Optimization of taper structures for III-V on Silicon lasers

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1. Introduction

Using silicon as a platform for realizing complex integrated photonic circuits is rapidly gaining interest both from the scientific community as from the industry. Tremendous progress in realizing passive devices, high speed modulators and Ge-based detectors has been made over the last decade (for a recent review see [1]). However, efficient light generation directly from silicon, given its indirect bandgap, has not yet been shown. Therefore an alternative approach based on bonding high quality epi-layers on prepatterned silicon waveguide structures has been developed by several groups [2][3][4][5]. We recently proposed a new structure [6] whereby light in the gain section is maximally confined in the III-V quantum well layers. At the ends of the gain section, light is coupled to the silicon waveguide layers using an adiabatic taper. Initial results showed Fabry-Perot type devices operating with threshold currents as low as 30mA and output powers up to 4mW [6]. Here we present a study focusing on the adiabatic taper and show how its design influences the operation of the device.

2. Device structure

Figure 1 shows a top view, longitudinal and transversal cross-sections of the proposed device. Its fabrication and operation was described in [6]. InP-wafers containing the active layers were bonded on prefabricated silicon waveguides with 400nm height. Next the InP-substrate was removed and the amplifier structure was defined using deep-UV lithography and plasma etching. Finally the p- and n-type contacts were formed. Figure 2 shows a cross-section of a fabricated taper tip.

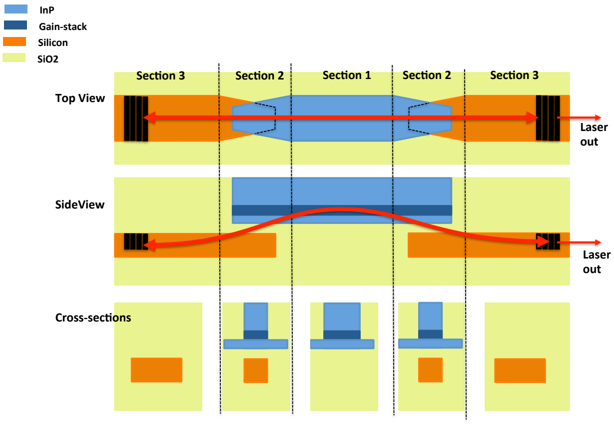


Figure 1 Top view and cross-sections of proposed laser structure.

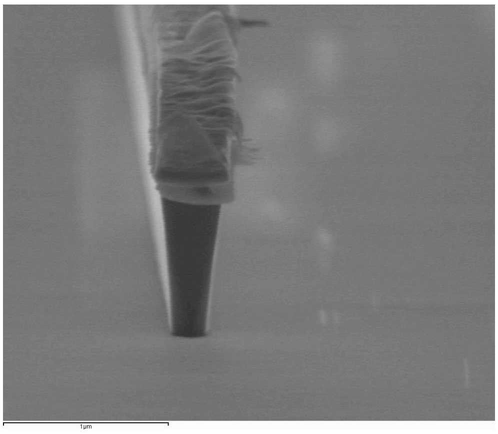


Figure 2 Cross-section of fabricated taper tip

3. Optimization of taper lengths

We carried out an extensive design study, investigating the influence of parameters such as taper length, tip width, thickness of the bonding layer and misalignment. Figure 3 shows that for a perfectly fabricated device (green curve) a taper as short as 100µm should allow for over 99% transmission. However, as soon as there is some misalignment, it is better to increase the length of the taper.

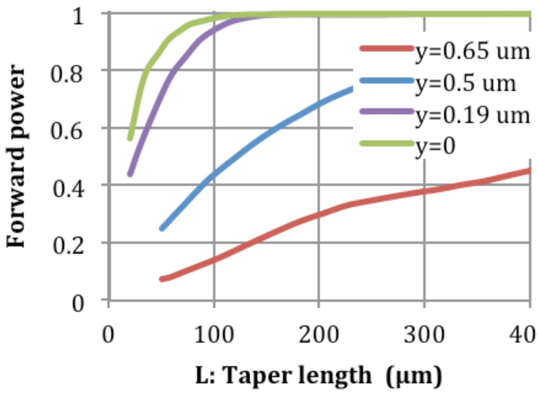


Figure 3 Simulation of power transmitted through tapered transition as function of taper length, and for different values of misalignment (500nm taper tip, 80nm bonding layer thickness).

