Characterization and Optimization Study of Silicon Evanescent Racetrack Lasers

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Introduction

The *electrically pumped hybrid silicon evanescent laser* has been presented as a novel device which satisfies the desire to manufacture low cost, high volume silicon lasers with the goal of using photonic circuitry to replace traditional metal interconnects for board to board and chip to chip applications. The hybrid silicon evanescent device platform has already been demonstrated in the form of a photodetector, an optical amplifier and a racetrack laser [1]. The silicon evanescent laser is achieved through bonding a III-V multiple quantum well (MQW) active layer structure to a silicon waveguide. For efficient current flow to the active region, protons are implanted into the cladding layer of the III-V structure in order to prevent lateral carrier diffusion and thereby increasing the current and optical mode overlap in the quantum wells.

We report here the optimization of this proton implant profile for two laser characteristics, threshold lasing current and device capacitance, and show an improvement of both these characteristics. This technique was implemented and used in the design of the silicon evanescent laser in an attempt to maximize the injection efficiency into the MQW active layer. Injection efficiency is the fraction of injected carriers which contribute to light generation, is one factor used to characterize lasers. Another factor which can affect performance of the silicon evanescent laser is the capacitance between the n contact layer and the p contact layer.

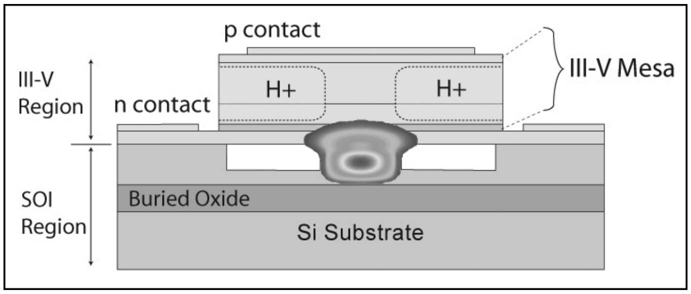

Figure 1: Cross-sectional illustration of device platform.

Device Structure/Fabrication

The silicon evanescent laser device platform consists of two separately regions bonded together. Figure 1 is an illustration of the cross-sectional view of the device. The top portion is a III-V heterostructure consisting of a n-region, multiple quantum well (MQW) active region and p-cladding region which are epitaxially grown on an indium phosphide (InP) substrate. The bottom portion is a silicon waveguide structure processed from a silicon-on-insulator (SOI) substrate. The two pieces are bonded using a low temperature O_2 plasma assisted wafer bonding technique [2]. The InP is then etched using both reactive ion etching (RIE) through the p region, and wet etching through the MQW to create a mesa ~ 10 μm wide in order to access the n layers. n and p contact pads are subsequently deposited and annealed in forming gas. The sides of the mesa are implanted with protons of varying energies in order to allow for efficient current flow as well as preventing lateral current diffusion. Detailed descriptions of the fabrication process of the hybrid silicon evanescent laser can be found in [3].

An illustration of the silicon evanescent racetrack laser device topography is shown in Figure 2. It consists of a racetrack resonator, two integrated photodetectors, and a directional coupler, which couples light from the resonator and directs it towards the photodetectors.

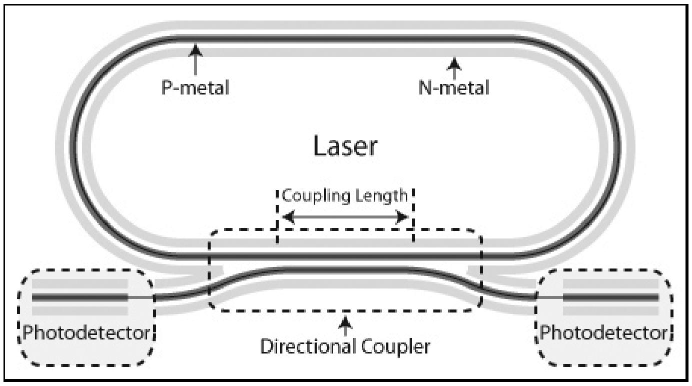

Figure 2: Illustration of silicon evanescent racetrack laser.

Experimental Procedure

This experiment used two different proton implantation profiles, the first being the standard baseline implantation profile as shown. The second implantation profile increased the depth of the protons to correspond to the top of the MQW active region while increasing the height of the protons implanted to correspond to the top of the mesa. By increasing the depth of the implantation to the top of the MQW active region, we intended to improve the injection efficiency into the active region directly above the silicon waveguide. Bringing the implantation profile to the top of the mesa is intended to reduce the capacitance between the p and n layers by decreasing the available area which is behaving as a parallel plate capacitor, in particular the highly doped P-InGaAs contact layer.

