coupling, whereby the optical mode is mainly confined in the silicon waveguide and interacts with the multi quantum wells (QW) layer [3]. This solution has given already very interesting results. However the laser performance is very sensitive to bonding quality because the optical mode experiences the interface between the III-V and the silicon. Moreover the very thin n-doped III-V layer results usually in a quite large electrical resistance, which leads to poor thermal behaviour under electrical injection. Another solution is to use a tapered silicon waveguide, which allows to couple the light from a III-V waveguide to the silicon waveguide in the tapered region [4]. However the InP waveguide as used in [4] is very wide (> 6 µm), leading to very high threshold current and low emission efficiency. The most efficient solution seems to be a double tapered structure, incorporating mode transformers in both the III-V and silicon waveguides [5]. Mode coupling occurs in the tapered region, while light generation and amplification takes place in a single mode III-V waveguide. In this paper we report on the first demonstration of such a hybrid III-V/Si laser.

DEVICE STRUCTURE

The device structure is shown in Fig. 1. The structure can be divided into three parts. In the center of the device there is a III-V waveguide that provides optical gain. At both sides of this section there is a coupling region that couples light from one guide to the other. The third part is a silicon waveguide without III-V on top. In the coupling region a double adiabatic taper structure is designed as described

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in [5]. In Fig. 1 we present the evolution of the optical mode profile inside the cavity, simulated using a full vectorial mode finder. We can observe that the mode is adiabatically transferred from the III-V waveguide to the Si waveguide and vice versa. A coupling efficiency of nearly 95% can be achieved for an InP taper width of 0.4µm.

The III-V region has a multiple QW double heterostructure, which consists of a p-InGaAs contact layer, a p-InP clad, 6 InGaAsP QW surrounded by two InGaAsP separate confinement heterostructure (SCH) layers, and an n-InP layer. The MQW layer consists of six 8nm thick 1.55Q-InGaAsP well layers separated by 10nm thick 1.17Q-InGaAsP barrier layers. The thickness of both SCH layers is 100nm and the thickness of the n-InP layer is 200nm.The SOI substrate (200mm wafer manufactured by SOITEC) is composed of a mono-crystalline silicon layer (thickness of 400nm) on top of a 2µm thick buried oxide layer on a silicon substrate. The silicon rib waveguides have a height of 400nm, an etch depth of 180nm and a width of 1µm. The III-V epitaxial layers are transferred to the patterned SOI wafer through DVS-BCB adhesive bonding. After removal of the InP substrate, ridge structures on III-V layers are formed by dry-etching down to the n-type InP layer using a CH_4/H_2 plasma reactive ion-etching. The length and width of the gain waveguide are respectively 300µm and 2.5µm. The taper section has a length of 175µm and the taper tip has a width of around 0.8µm. The III-V waveguide lies upon the silicon waveguides just in the coupling regions. Once the fabrication process is complete, the mirrors on the passive SOI waveguides are formed by cleaving the SOI wafer.