The same holds when calculating the influence of the bonding layer (Figure 4). Again it is clear that increasing the length of the taper leads to a more tolerant structure.

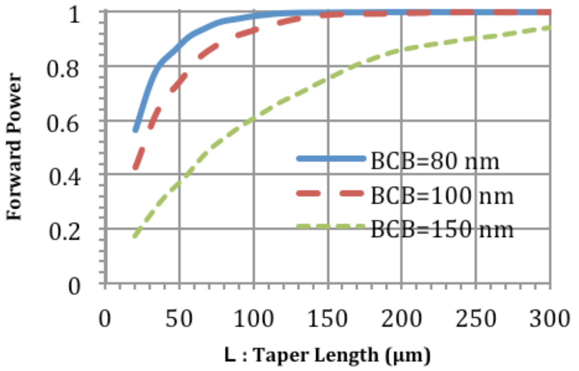
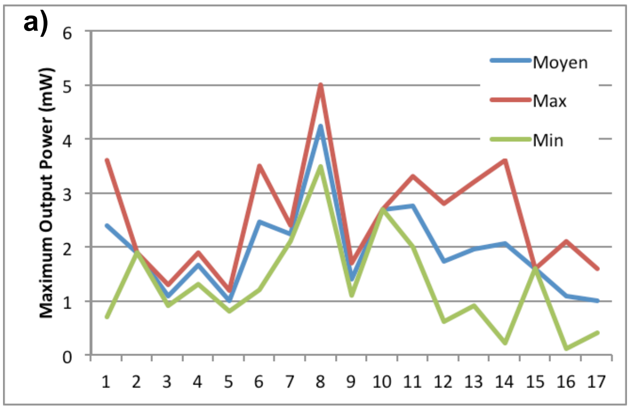


Figure 4 Simulation of power transmitted through tapered transition as function of taper length, and for different values of bonding layer thickness (500nm taper tip). Simulation was carried out for bonding layer with refractive index 1.56 (BCB), while in the fabricated devices presented in Figure 5 a SiO_2 bonding layer was used. This does not influence the overall conclusions however.

Following this design study, we fabricated a series of selected devices with different parameters for active region length and taper length. Figure 5 gives the associated measurement results, for 17 different device designs. In each case the blue curve gives the average value (over 5 devices), the red curve gives the maximum and the green one gives the minimum value.

Overall the shorter devices seem to perform better, not only in terms of threshold current but often also in terms of threshold current density and output power. A length of 150μm seems to be sufficient for the taper, with the device with a 100μm long taper clearly performing worse than all others.



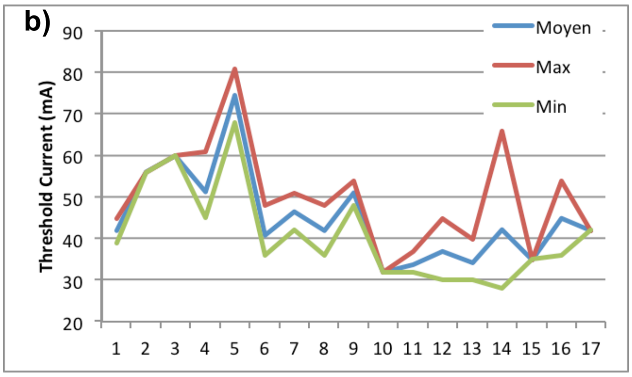


Figure 5 a) Maximum output power and b) threshold current for different laser designs. The horizontal axis denotes the design number. Red/Blue/Green denote maximum/average/minimum values over 5 identical devices per laser design.

4. Conclusions

We optimized and experimentally verified the design of an adiabatic taper to be used in a heterogeneous III-V on silicon laser. In addition we showed good reproducibility and yield when comparing identical devices. The optimized gain blocks were combined with a tunable ring resonator and a DBR-mirror to realize a tunable laser. Results will be presented at the conference.

Acknowledgements

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