

Laser annealed in-situ P-doped Ge for on-chip laser source applications (Conference Presentation)

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ABSTRACT

Realization of a monolithically integrated on-chip laser source remains the holy-grail of Silicon Photonics. Germanium (Ge) is a promising semiconductor for lasing applications when highly doped with Phosphorous (P) and or alloyed with Sn [1, 2]. P doping makes Ge a pseudo-direct band gap material and the emitted wavelengths are compatible with fiber-optic communication applications. However, in-situ P doping with Ge₂H₆ precursor allows a maximum active P concentration of $6 \times 10^{19} \text{ cm}^{-3}$ [3]. Even with such active P levels, n⁺⁺ Ge is still an indirect band gap material and could result in very high threshold current densities. In this work, we demonstrate P-doped Ge layers with active n-type doping beyond 10^{20} cm^{-3} , grown using Ge₂H₆ and PH₃ and subsequently laser annealed, targeting power-efficient on-chip laser sources.

The use of Ge₂H₆ precursors during the growth of P-doped Ge increases the active P concentration level to a record fully activated concentration of $1.3 \times 10^{20} \text{ cm}^{-3}$ when laser annealed with a fluence of 1.2 J/cm². The material stack consisted of 200 nm thick P-doped Ge grown on an annealed 1 μm Ge buffer on Si. Ge:P epitaxy was performed with PH₃ and Ge₂H₆ at 320°C. Low temperature growth enable Ge:P epitaxy far from thermodynamic equilibrium, resulting in an enhanced incorporation of P atoms [3]. At such high active P concentration, the n⁺⁺ Ge layer is expected to be a pseudo-direct band gap material. The photoluminescence (PL) intensities for layers with highest active P concentration show an enhancement of 18× when compared to undoped Ge grown on Si as shown in Fig. 1 and Fig. 2. The layers were optically pumped with a 640 nm laser and an incident intensity of 410 mW/cm². The PL was measured with a NIR spectrometer with a Hamamatsu R5509-72 NIR photomultiplier tube detector whose detectivity drops at 1620 nm. Due to high active P concentration, we expect band gap narrowing phenomena to push the PL peak to wavelengths beyond the detection limit (1620nm) of the setup. Therefore, the 18× enhancement is a lower limit estimation. In this contribution, an extensive study of laser annealing conditions and their impact on material properties will be discussed.

A major concern in using highly doped Ge as an active medium is the increase in free-carrier absorption (FCA). However, results reported in [4] suggest that FCA is significantly dominated by holes due to larger absorption cross-section of holes compared to electrons. The FCA results in [4] and JDOS modeling were used to calculate the gain spectrum for the highest doped Ge samples, including the typical 0.25% biaxial tensile strain of epitaxial Ge on Si. A carrier lifetime of 3 ns is required as shown in Fig. 3 for a target threshold current density of sub-20 kA/cm² which represents at least tenfold reduction when compared to active P-doping level of $6 \times 10^{19} \text{ cm}^{-3}$. As a result, laser annealed highly doped Ge layers grown with Ge₂H₆ precursors are a promising approach for realizing a power efficient on-chip Ge laser source.

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