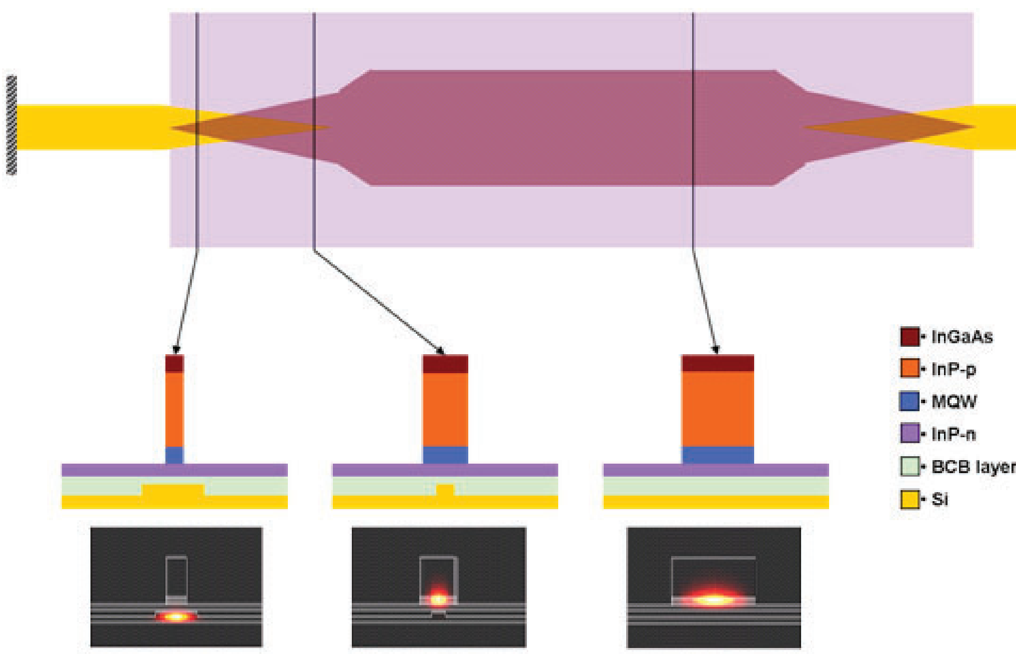

Fig. 1 Top view, cross sections and calculated mode profiles of the III-V/SOI laser

EXPERIMENTAL RESULTS

The device is mounted on a temperature controlled stage set to 20°C. The output laser beam is collected by a lensed fiber coupled to the silicon waveguide cleaved facet. The coupling losses are estimated to be higher than 8dB. The L-I curve is shown in figure 2(a). The laser is electrically pulse-pumped up to 200mA, with a pulse period and width of 10µs and 180ns. The device has a lasing threshold of 45mA and a maximum fiber coupled power of 0.75 mW at both sides. The series resistance is 12 Ohms. The lasing spectrum is shown on figure 2(b). A single wavelength operation regime is observed, due to parasite reflections at the end of the InP taper tips. In fact, the taper tips have a width of around 0.8µm, much larger than the optimum value found by simulations. Therefore several percent of the power that is not coupled into the silicon waveguide is back reflected to the III-V waveguide, generating a multiple cavity effect. Another consequence of the large taper width is that the coupling efficiency between InP and silicon waveguides is strongly reduced, leading to a lower power efficiency of the fabricated devices.

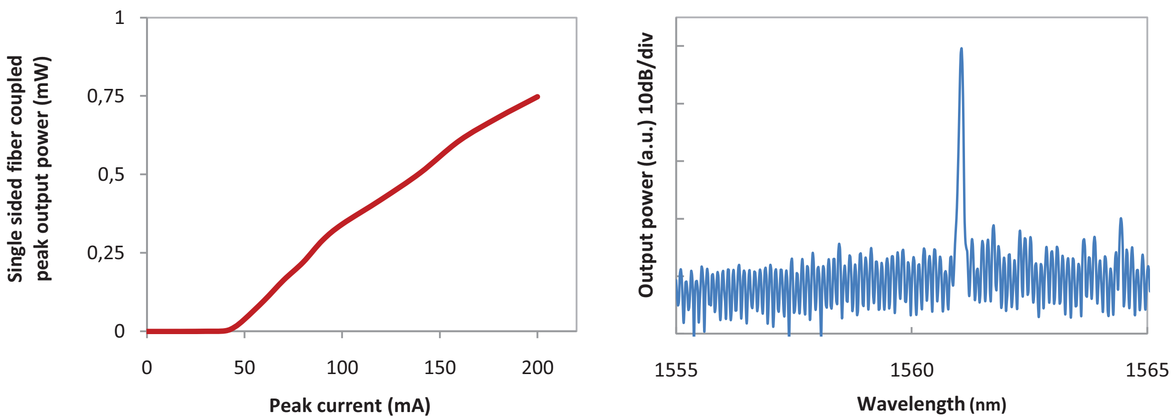

Fig. 2. (a) Fiber coupled laser power as a function of drive current (L-I curve) under pulsed operation at 20°C. (b) Optical spectrum of the laser driven at 55mA

CONCLUSIONS

We demonstrate hybrid III-V/Si lasers based on double taper adiabatic mode transfer and BCB bonding. We achieve laser action under pulsed regime with a threshold current of 45mA and a fiber coupled output power near 1mW. CW laser operation is also achieved for temperatures below 10°C. Significant improvement can be made further by reducing the taper width, which should lead to lower threshold current and much better power efficiency.

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