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A Germanium-on-Silicon Laser for On-chip Applications

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Abstract: Lasing from Ge was achieved by highly n-type doping and biaxially tensile strain to overcome free carrier absorption. High n-type doping and efficient carrier injection remain the most important issues for electrical excitation of lasing.
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1. Introduction

For several decades, the performance of Si microprocessors has increased exponentially following "Moore's Law" by scaling down the critical dimensions of transistors. However, over the last several years, microprocessor performance has not followed as expected trend from Moore's Law, mainly due to the increased power consumption and latency issues in traditional metal interconnects. It has become increasingly clear that parallelism is replacing the traditional clock frequency scaling, and electronic-photonic synergy that has the advantage of high bandwidth and energy-efficient photonic interconnects is the key to the increase in performance of microprocessors.

To integrate photonics into a CMOS process flow, active and passive Si based photonic devices have been developed over the past few years. Since III-V based materials have not yet been successfully implemented into CMOS processes, the materials options for active devices are limited. Since the development of direct epitaxial germanium growth on silicon, Ge has been widely used for near IR detectors, integrated in a CMOS process flow. More recent developments extended Ge based active photonic devices to Ge lasers.

2. Ge Lasers

Indirect band gap materials have generally not been considered for lasing since the light emission from the indirect transition is very inefficient. Despite the fact that Ge is an indirect semiconductor, the Ge band gap can be engineered to exhibit efficient direct gap recombination [1]. Using biaxial tensile strain and n-type doping, electrons in the indirect L valley are scattered into the Γ valley by a thermally activated process, leading to direct bandgap emission at room temperature and above. The required n-type doping level is $>10^{19}$ cm^{-3}. Although the maximum solid solubility of i.e. phosphorous in Ge is about 10^{20} cm^{-3} this level is very difficult to reach due to outdiffusion of P at elevated temperatures. Different approaches are currently evaluated to reach a P doping level of mid 10^{19} cm^{-3}. Our theoretical model shows that the gain spectrum can extend over a range of 100nm near the direct band edge of Ge [2]. We have demonstrated the first optically pumped Ge laser using direct growth of Ge on Si and forming a waveguide with polished facets as the laser cavity [3]. The excitation source was a Q-switched YAG laser at 1064nm with 1.5nm pulsed. We observed the characteristic threshold in the L-I (optical) curve as well as polarization condensation and linewidth narrowing. Electroluminescence has been demonstrated using a Ge LED with intrinsic Ge [4]. Electroluminescence from a heterojunction device with highly n-type Ge was recently demonstrated. Modeling of the heterostructure Fermi levels shows that efficient electrical injection can be achieved [2].

3. Conclusions

Ge lasers that are monolithically integrated into a Si CMOS process flow hold great promise for implementation into on-chip photonic networks for high volume manufacturing. While optically pumped lasers have already been demonstrated, to achieve electrical injection the P doping level needs to be increased to mid $10^{19} cm^{-3}$ levels. We have shown that heterostructure devices will be able to inject both types of carriers into the active Ge layer.

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