High-speed hybrid III-V-ON-SI vertical cavity lasers

Vertical cavity lasers (VCLs) are the dominating laser type for the short-reach fiber optical links, with rising interest in employing them across the wider range of optical interconnects. From micrometer length links in silicon (Si) photonics to long distance fiber links in mega data centers, the VCLs lasing at long wavelengths could satisfy the rising requirements for the high power efficiency and modulation speed. A novel design of hybrid III-V-on-Si VCLs is investigated in this thesis. It employs a high-index-contrast grating (HCG) as one mirror and dielectric distributed Bragg reflector (DBR) as second mirror to achieve very compact optical mode volume which results in potentially ultra-high intrinsic bandwidth. The aim of this work is the experimental demonstration of the electrically pumped VCLs based on this design. The first part of this thesis deals with the design of the proposed lasers. The theoretical background of the HCG is given, focusing on its application as a compact broadband reflector. Basic theory of the dynamic properties of the laser and the optimization of the design for the high modulation speeds is explained. The key features of the electrically pumped design are discussed, focusing on minimizing the parasitic elements. The methods of achieving current confinement, using proton implantation and selective undercut etching, are investigated. The low-resistance ohmic contacts are optimized to avoid deep metal diffusion. The complete fabrication of proposed laser design is discussed and presented in the second part of the thesis. The wafer bonding for integrating III-V layers onto a SOI wafer has been one of the main fabrication challenges. To solve it, the adhesive bonding method using ultra-thin polymer layers has been successfully implemented and optimized. The complete fabrication procedure for the hybrid VCLs has been developed using CMOS-compatible processes. In the third part, the fabrication and characterization of several versions of VCLs is presented. Considerable efforts have been put in to demonstrate lasing; however, due to numerous fabrication obstacles this was not achieved. The first fabricated lasers showed no light emission due to issues with the epitaxy design. The poor wafer quality of the second epitaxy caused deviations during fabrication and low yield. The final fabricated design showed better properties, although the lasing was not reached due to too high threshold. The results of the experimental work are discussed focusing on prospects of optimizing the device design and fabrication to achieve successful demonstration of high-speed lasers.

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