During testing, the laser was driven from 0-500 mA in 25 mA increments through the top p-contact. The photodetectors were reverse biased at -5V, and the current across them is measured as the driving current is increased. In order to determine the effect which the deeper proton implant profile has on the injection efficiency, we compared devices implanted with the two different profiles based upon their lasing threshold current. The capacitances of the devices were measured directly.

Results and Conclusions

Eight devices from each profile were tested and analyzed. Using the L-I (Power vs. Current) curve taken from the silicon evanescent racetrack lasers, the lasing threshold current can be determined experimentally. As a result of increasing the proton implant depth the lasing threshold current decreased. Devices 2-4, with a directional coupler length of 100 μm, demonstrated a 17.31% improvement in the average threshold current for proton implant profile 2 over profile 1. As can be seen in Figure 3, the average threshold current for devices 2-4 improved from ~ 192 mA, for proton implant profile 1 to ~ 158 mA for proton implant profile 2. Devices 6-10, with a directional coupler length of 300 μm, demonstrated a 4.71% improvement in the average threshold current for proton implant profile 2 over profile 1. The average threshold current for devices 6-10 improved from ~ 175 mA, for proton implant profile 1, to ~ 167 mA for proton implant profile 2. This decrease in the threshold current for these devices demonstrates that the injection efficiency was in fact improved by increasing the depth of the proton implant profile.

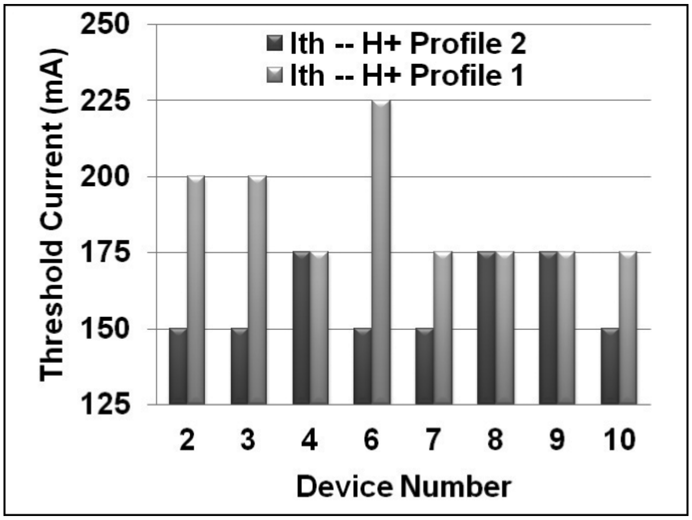

Figure 3: Threshold current comparison between proton implant profiles.

As can be seen in Figure 4, the capacitance decreased from an average of ~ 4.6 pF to ~ 3.6 pF with the increase in proton implant height. Overall there was a 21.4% decrease in the capacitances measured for the devices.

Acknowledgements

Thanks to Alex, Dr John Bowers and his group, Intel, and all the supporters of the Bowers Lab. Special thanks to the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program for this opportunity and to the NSF for funding.

References

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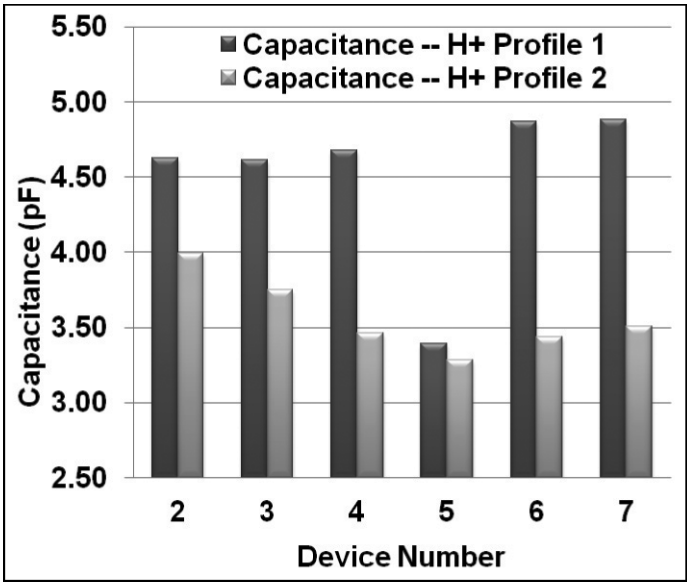

Figure 4: Capacitance comparison between proton implant profiles.